

# Computer-Aided VLSI System Design

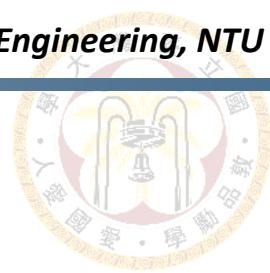
## Chapter 5. Synopsys Synthesis Design Compiler & Post-sim Part2

Lecturer: Shih-Hao Chen

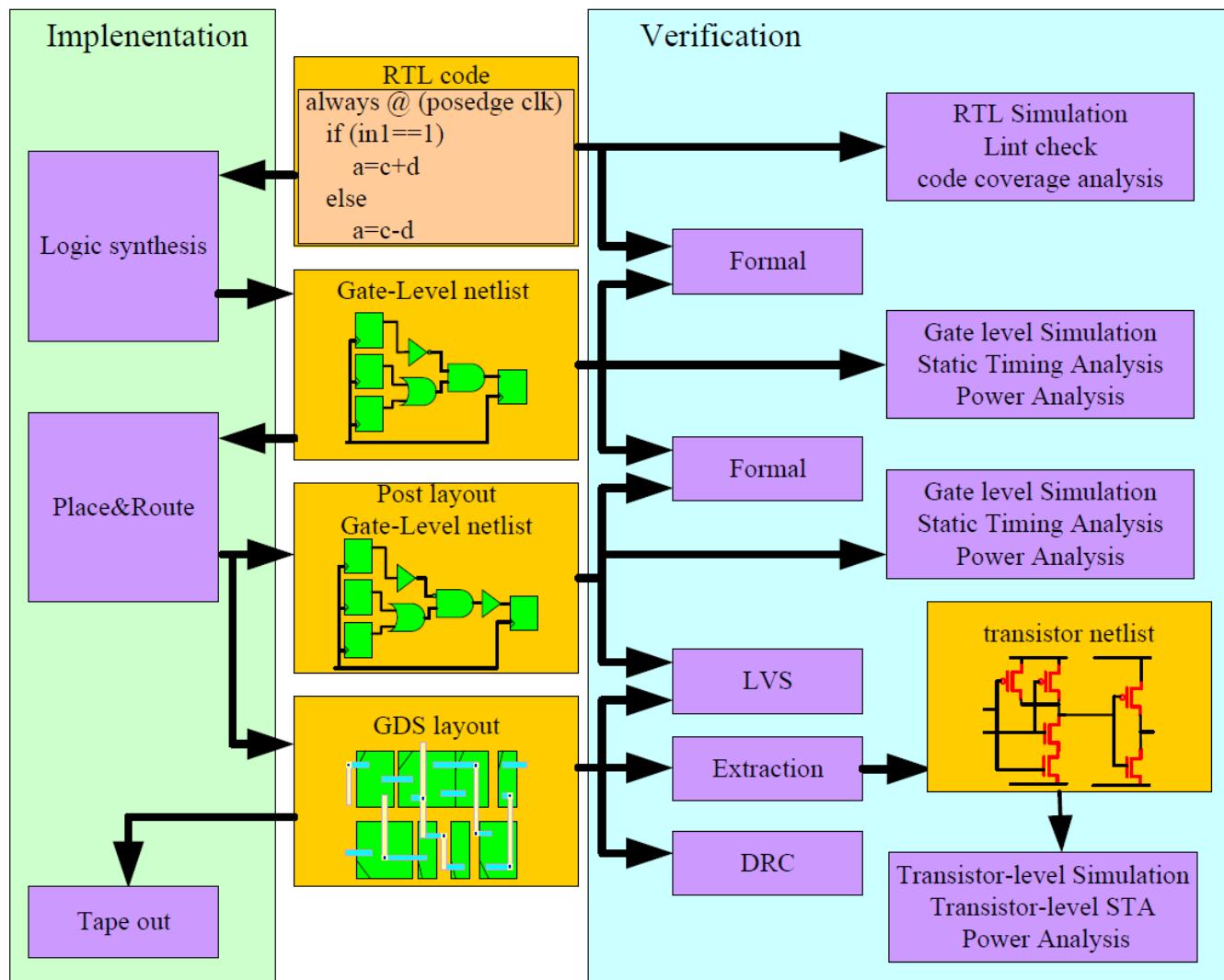
*Graduate Institute of Electronics Engineering, National Taiwan University*

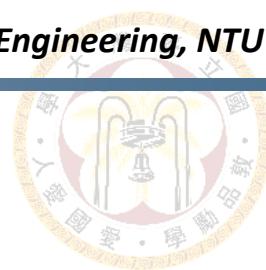


NTU GIEE



# Recap: Cell-based IC Design Flow





# Recap: Logic Synthesis

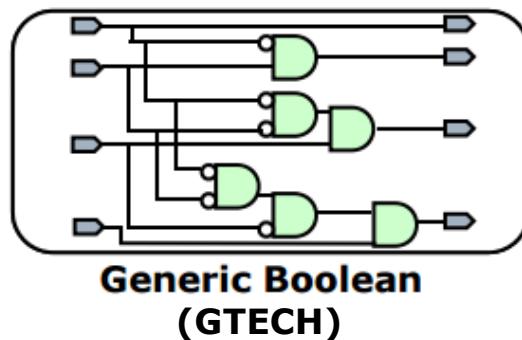
Synthesis = translation + optimization + mapping

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

HDL Source  
(RTL)

Translate (HDL Compiler)

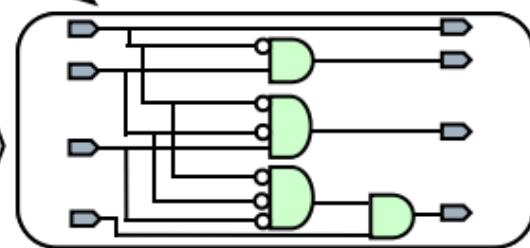
No Timing Info.



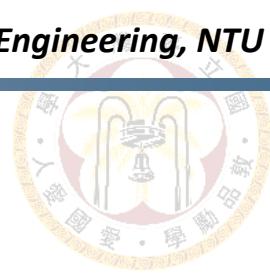
Generic Boolean  
(GTECH)

Optimize + Mapping  
(Design Compiler)

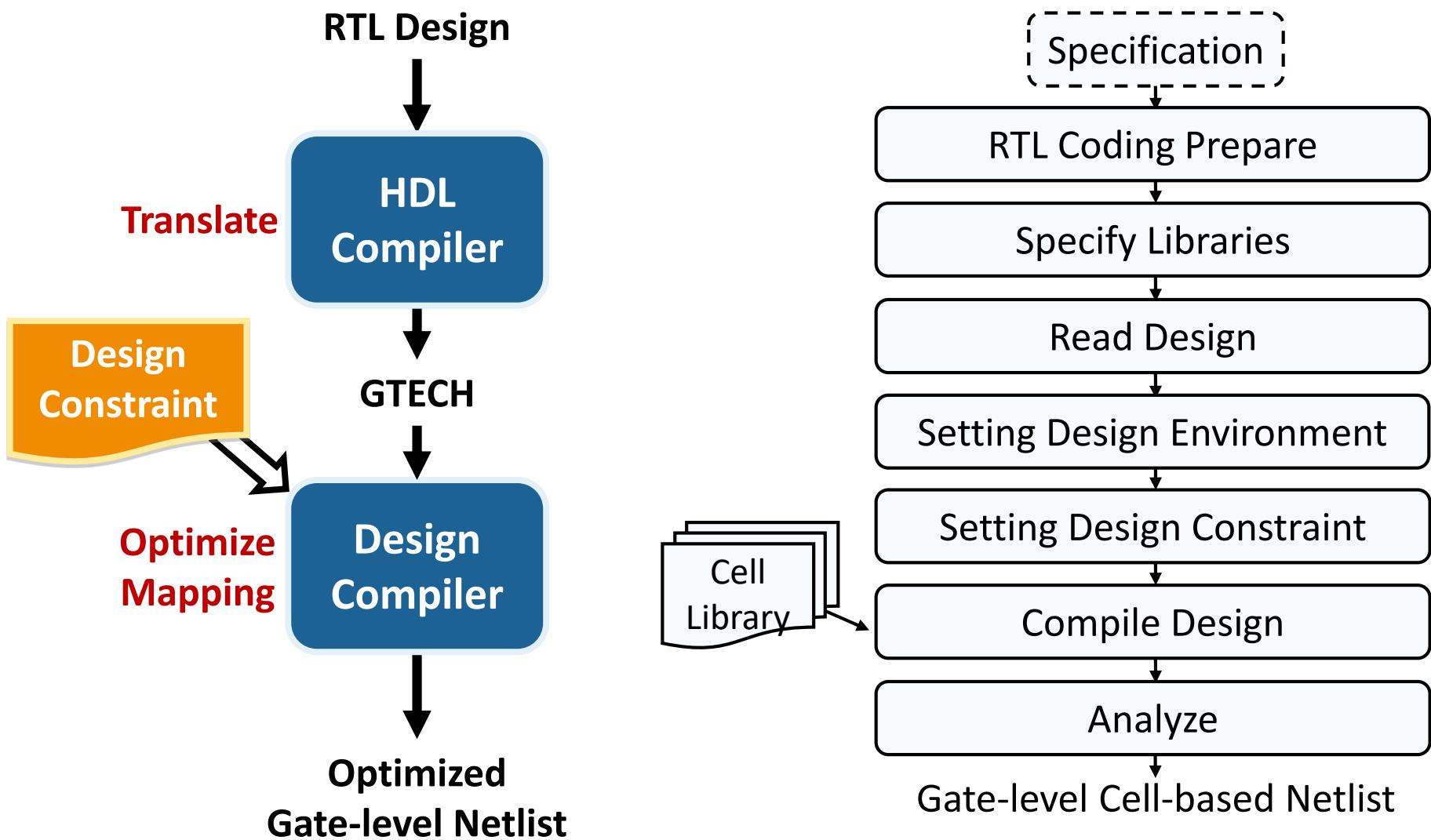
Timing Info.  
Constraints

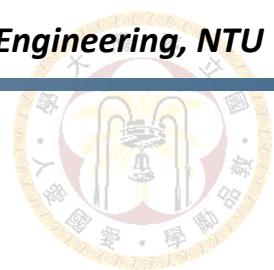


Target Technology



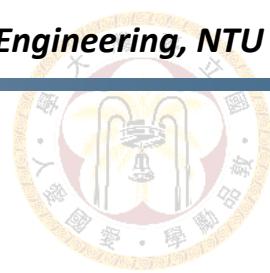
# Recap: Synthesis Design Flow





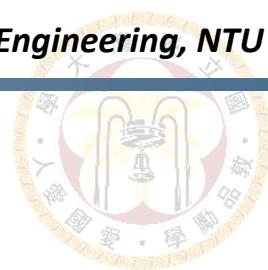
# Outline

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



# Outline

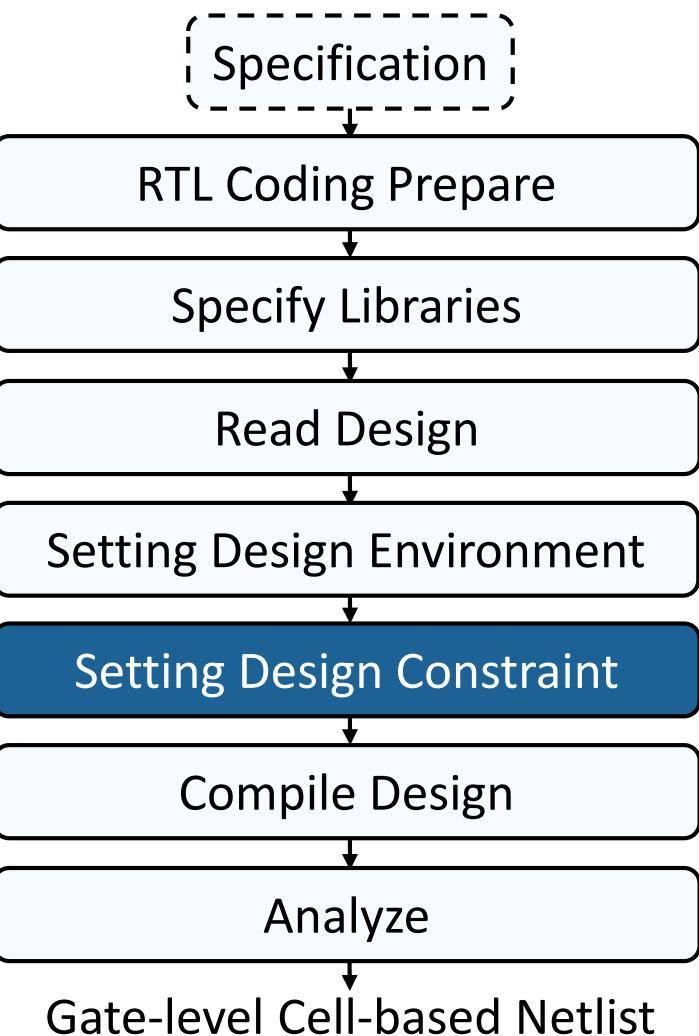
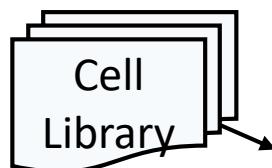
- Introduction
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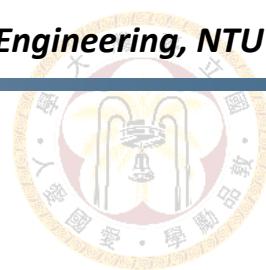


# Synthesis Design Flow

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

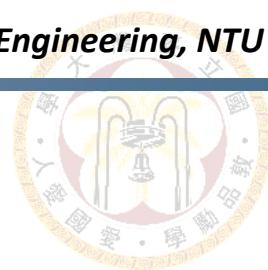
```
# Design Rule Constraints  
set_max_transition  
set_max_fanout  
set_max_capacitance
```





# Design Rule Constraints

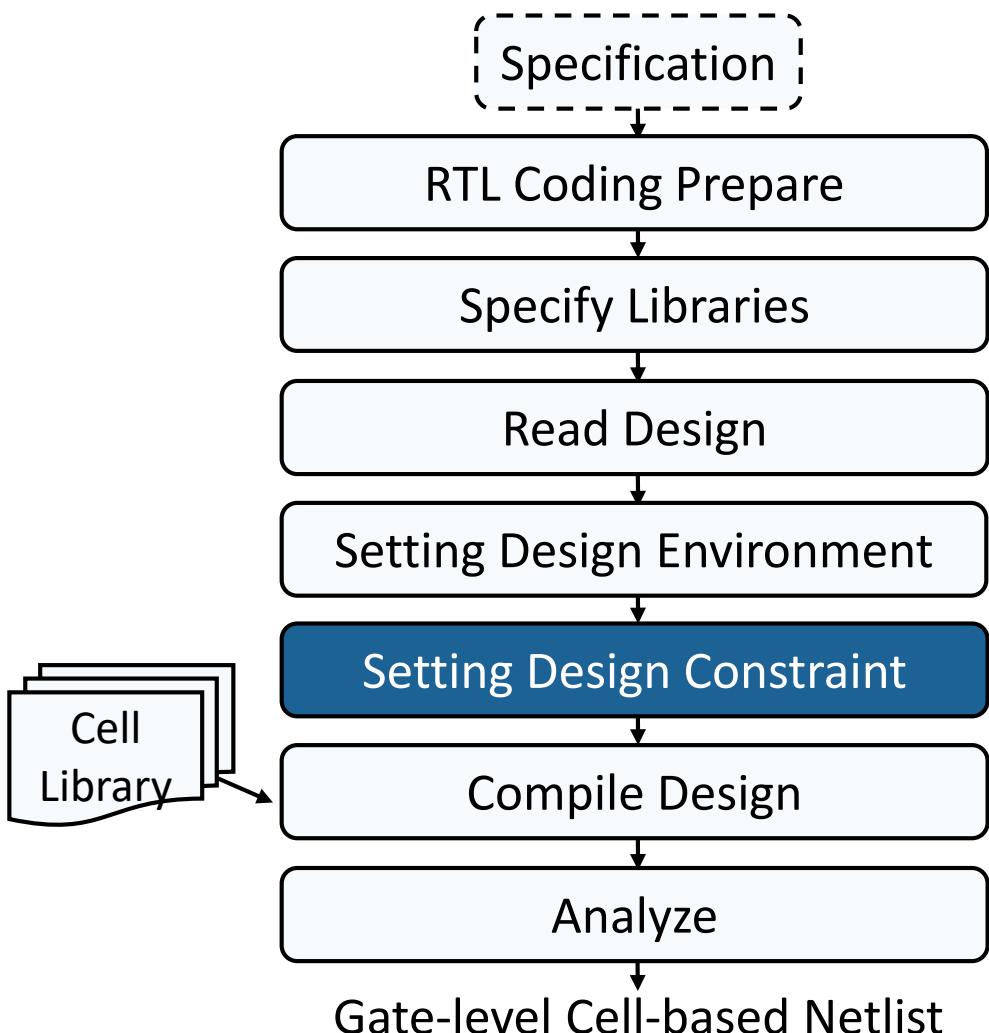
- Design rules constraints can't be violated at any cost, even if it will violate the timing and area goal.
- Three kinds of design rule constraint are set:
  - Maximum transition through a net, the longest time to drive a pin and change its value  
`set_max_transition 0.1`
  - Maximum capacitive load of a net, is total capacitive load(net) that an output pin can drive  
`set_max_capacitance 0.1`
  - Maximum fanout of each gate,  $\Sigma \text{fanout\_load} \leq \text{max\_fanout}$   
`set_max_fanout 20`

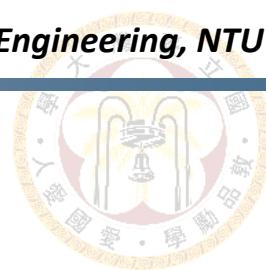


# Synthesis Design Flow

- Set constraints for synthesis
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  - Optimization objective

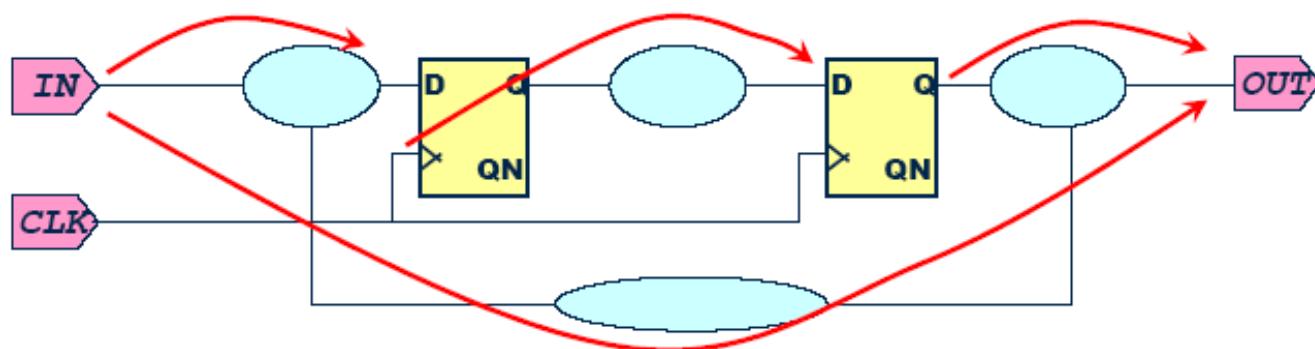
```
# Clock Constraints
create_clock
set_fix_hold
set_dont_touch_network
set_ideal_network
set_clock_uncertainty
set_clock_latency
set_input_transition
set_clock_transition
```

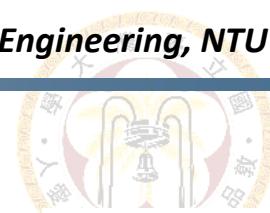




# Recall: Timing Path

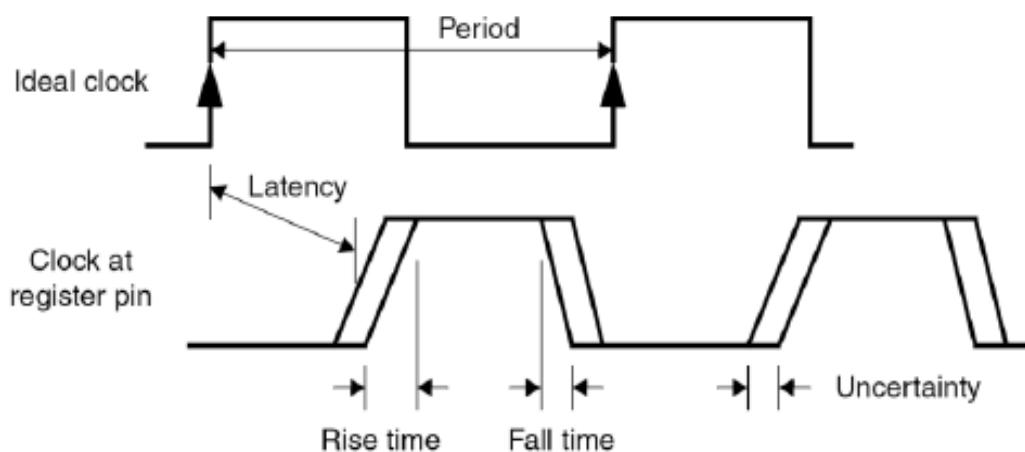
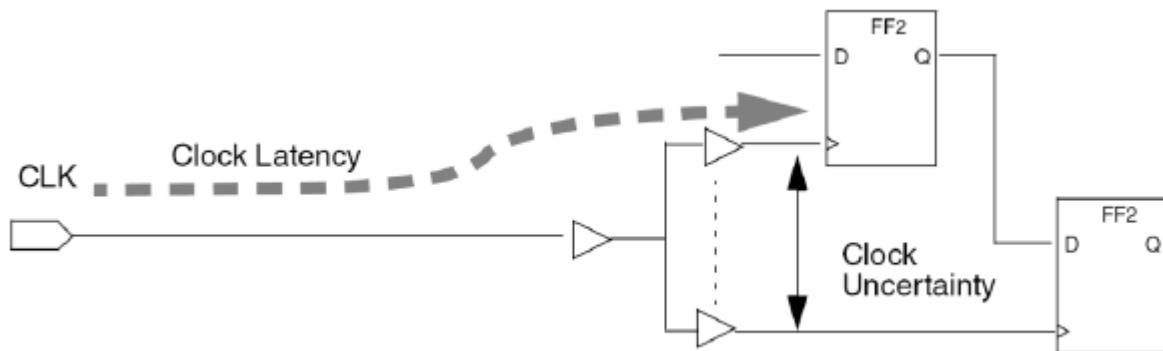
- Generally each timing path is analyzed for timing constraints when compiling
- 4 type of timing paths
  - Input to register
  - Register to register
  - Register to output
  - Input to output

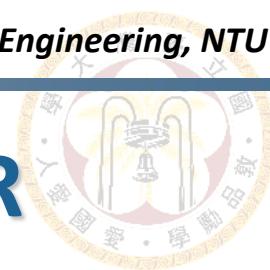




# Basic Clock Constraints

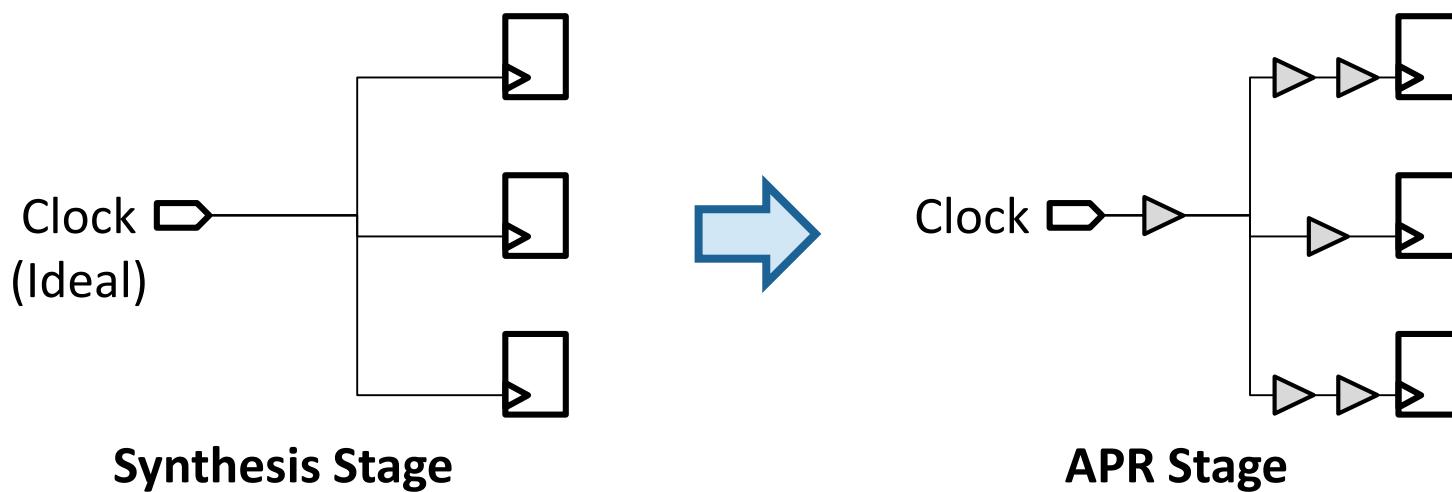
- Period
- Waveform
- Uncertainty
  - Skew
  - Jitter
- Latency
  - Source latency (optional)
  - Network latency
- Transition
  - Clock transition
  - Input transition

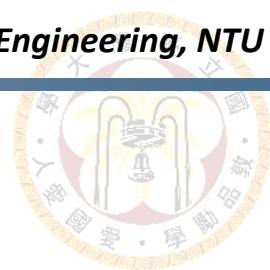




# Clock Modeling in Synthesis & APR

- Clock modeling in automatic place and route (APR) stage
  - Clock tree synthesis is performed
  - A buffer/inverter tree is built for the clock signal
  
- Clock modeling in synthesis stage
  - Ideal network + clock uncertainty + clock latency

