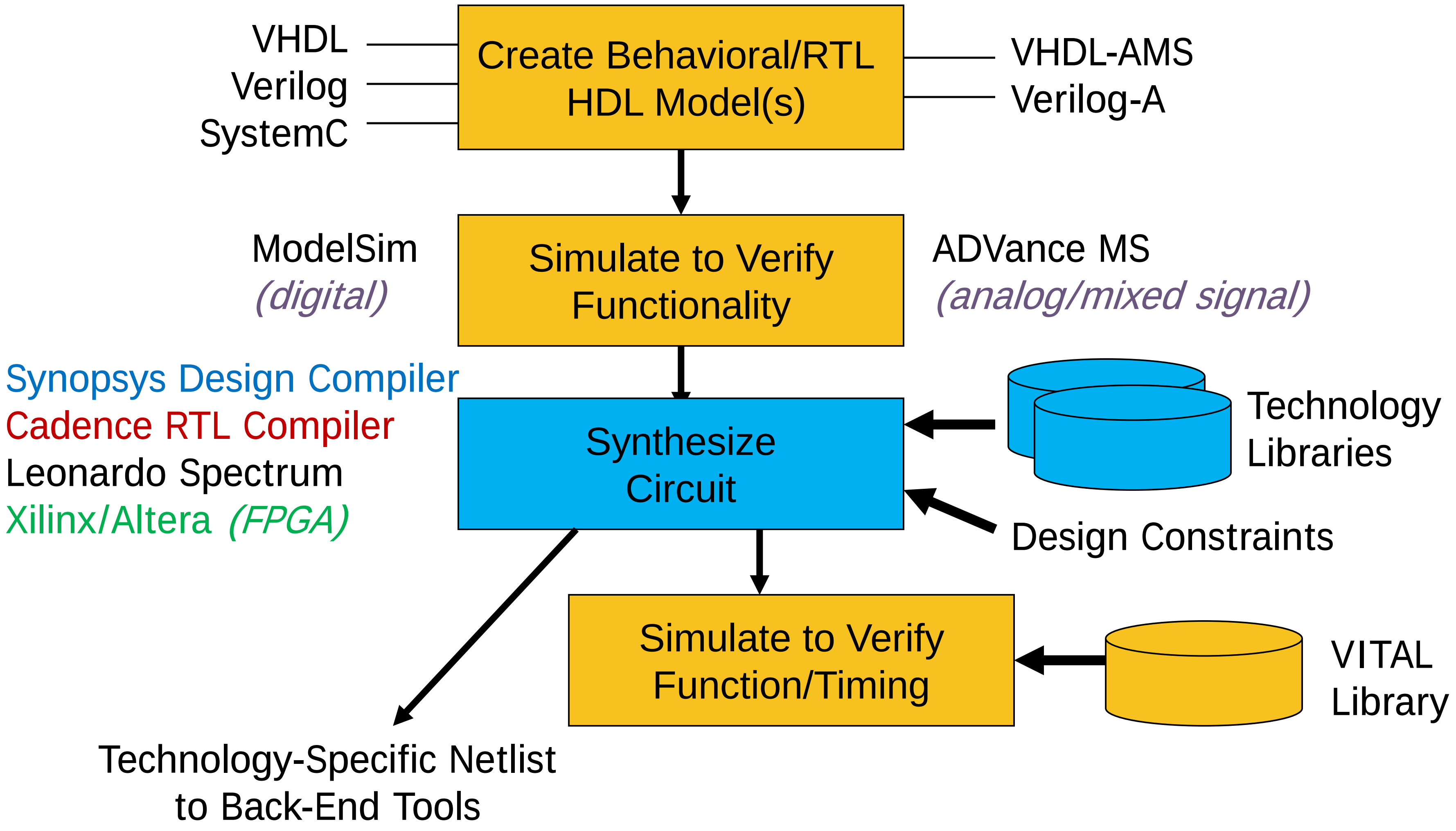
Automated Synthesis from HDL models

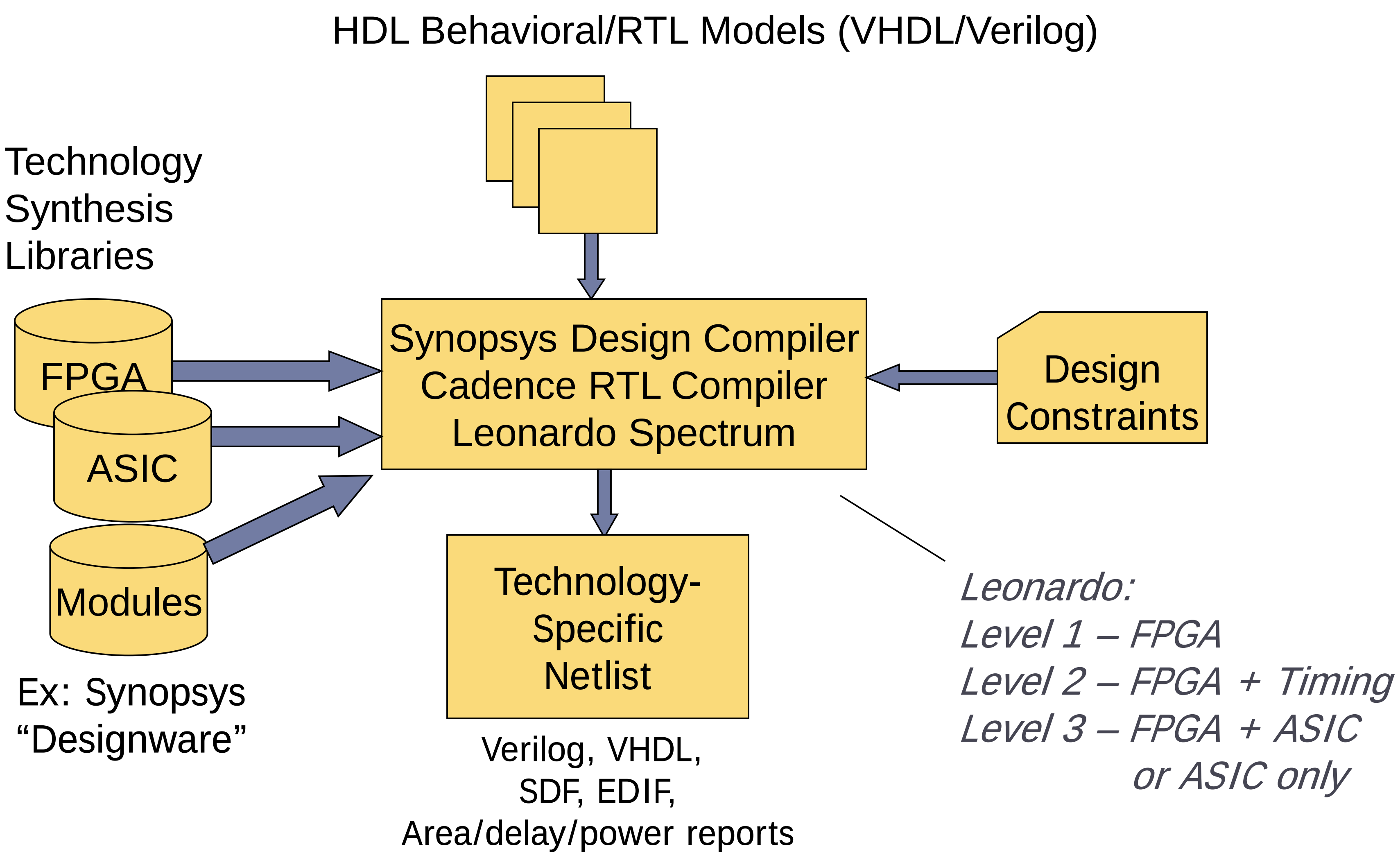
Design Compiler (Synopsys)

Leonardo (Mentor Graphics)

Front-End Design & Verification



Automated synthesis


HDL Behavioral/RTL Models (VHDL/Verilog)
Technology Synthesis Libraries
FPGA
ASIC
Modules
Ex: Synopsys "Designware"
Synopsys Design Compiler
Cadence RTL Compiler
Leonardo Spectrum
Design Constraints
Technology-Specific Netlist
Verilog, VHDL, SDF, EDIF, Area/delay/power reports
Leonardo:
Level 1 – FPGA
Level 2 – FPGA + Timing
Level 3 – FPGA + ASIC or ASIC only