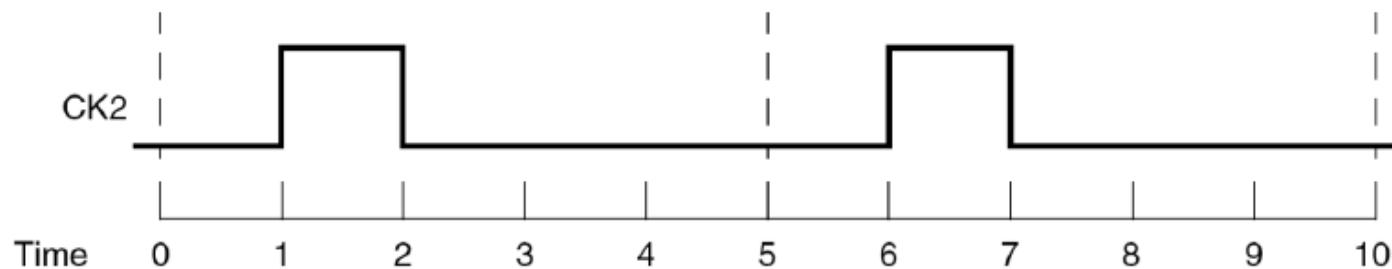


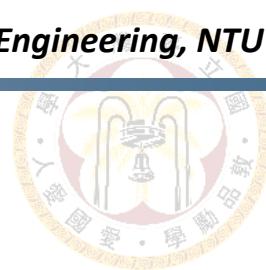


# 1. Create Clock

## ■ Default clock characteristics (ideal clock):

- 0 delay at clock port
- 0 propagation delay
- 0 transition delay
- 0 uncertainty





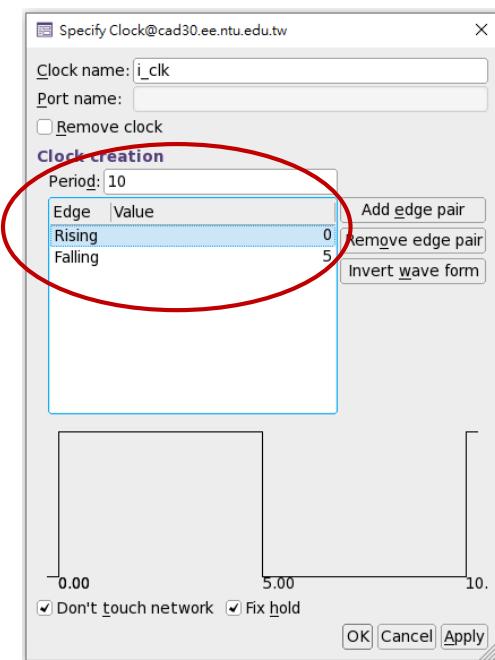
# 1. Create Clock

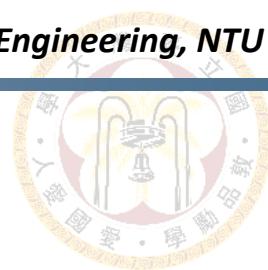
## ■ Arguments

- Name: name for the clock
- Period: period of the clock, value  $\geq 0$
- Waveform: alternating rise, fall times for 1 period
  - Must have even number of values
  - Default: {0 period/2}

## ■ Attributes/Specify Clock

```
create_clock -name clk -period 10 \
             -waveform {0 5} [get_ports clk]
```





# 1. Create Clock

## Arguments

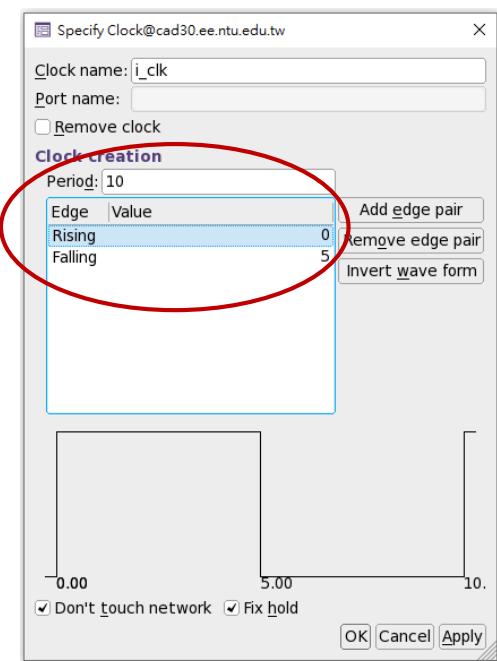
- Name: name for the clock
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- Waveform: alternating rise, fall times for 1 period
  - Must have even number of values
  - Default: {0 period/2}

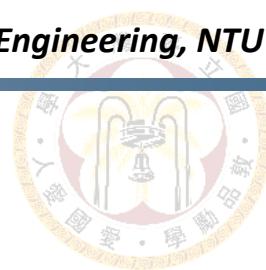
## Attributes/Specify Clock

```
create_clock -name clk_1 -period 10 \
-waveform {0 5} [get_ports clk]
```

Port name to apply clock & clock name can be different  
**(not suggested)**

```
get_clocks clk_1
get_ports clk
```

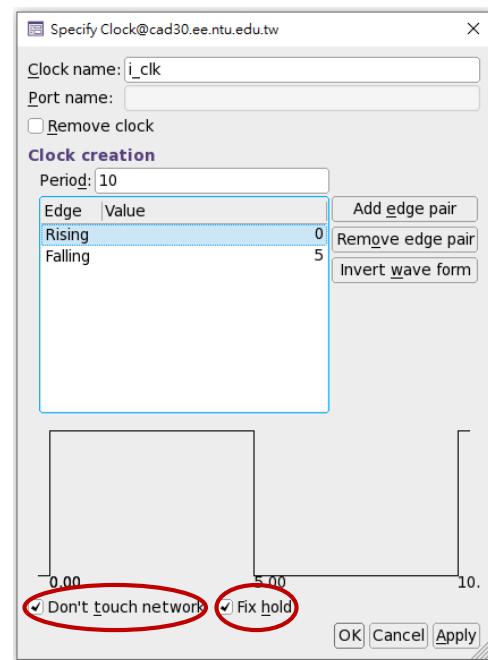


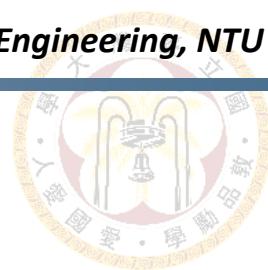


## 2. Specify Clock Constraints

- set\_fix\_hold
  - Respect hold time requirement of all clocked flip-flops
- set\_dont\_touch\_network
  - Do not re-buffer clk network
- set\_ideal\_network
  - No delay on specified net
  - Can be applied on clk, asyn reset, high fanout nets

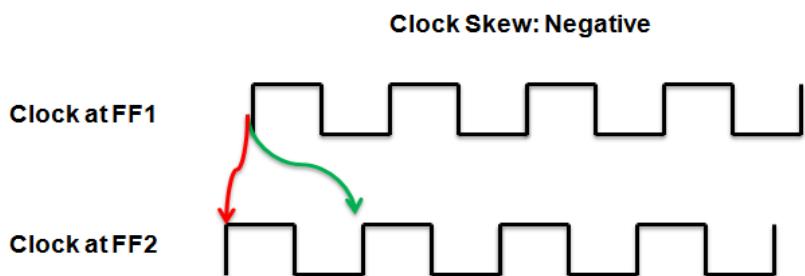
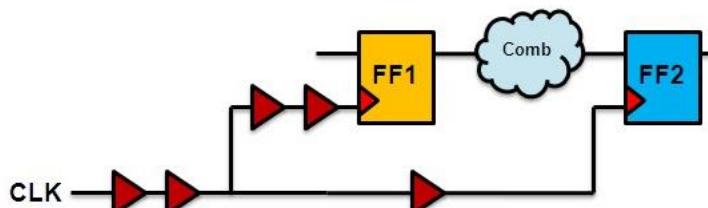
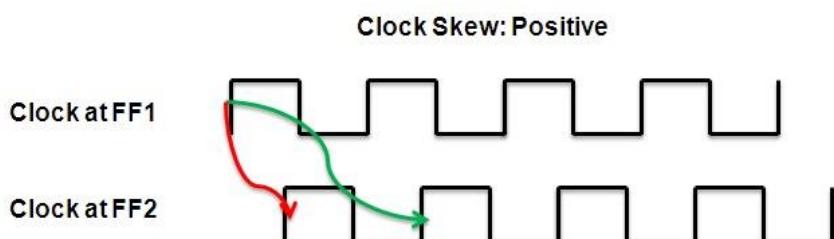
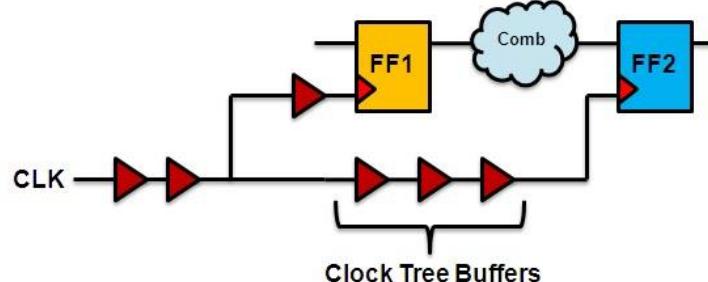
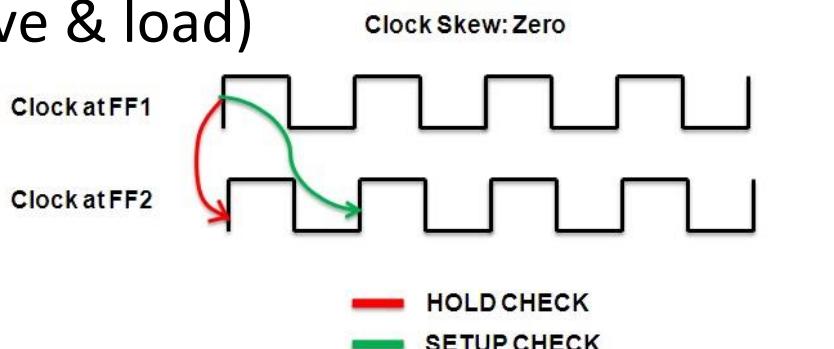
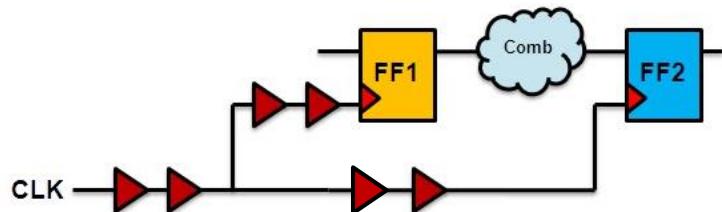
```
set_fix_hold [get_clocks clk]
set_dont_touch_network [get_clocks clk]
set_ideal_network [get_ports clk]
```

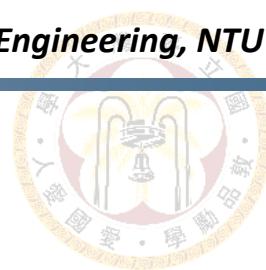




# Clock Uncertainty: Skew

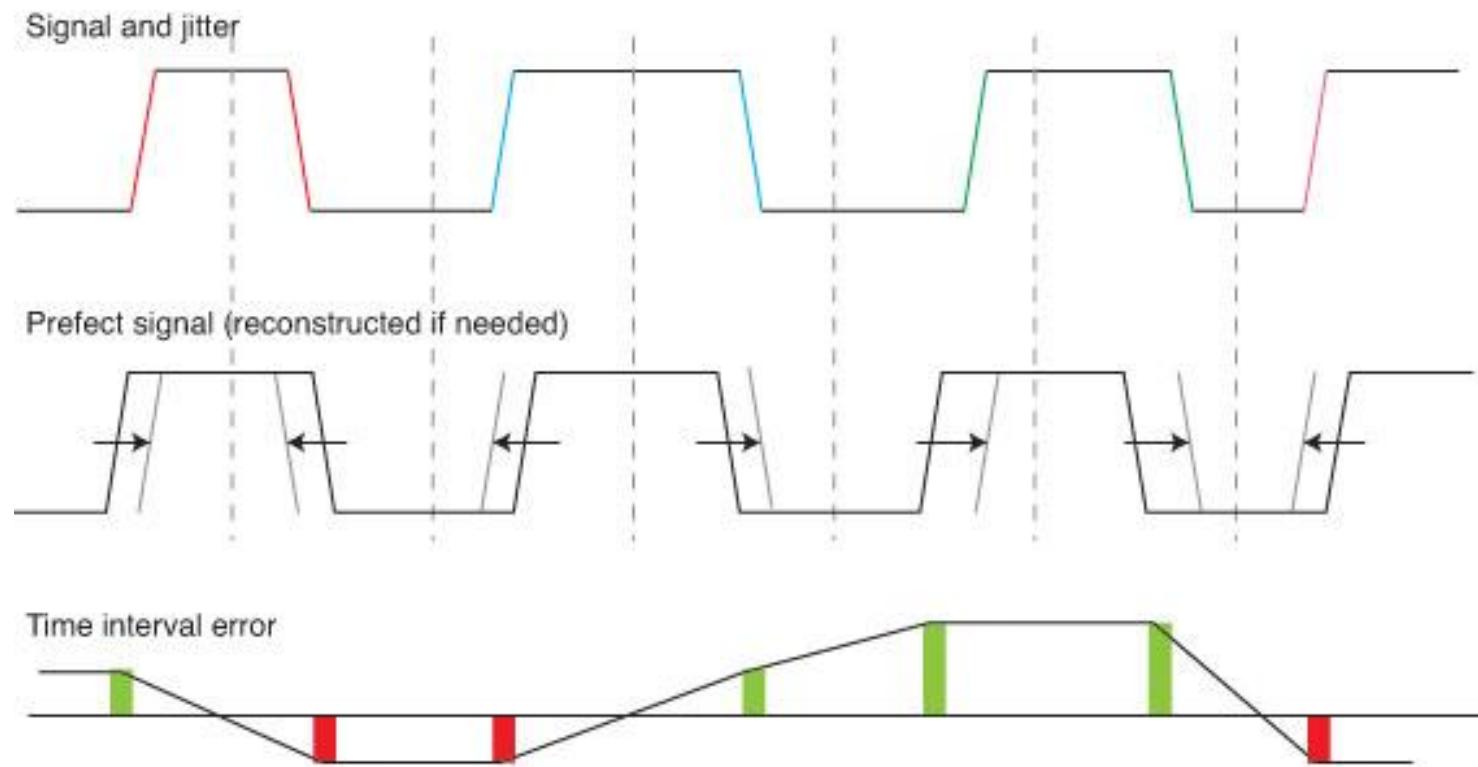
- The **spatial variation in arrival time** of a clock transition on an integrated circuit (different drive & load)

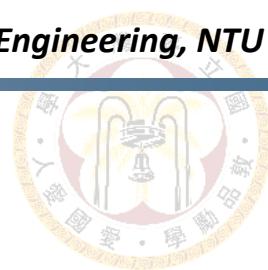




# Clock Uncertainty: Jitter

- The **temporal variation** of the clock period at a given point on an integrated circuit. (crystal oscillator variation)



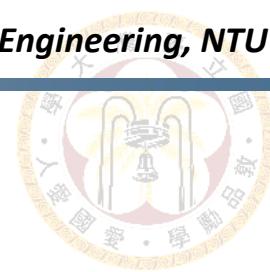


### 3. Setting Clock Uncertainty

- Variation in clock arrival time
  - Models clock skew + jitter effects on the clock
  - Experience
    - Small circuits: 0.1ns
    - Large circuits: 0.3ns

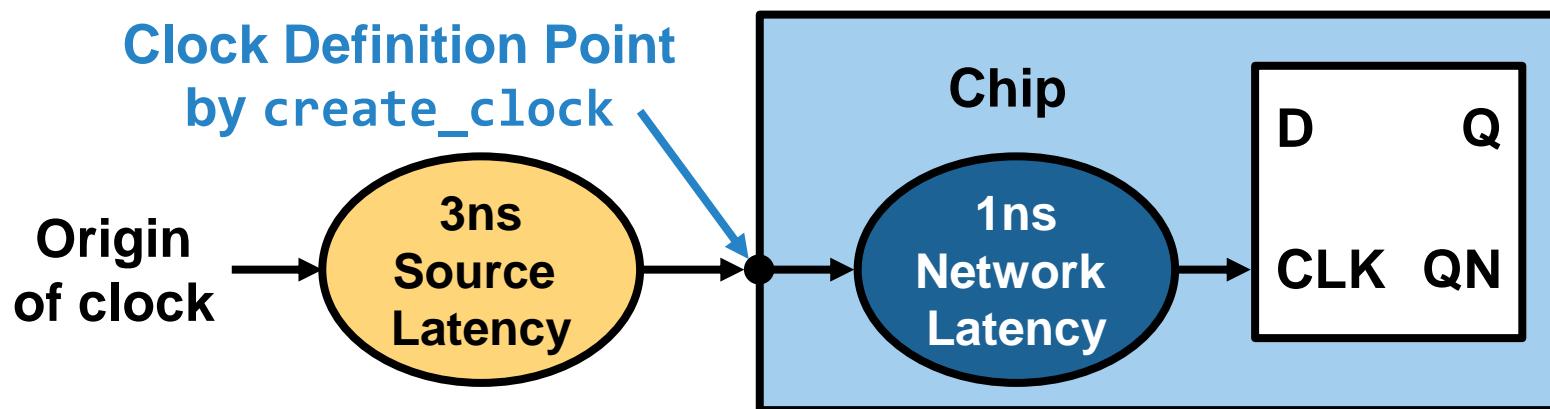
```
set_clock_uncertainty 0.1 [get_clocks clk]
```

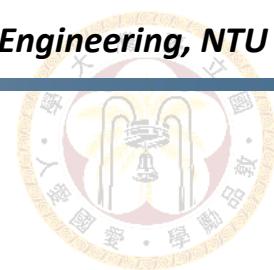
memory_8k_64_2r_2c/aru/U488/Y (MXI4X1)	0.40	10.69	r
memory_8k_64_2r_2c/aru/U566/Y (NOR2X1)	0.09	10.77	f
memory_8k_64_2r_2c/aru/data_in_sc[0] (aru)	0.00	10.77	f
memory_8k_64_2r_2c/sc_memory/D[0] (sc_memory)	0.00	10.77	f
data arrival time		10.77	
clock clk (rise edge)	10.00	10.00	
clock network delay (ideal)	1.00	11.00	
clock uncertainty	-0.10	10.90	
memory_8k_64_2r_2c/sc_memory/CLK (sc_memory)	0.00	10.90	r
library setup time	-0.12	10.78	
data required time		10.78	
<hr/>			
data required time		10.78	
data arrival time		-10.77	
<hr/>			
slack (MET)	0.00		



# Clock Network Latency

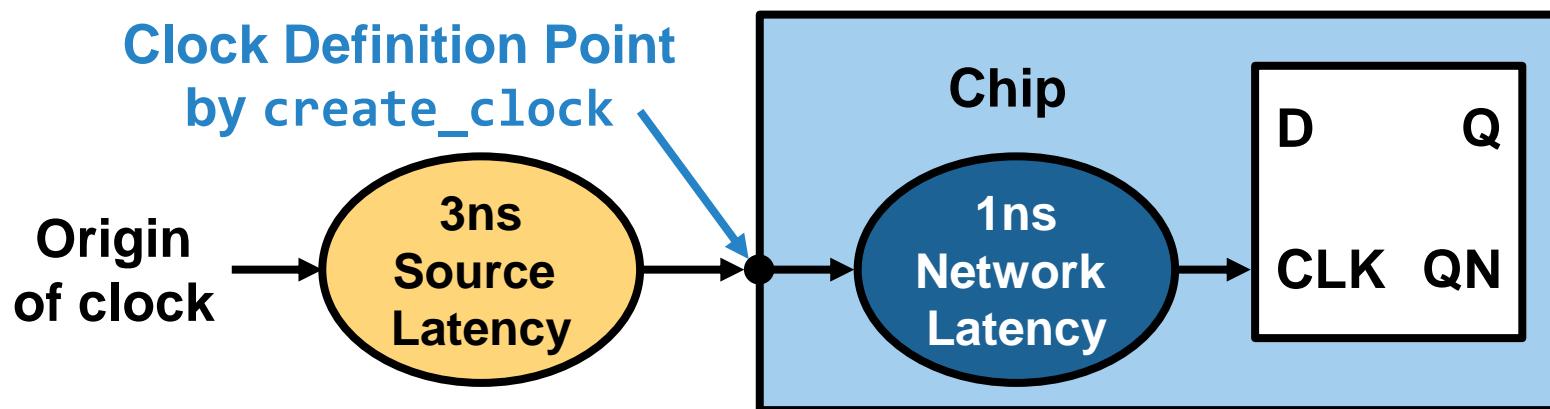
- The time it takes for clock signal to propagate **from the clock definition point to a register clock pin**
  - Clock definition by `create_clock` command
- Affects the slack of in-to-reg & reg-to-out paths

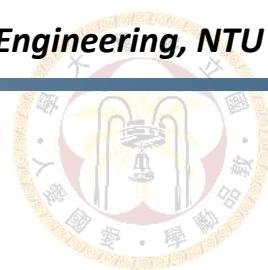




# Clock Source Latency (Optional)

- The time it takes for a clock signal to propagate from its origin point to the clock definition point
- May help in multi-clock design





## 4. Setting Clock Latency

### ■ Network latency

```
set_clock_latency 0.5 [get_clocks clk]
```

```
set_clock_latency -fall 0.5 [get_clocks clk]
```

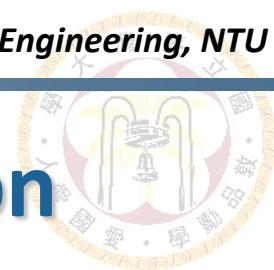
```
set_clock_latency -rise 0.5 [get_clocks clk]
```

### ■ Source latency (optional)

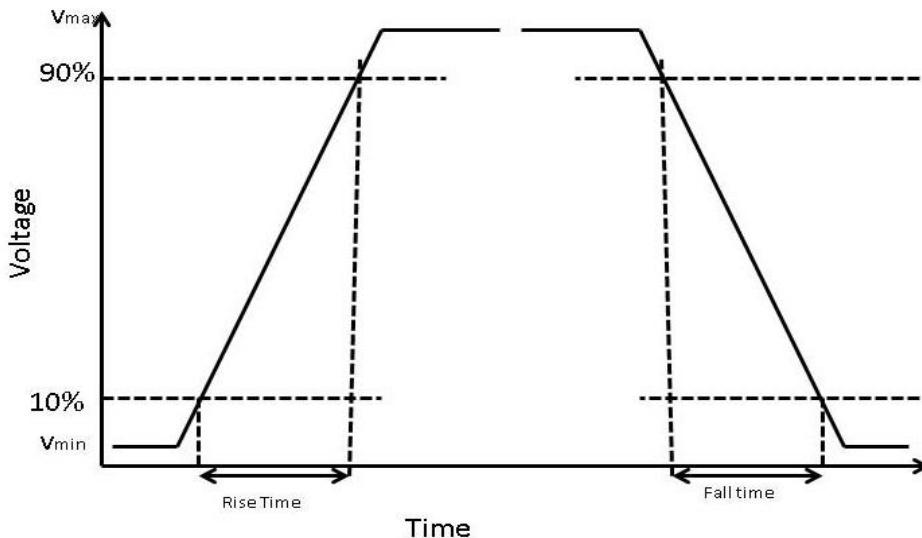
```
set_clock_latency 1.5 -source [get_clocks clk]
```

```
set_clock_latency 1.5 -source -early [get_clocks clk]
```

```
set_clock_latency 1.5 -source -late [get_clocks clk]
```



# 5 & 6. Setting Clock/Input Transition



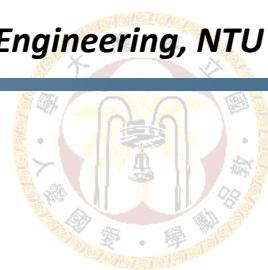
## Clock transition

```
set_clock_transition 0.1 [get_clocks clk]
```

```
set_clock_transition 0.1 -fall [get_clocks clk]  
set_clock_transition 0.2 -rise [get_clocks clk]
```

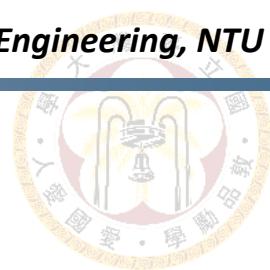
## Input Transition

```
set_input_transition 0.5 [all_inputs]
```



# Constraints for APR

- Synthesis uses approximated models for clock & wires
  - Clock: ideal network + clock uncertainty + clock latency
  - Wire: wire load model (estimates R, C, A based on fanout)
  
- In automatic placement & routing (APR) stage
  - Clock tree synthesis (CTS) for a more accurate clock model
  - Routing generates physical layout of wires



# Constraints for APR

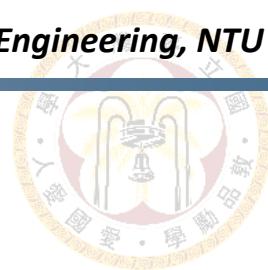
- Some constraints should be removed before APR

```
# set_wire_load_model -name tsmc18_w10 -library slow
# set_wire_load_mode top

create_clock -period 10      [get_ports clk]
set_fix_hold                 [get_clocks clk]

# set_dont_touch_network     [get_clocks clk]
# set_ideal_network          [get_ports clk]
# set_clock_uncertainty 0.1   [get_ports clk]
# set_clock_latency 0.5       [get_clocks clk]

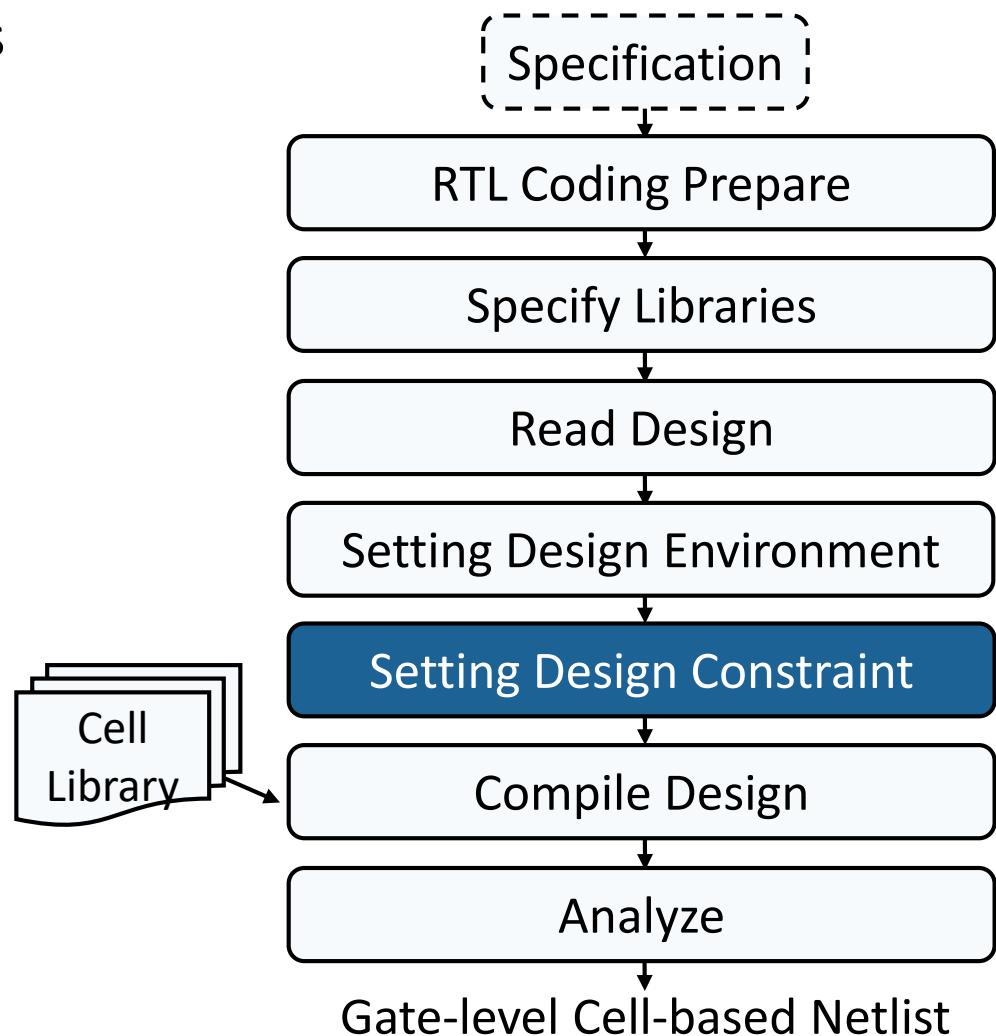
set_clock_transition 0.1     [get_clocks clk]
set_input_transition 0.5     [all_inputs]
```