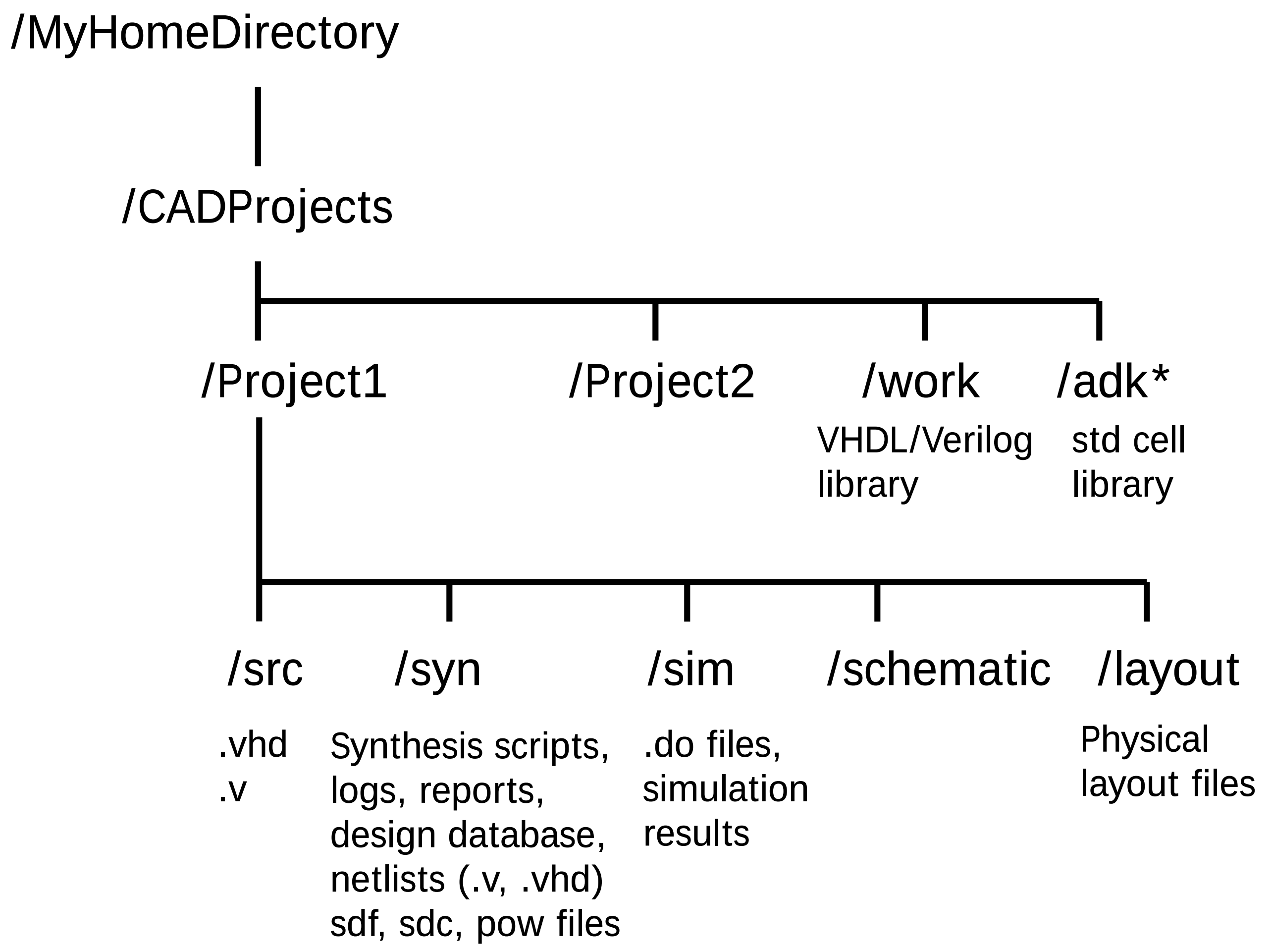
Synopsys Design Compiler Documents

Documents (pdf) located on Linux server in

/class/ELEC6250/Synopsys_Docs/

- DC User Guide
- DC Command Line
- DC Synthesis Quickref
- DC Ref Constraints and Timing
- DC Ref Timing Optimization
- DesignVision Tutorial
- DesignVision User Guide

Project directory structure



Invoking Design Compiler

- Interactive shell version:
  - *dc_shell –f scriptFile*
  - Most efficient and common usage is to put TCL commands into scriptFile, including "quit" at the end
    - TCL = Tool Command Language
  - Edit and rerun scriptFile as needed
- GUI version (Design Vision)
  - *design_vision*
  - From dc_shell: *gui_start*
  - Main advantage over dc_shell is to view the synthesized schematic

Synthesis stages and commands

Load tech libraries into database

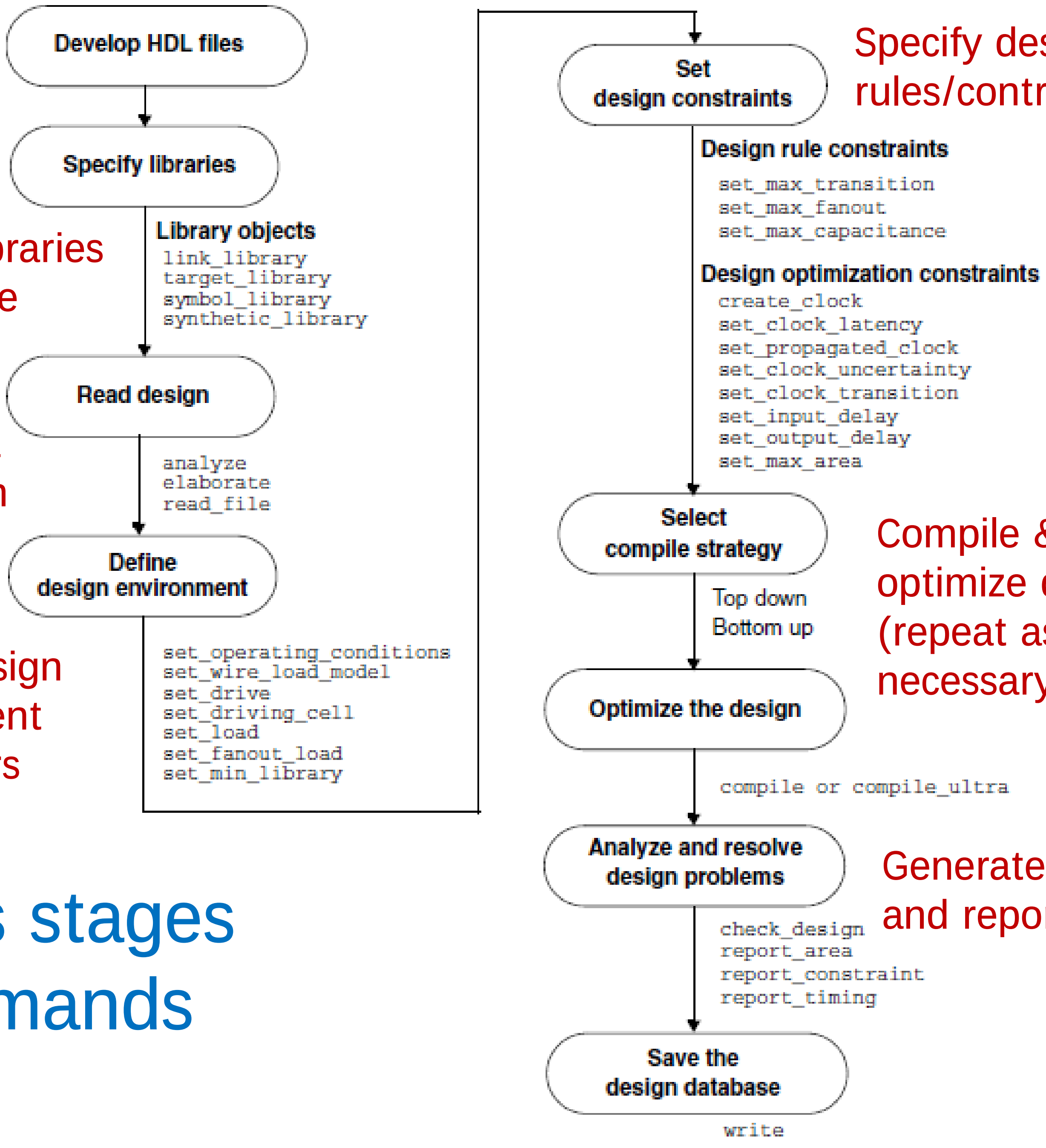
Read, analyze & elaborate design

Define design environment parameters

Specify design rules/contraints

Compile & optimize design (repeat as necessary)

Generate netlist and reports



```
link_library
target_library
symbol_library
synthetic_library
```

```
analyze
elaborate
read_file
```

```
set_operating_conditions
set_wire_load_model
set_drive
set_driving_cell
set_load
set_fanout_load
set_min_library
```

```
set_max_transition
set_max_fanout
set_max_capacitance
```

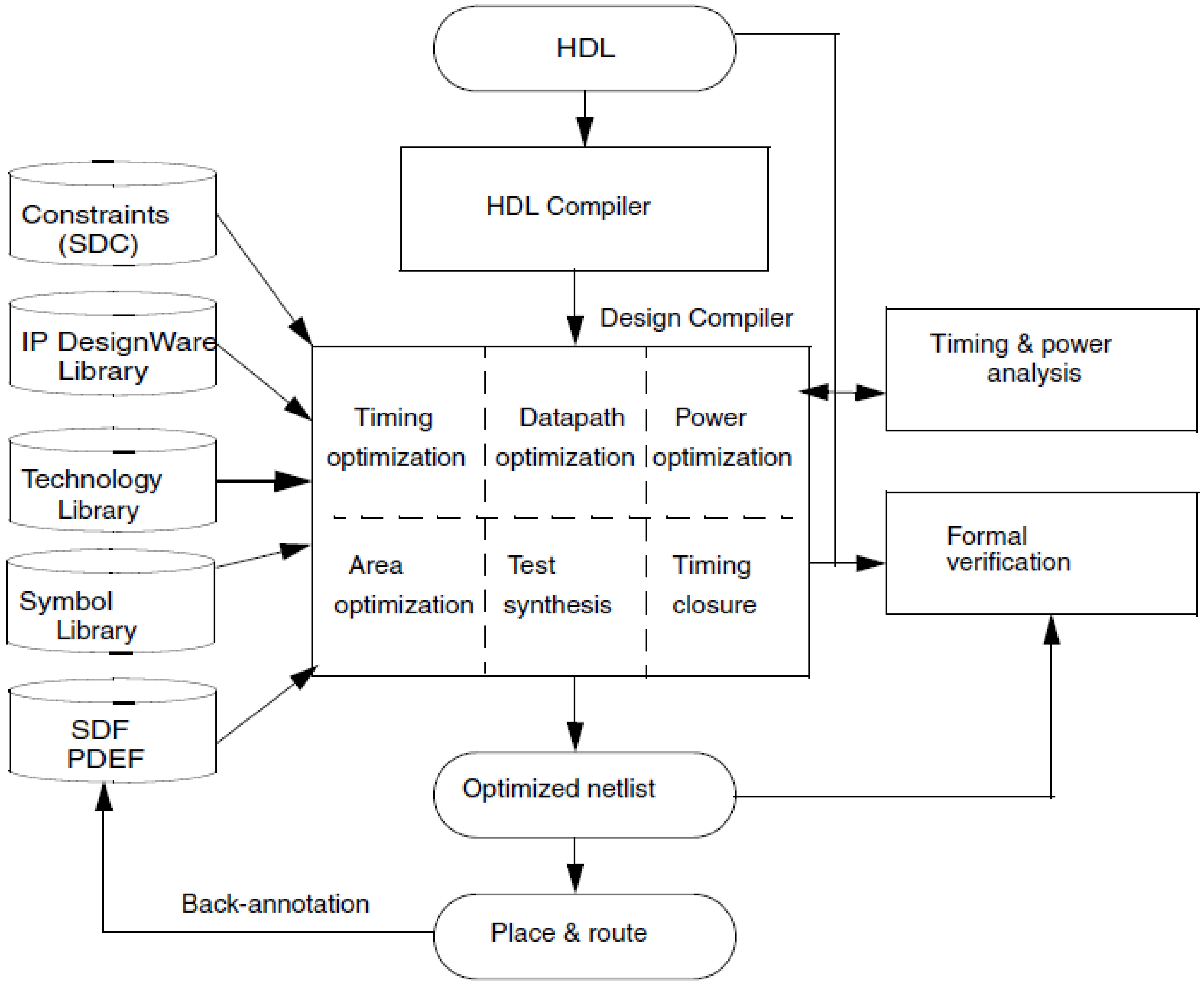
```
create_clock
set_clock_latency
set_propagated_clock
set_clock_uncertainty
set_clock_transition
set_input_delay
set_output_delay
set_max_area
```

```
compile or compile_ultra
```

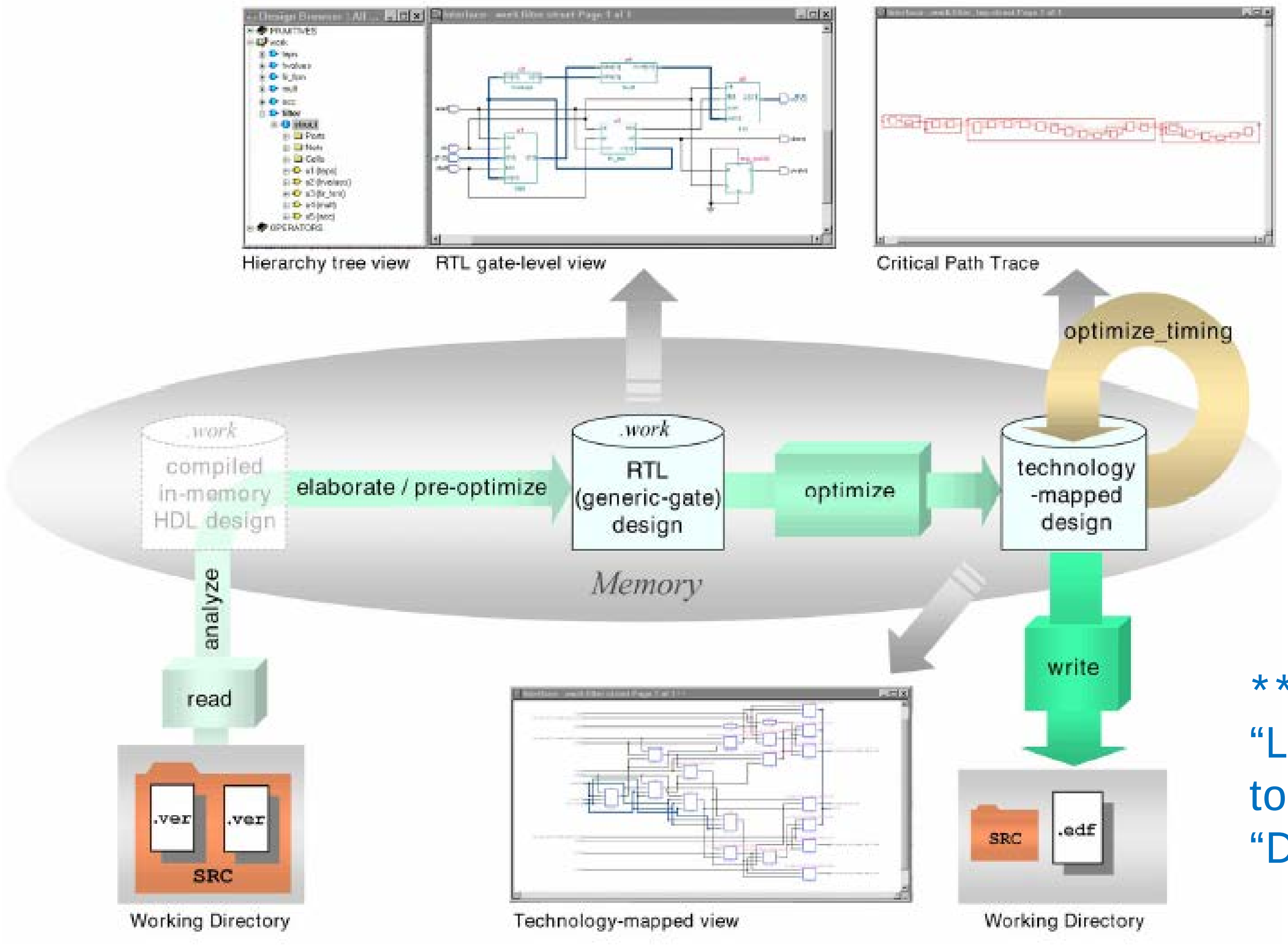
```
check_design
report_area
report_constraint
report_timing
```

```
write
```

Synopsys Design Compiler flow



ASIC synthesis flow**



** Mentor Graphics "Leonardo" - similar to Synopsys "Design Compiler"

Design Compiler library files

DC User Guide
Chapter 4

- target_library : standard cell database (binary)
  - cell area/pins/timing data (for synthesis decisions)
- synthetic_library: Synopsys DesignWare components
- link_library : use during linking
  - Includes target and link library plus internal data (*)
- symbol_library : schematic symbols
  - Synopsys installation includes a generic symbol library

- Define in file *.synopsys_dc.setup*

Setup file (8HP): *.synopsys_dc.setup*

DC reads *.synopsys_dc.setup* files in order:

1. Synopsys installation directory (all user projects)
2. User home directory (all projects for this user)
3. Current project directory (this project only)

```
set MyHome [getenv "HOME"]
set SynopsysInstall [getenv "STROOT"]
set CMOS8HP "/class/ELEC6250/cmos8hp/std_cell/v.20130404“
set search_path [list  \
   [format "%s%s" $CMOS8HP /synopsys/typ_v150_t025] \
   [format "%s%s" $CMOS8HP /symbols/synopsys] \
   [format "%s%s" $SynopsysInstall /libraries/syn] \
   [format "%s%s" $SynopsysInstall /dw/sim_ver] \
   [format "%s%s" $SynopsysInstall /dw]]
set target_library [list PnomV1p50T025_STD_CELL_8HP_12T.db]
set synthetic_library [list dw_foundation.sldb]
set link_library   [list "*" $target_library $synthetic_library]
set symbol_library [list generic.sdb]
```