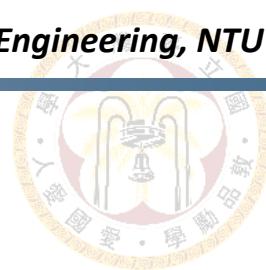


# Synthesis Design Flow

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

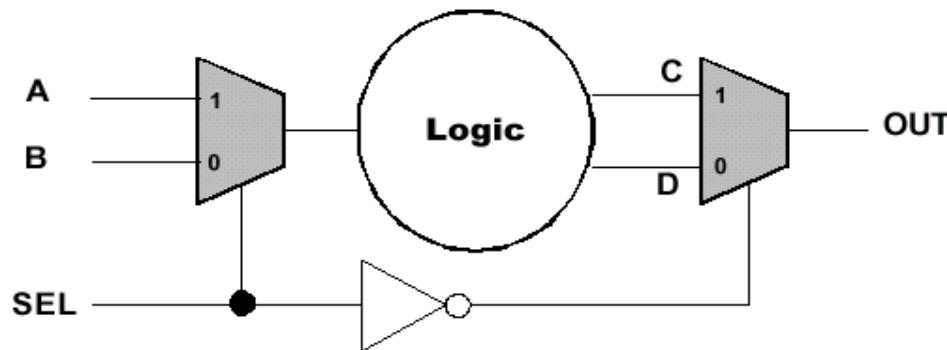
```
# Special Circuits  
set_false_path  
replace_clock_gates  
  
# Optimization Objective  
set_max_area
```



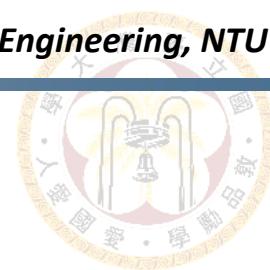


# False Path

- Timing path that we wish to **ignore timing constraints**
- Command `set_false_path` disables timing-based synthesis for specified path
- It is useful for:
  - Constraining asynchronous paths
  - Constraining logically false paths



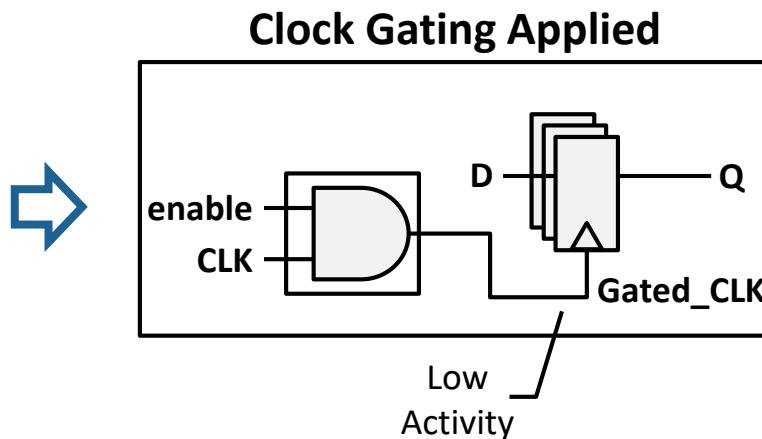
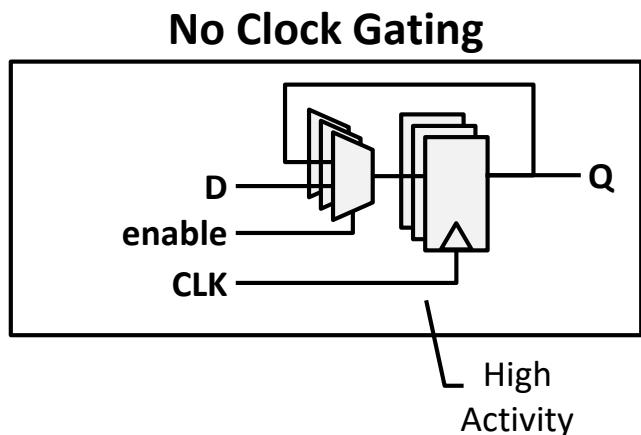
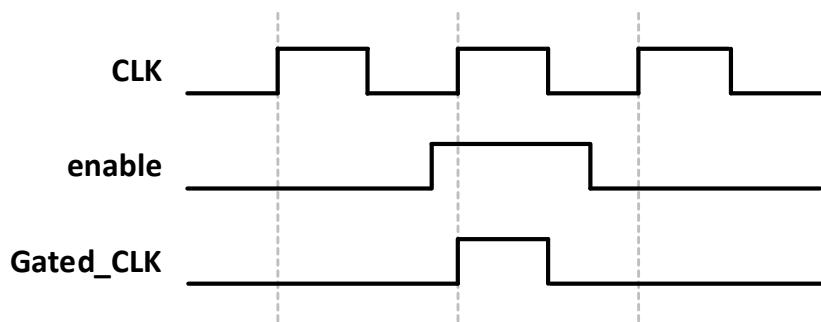
```
set_false_path -from {A} -through {C} -to {OUT}
set_false_path -from {B} -through {D} -to {OUT}
```

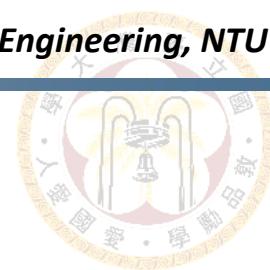


# Clock Gating (CG) Concept (1/2)

- Concept: clock signal arrives only when data is to be switched
  - Reduce dynamic power dissipation

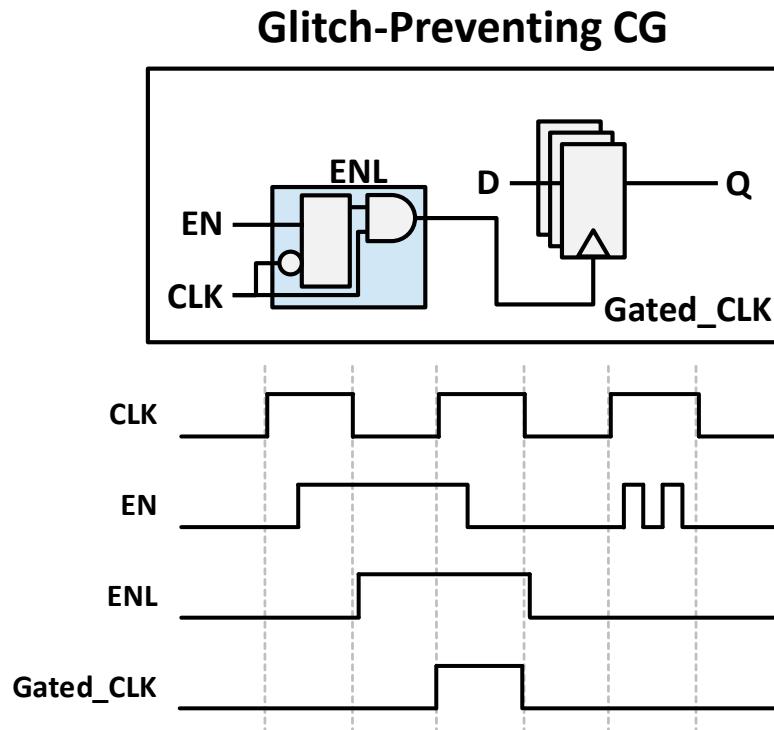
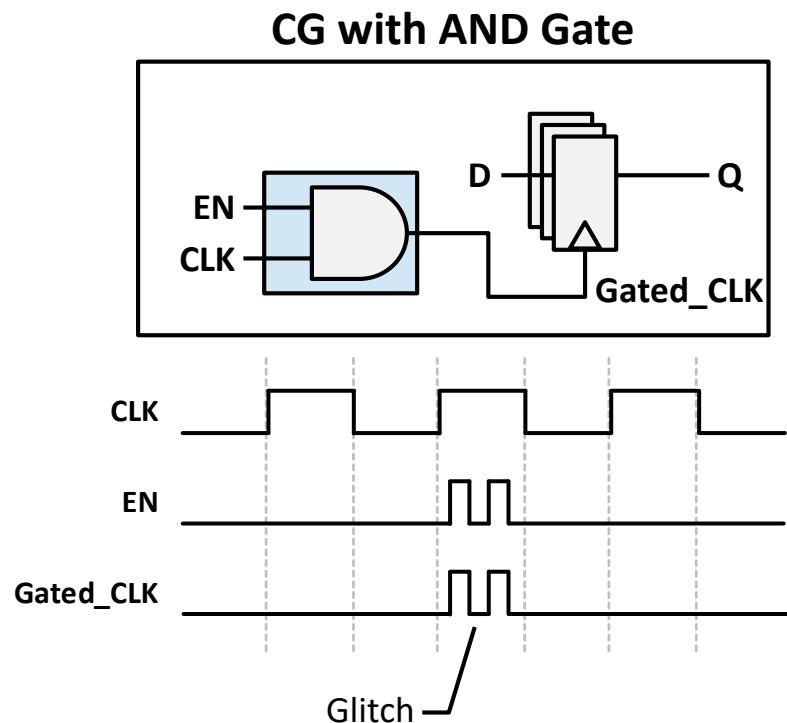
```
always@(posedge clk) begin
    if (enable) Q <= D;
    else         Q <= Q;
end
```

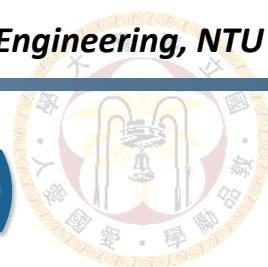




# Clock Gating (CG) Concept (2/2)

- Unstable enable signal causes glitch on clock gating output
- Glitch prevention: enable generated by **latch with negative clk**





# Clock Gating Commands (Auto CG)

## If Statement

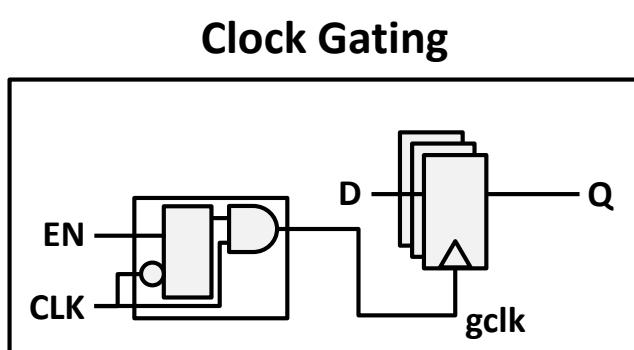
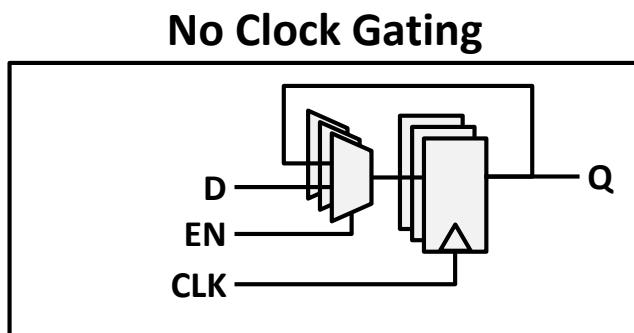
```
always@(posedge clk) begin
    if (enable) Q <= D;
    else          Q <= Q;
end
```

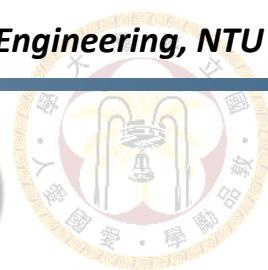
## Conditional Assignment

```
always@(posedge clk) begin
    Q <= (enable)? D:Q;
end
```

## Clock gating example script

```
set_clock_gating_style \
    -max_fanout 4 \
    -pos integrated \
    -control_point before \
    -control_signal scan_enable
compile -gate_clock
```





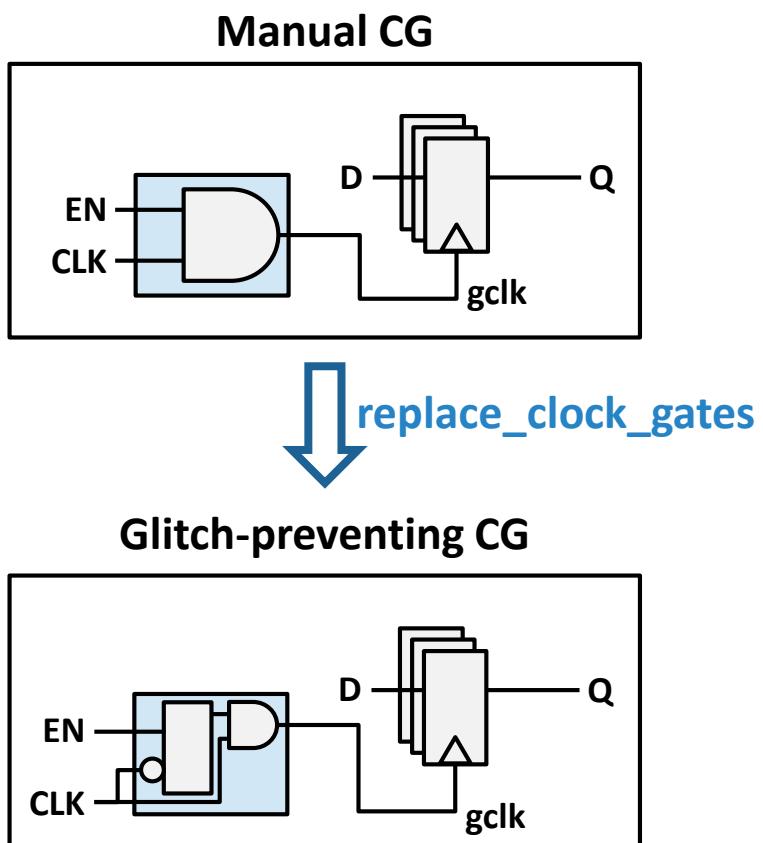
# Clock Gating Commands (Manual)

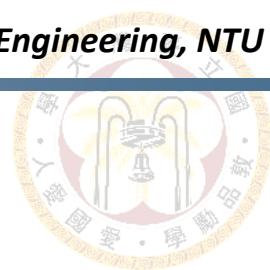
- User manually defined gated clock signal

```
// Note: `define SYN in synthesis
assign gclk = clk & enable;
`ifdef SYN
    always@(posedge gclk) begin
        Q <= D;
    end
`else
    always@(posedge clk) begin
        if (enable) Q <= D;
    end
`endif
```

- Clock gating example script

```
set_clock_gating_style ...
replace_clock_gates
compile
```





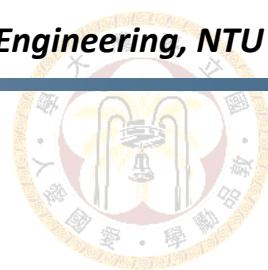
# Report Clock Gating

## report\_clock\_gating -gating\_elements

Clock Gating Report by Origin	
	Actual (%) Count
Number of tool-inserted clock gating elements	54 (100.00%)
Number of pre-existing clock gating elements	0 (0.00%)
Number of gated registers	214 (99.53%)
Number of tool-inserted gated registers	214 (99.53%)
Number of pre-existing gated registers	0 (0.00%)
Number of ungated registers	1 (0.47%)
Number of registers	215

## report\_clock\_gating -ungated

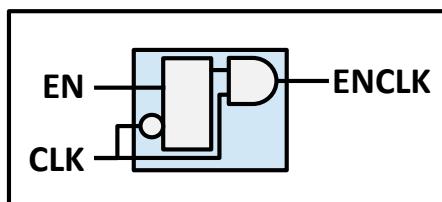
Ungated Register Report			
Ungated Register	Reason	What Next?	
reg_enable_reg	Always enabled register	-	
Tool-inserted ungated reasons			
Reason for not gating	Regs	Regs %	Bits
Always enabled register	1	100.00	1
			100.00



# Using Integrated CG (ICG) Cell

- Identify CG cell to use in `set_clock_gating_style -pos`
- Pos: specify CG cell for posedge triggered FFs
  - And (default): DC selects gates to form CG cell
  - Integrated: foundry-provided ICG cell

```
set_clock_gating_style \
    -pos {and | integrated}
compile -gate_clock
```



**Gate-level Netlist:  
Gates Selected by DC**

```
module SNPS_CLOCK_GATE_HIGH_top_2 ( CLK, EN, ENCLK );
  input CLK, EN;
  output ENCLK;
  wire net350;

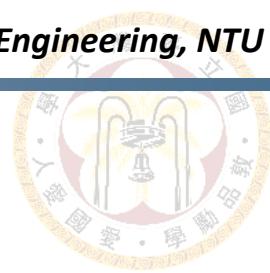
  TLATNX1 latch ( .D(EN), .GN(CLK), .Q(net350) );
  AND2X1 main_gate ( .A(net350), .B(CLK), .Y(ENCLK) );
endmodule
```

**Gate-level Netlist:  
Integrated CG Cell from TSMC**

```
module SNPS_CLOCK_GATE_HIGH_top_2 ( CLK, EN, ENCLK );
  input CLK, EN;
  output ENCLK;

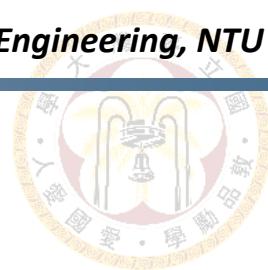
  TLATNCAX2 latch ( .E(EN), .CK(CLK), .ECK(ENCLK) );
endmodule
```

**Better Power/Performance/Area**



# Other Special Circuits

- Multi-cycle path
- Positive & negative edge clock trigger
- Multiple clocks design

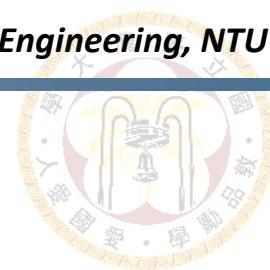


# Setting Power Constraint

- Make DC to minimize power for the design
- These commands are deprecated, DC minimizes power by default

```
set_max_dynamic_power 0 uw
```

```
set_max_leakage_power 0 uw
```



# Setting Area Constraint

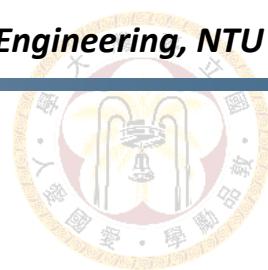
- ***Attributes / Optimization Constraints / Design Constraints***
- Area unit (find the unit definition in technology library):
  - Equivalent gate counts
    - Gate counts = Chip Area / **NAND2** Area
  - $\mu\text{m} \times \mu\text{m}$
  - Transistor count (number of transistors)
- If we want to minimize the chip area

```
set_max_area 0
```



Cell Size (In TSMC CL018G process)

Drive Strength	Height ( $\mu\text{m}$ )	Width ( $\mu\text{m}$ )
NAND2XL	5.0	2.0
NAND2X1	5.0	2.0
NAND2X2	5.0	3.3
NAND2X4	5.0	4.6



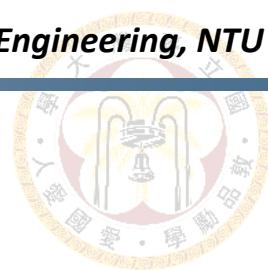
# Constraints Priority

- During the optimization, there exists a constraint priority relationship
  - Design Rule Constraints (max\_transition, max\_fanout, max\_capacitance)
  - Timing constraints (max\_delay, min\_delay)
  - Power
  - Area
- There exists a trade-off between constraints
- Use set\_cost\_priority to modify the order (optional)

```
set_cost_priority -default
```

```
set_cost_priority -delay
```

```
set_cost_priority {max_fanout max_capacitance max_delay}
```



# Check Design/Check Timing

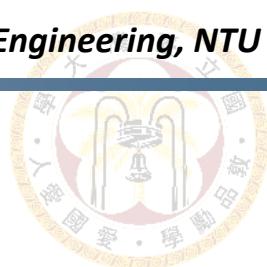
- After you set up the design attributes & design constraints, we recommend the next step is to check design

```
check_design > Report/check_design.txt
```

- Verify there are no remaining unconstrained paths

```
check_timing > Report/check_timing.txt
```

- *Design/Check Design*

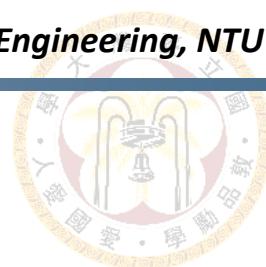


# Example of Check Design

```
*****
check_design summary:
Version:      R-2020.09-SP5
Date:        Tue Dec 20 17:14:21 2022
*****
```

Name	Total
<hr/>	
Inputs/Outputs	2
Unconnected ports (LINT-28)	2
<hr/>	
Cells	7
Cells do not drive (LINT-1)	7
<hr/>	

```
Warning: In design 's4_BUU_unfold', cell 'B_32' does not drive any nets. (LINT-1)
Warning: In design 's4_BUU_unfold', cell 'B_33' does not drive any nets. (LINT-1)
Warning: In design 's4_BUU_unfold', cell 'B_34' does not drive any nets. (LINT-1)
Warning: In design 's4_BUU_unfold', cell 'B_35' does not drive any nets. (LINT-1)
Warning: In design 's4_BUU_unfold', cell 'B_36' does not drive any nets. (LINT-1)
Warning: In design 's4_BUU_unfold', cell 'B_37' does not drive any nets. (LINT-1)
Warning: In design 's4_BUU_unfold', cell 'B_38' does not drive any nets. (LINT-1)
Warning: In design 's4_BUU_unfold', port 'i_enable' is not connected to any nets. (LINT-28)
Warning: In design 's4_BUU_unfold', port 'i_clear' is not connected to any nets. (LINT-28)
```



# Example of Check Timing

```
Information: Checking out the license 'DesignWare'. (SEC-104)
Information: Updating design information... (UID-85)
```

```
Information: Checking generated_clocks...
```

```
Information: Checking loops...
```

```
Information: Checking no_input_delay...
```

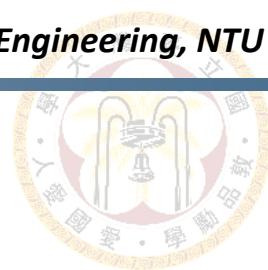
```
Information: Checking unconstrained_endpoints...
```

```
Information: Checking pulse_clock_cell_type...
```

```
Information: Checking no_driving_cell...
```

```
Information: Checking partial_input_delay...
```

```
1
```



# Synthesis Design Flow

## ■ Optimization & mapping to gate-level netlist

- Solving multiple instances
- Compile Options
- Commands to compile

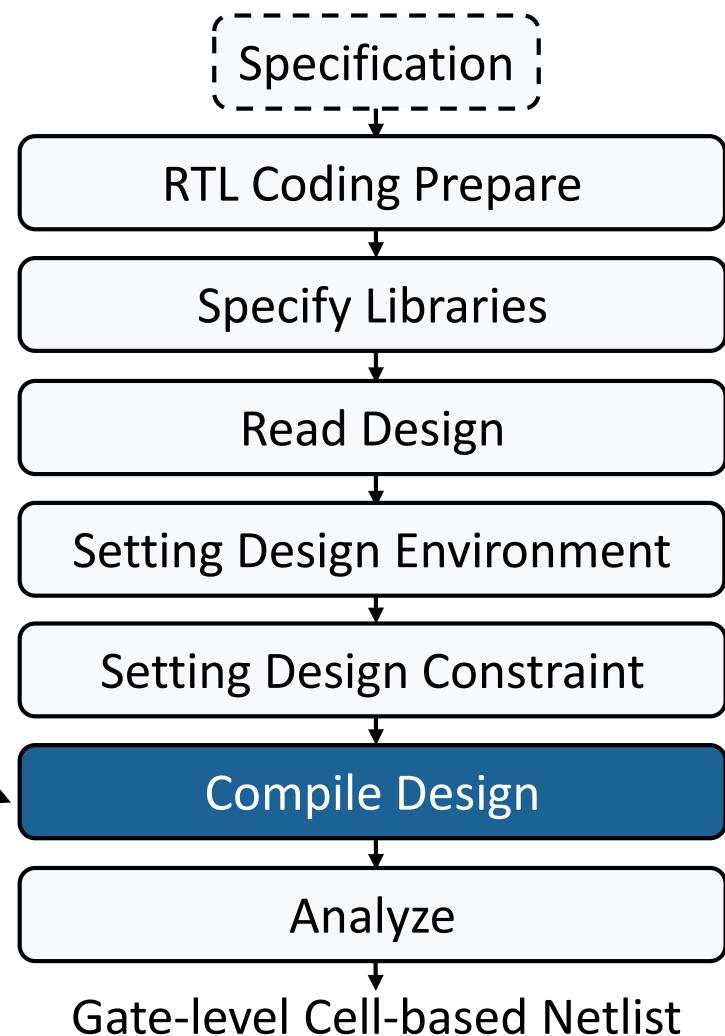
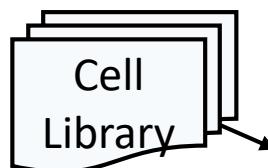
```
compile
```

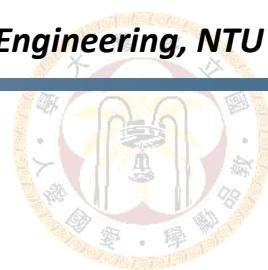
or

```
compile -inc
```

or

```
compile_ultra
```



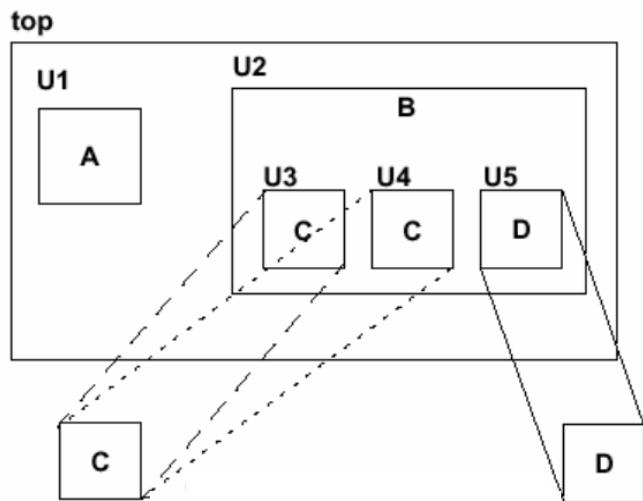


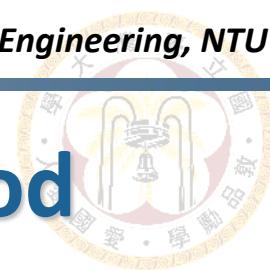
# Solving Multiple Instances

- In a hierarchical design, submodules are sometimes referenced by more than one cell instance
- Methods for solving multiple instances
  - Compile-once-don't-touch
  - Uniquify
  - Ungroup

```
module B (
    ...
    C U3(.pin1(w1), .pin2(w2));
    C U4(.pin1(w3), .pin2(w4));
    D U5(.pinA(w5), .pinB(w6));
    ...
) endmodule
```

Module C Referenced Twice

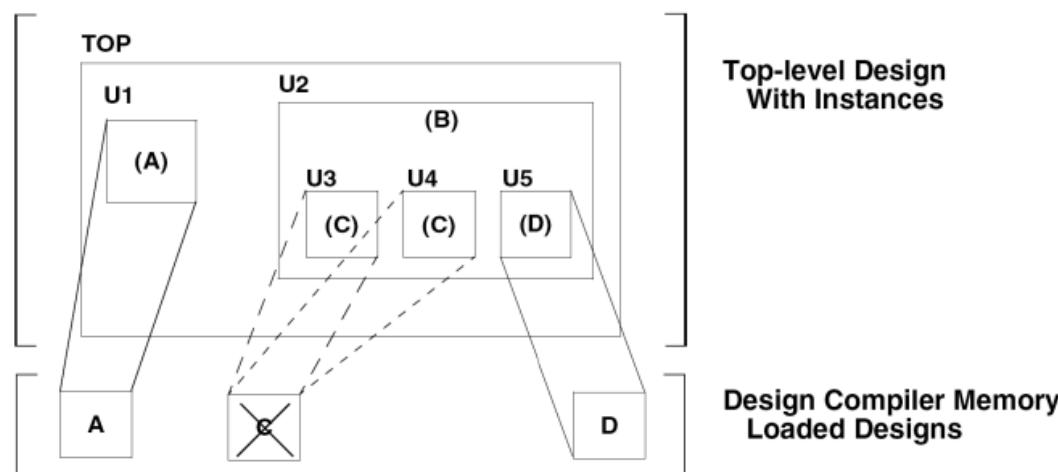




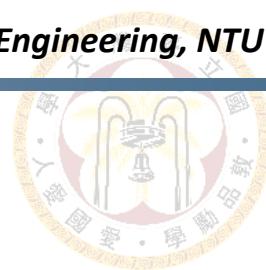
# 1. Compile-once-don't-touch Method

- Two steps:
  - Pre-compile the submodule
  - Set submodules as **don't touch** for compiling entire design
- **Attributes/Optimization Directives/Design & set Don't Touch**

- Pros
  - Less memory
  - Shorter compile time



```
set_dont_touch [$Cell_list]
```

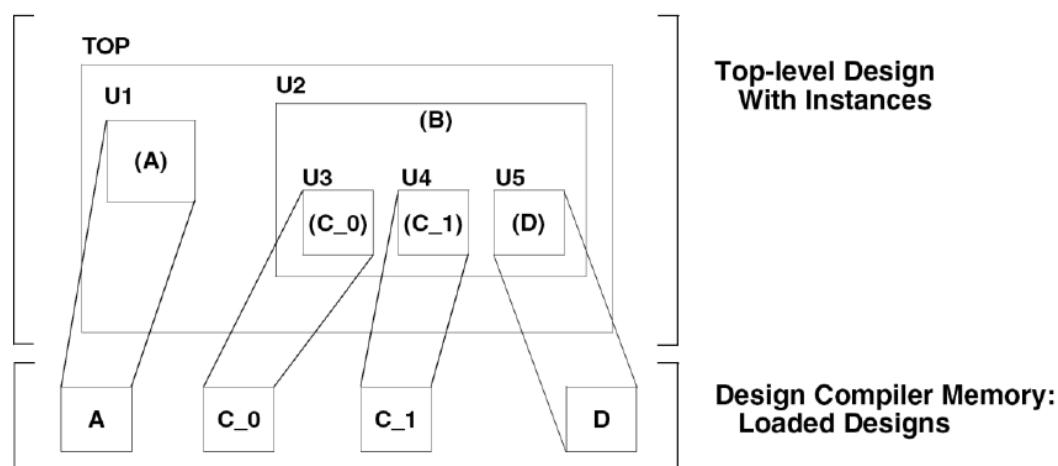


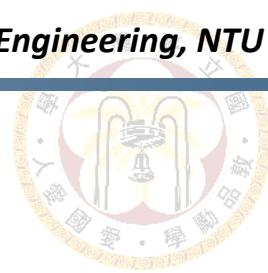
## 2. Uniquify Method

- Create an unique design for each instance, even if it is resolved from identical reference
- **Hierarchy of design is preserved**
- ***Hierarchy/Uniquify/Hierarchy***

- Pros and cons
  - More memory
  - Longer compile time
  - Better performance

**uniquify**

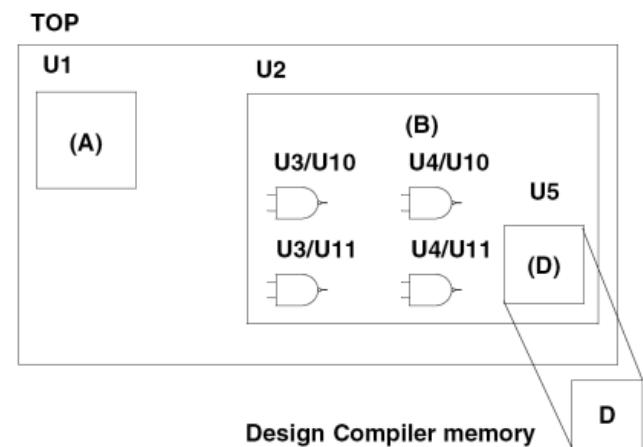


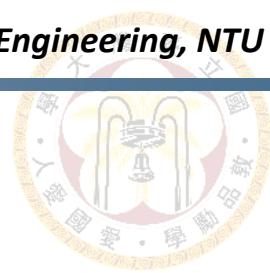


### 3. Ungroup Method

- The same effect as uniquify but it removes hierarchical levels
- **Hierarchy of design is broken.**
- ***Attributes/Optimization Directives/Design & set the Ungroup***
- Pros and cons
  - More memory
  - Longer compile time
  - Better performance
  - Removing user-defined design hierarchy

```
ungroup [$Cell_list]
```

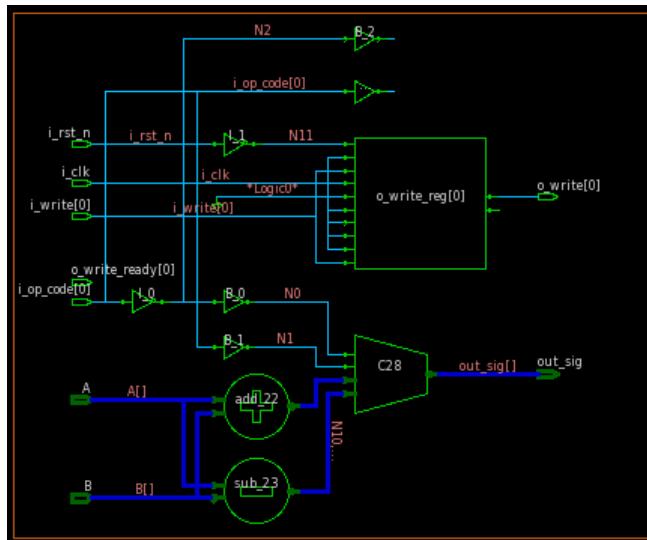




# Compile Design

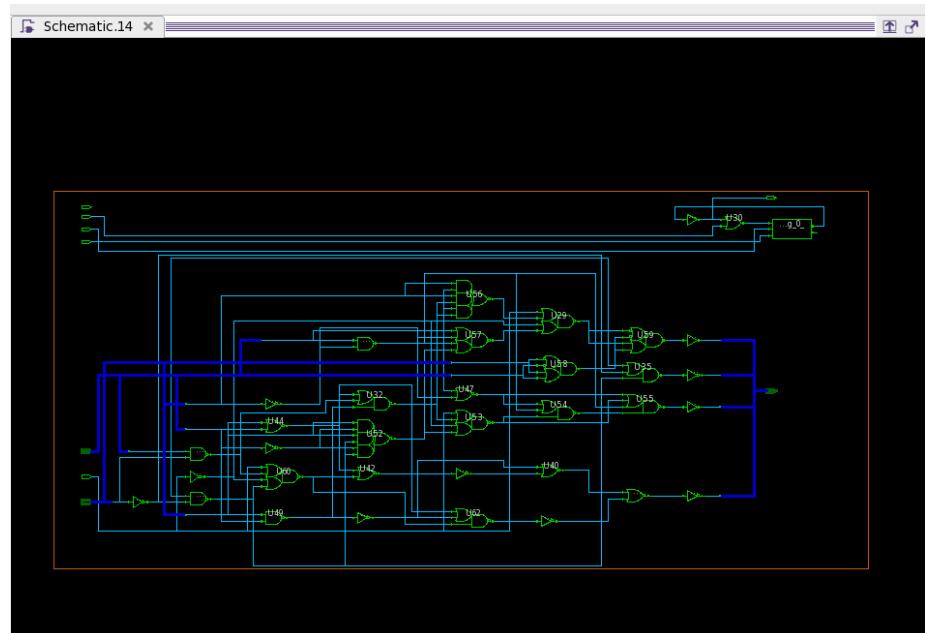
## Maps GTECH to gate-level netlist

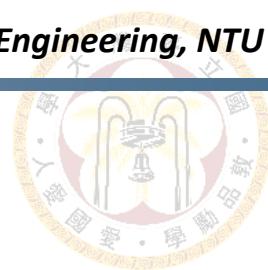
- Using cells from user-specified technology library (e.g., 0.18um TSMC)
- Optimized with area/timing constraints



Compile

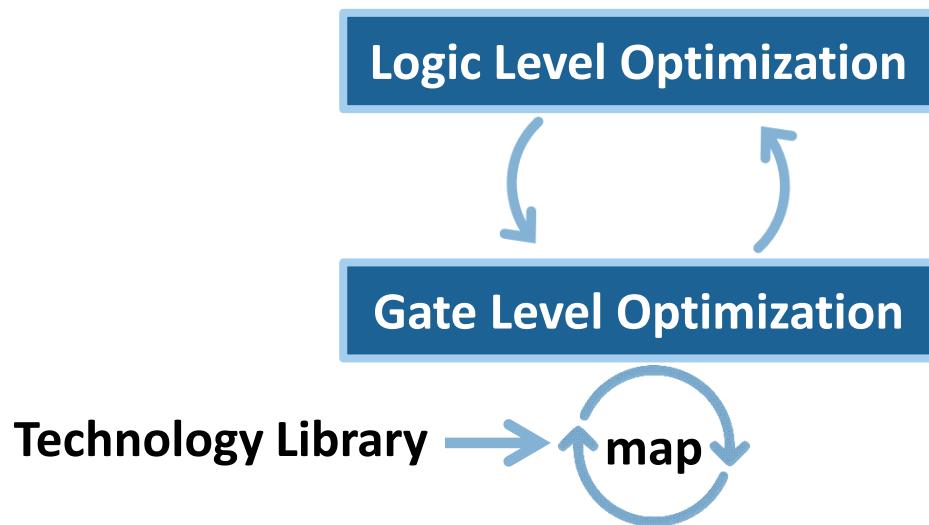
GTECH

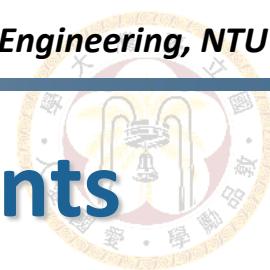




# Compile Concept: Optimization

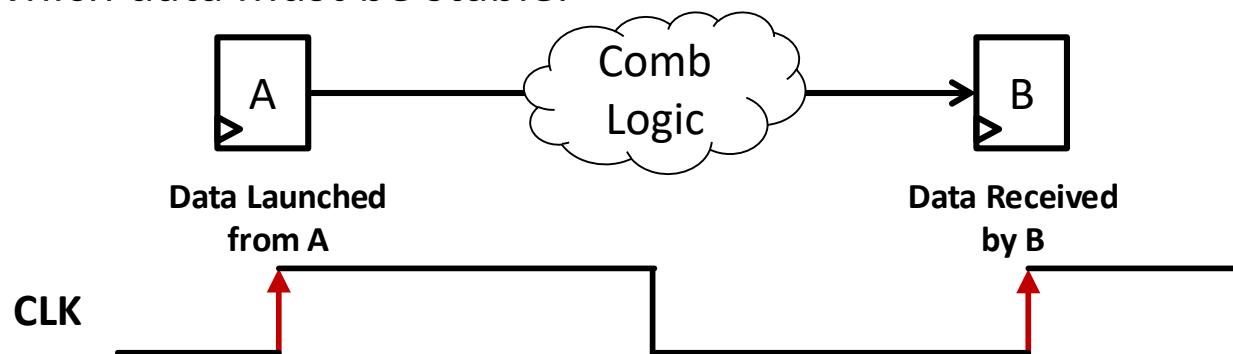
- Constraint-driven optimization, not exhaustive search
- Logic level optimization
  - Structuring: group subfunctions & intermediate variables
  - Flattening: break logics to 2-level, sum-of-products representation
- Gate level optimization (using **technology library**)
  - Generates netlist from gates in target library, check timing & area goals

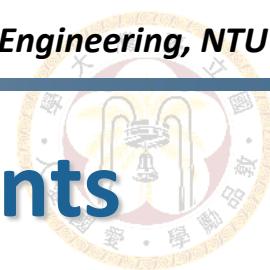




# Compile Concept: Timing Requirements

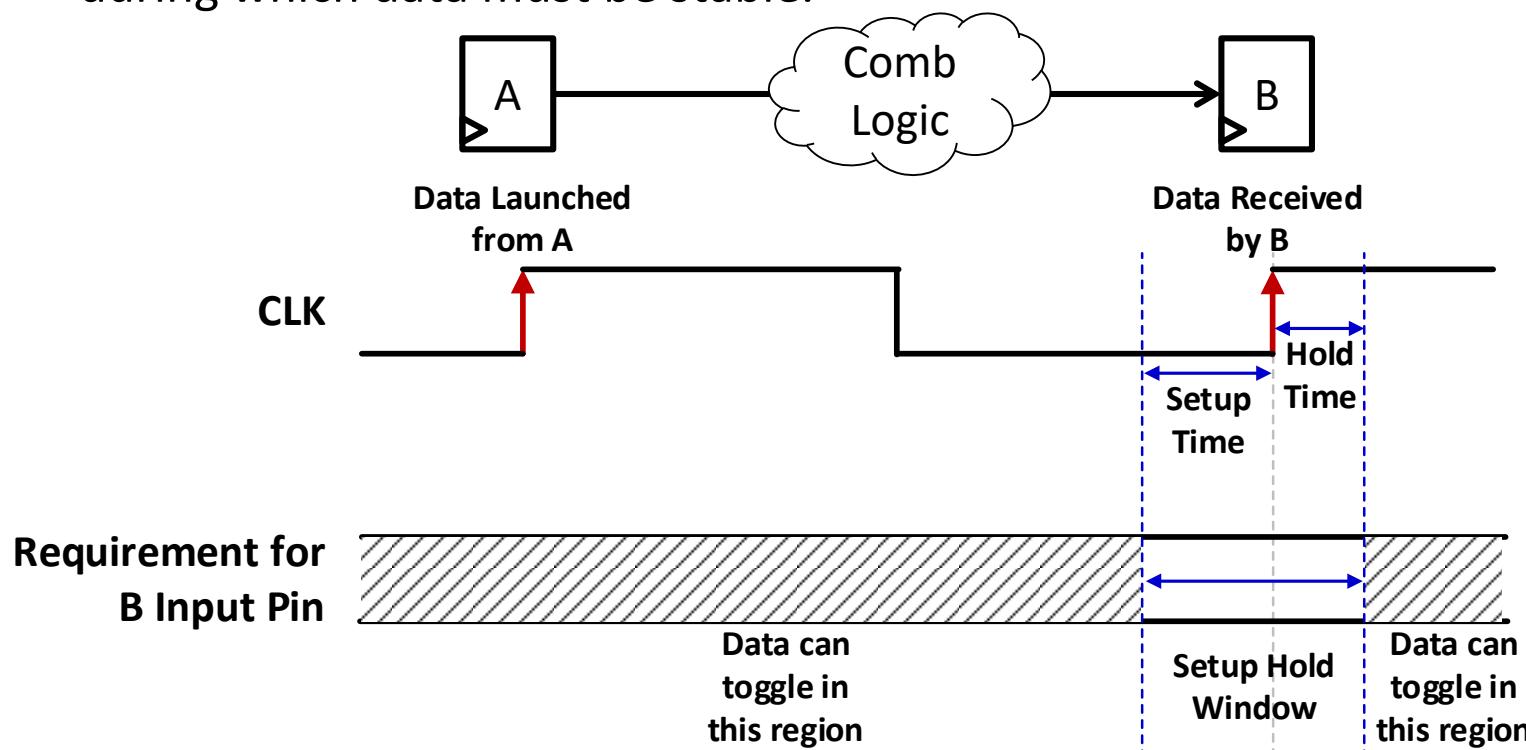
- Each path in the design is analyzed for timing requirements
  - **Setup time**: the minimum amount of time before clock's active edge that the data must be stable.
  - **Hold time**: the minimum amount of time after the clock's active edge during which data must be stable.

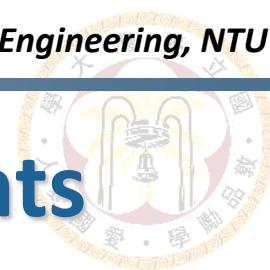




# Compile Concept: Timing Requirements

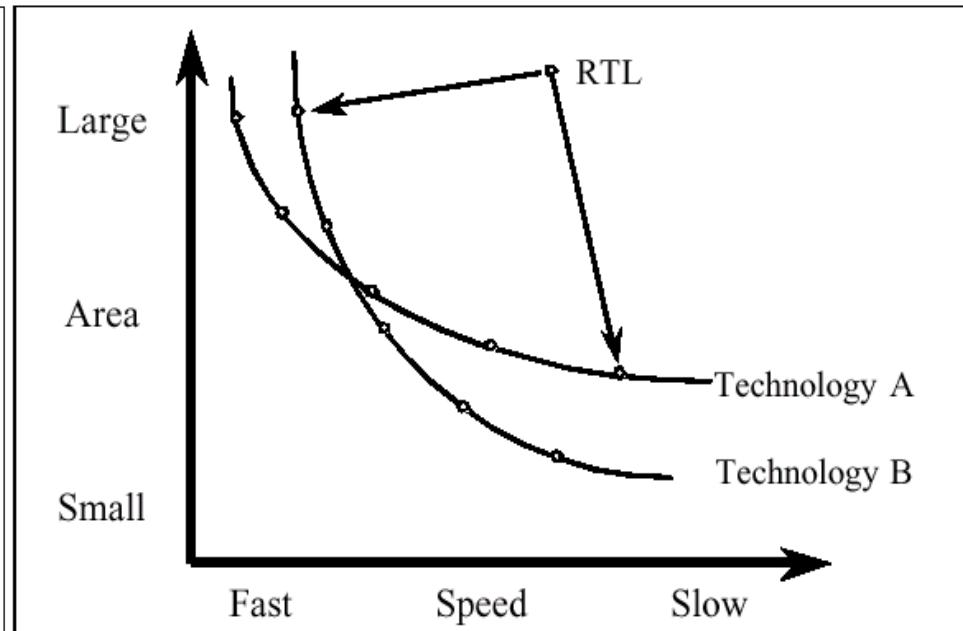
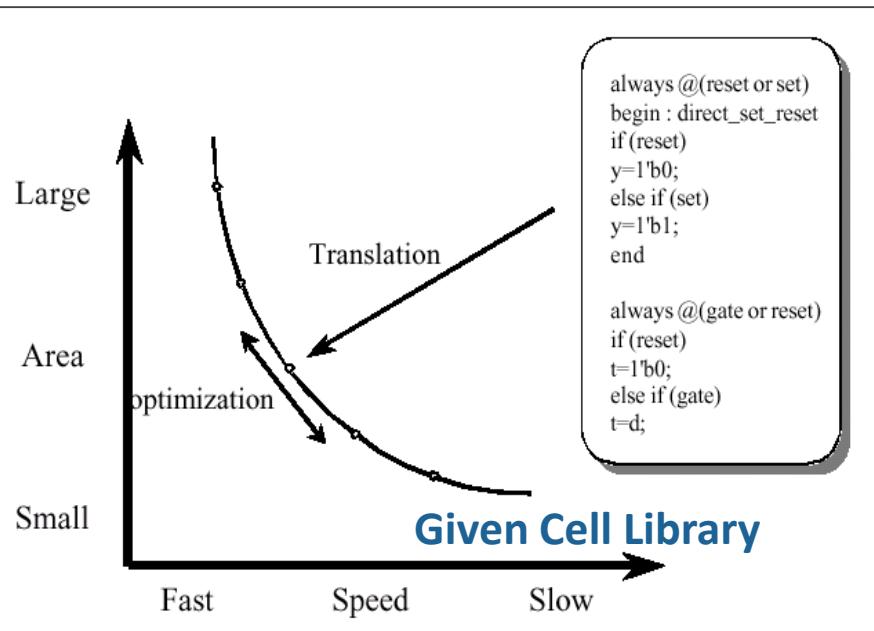
- Each path in the design is analyzed for timing requirements
  - Setup time:** the minimum amount of time before clock's active edge that the data must be stable.
  - Hold time:** the minimum amount of time after the clock's active edge during which data must be stable.