Synopsys *DesignWare* Package

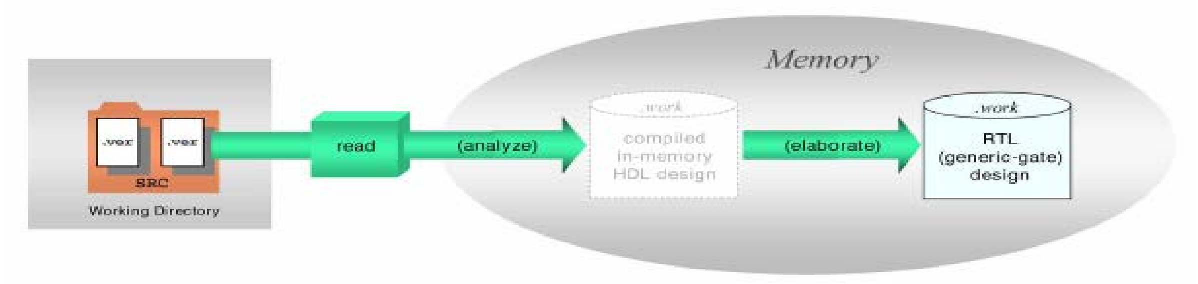
- Predesigned components (tech-independent)
  - arithmetic, filters, CRC gen's, counters, decoders, FIFOs, flip-flop RAMs, etc.
- Let DC choose a component, or instantiate directly
  - components chosen to implement arithmetic operators
- Example DW decrementer:

```
module decrementer (in_A, SUM_out);
    parameter width = 8;
    input [width-1 : 0] in_A;
    output [width-1 : 0] SUM_out;
    DW01_dec #(width) U1( .A(in_A), .SUM(SUM_out));
 endmodule;
```

Load design into the database

DC User Guide
Chapter 5

- **Analyze** – syntax check and build database
  - input VHDL and/or Verilog models
  - check dependencies & resolve generics/parameters
- **Elaborate** – synthesize to generic gates and black boxes
  - technology-independent gates
  - operators (arithmetic, relational, etc.) recognized and implemented with "black boxes" (no logic in them yet)



- **Read** command does analyze + elaborate + pre-optimize

Analyze Command

- analyze {f1.v src/f2.v "top file.v"}
  - Read and analyze into default memory database library "work"
  - List HDL files in bottom-up order – top level last
  - Use quotes if embedded spaces in file name: "top file.v"
  - Include directory if necessary: src/f2.v
- Analyze command switches:
  - -format verilog (or vhdl) [default VHDL if file ext = .vhd/.vhdl or Verilog if file ext = .v/.verilog]
  - -work lib_name [lib where design to be stored (default = "work".) Different libraries might be used for comparing designs]
- Examples:
  - analyze {src/f1.v src/f2.vhd} (store in "work")
  - analyze {src/f1.v src/f2.vhd} –work lib_version2

Elaborate Command

- "Elaborate" a design currently in the memory database – producing tech-independent circuit
  - elaborate divider ["divider" = VHDL entity/Verilog module]
  - Switches
    - -single_level [only do top level – for bottom-up design]
    - -architecture a1 [if other than most recently analyzed]
    - -work lib_name [if name other than work]
    - -generics { size=9 use_this=TRUE initval="10011" }
      - List format is { generic=value generic=value …. }
    - -parameters [format same as generics]

Example script

```
#Design-specific information – create variables for use in commands
set myFiles [list ./src/top.v ./src/Muxbig.v ]
set basename TOP
set fileFormat verilog
define_design_lib WORK –path ./syn
```

Unique for each design - not necessary, but convenient for multiple projects

```
#Design-independent: these commands need not be changed
analyze –format $fileFormat  -lib WORK $myFiles
elaborate $basename –lib WORK –update
current_design $basename
link                (link all design parts)
uniquify            (make unique copies of replicated modules)
```

Commands using above design information

Read command

- Performs both analyze and elaborate steps
- Useful for single HDL file:

  read_file –f verilog filename.v

- Same switches as ***analyze*** and ***elaborate*** commands, plus (optional):

  -dont_elaborate {f1.vhd} – do analysis but not elaborate

Design environment

DC User Guide
Chapter 6

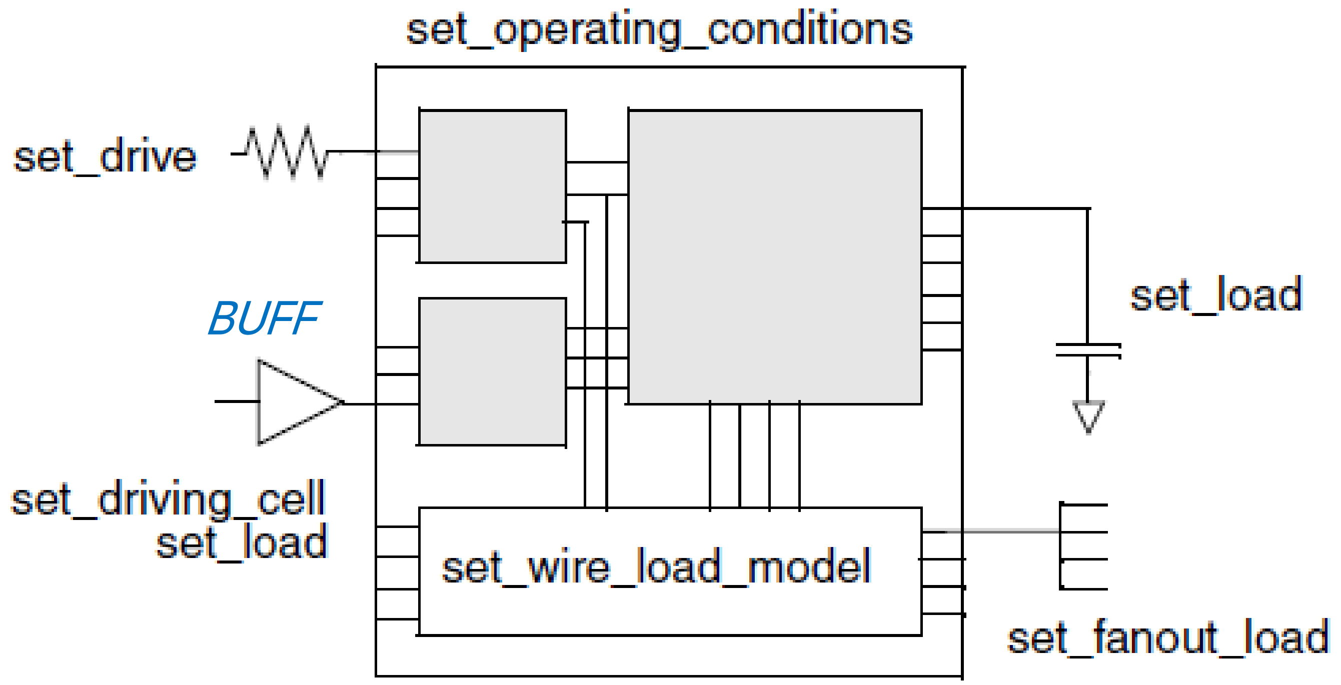
- Technology variables affect **delay** calculations
  - Manufacturing process, temperature, voltage, fanouts, loads, drives, wireload models
- Defaults specified in the technology library
  - 8HP technology libraries on next slide
- Design environment variables can be set
  - Use tech library defaults if variables not set
    - set voltage 2.5 (volts)
    - set temp 40 (degrees celsius/centigrade)
    - set process 1 (process variation # – if available)

Available 8HP technology files

- Located in: *$CMOS8HP/synopsys/*
- Each file contains data for each library cell for a specific operating voltage and temperature

Directory	Technology File
typ_v120_t025	*PnomV1p20T025_STD_CELL_8HP_12T.db*
typ_v150_t025	*PnomV1p50T025_STD_CELL_8HP_12T.db*
fast_v132_tm40	*PbcV1p32Tm40_STD_CELL_8HP_12T.db*
fast_v132_tm55	*PbcV1p32Tm55_STD_CELL_8HP_12T.db*
fast_v160_tm40	*PbcV1p60Tm40_STD_CELL_8HP_12T.db*
fast_v160_tm55	*PbcV1p60Tm55_STD_CELL_8HP_12T.db*
slow_v108_t125	*PwcV1p08T125_STD_CELL_8HP_12T.db*
slow_v140_t125	*PwcV1p40T125_STD_CELL_8HP_12T.db*