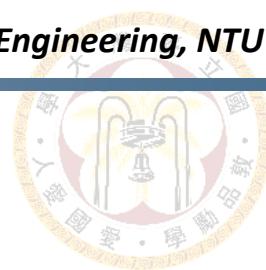




# Recall: Trade-off between Constraints

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





# Option: Retiming Method

- Enable DC to **move registers through combinational logics**
- Pros and cons
  - More balanced pipeline for better area & timing
  - Opportunity to reduce number of registers
  - Longer compilation time for large design

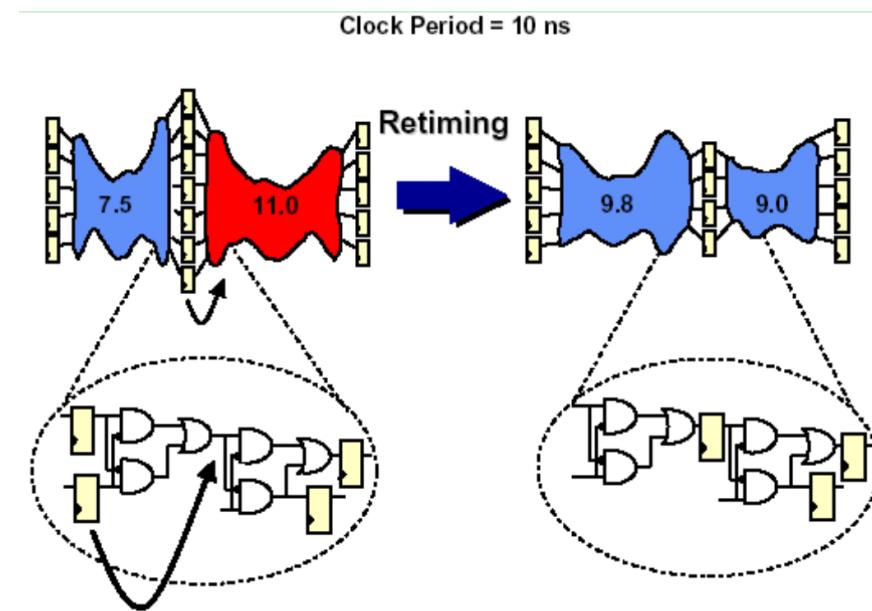
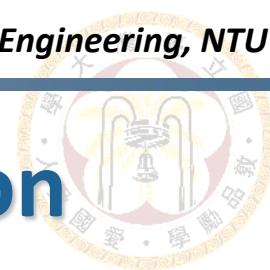


Image source: <http://blog.chinaaet.com/justlxy/p/5100052114>



# Option: Leakage Power Optimization

- **Multi-threshold voltage ( $V_t$ ) libraries to reduce leakage power**
  - Low  $V_t$  cells: higher speed, higher leakage
  - High  $V_t$  cells: lower speed, lower leakage
- Note: Different doping concentration for high & low  $V_t$  MOSFETs
  - High  $V_t$ : Lower source-drain current → slower, lower leakage

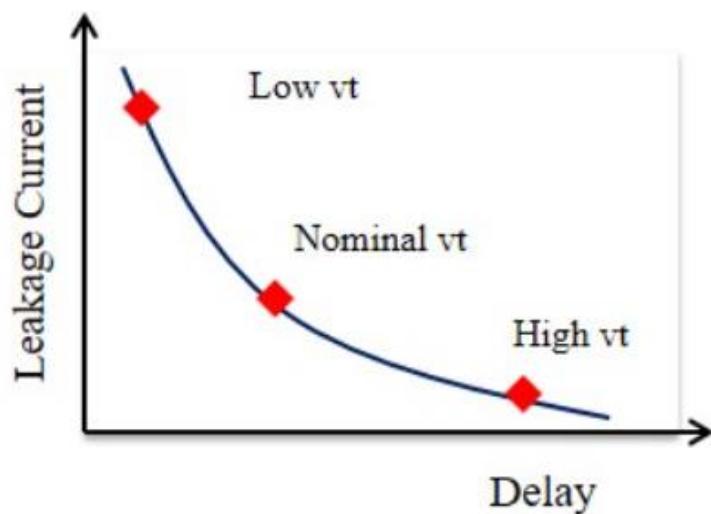
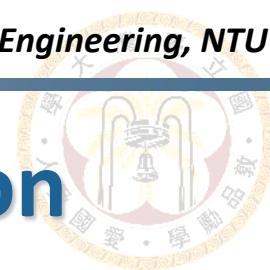
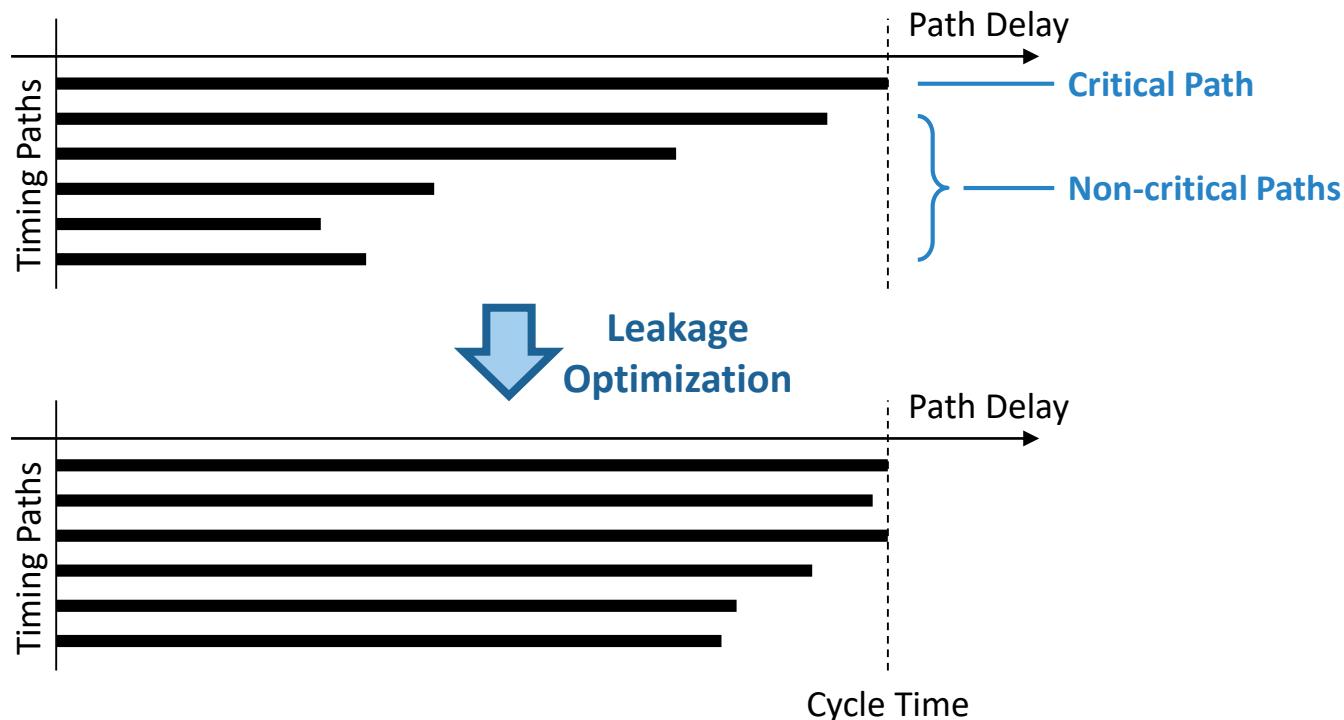


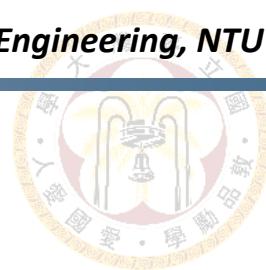
Image source: <https://www.vlsiguru.com/low-power-pavan/>



# Option: Leakage Power Optimization

- Trade-off between timing & power
  - Use **low  $V_t$**  cells on critical paths to **improve timing**
  - Use **high  $V_t$**  cells on non-critical paths to **save power**
- Usually optimize leakage power after timing optimization





# Commands to Compile (1/3)

## ■ Compile Mapping effort levels

- **Low**: quick synthesis, does not do all algorithms
- **Medium**: default setting, good for many design
- **High**: highest effort, sometimes hard to converge

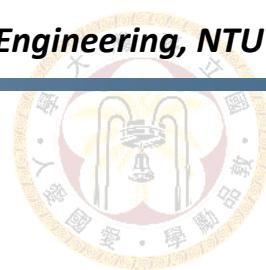
```
compile
```

```
compile -map_effort high
```

## ■ Compile ultra

- Using high effort
- Enable several optimization options
  - E.g., auto-ungroup, boundary optimization

```
compile_ultra
```



# Commands to Compile (2/3)

## ■ Incremental mapping

- Perform gate-level optimization only
- Can be used to optimize current gate-level netlist

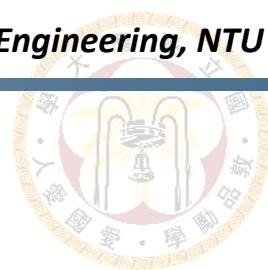
```
compile -inc
```

## ■ Retiming

```
set_optimize_registers  
compile_ultra -retime
```

```
compile  
optimize_registers
```

```
compile  
optimize_registers -no_compile  
compile_ultra -inc
```



# Commands to Compile (3/3)

## ■ Compile with leakage optimization

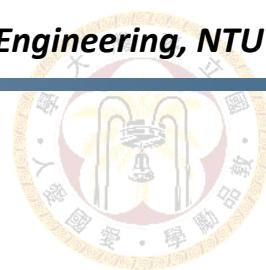
```
# in .synopsys_dc.setup  
set target_library "slow_hvt.db fast_hvt.db \  
slow_rvt.db fast_rvt.db"
```

```
compile  
set_leakage_optimization true  
compile -inc
```

## ■ Other options can be checked by

```
compile -help
```

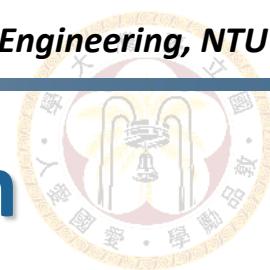
```
compile_ultra -help
```



# Compile Process

- Recall: constraint-driven
  - We can roughly see the **trade-off between the constraints** and their priorities

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
<hr/> Beginning Constant Register Removal <hr/>							
<hr/> Beginning Global Optimizations <hr/>							
Numerical Synthesis (Phase 1)							
Numerical Synthesis (Phase 2)							
Global Optimization (Phase 1)							
Global Optimization (Phase 2)							
Global Optimization (Phase 3)							
Global Optimization (Phase 4)							
<hr/> Beginning Isolate Ports <hr/>							
<hr/> <b>Trade-off between constraints</b> <hr/>							
<hr/> Beginning Delay Optimization <hr/>							
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
<hr/> Beginning WLM Backend Optimization <hr/>							
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



# Solving Setup/Hold Time Violation

## ■ Solving setup time violation

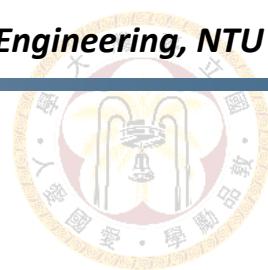
- Increase compile effort/use compile\_ultra
- Apply additional incremental compile (gate-level opt. only)

```
compile -inc -map_effort high
```

## ■ Solving hold time violation

- Perform only hold time fixing, ignoring other rules
- Note: set\_fix\_hold command must be specified

```
set_fix_hold [all_clocks]
compile -inc -only_hold_time
```



# How to Fix Assignment Error

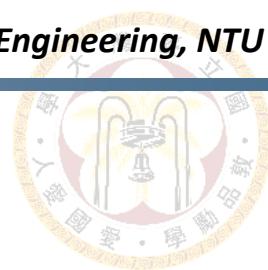
```
assign ABSVAL[19] = A[19];  
assign ABSVAL[18] = A[18];  
assign ABSVAL[17] = A[17];  
assign ABSVAL[16] = A[16];  
assign ABSVAL[15] = A[15];
```



```
BUFX1 X37X( .I(A[19]), .Z(ABSVAL[19]) );  
BUFX1 X38X( .I(A[18]), .Z(ABSVAL[18]) );  
BUFX1 X39X( .I(A[17]), .Z(ABSVAL[17]) );  
BUFX1 X40X( .I(A[16]), .Z(ABSVAL[16]) );  
BUFX1 X41X( .I(A[15]), .Z(ABSVAL[15]) );
```

- Sometimes there are still some assign syntax in gate level RTL
- The syntax of “assign” may cause problems in the layout versus schematic verification (LVS)

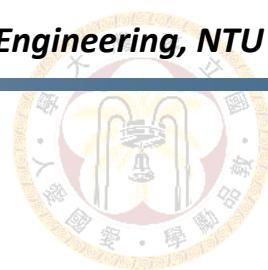
```
set_fix_multiple_port_nets -all -buffer_constants [get_designs *]
```



# Change Naming Rule

- Let the naming-rule definitions in the gate-level netlist are the same as in the timing file
- Wrong naming rules may cause problems in the layout versus schematic verification (LVS)

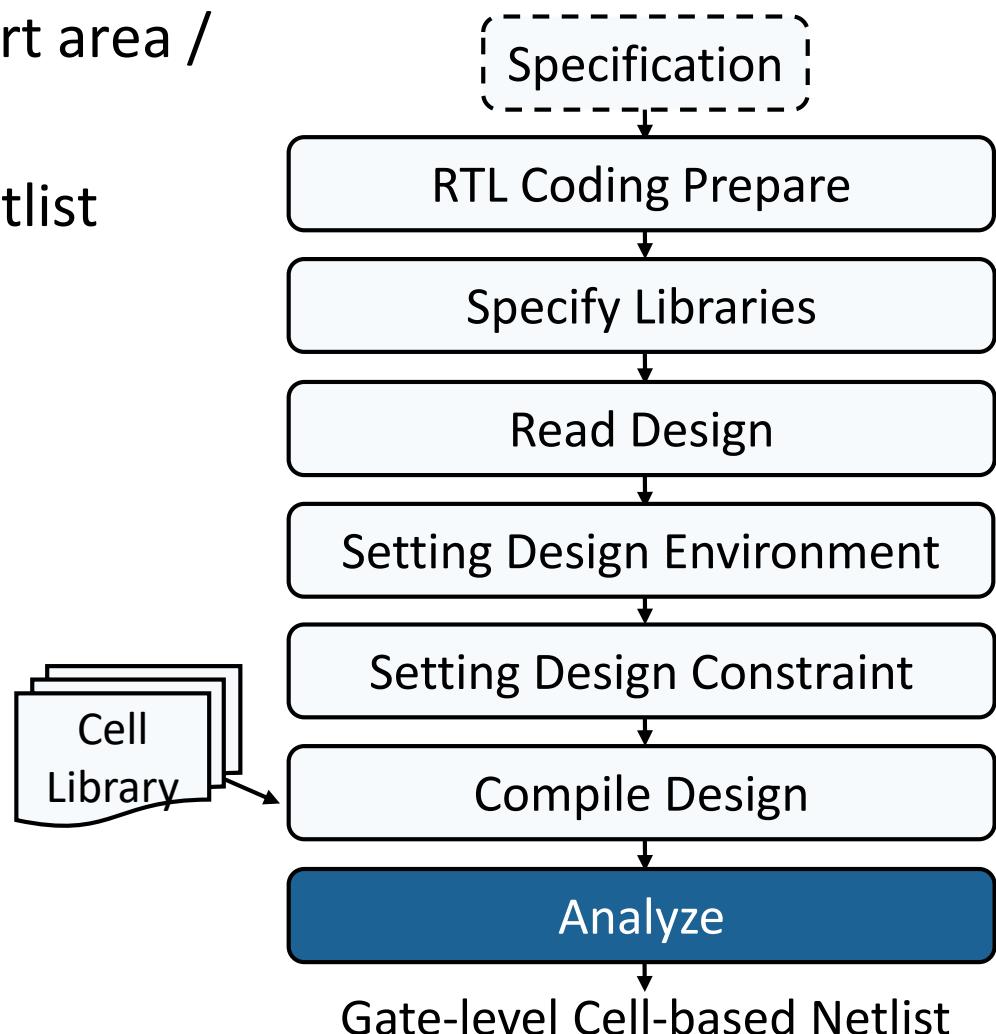
```
set bus_inference_style "%s\[%d\]"
set bus_naming_style "%s\[%d\]"
set hdlout_internal_busses true
change_names -hierarchy -rule verilog
define_name_rules name_rule -allowed "a-z A-Z 0-9 _" -max_length 255 -type cell
define_name_rules name_rule -allowed "a-z A-Z 0-9 _[" -max_length 255 -type net
define_name_rules name_rule -map {"\\*cell\\*" "cell"}
change_names -hierarchy -rules name_rule
```

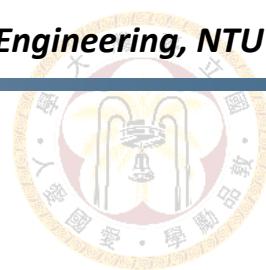


# Synthesis Design Flow

- 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
```





# Report Your Synthesis Results

## ■ Timing

- Shows maximum or minimum delay path of design
- Specify number of paths to show in -max\_paths

```
report_timing -delay max -max_paths 5 > Design.timing
```

## ■ Area

- Shows the area in um<sup>2</sup> of the design

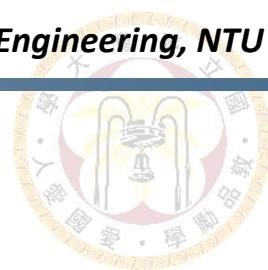
```
report_area -nosplit > Design.area
```

```
report_area -hierarchy > Design.area_hier
```

## ■ Power

- Report both dynamic and static power
- PrimeTime is more accurate

```
report_power > Design.power
```



# Timing Report

- Reports the timing info of the longest/shortest path in design
- We check if there's negative slack (violated timing path)

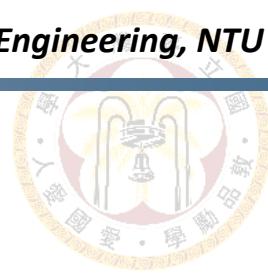
```

1
2 ****
3 Report : timing
4     -path full
5     -delay max
6     -max_paths 5
7 Design : alu
8 Version: N-2017.09-SP2
9 Date   : Fri Oct 16 16:09:07 2020
10 ****
11
12 Operating Conditions: slow Library: slow
13 Wire Load Model Mode: top
14
15 Startpoint: i_inst[0] (input port clocked by i_clk)
16 Endpoint: o_data_reg[1]
17     (rising edge-triggered flip-flop clocked by i_clk)
18 Path Group: i_clk
19 Path Type: max
20
21 Des/Clust/Port      Wire Load Model      Library
22 -----
23 alu                  tsmc13_w110        slow
24

```

	Point	Incr	Path
21	clock i_clk (rise edge)	0.00	0.00
22	clock network delay (ideal)	0.50	0.50
23	input external delay	5.00	5.50 f
24	i_inst[0] (in)	0.00	5.50 f
25	U188/Y (CLKBUFX3)	0.11	5.61 f
26	U186/Y (NAND2XL)	0.08	5.69 r
27	U152/Y (CLKINVX1)	0.05	5.74 f
28	U150/Y (NAND2XL)	0.05	5.79 r
29	U148/Y (OA21XL)	0.11	5.91 r
30	U141/Y (OAI21XL)	0.05	5.96 f
31	U140/Y (NAND2XL)	0.11	6.07 r
32	U175/Y (OAI21XL)	0.06	6.13 f
33	U216/Y (AOI221XL)	0.20	6.32 r
34	U214/Y (NAND2XL)	0.04	6.36 f
35	o_data_reg[2]/D (DFFRX1)	0.00	6.36 f
36	data arrival time		6.36
37			
38			
39			
40	clock i_clk (rise edge)	10.00	10.00
41	clock network delay (ideal)	0.50	10.50
42	clock uncertainty	-0.10	10.40
43	o_data_reg[2]/CK (DFFRX1)	0.00	10.40 r
44	library setup time	-0.13	10.27
45	data required time		10.27
46			
47			
48	data required time		10.27
49	data arrival time		-6.36
50	slack (MET)		3.91

Requirement: Slack  $\geq 0$



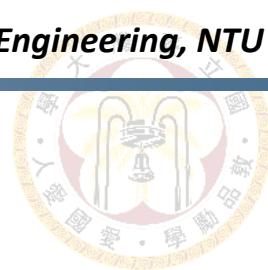
# Area Report

- Reports area of combinational/sequential blocks
  - **Macro/black box** refers to hard macros
  - To fix undefined net interconnect area, **set wire load model**
- We check area of each part & total cell area
  - Net interconnect area by WLM only provides a rough estimation
  - More accurate after place and route

```
9 Library(s) Used:  
10  
11     slow (File: /home/raid7_2/course/cvsd/CBDK_IC_Contest/CIC/SynopsysDC/db/slow.db)  
12  
13 Number of ports:          44  
14 Number of nets:           282  
15 Number of cells:          243  
16 Number of combinational cells: 170  
17 Number of sequential cells: 72  
18 Number of macros/black boxes: 0  
19 Number of buf/inv:          23  
20 Number of references:      2  
21  
22 Combinational area:       1834.889360  
23 Buf/Inv area:             308.926804  
24 Noncombinational area:    2378.057323  
25 Macro/Black Box area:     0.000000  
26 Net Interconnect area:   36622.517365  
27  
28 Total cell area:          4212.946684  
29 Total area:               10846.464048
```

Hard macros, e.g., SRAM

Don't care net area!



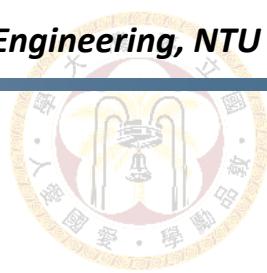
# Area Report

## ■ Hierarchical area distribution

- Reports area breakdown for all hierarchies in design
- Note: auto ungroup (default in compile\_ultra) breaks the hierarchy in logics
- We can disable auto ungroup with compile\_ultra -no\_autoungroup

```
31 Hierarchical area distribution
32 -----
33
34                               Global cell area          Local cell area
35                               -----          -----
36 Hierarchical cell           Absolute    Percent   Combi-   Noncombi- Black-
37                   Total      Total     national  national  boxes   Design
38 -----      -----      -----      -----      -----      -----
39 top                  4212.9467  100.0    203.6880  0.0000  0.0000  top
40 u_fifo_0              4009.2587  95.2    1631.2014 2378.0573  0.0000  fifo
41 -----      -----      -----      -----      -----      -----
42 Total                           1834.8894  2378.0573  0.0000
43
44 1
45
```

report\_area -hierarchy

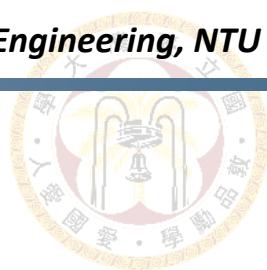


# Power Report

- Reports a rough power dissipation (fixed toggle rate)
- For a more accurate power estimation, we use
  - Gate-level simulation to generate waveform based on input pattern
  - PrimeTime to estimate power dissipation **with waveform**

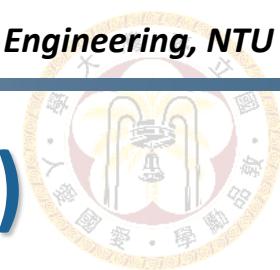
```
23 Design      Wire Load Model          Library
24 -----
25 alu          tsmc13_wl10           slow
26
27
28 Global Operating Voltage = 1.08
29 Power-specific unit information :
30   Voltage Units = 1V
31   Capacitance Units = 1.000000pf
32   Time Units = 1ns
33   Dynamic Power Units = 1mW      (derived from V,C,T units)
34   Leakage Power Units = 1pW
35
36
37   Cell Internal Power = 96.1401 uW  (53%)
38   Net Switching Power = 86.3698 uW  (47%)
39   -----
40   Total Dynamic Power = 182.5099 uW (100%)
41
42   Cell Leakage Power = 1.1657 uW
43
44
45           Internal          Switching          Leakage          Total
46 Power Group    Power        Power            Power            Power  (  %  )  Attrs
47 -----
48 io_pad        0.0000       0.0000       0.0000       0.0000 ( 0.00%)
49 memory        0.0000       0.0000       0.0000       0.0000 ( 0.00%)
50 black_box     0.0000       0.0000       0.0000       0.0000 ( 0.00%)
51 clock_network 0.0000       0.0000       0.0000       0.0000 ( 0.00%)
52 register      7.7090e-02  8.0832e-03  2.4367e+05  8.5416e-02 ( 46.50%)
53 sequential     0.0000       0.0000       0.0000       0.0000 ( 0.00%)
54 combinational 1.9051e-02  7.8287e-02  9.2205e+05  9.8259e-02 ( 53.50%)
55
56 Total         9.6140e-02 mW   8.6370e-02 mW   1.1657e+06 pW   0.1837 mW
57 1
```

Leakage power will become more dominant in the advanced process



# Save Design

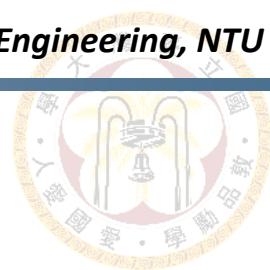
- Synopsys Design Constraints (.sdc)
- Standard Delay Format (.sdf) Required in gate-level simulation
- Gate-Level Netlist (.v)
- Test protocol file for ATPG tools (.spf)
- Synopsys encrypted binary file (\*.ddc)
  - Record the constraints and synthesis results



# Synopsys Design Constraints (.sdc)

- A format used to **specify the design intent**, including the timing, power and area constraints for a design
- SDC is TCL based

```
set DESIGN "alu"
write_sdc Netlist/$DESIGN\_SYN.sdc -version 1.8
```



# .sdc Example

```

1 #####
2
3 # Created by write_sdc on Sun Oct 25 11:11:28 2020
4
5 #####
6 set sdc_version 2.0
7
8 set units -time ns -resistance kOhm -capacitance pF -voltage V -current mA
9 set_operating_conditions typical -library typical
10 set_wire_load_mode segmented
11 set_wire_load_model -name "ForQA" library "typical"
12 set_max_transition 1 [current_design]
13 set_max_fanout 8 [current_design]
14 set_max_area 0
15 create_clock [get_ports clk] -period 10 -waveform {0 5}
16 set_input_delay -clock clk 2.5 [get_ports {inputA[7]}]
17 set_input_delay -clock clk 2.5 [get_ports {inputA[6]}]
18 set_input_delay -clock clk 2.5 [get_ports {inputA[5]}]
19 set_input_delay -clock clk 2.5 [get_ports {inputA[4]}]
20 set_input_delay -clock clk 2.5 [get_ports {inputA[3]}]
21 set_input_delay -clock clk 2.5 [get_ports {inputA[2]}]
22 set_input_delay -clock clk 2.5 [get_ports {inputA[1]}]
23 set_input_delay -clock clk 2.5 [get_ports {inputA[0]}]
24 set_input_delay -clock clk 3.8 [get_ports {inputB[7]}]
25 set_input_delay -clock clk 3.8 [get_ports {inputB[6]}]
26 set_input_delay -clock clk 3.8 [get_ports {inputB[5]}]
27 set_input_delay -clock clk 3.8 [get_ports {inputB[4]}]
28 set_input_delay -clock clk 3.8 [get_ports {inputB[3]}]
29 set_input_delay -clock clk 3.8 [get_ports {inputB[2]}]
30 set_input_delay -clock clk 3.8 [get_ports {inputB[1]}]
31 set_input_delay -clock clk 3.8 [get_ports {inputB[0]}]
32 set_input_delay -clock clk 4.5 [get_ports {instruction[3]}]
33 set_input_delay -clock clk 4.5 [get_ports {instruction[2]}]
34 set_input_delay -clock clk 4.5 [get_ports {instruction[1]}]
35 set_input_delay -clock clk 4.5 [get_ports {instruction[0]}]
36 set_input_delay -clock clk 5.2 [get_ports reset]
37 set_output_delay -clock clk 8 [get_ports {alu_out[7]}]
38 set_output_delay -clock clk 8 [get_ports {alu_out[6]}]
39 set_output_delay -clock clk 8 [get_ports {alu_out[5]}]
40 set_output_delay -clock clk 8 [get_ports {alu_out[4]}]
41 set_output_delay -clock clk 8 [get_ports {alu_out[3]}]
42 set_output_delay -clock clk 8 [get_ports {alu_out[2]}]
43 set_output_delay -clock clk 8 [get_ports {alu_out[1]}]
44 set_output_delay -clock clk 8 [get_ports {alu_out[0]}]

```

```

set_operating_conditions "typical" library "typical"
set_wire_load_mode "segmented"
set_wire_load_model -name "ForQA" library "typical"
set_max_transition 1 ALU
set_max_fanout 8 ALU
set_max_area 0

```

```

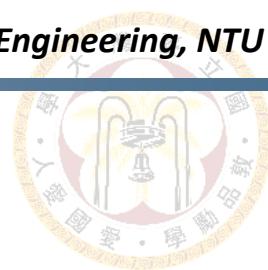
create_clock -name "clk" -period 10 -waveform {"0" "5"} {"clk"}
set_dont_touch_network [find clock clk]
set_fix_hold clk

```

```

set_input_delay -clock clk 2.5 inputA[*]
set_input_delay -clock clk 3.8 inputB[*]
set_input_delay -clock clk 4.5 instruction[*]
set_input_delay -clock clk 5.2 reset
set_output_delay -clock clk 8 alu_out[*]

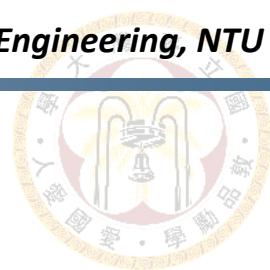
```



# Standard Delay Format (.sdf)

- SDF format
  - IEEE standard for representation & interpretation of timing data for electronic design process
  
- SDF file generated in synthesis
  - Detailed **delay information of each cell** in gate-level netlist
  - Timing check of each cell (e.g., setup check, hold check)

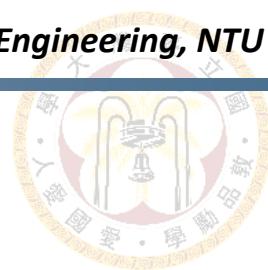
```
write_sdf -version 2.1 -context verilog -load_delay  
cell Netlist/$DESIGN\_SYN.sdf
```



# SDF File Example

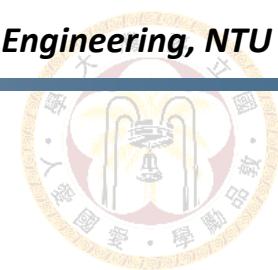
- Delay & timing check for each cell in design

```
(DELAYFILE
(SDFVERSION "OVI 2.1")
(DESIGN "adder")
(DATE "Tue Nov 1 22:48:09 2022")
(VENDOR "slow")
(PROGRAM "Synopsys Design Compiler cmos")
(VERSION "R-2020.09-SP5")
(DIVIDER /)
(VOLTAGE 1.08:1.08:1.08)
(PREPROCESS "slow")
(TEMPERATURE 125.00:125.00:125.00)
(TIMESCALE 1ns)
(CELL
  (CELLTYPE "adder")
  (INSTANCE)
  (DELAY
    (ABSOLUTE
      (INTERCONNECT U30/S U31/AN (0.000:0.000:0.000))
      (INTERCONNECT U24/Y U31/B (0.000:0.000:0.000))
      (INTERCONNECT in_a[3] U30/A (0.000:0.000:0.000))
      (INTERCONNECT in_b[3] U30/B (0.000:0.000:0.000))
      (INTERCONNECT U28/CO U30/CI (0.000:0.000:0.000))
      (INTERCONNECT U30/CO U29/AN (0.000:0.000:0.000))
      (INTERCONNECT U24/Y U29/B (0.000:0.000:0.000))
      (INTERCONNECT in_a[2] U28/A (0.000:0.000:0.000))
      (INTERCONNECT in_b[2] U28/B (0.000:0.000:0.000))
    )
  )
  (CELL
    (CELLTYPE "BUFX12")
    (INSTANCE U13)
    (DELAY
      (ABSOLUTE
        (IOPATH A Y (0.701:0.701:0.701) (0.520:0.520:0.520))
      )
    )
  )
  (CELL
    (CELLTYPE "DFFQX1")
    (INSTANCE out_reg_0_)
    (DELAY
      (ABSOLUTE
        (IOPATH (posedge CK) Q (0.466:0.466:0.466) (0.346:0.346:0.346))
      )
    )
    (TIMINGCHECK
      (WIDTH (posedge CK) (0.176:0.176:0.176))
      (WIDTH (negedge CK) (0.249:0.249:0.249))
      (SETUP (posedge D) (posedge CK) (0.152:0.152:0.152))
      (SETUP (negedge D) (posedge CK) (0.265:0.283:0.283))
      (HOLD (posedge D) (posedge CK) (-0.107:-0.107:-0.107))
      (HOLD (negedge D) (posedge CK) (-0.088:-0.113:-0.113))
    )
  )
)
```



# Gate-Level Netlist (.v)

- Description of the connectivity of an electronic circuit, containing all of the logic and delays of the entire circuit
- Used in gate-level simulation
- Write out gate-level netlist
  1. *File/Save As ➔ Verilog*
  2. `write -format verilog -output Netlist/$DESIGN\_SYN.v -hierarchy`



# Gate-Level Netlist (.v) Example

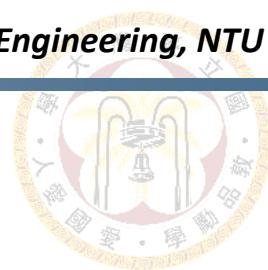
```
module counter (
    input i_clk, rstn, load,
    input [1:0] in,
    output reg [1:0] out);
    always@(posedge i_clk) begin
        if(!rstn) out <= 2'b0;
        else if (load) out <= in;
        else out <= out+1;
    end
endmodule
```

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;

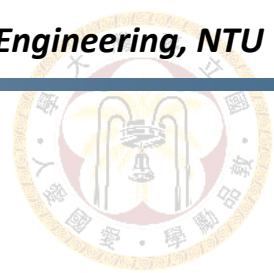
    DFFQX1 out_reg_1_ ( .D(N7), .CK(i_clk), .Q(n12) );
    DFFQX1 out_reg_0_ ( .D(N6), .CK(i_clk), .Q(n13) );
    CLKINVX1 U9 ( .A(n13), .Y(n5) );
    INVX16 U10 ( .A(n5), .Y(out[0]) );
    BUFX16 U11 ( .A(n12), .Y(out[1]) );
    INVXL U12 ( .A(load), .Y(n9) );
    OAI21XL U13 ( .A0(in[0]), .A1(n9), .B0(rstn), .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  
counte\_syn.v



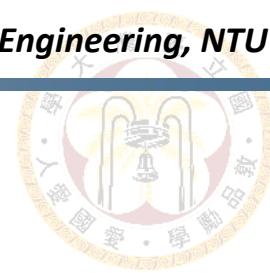
# Synthesis the Design Vision

- 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



# Outline

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



# 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

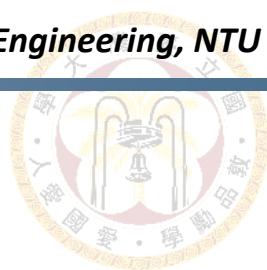
- Modify your testbench file to **include timing delay from SDF file**

```
$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

```
"/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) );

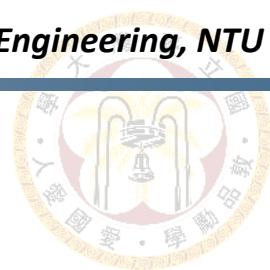
"/home/raid7_2/course/cvsd/CBDK_IC_Contest_v2.5/Verilog/tsmc13_neg.v", 18348: Timing violation in test_alu.my_alu.alu_out_reg_5_
$setuphold( posedge CK && (flag == 1'b1):2602180000, negedge D:2602180000, limits: (1000,500) );

"/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

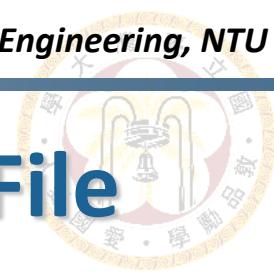
- With SDF file properly included, timing paths are denoted and can be checked in gate-level simulation

```
*** $sdf_annotation() version 1.2R
*** SDF file: "Lab2_alu.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"

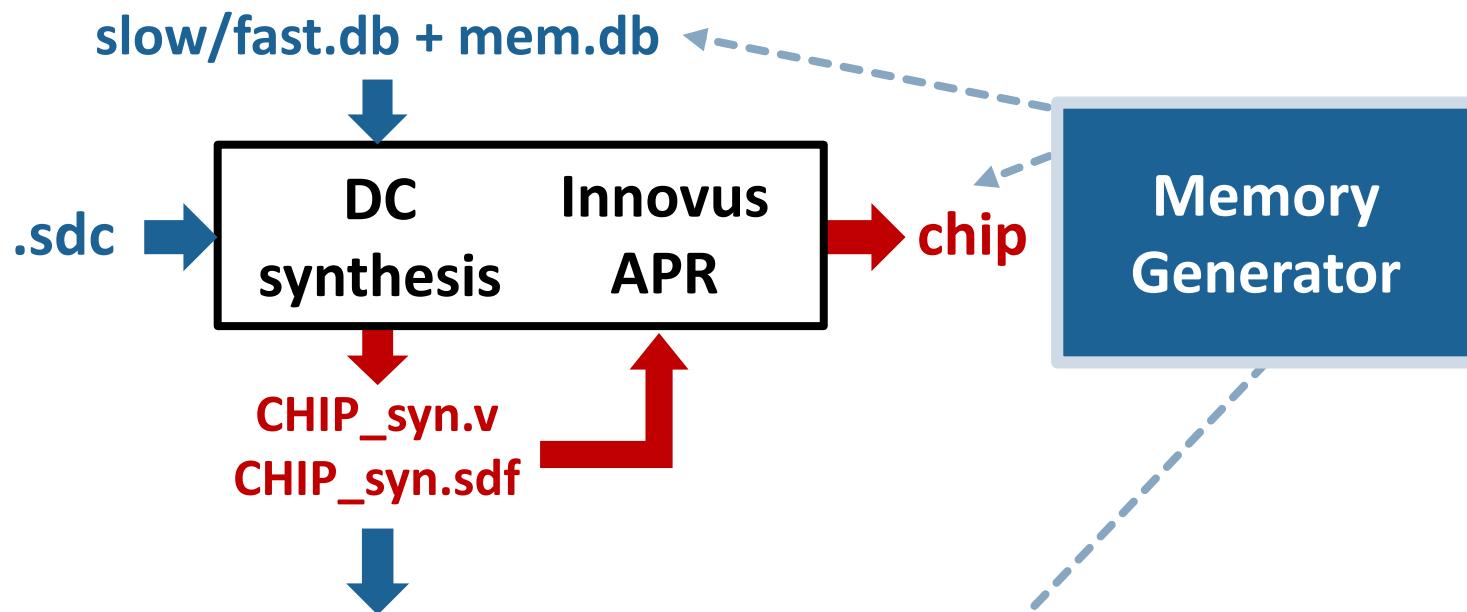
*** SDF annotation begin: Mon Mar 27 12:27:09 2023

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
```



# Synthesis & Simulation w/ Memory File

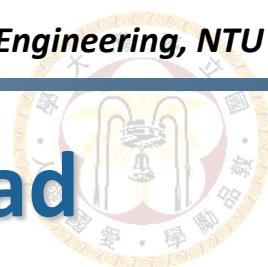


## Gate-level simulation

```
ncverilog tb.v CHIP_syn.v tsmc13.v mem.v +define+SDF +access+r
```

- 1) Behavior description
- 2) Default timing & timing check

Timing info.      Dump waveform  
& timing check    authorization



# Pre/Post-layout Simulation w/ IO Pad

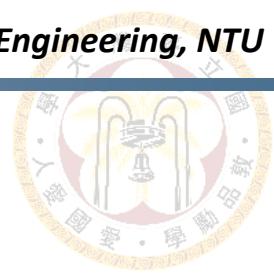
- For accurate simulation, I/O pads should be also considered for timing delay assumptions.
- The file ***tpz973g.v*** should be included for tsmc180 process

path:

```
/home/raid7_4/raid1_1/cic/CBDK018_TSMC_Artisan/orig_lib/fe_tpz973g_240b  
/TSMCHOME/digital/Front_End/verilog/tpz973g_240b/
```

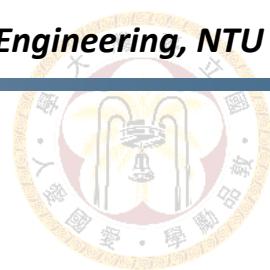
- For ncverilog simulation, you should use

```
ncverilog tb.v CHIP.v tpz973g.v tsmc18.v +define+SDF +access+r
```



# Outline

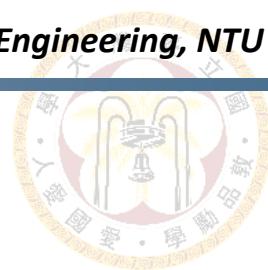
- Introduction
- RTL Coding Related to Synthesis
- Synopsys Environment
- Synthesis Design Flow
- Gate-Level Simulation
- Files Demo
  - Syn.tcl Example
  - SRAM File
  - Pad Example
  - Cell Model Example



# Syn.tcl Example (1/7)

```
#=====
# .synopsys_dc setup
#=====
# Library Setting
#=====
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_foundations.sldb"
set target_library    "typical.db slow.db fast.db"
set symbol_library    "generic.sdb"
set synthetic_library "dw_foundations.sldb"
```



# Syn.tcl Example (2/7)

```
#=====
#   Synopsys Design Environmental Setting
#=====

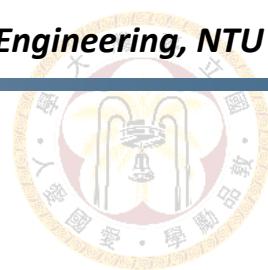
# Treat text between translate statements as comments
set hdlin_translate_off_skip_text    {true}

# Enable Presto compiler for analyzing and elaborating VHDL/verilog design files,
# which allows high-level behavior structure such as extracting memory.
set hdlin_enable_presto_for_vhdl    {true}

# In order to generate compatible EDIF files
set edifout_netlist_only           {true}

# if inout used, tri net will be used
set verilogout_no_tri              {true}

set plot_command                   {lpr -Plp}
```



## Syn.tcl Example (3/7)

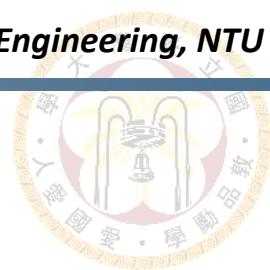
```
#=====
#  Read file and set current design and parameters
#=====

set DESIGN "alu"
set period 10.0
read_verilog -rtl ../01_RTL/$DESIGN.v
current_design $DESIGN

#=====
#  Design Clock Constraints
#=====

create_clock -name "i_clk" -period $period i_clk
set_fix_hold [get_clocks i_clk]
set_dont_touch_network [get_clocks i_clk]
set_ideal_network [get_ports i_clk]
set_clock_uncertainty 0.1 [get_clocks i_clk]
set_clock_latency 0.5 [get_clocks i_clk]
set_clock_transition 0.1 [get_clocks i_clk]
```

Remove these lines  
Before APR



# Syn.tcl Example (4/7)

```
#=====
#  Synthesis Environmental Setting
#=====

set t_in      [expr $period/2]
set t_out     [expr $period/2]

set operating_conditions -max_library slow -max slow -min_library fast -min fast
set_wire_load_model -name tsmc13_wl10 -library slow
set_wire_load_mode top

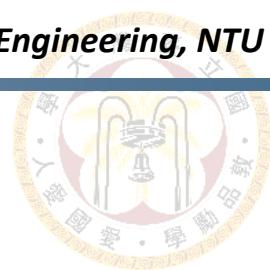
set_load      0.05  [all_outputs]
set_drive     0.05  [all_inputs]
set_input_delay $t_in -clock i_clk [remove_from_collection [all_inputs] [get_ports i_clk]]
set_output_delay $t_out -clock i_clk [all_outputs]

#=====
#  Design Rule Constraints
#=====

set_max_transition 0.1 -clock i_clk
set_max_capacitance 0.1 [get_ports *]
set_max_fanout 20      [all_inputs]
```

**Remove these lines before APR**

**Synthesis w/ IO Pad**



# Syn.tcl Example (5/7)

```
#=====
# Optimization Objective (e.g. area, power...etc)
#=====

set_max_area 0
#=====

#=====
# Check Design and Compile
#=====

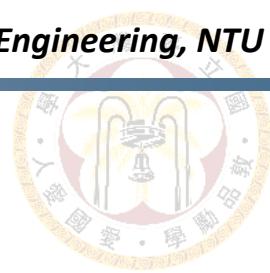
check_design > Report/check_design.txt
check_timing > Report/check_timing.txt

# Resolve multiple references
uniquify

# Fix Assignment Problem
set_fix_multiple_port_nets -all -buffer_constants [get_designs *]

# Fix Hold Time violation
set_fix_hold [all_clocks]

compile
```



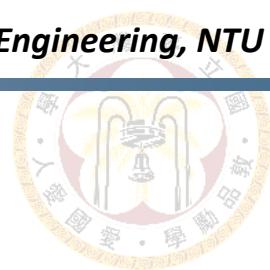
# Syn.tcl Example (6/7)

```
#=====
# Report Synthesis Results
#=====

report_design > Report/$DESIGN\.design
report_timing_requirements > Report/$DESIGN\.timingrequirement
report_constraint -all_violators > Report/$DESIGN\.constraint
report_timing -delay min -max_paths 5 > Report/$DESIGN\.timing_min
report_timing -delay max -max_paths 5 > Report/$DESIGN\.timing_max
report_area > Report/$DESIGN\.area
report_resource -hierarchy > Report/$DESIGN\.resource
report_power > Report/$DESIGN\.power

#=====
# Change Naming Rule
#=====

set bus_inference_style "%s\[%d\]"
set bus_naming_style "%s\[%d\]"
set hd dout_internal_busses true
change_names -hierarchy -rule verilog
define_name_rules name_rule -allowed "a-z A-Z 0-9 _" -max_length 255 -type cell
define_name_rules name_rule -allowed "a-z A-Z 0-9 _[]" -max_length 255 -type net
define_name_rules name_rule -map {{"\\"*cell\\"*"} "cell"}
change_names -hierarchy -rules name_rule
```



# Syn.tcl Example (7/7)

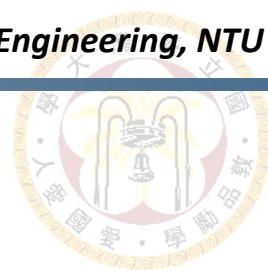
```
#=====
#  Write Output Files
#=====

set verilogout_higher_designs_first true
write -format verilog -output Netlist/$DESIGN\_SYN.v -hierarchy
write_sdf -version 2.1 -context verilog -load_delay cell Netlist/$DESIGN\_SYN.sdf
write_sdc Netlist/$DESIGN\_SYN.sdc -version 1.8
write -hierarchy -format ddc -output Netlist/$DESIGN\_SYN.ddc

#=====
#  Finish and Quit
#=====

report_timing
report_area
check_design

exit
```



# SRAM File (1/5)

In sram\_256x8.pdf

**Process Technology:**  
TSMC CL013G

## Features

- Precise Optimization for TSMC's Eight-Layer Metal 0.13μm CL013G CMOS Process
- High Density (area is 0.018mm<sup>2</sup>)
- Fast Access Time (1.20ns at fast@0C process 1.32V, 0°C)
- Fast Cycle Time (1.31ns at fast@0C process 1.32V, 0°C)
- One Read/Write Port
- Completely Static Operation
- Near-Zero Hold Time (Data, Address, and Control Inputs)

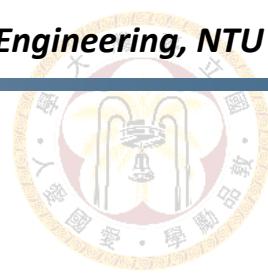
**High-Speed Single-Port Synchronous Flex-Repair™ SRAM with Redundancy**

**sram\_256x8  
256X8, Mux 8, Drive 6**

## Memory Description

The 256X8 SRAM is a high-performance, synchronous single-port, 256-word by 8-bit memory designed to take full advantage of TSMC's eight-layer metal, 0.13μm CL013G CMOS process.

The SRAM's storage array is composed of six-transistor cells with fully static memory circuitry. The SRAM operates at a voltage of 1.2V ± 10% and a junction temperature range of -40°C to +125°C.



# SRAM File (2/5)

In sram\_256x8.pdf

## Pin Description

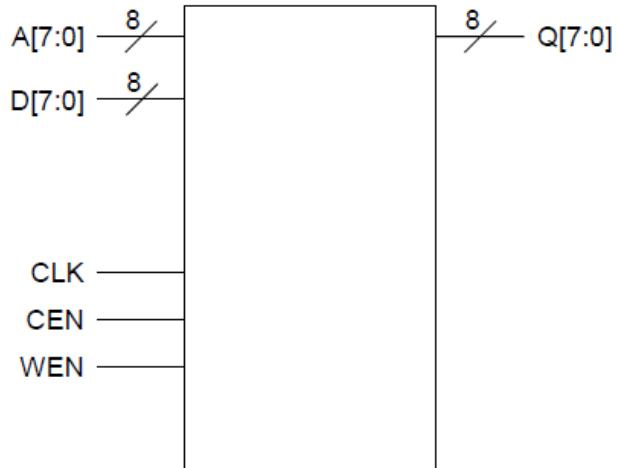
Pin	Description
A[7:0]	Addresses (A[0] = LSB)
D[7:0]	Data Inputs (D[0] = LSB)
CLK	Clock Input
CEN	Chip Enable
WEN	Write Enable
Q[7:0]	Data Outputs (Q[0] = LSB)

## Area

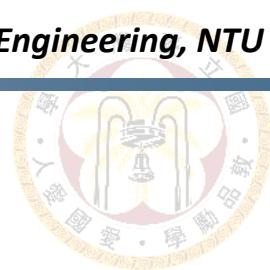
Area Type	Width (mm)	Height (mm)	Area (mm <sup>2</sup> )
Core	0.143	0.125	0.018
Footprint	0.153	0.136	0.021

The footprint area includes the core area and user-defined power ring and pin spacing areas.

## Symbol

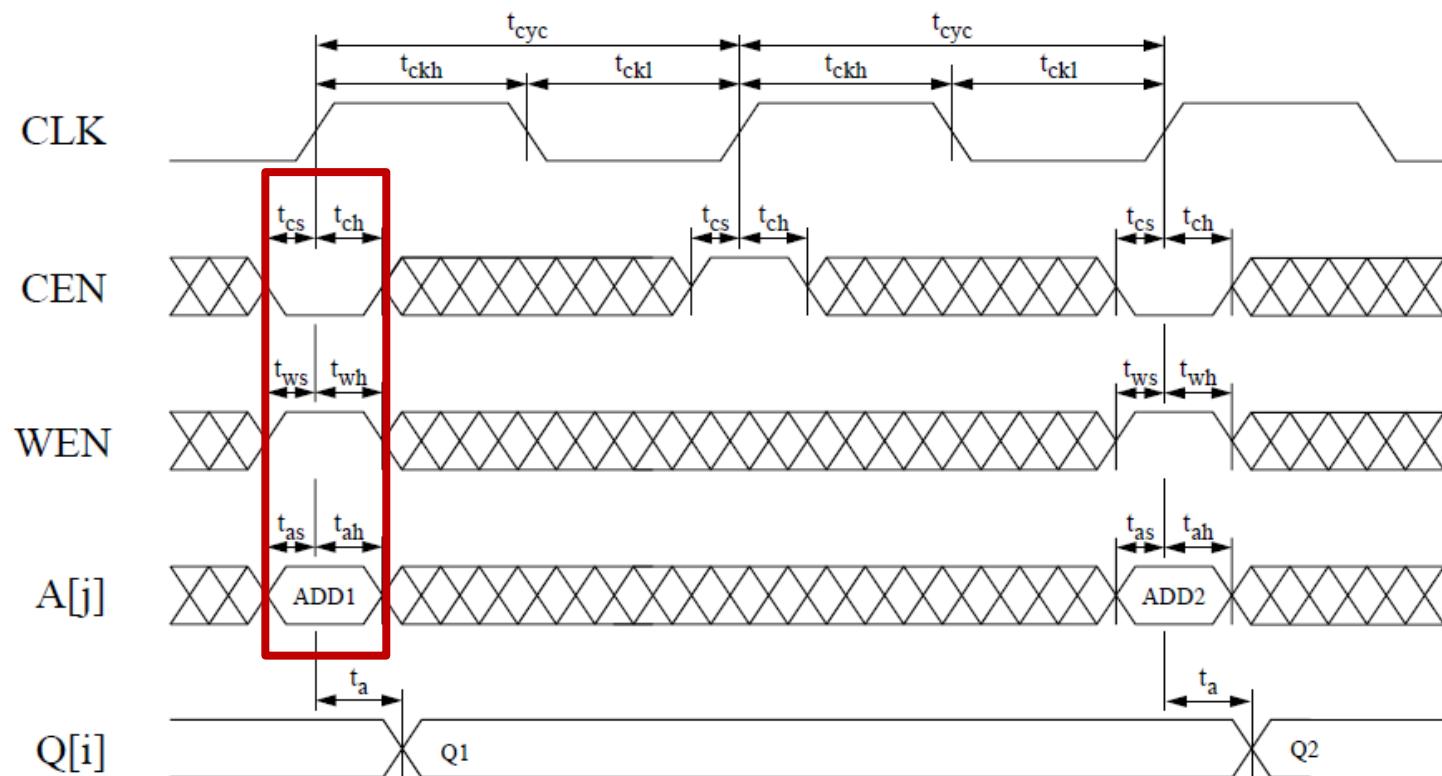


CEN	WEN	Data Out	Mode
H	X	Last Data	Standby
L	L	Data In	Write
L	H	SRAM Data	Read



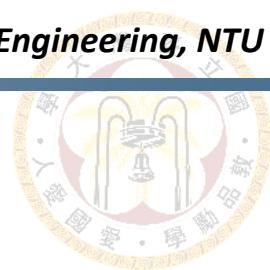
# SRAM File (3/5)

## Synchronous Single-Port SRAM Read-Cycle Timing



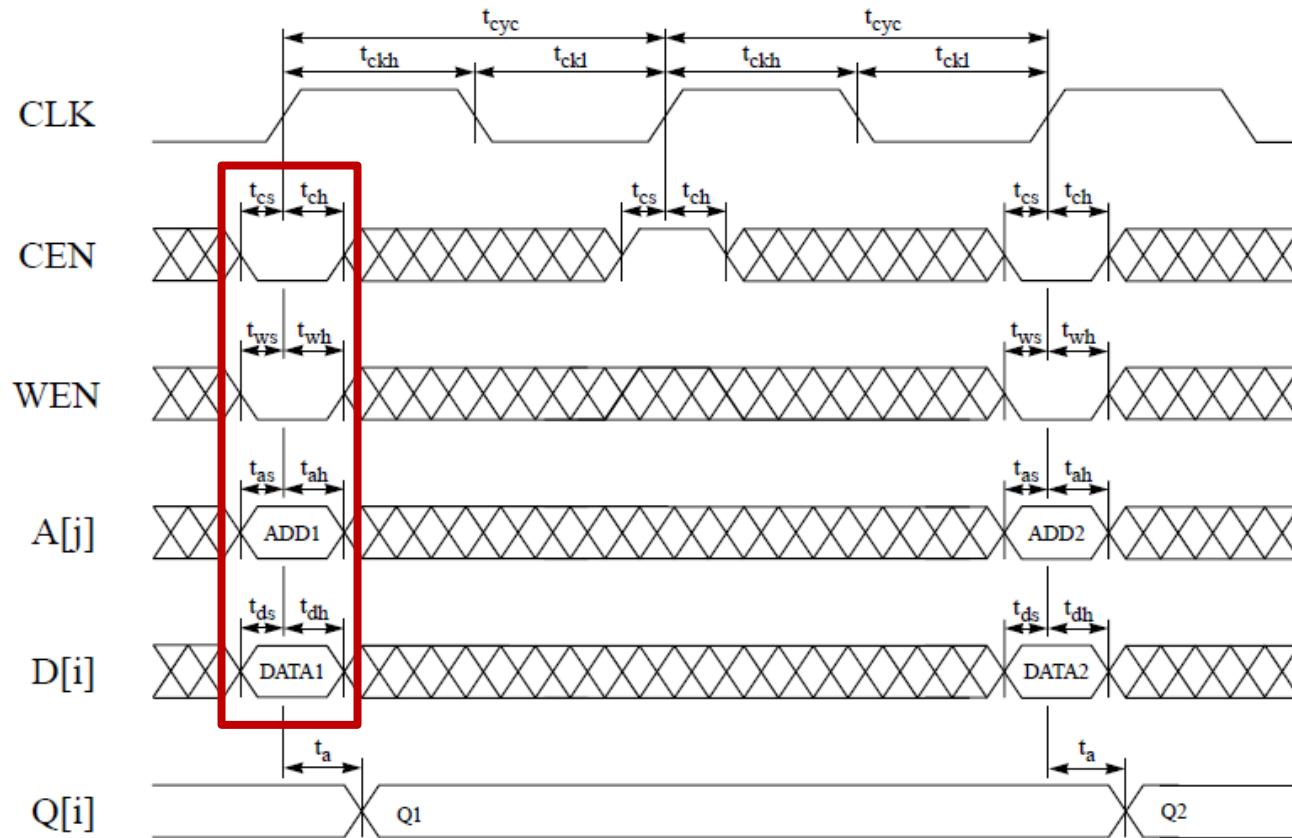
Rising delays are measured at 50% of VDD and falling delays are measured at 50% of VDD.

Rising and falling slews are measured from 10% VDD to 90% VDD.



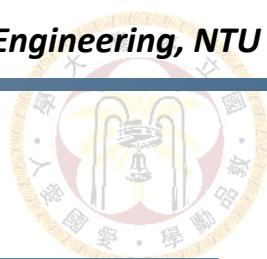
# SRAM File (4/5)

## Synchronous Single-Port SRAM Write-Cycle Timing



Rising delays are measured at 50% of VDD and falling delays are measured at 50% of VDD.

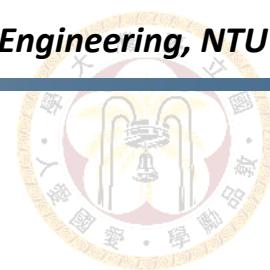
Rising and falling slews are measured from 10% VDD to 90% VDD.



# SRAM File (5/5)