Design environment variables/commands



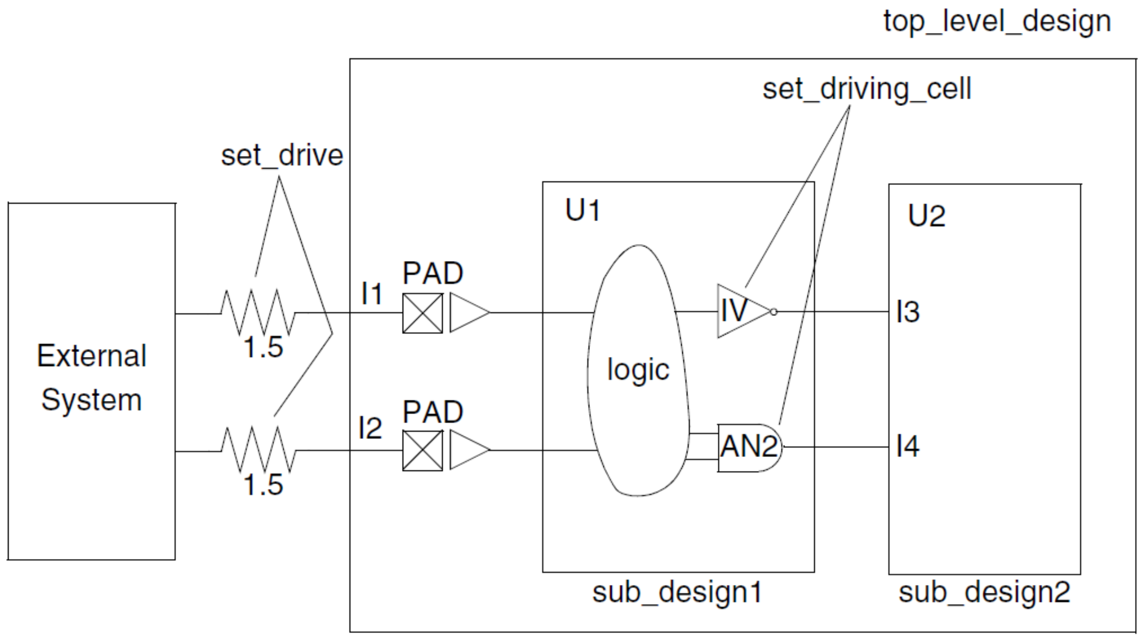
"drive" strength =
1/R of output driver
(default 0)

Transition delay=
Rdriver*Cinput

"load" = capacitive load
(units from tech library)
(default 0)

"fanout_load" = #units
(associated with input pins)

Example: define drive characteristics



- *current_design top_level_design* (define external input drives)
- *set_drive 1.5 {I1 I2}* (resistance units from library)
- *current_cell sub_design2* (define input drivers for U2)
- *set_driving_cell –lib_cell IV {I3}* (default pin = IV output)
- *set_driving_cell –lib_cell AN2 –pin Z –from_pin B {I4}*
  (arc from AN2 gate input B to output Z)
- *set_fanout_load 4 {out1 out2}* (#fanout units for output pins)

Wire Load Table (not available for 8HP)

- Estimate effects of wire length & fanout on resistance, capacitance and area of net
  - Affects switching times/delays
  - Precise delays known only after place and route
  - Function of cell sizes, fanouts, wire characteristics
- Wire Load Table may be provided by vendor
  - Determined from analysis of previous process runs
- Variables:
  - wire_load_library name
    (lib to which designed mapped - or NIL)
  - wire_table name (if named table loaded)
  - wire_tree (best,balanced,worst, or not set)
  - wire_load_mode (<u>top</u>, segmented)

Setting design constraints

DC User Guide Chapter 7

- **Design rule** constraints: rules from library vendor for proper functioning of the fabricated circuit
  - Must not be violated
  - Common constraints: transition time, fanout load, capacitance
- **Design optimization** constraints: user-specified timing and area optimization goals
  - DC tries to optimize these without violating design rules
  - Common constraints: timing and area

Design rule constraints

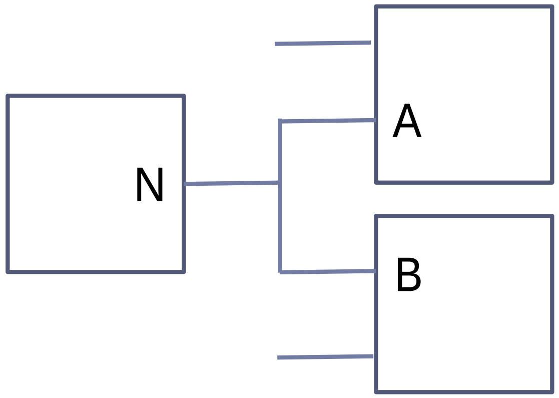
- **max_fanout** = max #loads a net can drive
  - Input pins have fanout_load attribute.

    (load they place on driving nets)
  - Output pins have max_fanout attribute.

    (max load they can drive)

    Example: Pin N drives loads A and B
    - Pin A has fanout_load value 2.0
    - Pin B has fanout_load value 3.0
    - Pin N requires max_fanout ≥ 5.0 to drive A and B

      Otherwise, use different cell or insert a buffer to drive the net.



  - Change max_fanout attribute to restrict it more than its default value

    set_max_fanout 5 [object_list] (object_list is list of ports)
  - Other design rule constraints:
    - **max_transition** (output pins): transition time to change logic values
    - **max_capacitance** (output pins): sum of net and pin capacitances driven by output

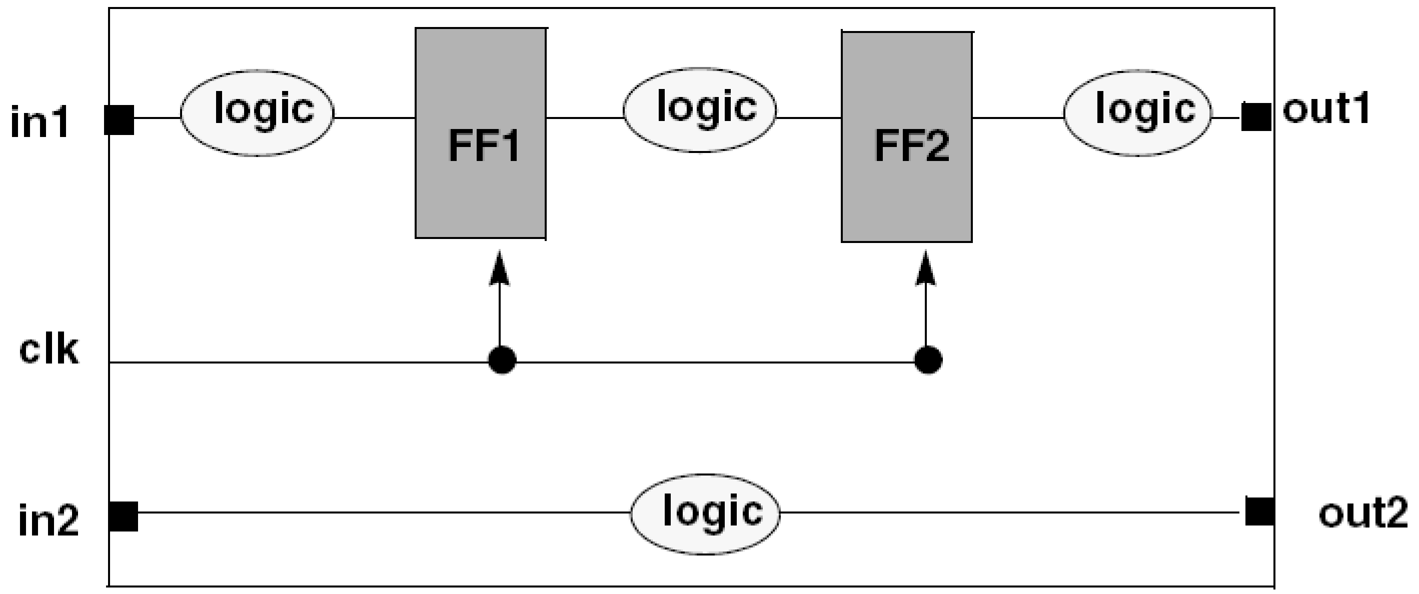
Design optimization constraints

- **Speed**
  - path delays (min,max)
  - clock specifications (period/frequency/duty)
- **Area**
  - speed is primary goal
  - optimize area if timing constraints met
  - target area 0 forces small as possible
  - *set_max_area 2000*
- Choose **realistic** constraints (within 1-10%)
  - avoid extra buffers/gates on loaded nets