```
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 subject 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";  
  
    /* additional header data */  
    default_cell_leakage_power  : 0;  
    default_fanout_load        : 1;  
    default inout_pin_cap      : 0.005;  
    default input_pin_cap       : 0.005;  
    default output_pin_cap      : 0.0;  
    default max_transition      : 1.500;
```

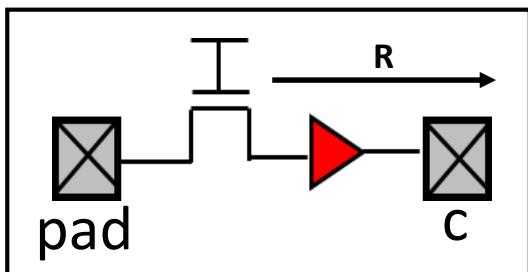
sram\_256x8\_slow\_syn.lib



# Pad Example: tpz973g.v

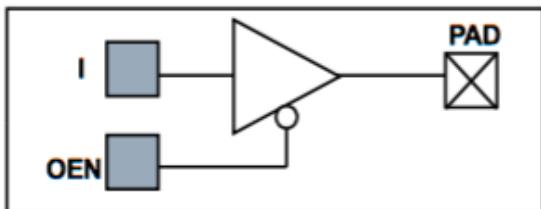
## Input Pad

TSMC18: PDIDGZ



```
// type: PDIX
`celldefine
module PDIDGZ (PAD, C);
  input PAD;
  output C;
  buf  (C, PAD);
  specify
    (PAD => C)=(0, 0);
  endspecify
endmodule
`endcelldefine
```

## Output Pad

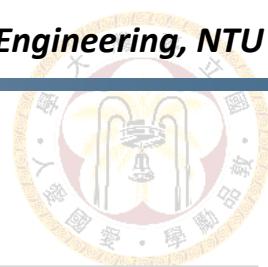


(PDO24CDG)

PDO02CDG / PDO04CDG / PDO08CDG  
PDO12CDG / PDO16CDG / PDO24CDG

```
// type: PDOx
`celldefine
module PDO02CDG (I, PAD);
  input I;
  output PAD;
  buf  (PAD, I);
  specify
    (I => PAD)=(0, 0);
  endspecify
endmodule
`endcelldefine
```

```
// type: PDOx
`celldefine
module PDO024CDG (I, PAD);
  input I;
  output PAD;
  buf  (PAD, I);
  specify
    (I => PAD)=(0, 0);
  endspecify
endmodule
`endcelldefine
```



# Cell Model Example: tsmc13.v

```
`timescale 1ns/1ps
`celldefine
module BUFX2 (Y, A);
output Y;
input A;

buf I0(Y, A);
specify
    // delay parameters
    specparam
        tplh$A$Y = 1.0,
        tphl$A$Y = 1.0;

    // path delays
    (A *> Y) = (tplh$A$Y, tphl$A$Y);
endspecify

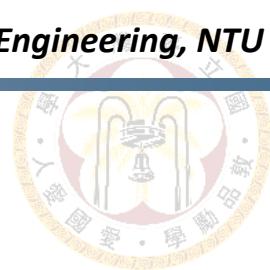
endmodule // BUFX2
`endcelldefine
```

```
`timescale 1ns/1ps
`celldefine
module INVX1 (Y, A);
output Y;
input A;

not I0(Y, A);
specify
    // delay parameters
    specparam
        tplh$A$Y = 1.0,
        tphl$A$Y = 1.0;

    // path delays
    (A *> Y) = (tplh$A$Y, tphl$A$Y);
endspecify

endmodule // INVX1
`endcelldefine
```

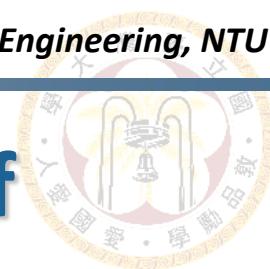


# Cell Model Example: tsmc13.v