Timing path types

Path delays of interest

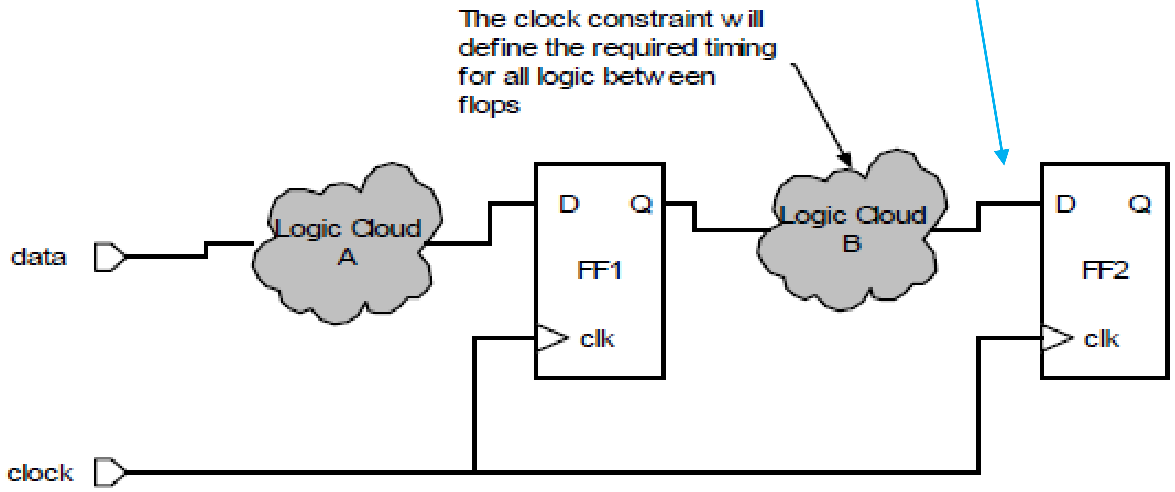
1. Combinational: primary input to primary output (in2 -> out2)
2. Primary input to register input (in1 -> FF1/D1)
3. Clock/register output to primary output (clk -> Q2 -> out1)
4. Clock/register output to register input (clk -> Q1 -> D2)



Timing Constraints

- Simple: specify target clock frequency
- Advanced: specify globally or on specific blocks
  - Clock: period/frequency, pulse width, duty cycle
  - Input: arrival time, transition times, driver strength
  - Output: required time, transition times

required time – arrival time = "slack"


The clock constraint will define the required timing for all logic between flops
data
Logic Cloud A
D
Q
FF1
clk
Logic Cloud B
D
Q
FF2
clk
clock

Clock specifications

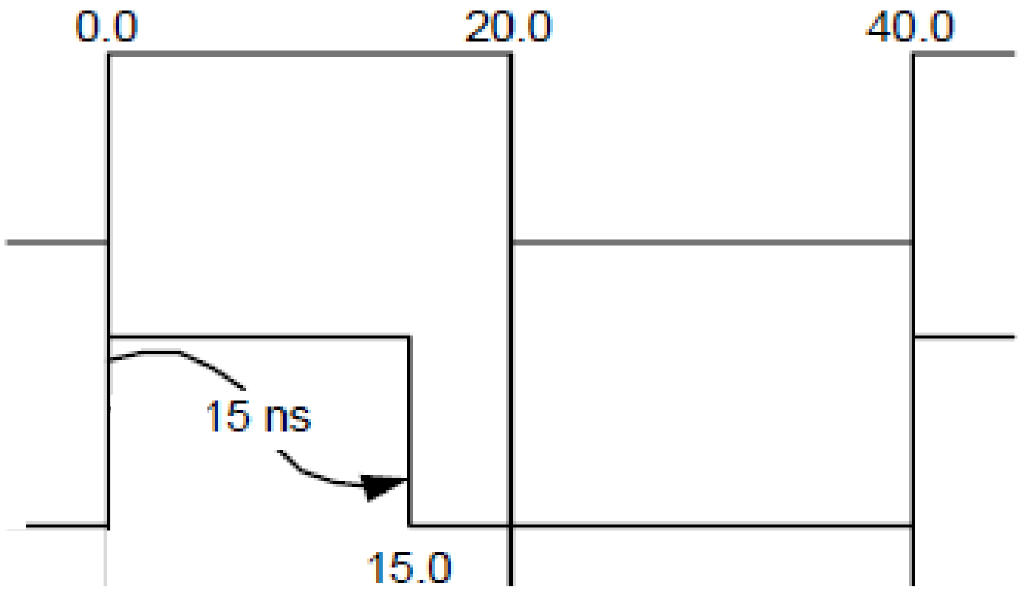
- Define **required** period/waveform for each clock
  - *create_clock ckname –period 5*
  - *create_clock ckname –period 5 –waveform {2 4}*
    - *period=5, rise at 2, fall at 4*
- DC does not automatically imply clock signals
  - *create_clock –name ckname –period 5*
    - *creates a "virtual clock" associated with a port/pin*
- Clock latency = delay through clock network
  - *set_clock_latency 2.1 –rise CLK1*
  - *set_clock_latency 0.7 –source CLK1*
    - from clock origin to clock pin
- Clock uncertainty = margin of error to allow variances
  - *set_clock_uncertainty –setup 0.2 CLK1*
  - *set_clock_uncertainty –hold 0.2 CLK1*

Add 0.2 margin on either side of clock edge to account for variances in clock network

Clock constraint examples

create_clock clk –period 40

create_clock clk
–period 40 {0, 15}

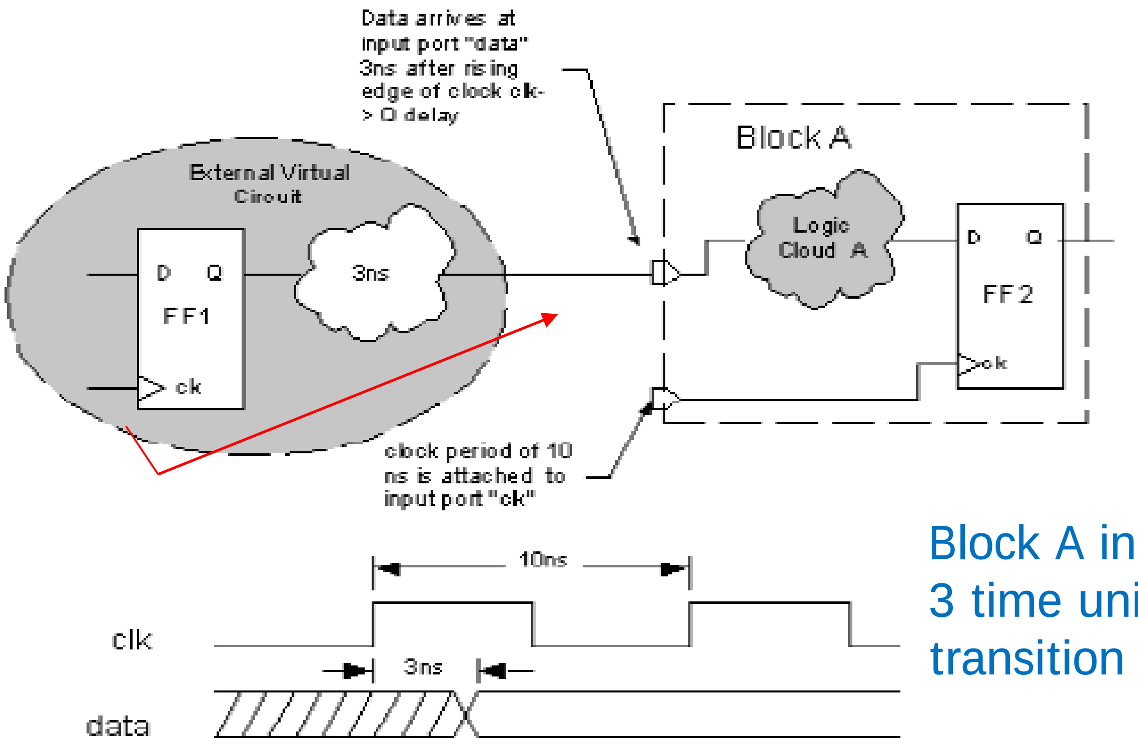


Input and output delays

- Delay from clock edge through "external" logic to an input port or internal pin.
  - *set_input_delay 2.3 {in1 in2}*
  - default input delay = 0
- Time a signal is required at output port by external destination before a clock edge
  - external circuit logic delay + external ff setup time
  - *set_output_delay 7 –clock CLK1 [all_outputs]*
  - default output delay = 0

Input constraints

- Arrival time from previous ckt to input pin, relative to clock.
  - attribute: input_delay (default is 0)
  - command: *set_input_delay 3 –clock clk dpin*



Data arrives at input port "data" 3ns after rising edge of clock clk->Q delay
External Virtual Circuit
D
Q
FF1
ck
3ns
Block A
Logic Cloud A
D
Q
FF2
ck
clock period of 10 ns is attached to input port "ck"
10ns
clk
3ns
data