```

`timescale 1ns/1ps
`celldefine
module DFFRX1 (Q, QN, D, CK, RN);
output Q, QN;
input D, CK, RN;
reg NOTIFIER;
supply1 xSN;
buf    XX0 (xRN, RN);
buf    IC (clk, CK);
udp_dff I0 (n0, D, clk, xRN, xSN, NOTIFIER);
and   I4 (flag, xRN, xSN);
buf    I1 (Q, n0);
not   I2 (QN, n0);
specify
  specparam
    tplh$RN$Q      = 1.0,
    tphl$RN$Q      = 1.0,
   tplh$RN$QN     = 1.0,
    tphl$RN$QN     = 1.0,
    tplh$CK$Q      = 1.0,
    tphl$CK$Q      = 1.0,
    tplh$CK$QN     = 1.0,
    tphl$CK$QN     = 1.0,
    tsetup$D$CK     = 1.0,
    thold$D$CK      = 0.5,
    tsetup$RN$CK     = 1.0,
    thold$RN$CK      = 0.5,
    tminpw1$RN      = 1.0,
    tminpw1$CK      = 1.0,
    tminpwh$CK      = 1.0;
  begin
    if (flag)
      (posedge CK *-> (Q      +: D)) = (tplh$CK$Q,      tphl$CK$Q);
    if (flag)
      (posedge CK *-> (QN     -: D)) = (tplh$CK$QN,     tphl$CK$QN);
    $setuphold(posedge CK && (flag == 1), posedge D, tsetup$D$CK, thold$D$CK, NOTIFIER);
    $setuphold(posedge CK && (flag == 1), negedge D, tsetup$D$CK, thold$D$CK, NOTIFIER);
    (negedge RN *-> (Q      +: 1'b0)) = (tphl$RN$Q);
    (negedge RN *-> (QN     -: 1'b0)) = (tplh$RN$QN);
    $setuphold(posedge CK, posedge RN, tsetup$RN$CK, thold$RN$CK, NOTIFIER);
    $width(negedge RN, tminpw1$RN, 0, NOTIFIER);
    $width(negedge CK && (flag == 1), tminpw1$CK, 0, NOTIFIER);
    $width(posedge CK && (flag == 1), tminpwh$CK, 0, NOTIFIER);
  endspecify
endmodule // DFFRX1
`endcelldefine

```



# Cell Model Example: TSMC13g.pdf

Path: /home/raid7\_2/course/cvsd/CBDK\_IC\_Contest/orig\_lib/aci/sc-x/doc/tsmc13g.pdf



NAND2

## Cell Description

The NAND2 cell provides the logical NAND of two inputs (A, B). The output (Y) is represented by the logic equation:

$$Y = \overline{(A \bullet B)}$$

## Functions

A	B	Y
0	x	1
x	0	1
1	1	0

## Logic Symbol



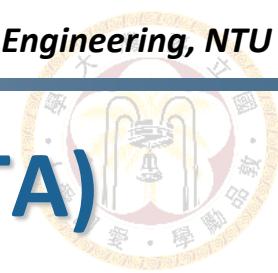
## Cell Size

Drive Strength	Height (μm)	Width (μm)
NAND2XL	3.69	1.38
NAND2X1	3.69	1.38
NAND2X2	3.69	2.30
NAND2X4	3.69	3.22
NAND2X6	3.69	4.60
NAND2X8	3.69	5.52

Gate counts =  
Chip Area / **NAND2 Area**

## Functional Schematic

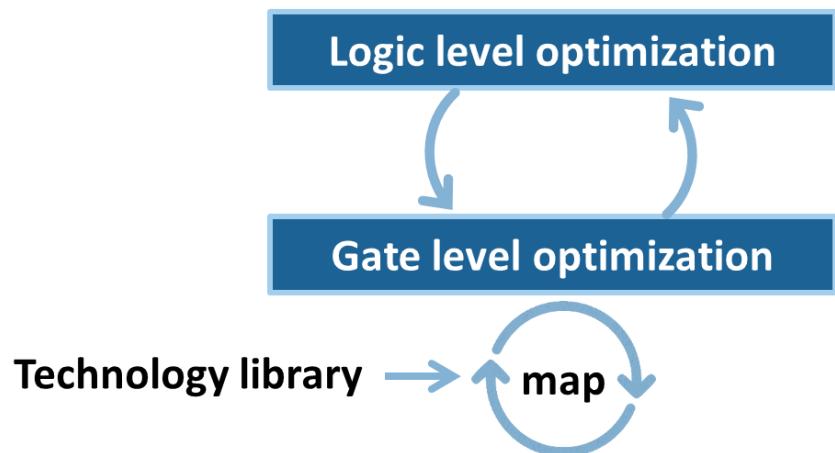




# Appendix: Static Timing Analysis (STA)

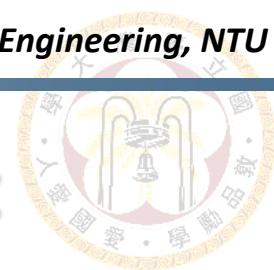
- Gate level optimization
  - Generates gate-level netlist
  - Check timing & area goals

**How?**

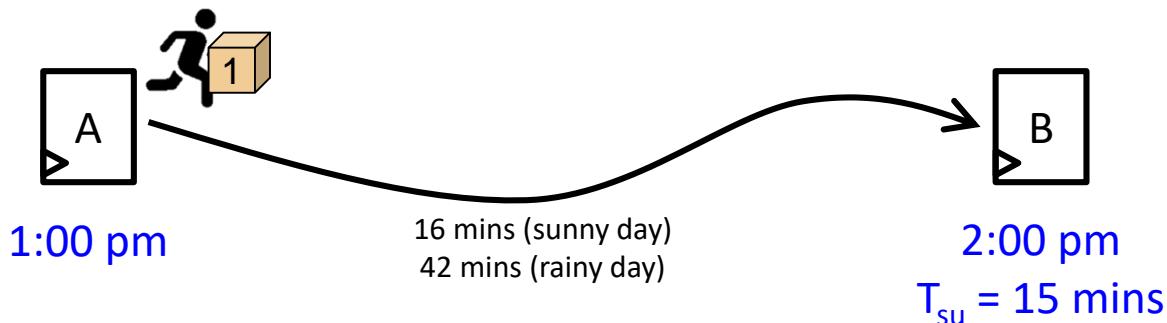


	Point	Incr	Path
21			
22			
23	clock i_clk (rise edge)	0.00	0.00
24	clock network delay (ideal)	0.50	0.50
25	input external delay	5.00	5.50 f
26	i_inst[0] (in)	0.00	5.50 f
27	U188/Y (CLKBUFX3)	0.11	5.61 f
28	U186/Y (NAND2X1)	0.08	5.69 r
29	U152/Y (CLKINVX1)	0.05	5.74 f
30	U150/Y (NAND2X1)	0.05	5.79 r
31	U148/Y (OA21XL)	0.11	5.91 r
32	U141/Y (OAI21XL)	0.05	5.96 f
33	U140/Y (NAND2X1)	0.11	6.07 r
34	U175/Y (OAI21XL)	0.06	6.13 f
35	U216/Y (AOI221XL)	0.20	6.32 r
36	U214/Y (NAND2X1)	0.04	6.36 f
37	o_data_reg[2]/D (DFFRX1)	0.00	6.36 f
38	data arrival time		6.36
39			
40	clock i_clk (rise edge)	10.00	10.00
41	clock network delay (ideal)	0.50	10.50
42	clock uncertainty	-0.10	10.40
43	o_data_reg[2]/CK (DFFRX1)	0.00	10.40 r
44	library setup time	-0.13	10.27
45	data required time		10.27
46			
47	data required time		10.27
48	data arrival time		-6.36
49			
50	slack (MET)	3.91	

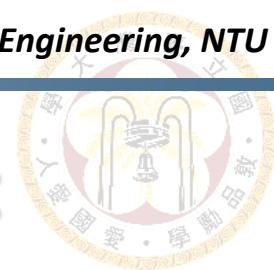
**How to calculate the slack?**



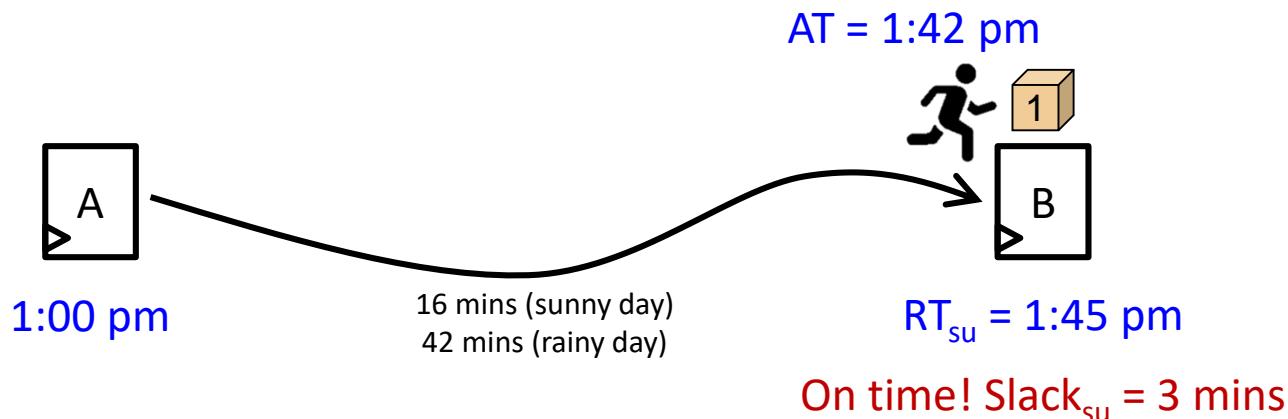
# STA Example: Setup Requirement



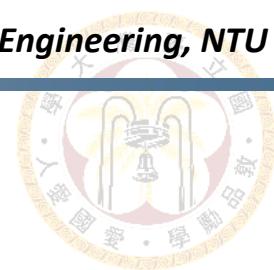
- Given conditions (assume clock is ideal)
  - Clock period  $D_p = 60 \text{ mins}$
  - Setup time  $T_s = 15 \text{ mins}$
  - Path delay (slow condition) = 42 mins
- Requirement 1: **data ready before 1:45 pm**



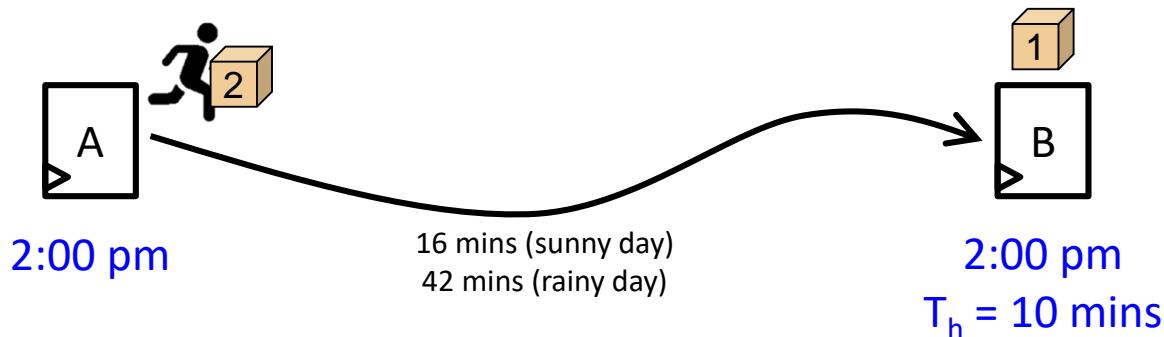
# STA Example: Setup Requirement



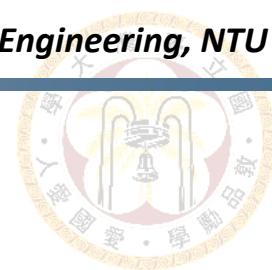
- Given conditions (assume clock is ideal)
  - Clock period D<sub>p</sub> = 60 mins
  - Setup time T<sub>s</sub> = 15 mins
  - Path delay (slow condition) = 42 mins
- Requirement 1: **data ready before 1:45 pm**
- We get
  - Require time<sub>setup</sub> RT<sub>su</sub> = 1:45 pm
  - Arrival time AT = 1:42 pm
  - Slack<sub>su</sub> = RT<sub>su</sub> – AT = 3 mins



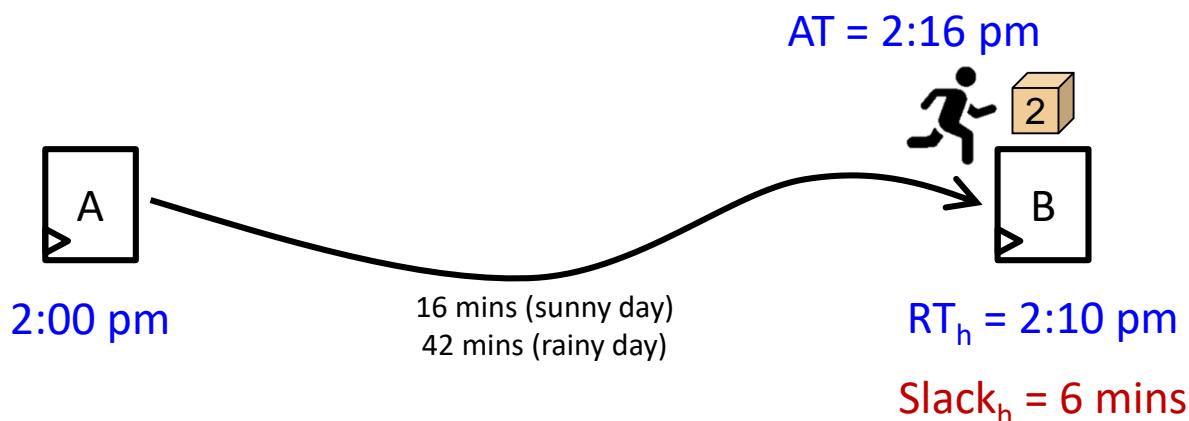
# STA Example: Hold Requirement



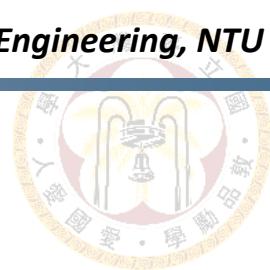
- Given conditions (assume clock is ideal)
  - Clock period  $D_p = 60$  mins
  - Hold time  $T_h = 10$  mins
  - Path delay (fast condition) = 16 mins
- Requirement 2: **data not overwritten until 2:10 pm**



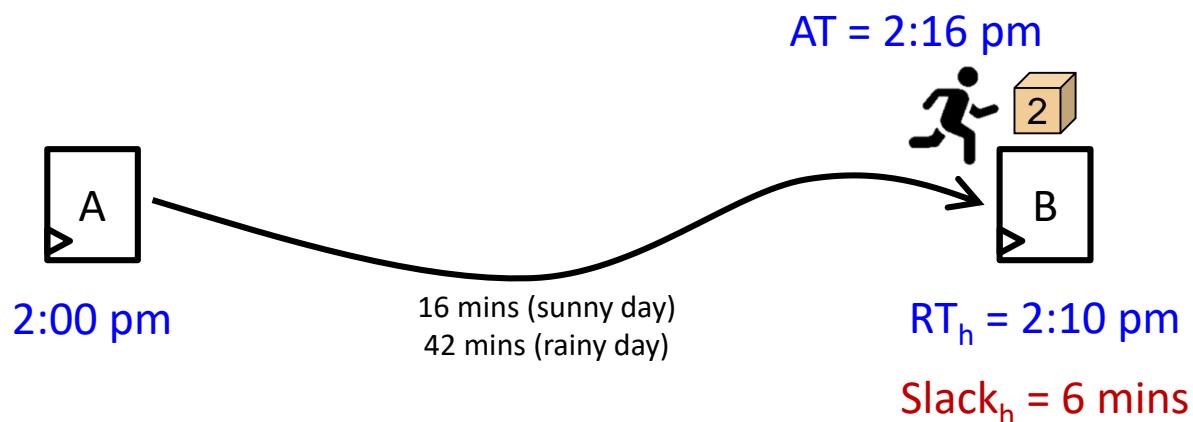
# STA Example: Hold Requirement



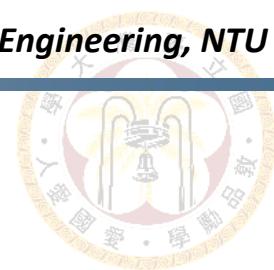
- Given conditions (assume clock is ideal)
  - Clock period  $D_p = 60 \text{ mins}$
  - Hold time  $T_h = 10 \text{ mins}$
  - Path delay (fast condition) = 16 mins
- Requirement 2: **data not overwritten until 2:10 pm**
- We get
  - Require time<sub>hold</sub>  $RT_h = 2:10 \text{ pm}$
  - Arrival time  $AT = 2:16 \text{ pm}$
  - $Slack_h = AT - RT_h = 6 \text{ mins}$



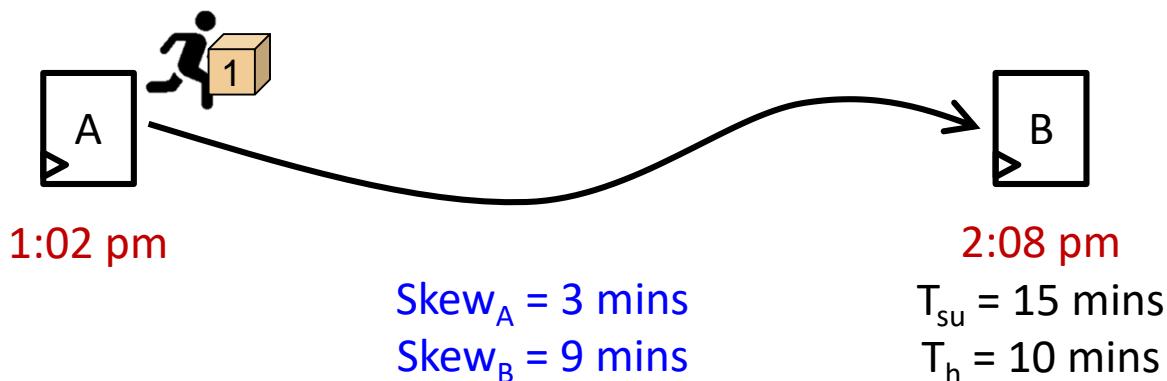
# Simplified STA Formulas



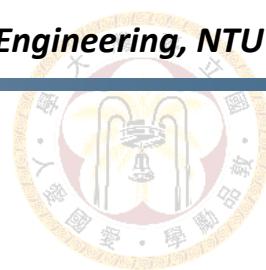
- Ideal clock, reg-to-reg timing path
- Requirement 1: setup requirement
  - $RT_{su} = D_p - T_{su}$
  - Require  $Slack_{su} = RT_{su} - AT \geq 0$
- Requirement 2: hold requirement
  - $RT_h = T_h$
  - Require  $Slack_h = AT - RT_h \geq 0$



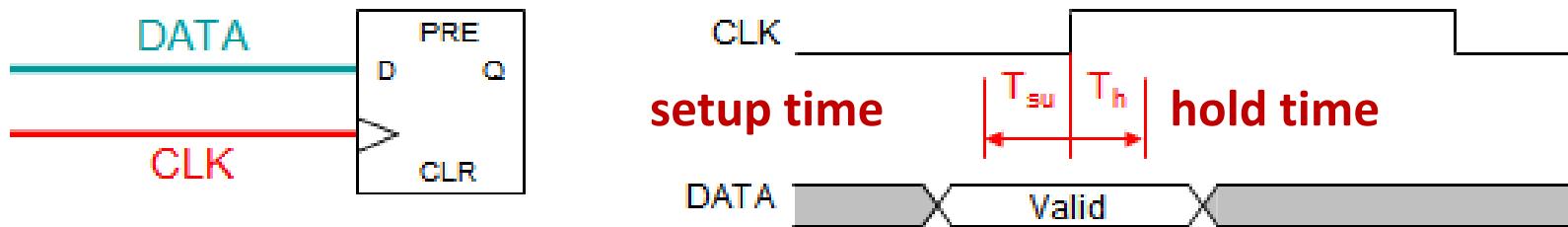
# STA Example: Non-ideal Clock



- Consider clock skew: Clock arrival time = clock edge + clock skew
- Case 1:  $\text{Skew}_A < \text{Skew}_B$ 
  - E.g., clk arrives at B 6 mins after A
  - Good for setup requirement, bad for hold requirement
- Case 2:  $\text{Skew}_A > \text{Skew}_B$ 
  - E.g., clk arrives at B 8 mins before A
  - Bad for setup requirement, good for hold requirement
- Consider clock uncertainty: bad for both setup & hold requirements



# Setup Time & Hold Time

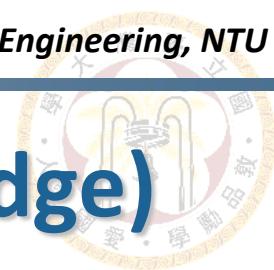


## ■ Setup Time

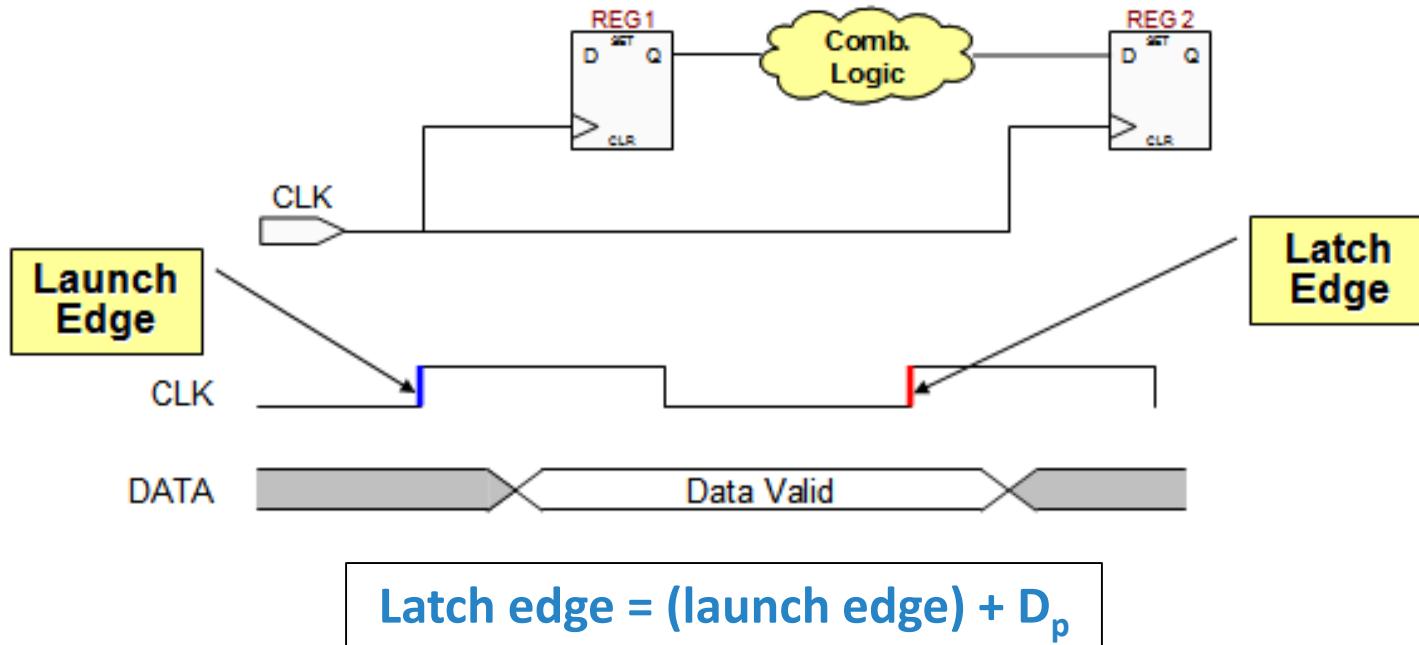
- The minimum amount of time before the clock's active edge that the data must be stable
- Violation may cause incorrect data to be captured

## ■ Hold Time

- The minimum amount of time after the clock's active edge during which data must be stable
- Violation may cause incorrect data to be latched



# Launch Edge & Latch Edge (Capture Edge)

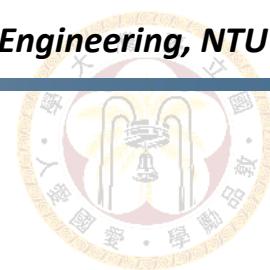


## ■ Launch Edge

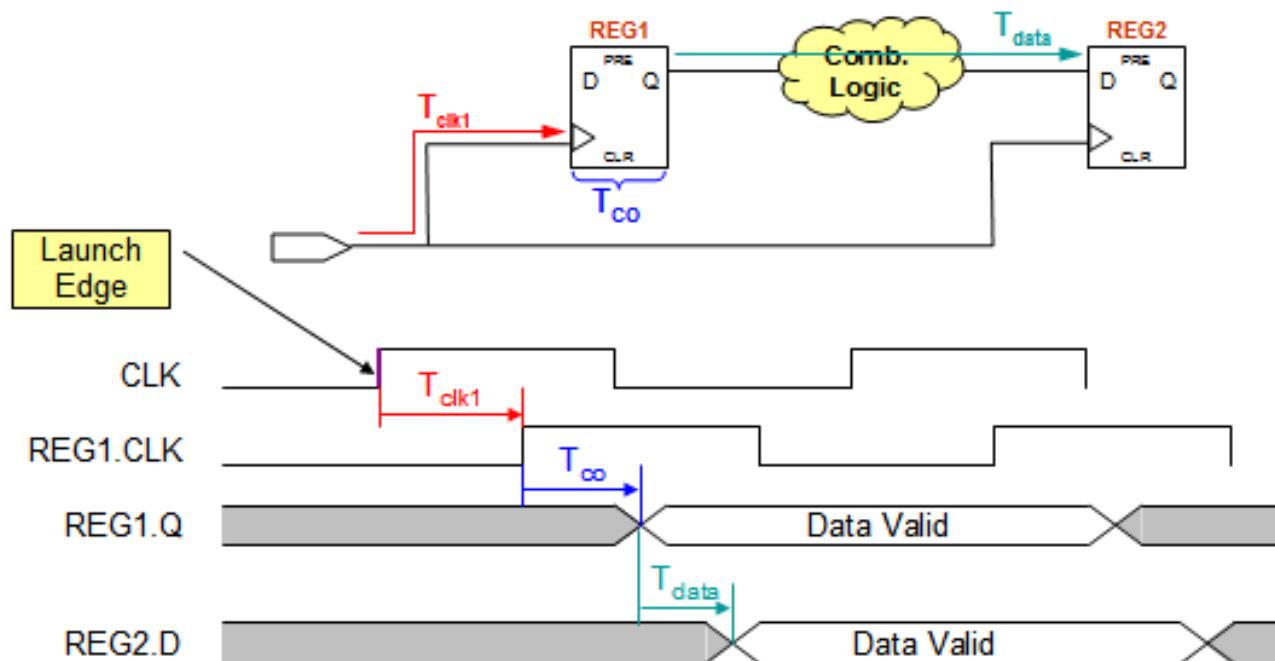
- CLK rising edge of register 1 for generating data

## ■ Latch Edge

- CLK rising edge of register 2 for receiving data



# Data Arrival Time (Setup Time)

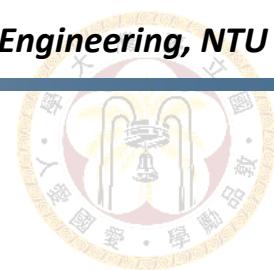


Clock Arrival Time<sub>REG1</sub> =  $T_{clk1}$

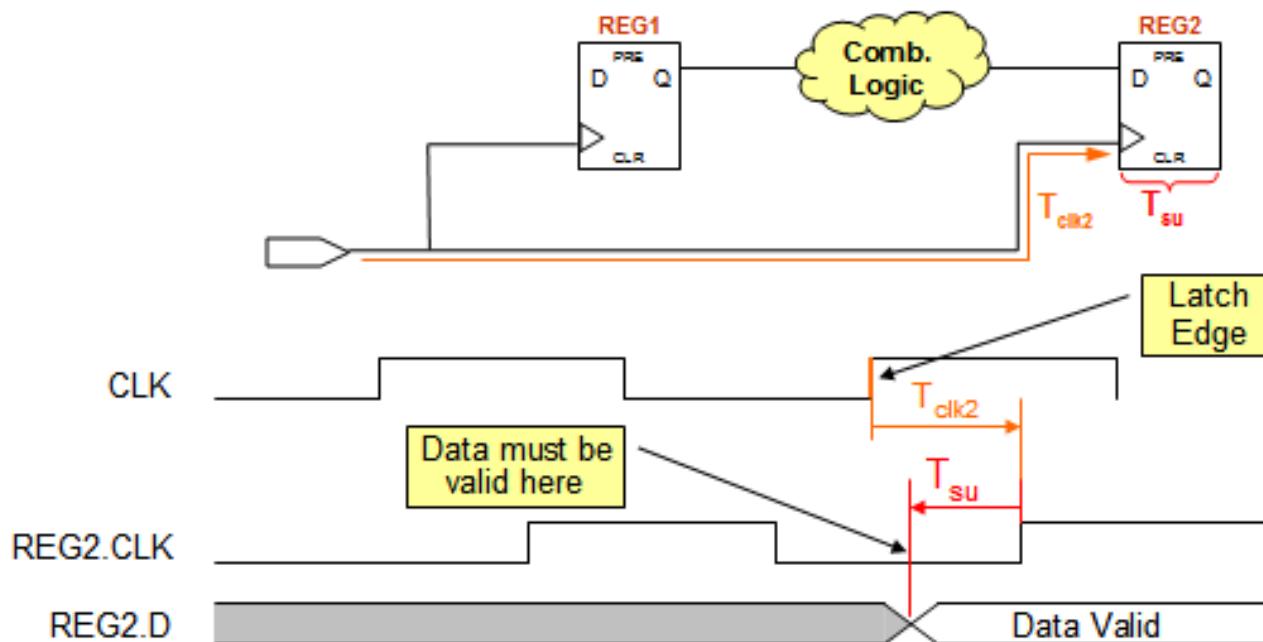
$$AT = T_{clk1} + [T_{co} + T_{data}]$$

Path Delay

- $T_{clk1}$ : clock skew of register 1
- $T_{co}$ : clock to output delay of register 1
- $T_{data}$ : combinational logic delay



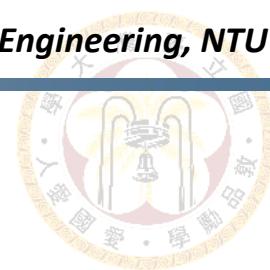
# Data Required Time (Setup Time)



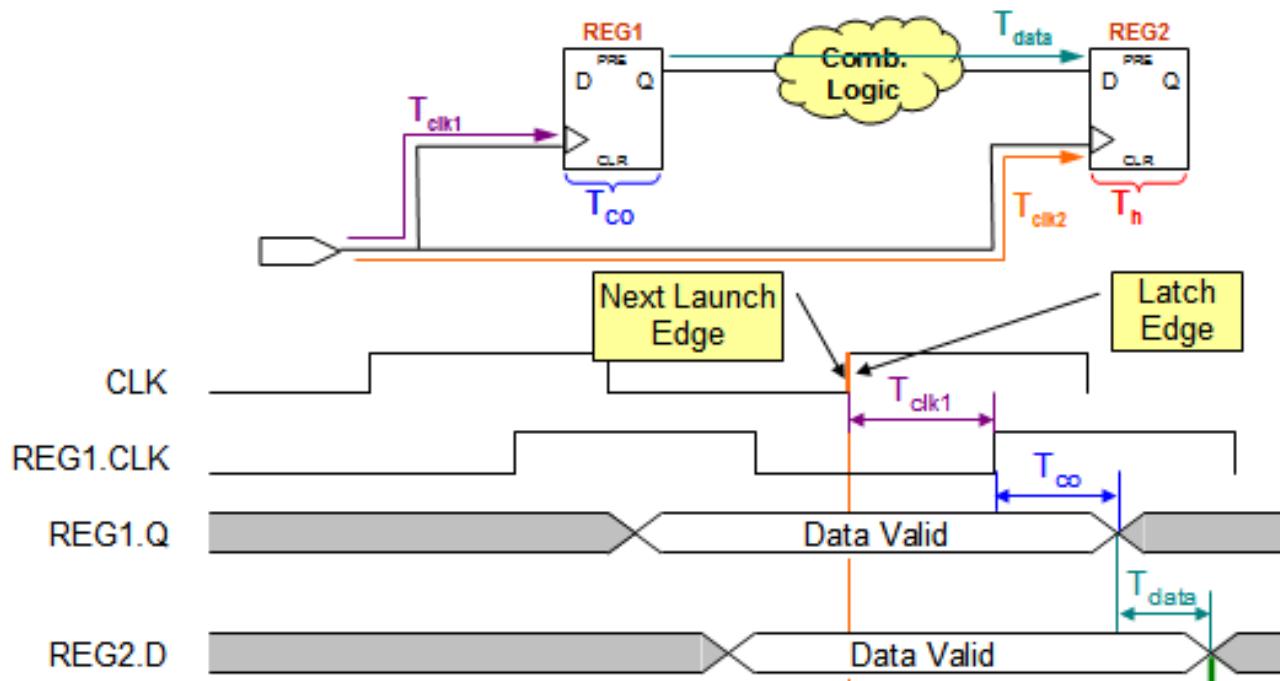
$$\text{Clock Arrival Time}_{\text{REG2}} = D_p + T_{clk2}$$

$$RT_{su} = D_p + T_{clk2} - T_{su} - \text{Uncertainty}$$

- $T_{clk2}$ : clock skew of register 2
- $T_{su}$ : setup time of data



# Data Arrival Time (Hold Time)

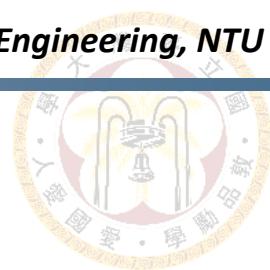


$$\text{Clock Arrival Time}_{\text{REG1}} = D_p + T_{clk1}$$

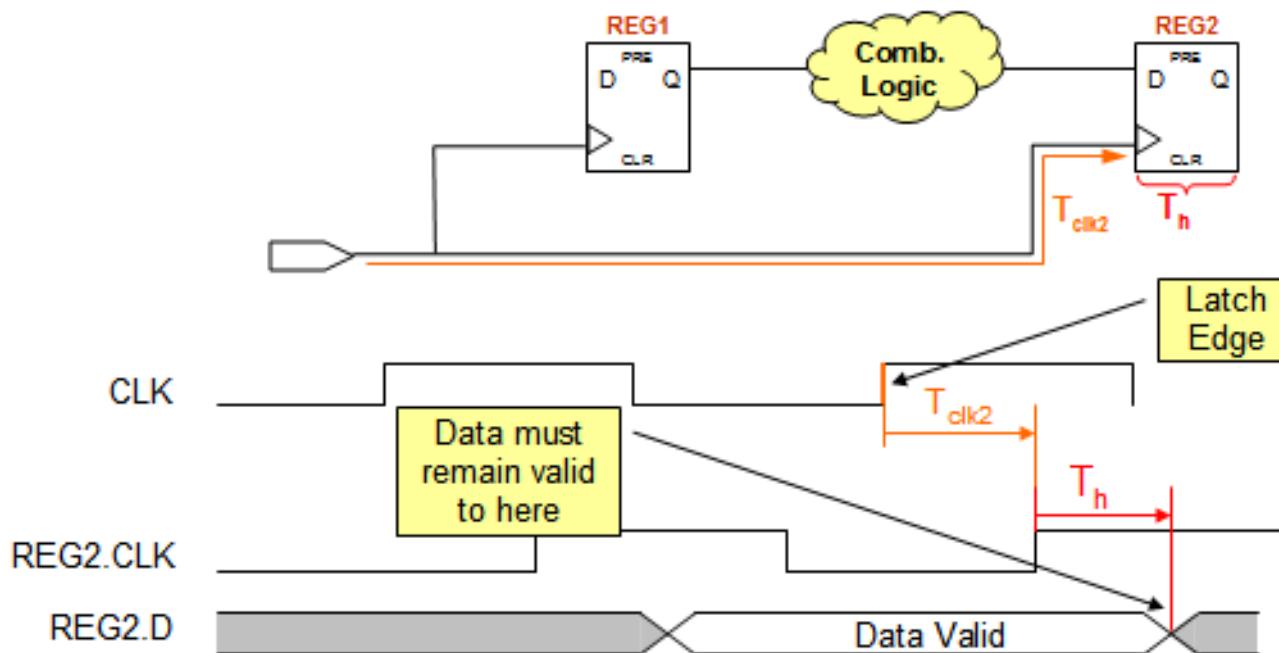
$$AT = D_p + T_{clk1} + \boxed{T_{co} + T_{data}}$$

Path Delay

- $T_{clk1}$ : clock skew of register 1
- $T_{co}$ : clock to output delay of register 1
- $T_{data}$ : combinational logic delay



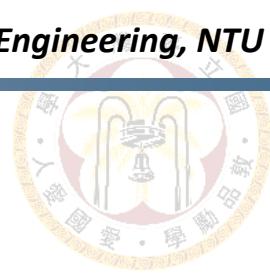
# Data Required Time (hold time)



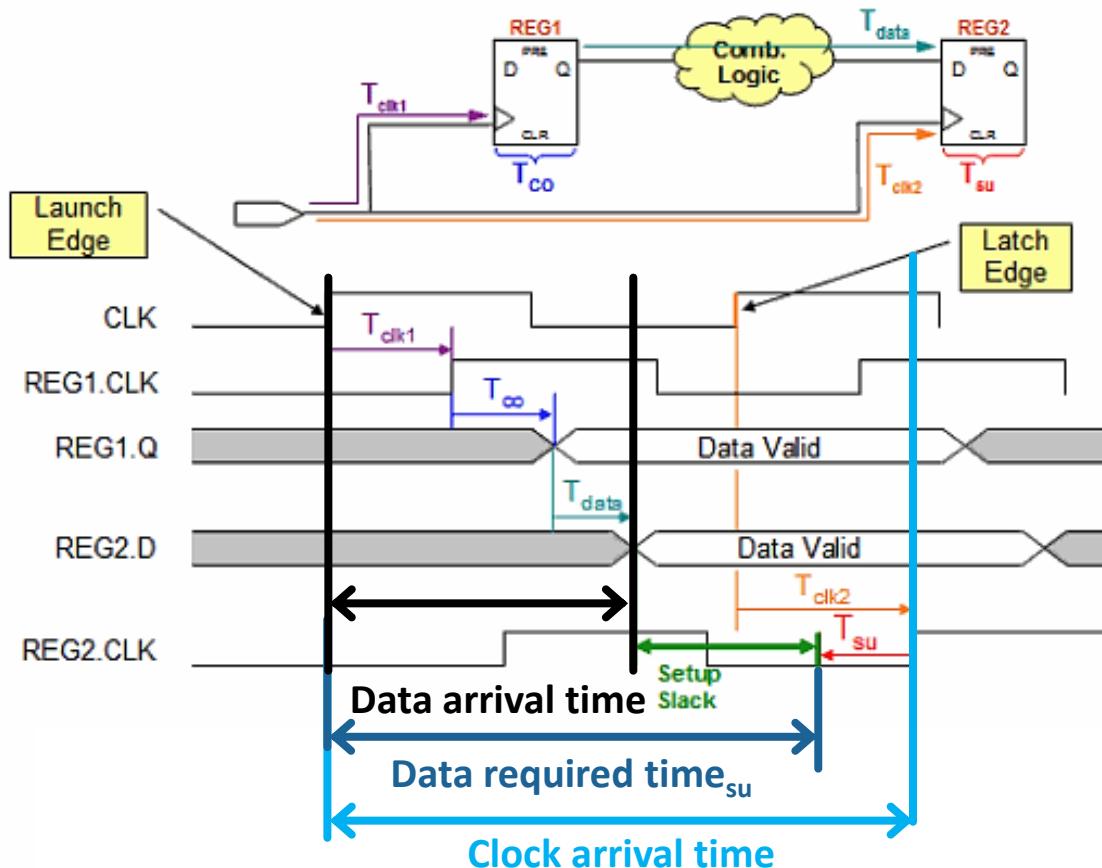
$$\text{Clock Arrival Time}_{\text{REG2}} = D_p + T_{clk2}$$

$$RT_h = D_p + T_{clk2} + T_h + \text{Uncertainty}$$

- $T_{clk2}$ : clock skew of register 2
- $T_h$ : hold time of data



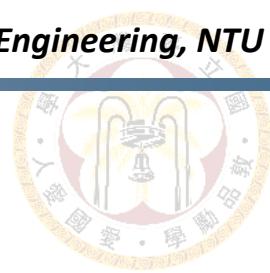
# Setup Slack



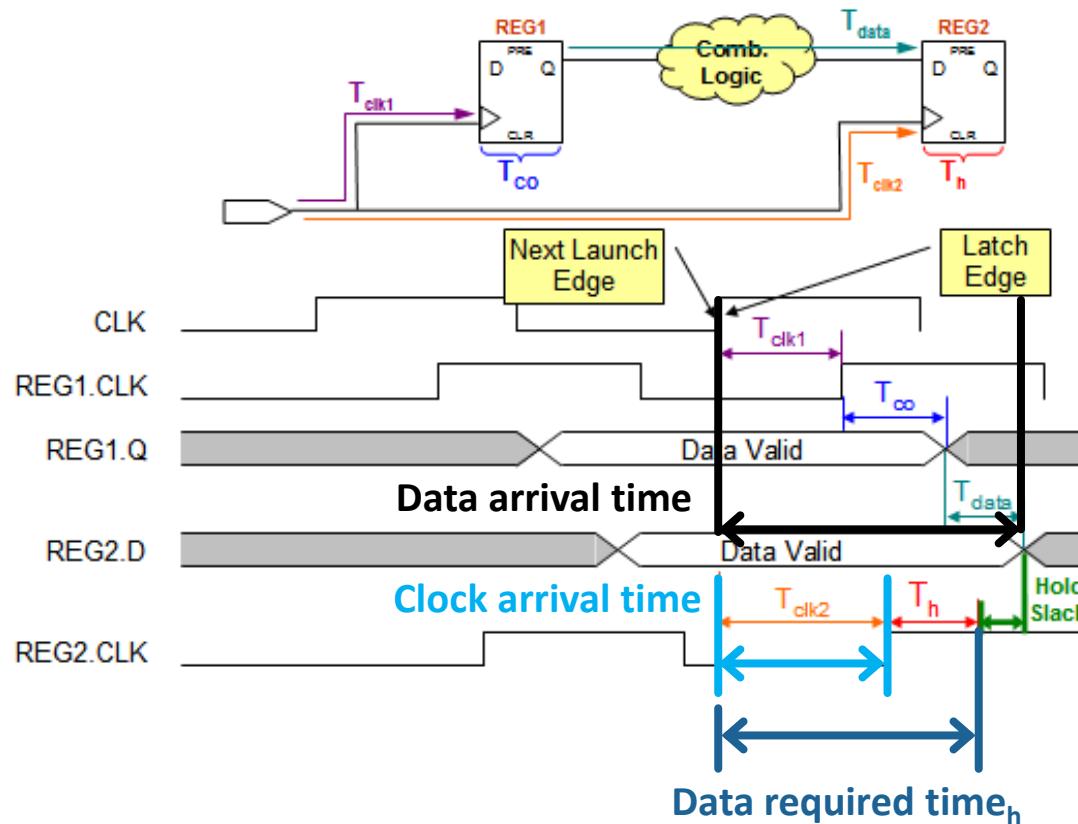
$$RT_{su} = D_p + T_{clk2} - T_{su} - \text{Uncertainty}$$

$$AT = T_{clk1} + T_{co} + T_{data}$$

$$\text{Setup Slack} = RT_{su} - AT$$



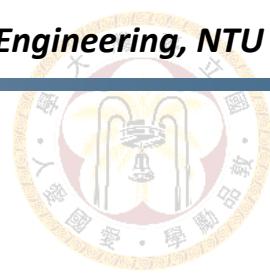
# Hold Slack



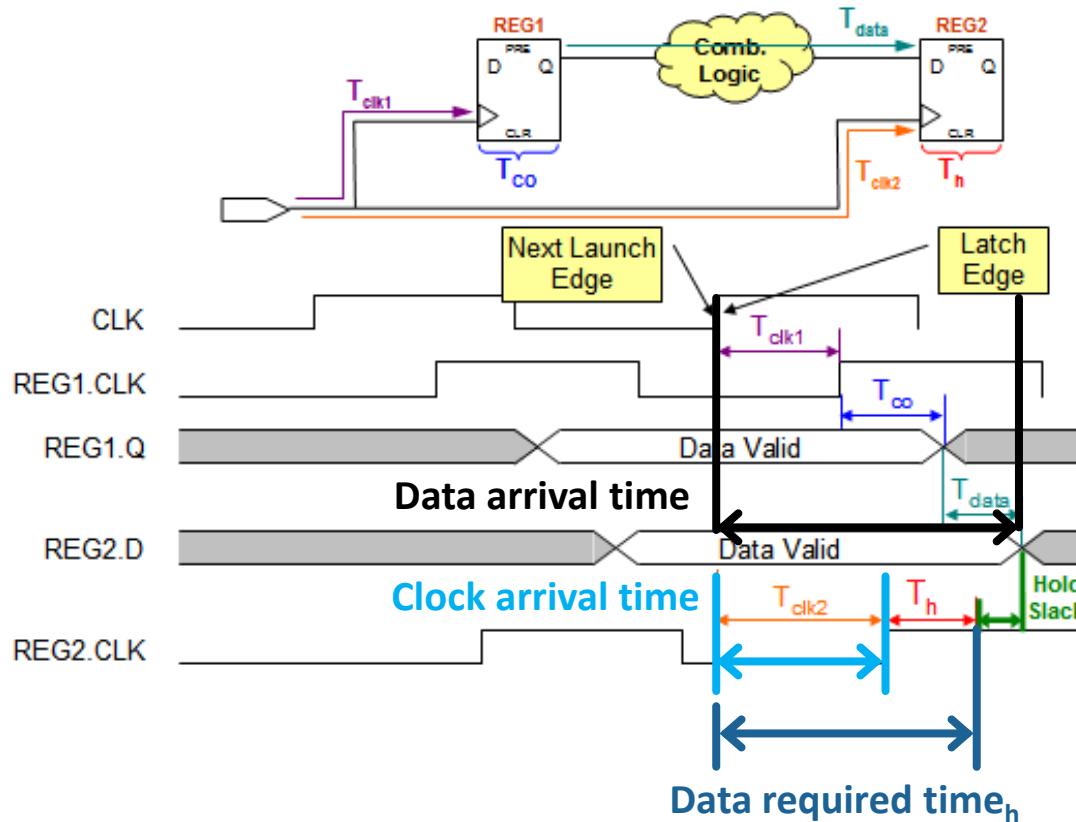
$$RT_h = (D_p) + T_{clk2} + T_h + \text{Uncertainty}$$

$$AT = (D_p) + T_{clk1} + T_{co} + T_{data}$$

$$\text{Hold Slack} = AT - RT_h$$



# Hold Slack



$$RT_h = \cancel{(D_p)} + T_{clk2} + T_h + \text{Uncertainty}$$

$$AT = \cancel{(D_p)} + T_{clk1} + T_{co} + T_{data}$$

$$\text{Hold Slack} = AT - RT_h$$

Same edge, clock period  
doesn't affect hold slack