Input_delay 3 { data}

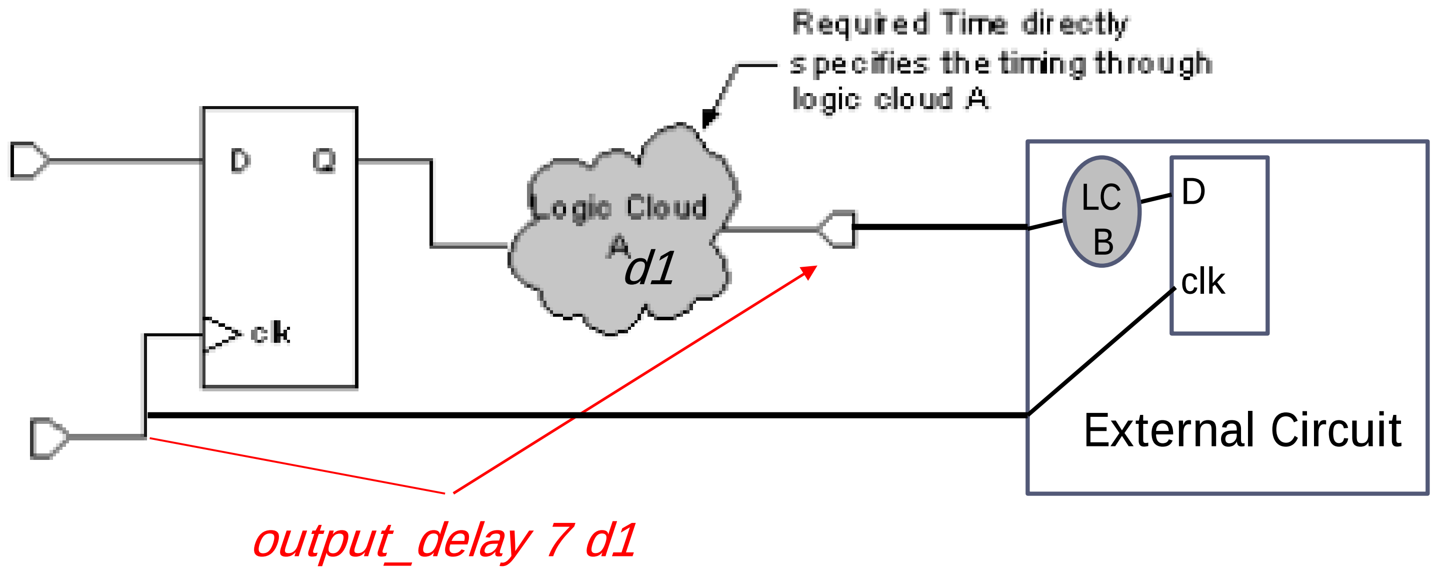
Block A input available 3 time units after clock transition

Need Logic Cloud A delay + FF2 setup time ≤ 7

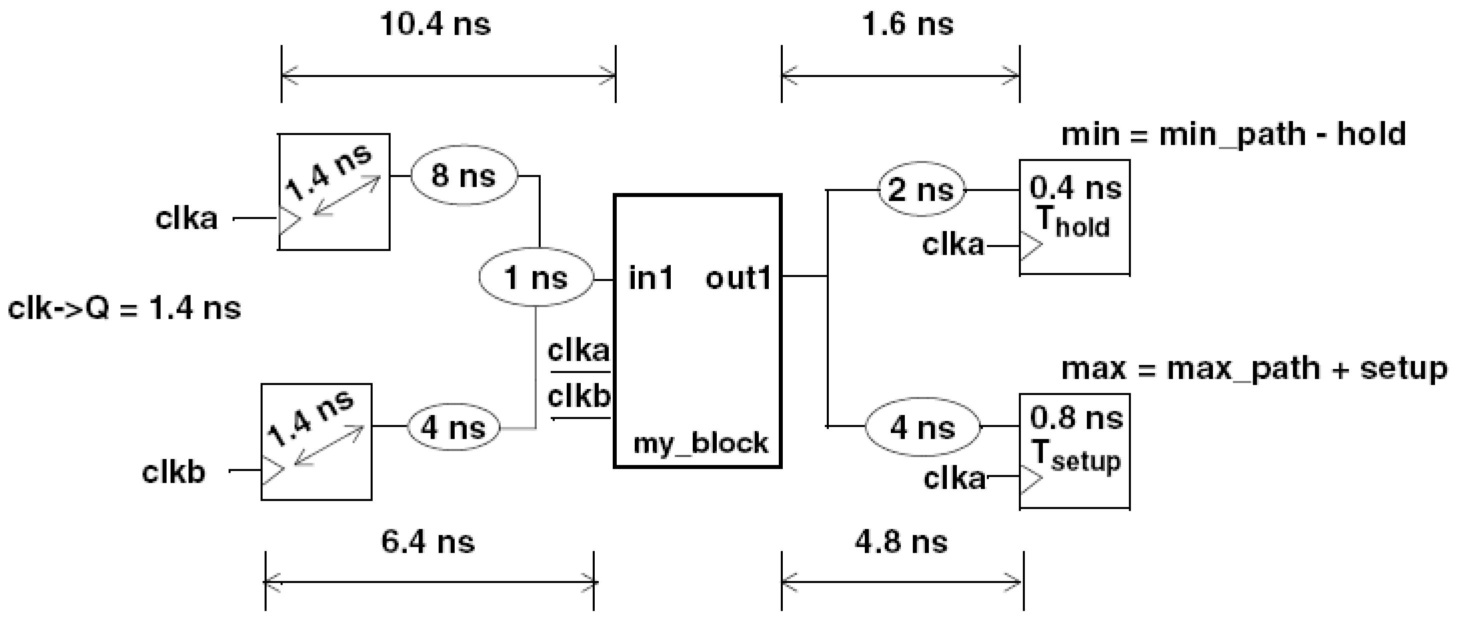
Output constraints

- Time from clock to valid output at pin, to be used by external ckt
  - attribute: output_delay
  - command: *set_output_delay 7 –clock CLK d1*

Example: Clock cycle = 20
External ckt flip-flop setup time = 2
External ckt logic cloud (LC B) delay = 11
Output at d1 needed by 20 – (11 + 2) = 7


Required Time directly specifies the timing through logic cloud A
D
Q
clk
Logic Cloud A
d1
LC B
D
clk
External Circuit
output_delay 7 d1

Sequential circuit example



```
create_clock -period 20 -waveform {5 15} clka
create_clock -period 30 -waveform {10 25} clkb
set_input_delay 10.4 -clock clka in1
set_input_delay 6.4 -clock clkb -add_delay in1
set_output_delay 1.6 -clock clka -min out1
set_output_delay 4.8 -clock clka -max out1
```

Required clock periods

Arrival at input pin from previous clock edge

Setup time of output pin from next clock edge

Path-based commands

- Path startpoint = input pin or register clock pin
- Path endpoint =output pin or register data pin
- Path constraint

  set_max_delay –from from-list –to to-list value

  - to/from-list = port, pin, clock or cell names
  - If clock in *from-list*: all paths affected by that clock
  - If clock in *to-list*: all related register data pins
  - Register data pin: FF1 or FF1/D
  - Can specify *–rise* and/or *–fall* times
  - Can add *–through P* to capture paths passing through P
  - Can specify *[all_outputs]* or *[all_inputs]*

Path delay examples

- Max delay requirements
  - *set_max_delay 10 -to out1 –from Reset*
  - *set_max_delay 5.1 –from {ff1 ff2} -to {o1 o2}*
  - *set_max_delay 3 –from busA[*] –to u1/Z*
  - *set_max_delay 6 –to [all_outputs]*
    - If no "from list", constrain paths from all start points
  - *set_max_delay 8 –from [all_inputs]*
    - If no "to list", constrain paths to all end points

- Above also applies to: *set_min_delay*

Compiling the design

DC User Guide
Chapter 8

- Compile (and optimize) the design
  - *compile –map_effort $mapEffort1*
    - *design hierarchy preserved*
    - *map_effort = medium(default) or high*
  - *compile –ungroup_all –map_effort $mapEffort1*
    - *design "flattened" (ungrouped – all levels collapsed)*
  - *compile –incremental_mapping –map_effort $mapEffort2*
    - *work on it some more – incremental improvements*
- High-effort compile
  - *compile_ultra*
  - use on high-performance designs, tight time constraints
  - specify *–no_autoungroup* to preserve hierarchy

Synthesis Output Files

- **Design.v** – verilog structural netlist
  - *change_names –rules verilog*
  - *write –format verilog –output file.v*
- **Design.sdf** – standard delay file for timing simulation
  - *write_sdf –version 1.0 file.sdf*
- **Design.rep** – synthesis report (timing, area, etc)
  - *redirect file.rep {report_timing}*
  - *redirect –append file.rep {report_area –hier }*

More timing options on next slide.

- **Design.ddc** – Synopsys database format (to view in DV)
  - *write –format ddc –hierarchy -o file.ddc*
- **Design.sdc** – constraints for Encounter place/route
  - *write_sdc file.sdc*
- **Design.pow** – power estimate
  - *redirect file.pow { report_power }*

Additional timing report options

report_timing

-to {list of signals}	Inputs/flipflop outputs to these signals
-from {list of signals}	Flip-flop outputs/inputs to these signals
-through {list of pins}	Paths that go through these pins
-max_paths N	Number of paths to report
-loops {timing loops}	Timing loops (comb. logic feedback)

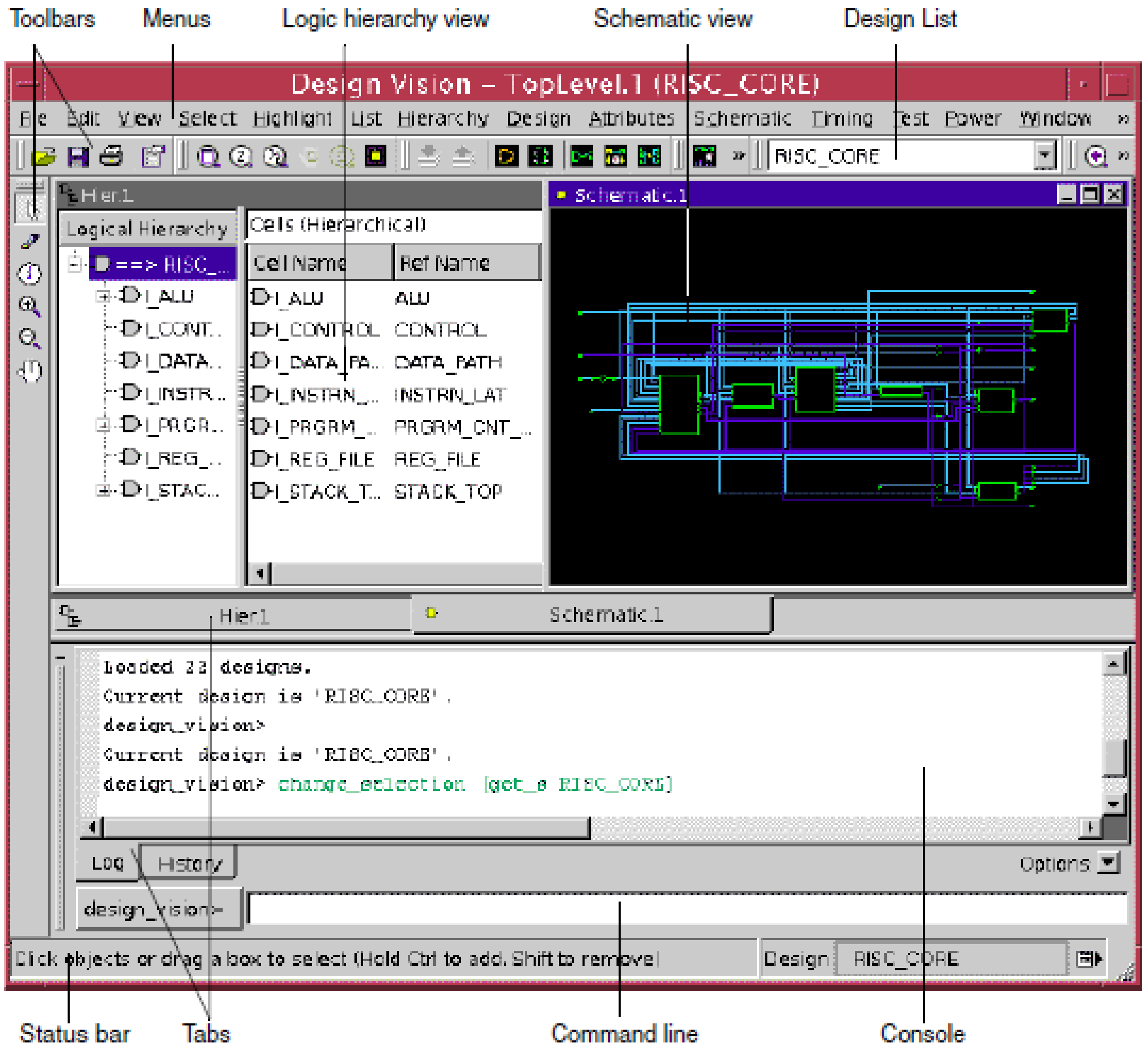
Balancing Loads

- Resolve load violations throughout the design
  - Fix loads after changing attributes, without rerunning optimize
    - Load balancing always done as part of optimize
  - Pays attention to OUTPUT_LOADS, OUTPUT_FANOUTS
- Mostly used at boundaries of hierarchical modules
  - Optimize balances loads within modules

- Command:

```
balance_loads [design-name] [-single]
```

DesignVision window



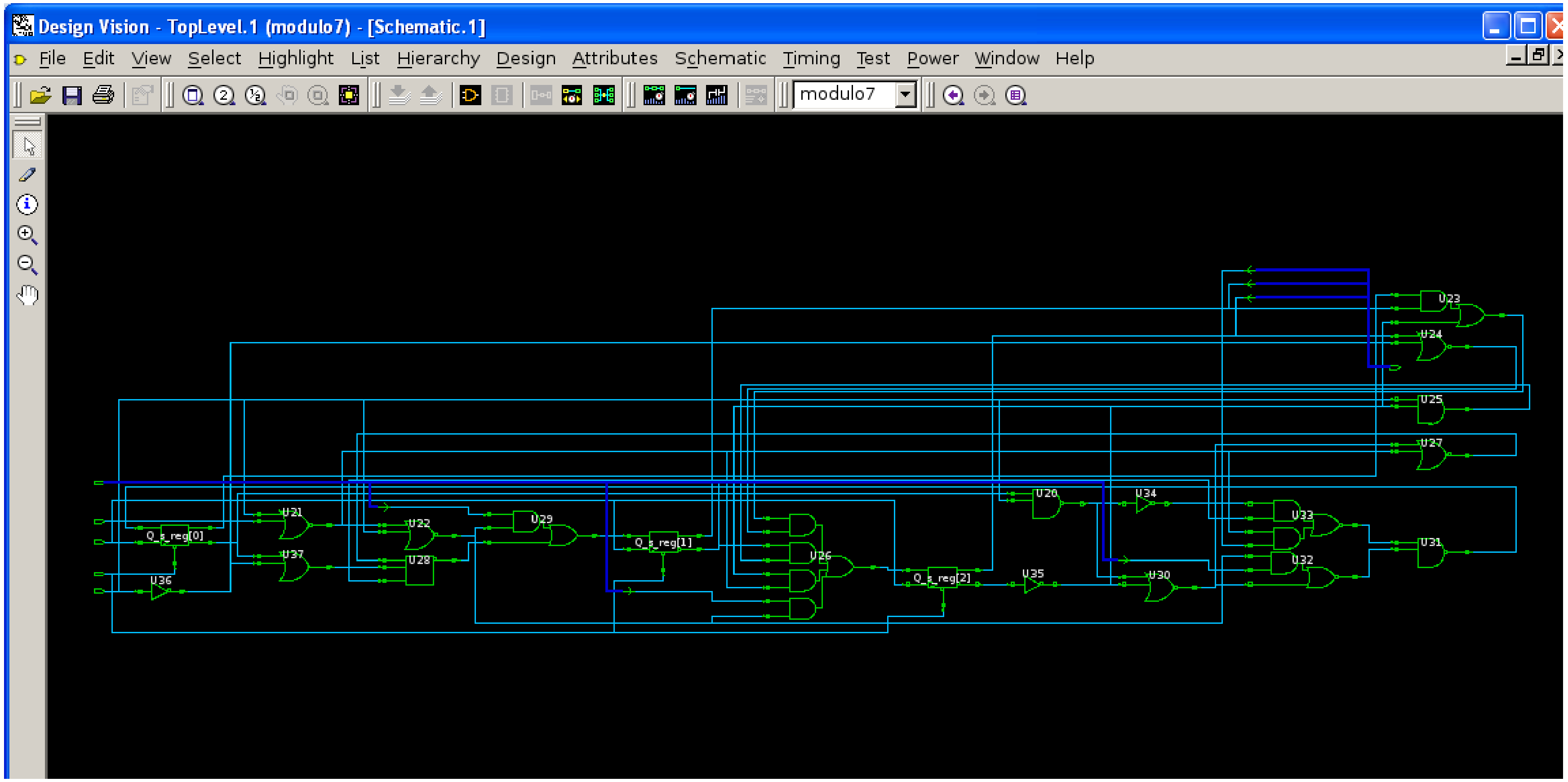
Cells (Hierarchical)

Cell Name	Ref Name
I_ALU	ALU
I_CONTROL	CONTROL
I_DATA_PA...	DATA_PATH
I_INSTRN_...	INSTRN_LAT
I_PRGRM_...	PRGRM_CNT_...
I_REG_FILE	REG_FILE
I_STACK_T...	STACK_TOP

```
Loaded 22 designs.
Current design is 'RISC_CORE'.
design_vision>
Current design is 'RISC_CORE'.
design_vision> change_selection [get_s RISC_CORE]
```

Click objects or drag a box to select (Hold Ctrl to add, Shift to remove)

Modulo7 counter in *DesignVision*


Design Vision - TopLevel.1 (modulo7) - [Schematic.1]
File Edit View Select Highlight List Hierarchy Design Attributes Schematic Timing Test Power Window Help
modulo7
Q_s_reg[0]
U36
U21
U37
U22
U28
U29
Q_s_reg[1]
U26
Q_s_reg[2]
U20
U34
U35
U30
U33
U32
U23
U24
U25
U27
U31