



Politecnico di Torino

Microelectronic Systems

DLX Microprocessor: Design & Development

Final Project Report

Master degree in Computer Engineering

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CHAPTER 1

Introduction

The DeLuXe (aka DLX) is a RISC processor architecture designed by John L. Hennessy and David A. Patterson. It is a modernized and simplified 32-bit load/store big endian architecture of the MIPS CPU, primarily intended for teaching purposes.

In the following pages the ASIC design flow has been applied starting from the basic requirements of DLX, it has been developed accordingly with basic features, i.e. the pipeline and the basic instruction set. As next step the integer multiplication has been added to the basic instruction set. For doing that, the Booth's multiplier studied during the course and developed during the laboratories has been pipelined in order to obtain a pipelined multiplier on eight clock cycles.

An important aspect of Digital Design, in the development step, is to verify the functional behaviour of the components. In order to do that, testbenches in System Verilog have been used (resorting to a mixed language simulation) in order to maximise the efficiency and speeding up the development time, it has also allowed to removed bugs during the early functional testing of the stages composing the pipeline by the mean of defining temporal properties on signals. Moreover, at the end, another testbench using the Universal Verification Methodology has been developed, which is a de facto standard in the Functional Verification Testing in the industry¹.

As last step of the design flow, the design is synthesized with different approaches in order to move the CPU in different design point of the space (area and clock frequency). After that, a subset of the synthesized designs is physically designed. Starting with the routing of the power supply system and ending with the placed and routed of the actual transistors.

¹1800.2-2017 - IEEE Standard for Universal Verification Methodology Language Reference Manual

CHAPTER 2

Functional Verification Testing

In Digital Design, functional verification testing is the task of verifying that the logic design is conformed to its specifications, it answers to the question *Does it do what it is intended do?*. The answer to this question is a complex task and takes the majority of time in integrated circuit design.

Thanks to the Moore's law [?] the complexity of integrated circuit has grow exponentially, putting more and more peripheral and modules in the same die's area it has leaded to the SoC area. This has lead to very complex circuits and it comes naturally that the old test benches architectures are no more suitable for checking the intended behaviour.

The task of Functional verification testing can be done through different methods:

- Logic simulation, it simulates the logic before it is built.
- Simulation acceleration, it applies special purpose hardware to the logic simulation problem.
- Emulation, it builds a version of system using programmable logic.
- Formal verification, it attempts to prove mathematically that certain requirements are met.
- Intelligent verification, it uses automation to change testbenches at RTL level.

From now on, the logic simulation based functional verification will be used. In this approach the stimulus are provided by a testbench which emulates a meaningful scenario in order to check that for a certain input, the related output is generated as the specifications indicates.

A test bench can be divided in several components, each one of them with a specific purpose:

- the generator, it generates stimuli according to specifications and the expected environment. Stimuli are manually generated. On the other hand, a modern solution may be to create random stimuli that are statistically driven in order to verify part of the unit under test.
- the driver, it translates the stimuli produced by the generator into the actual inputs for the design under verification.
- the monitor, it stores the state and the outputs of the design into a database.
- the checker, it validates wrt to the specifications the stored values of the monitor.
- the arbitration manager, it manages all the above components together.

2.1 Testbenches with System Verilog

The usage of System Verilog as preferred language for testbenches has become increased more and more in the last years. One of the motivation is its C-like features, and easyness of usage. Moreover, it offers a lot of randomization of values features, the OOP paradigm and the possibility of defining interfaces (which are also synthesizable construct).

It has been developed as language that encapsulates the HDL and the HDL. Therefore, the usage of System Verilog as language for verification testbenches has allowed to use a different architecture for functionally testing the DLX, the UVM approach.

Another important aspect is the possibility of using assertions (SVA), they allow to specify the expected behavior of a design with temporal property on signals speeding up the developing process and the checking of correct behaviour (see Appendix I for properties definition related to the DLX top level entity). The usage of the SVAs has allowed the speed-up, in this particular case, of pipeline property for each subunit of the DLX. This has been done in order to reduce the overhead of checking and fixing problems when integration comes.

Following the previous mentioned ideas, the memories and their interfaces have been implemented in System Verilog (while the DLX has been described in VHDL). At the end, the testbench has been writtein in System Verilog with the following architecture:

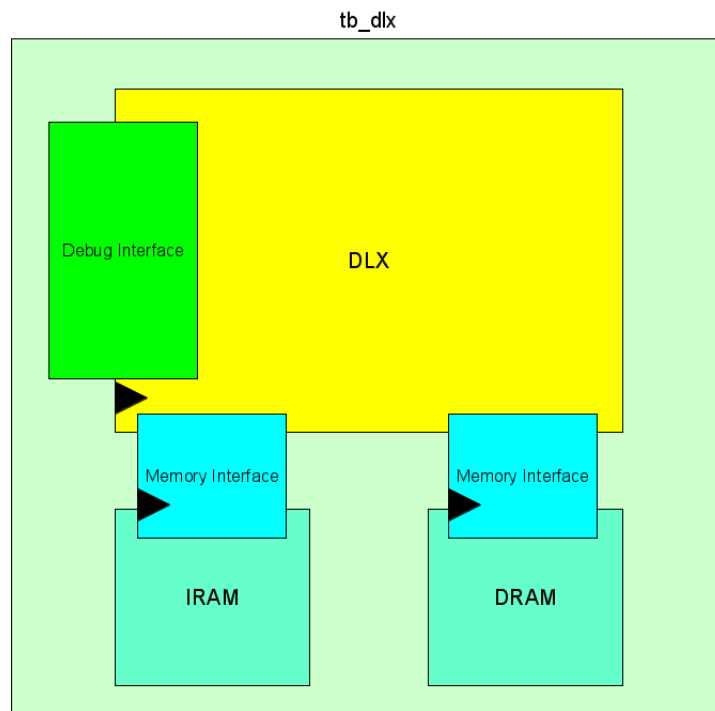


Figure 2.1: Testbench architecture

In Figure 2.1 are missing the clock interconnections and the reset just for a matter of readability. In this case the:

- DLX, it is the microprocessor under test.
- IRAM: it is the instruction ram which loads the program (compiled offline) for the unit under test.

- DRAM: it is the data ram which loads at the beginning a file with random values and at every write operation it refresh the content of another file.
- Memory interface: it is the interface connecting the memories with the microprocessor. It has been defined as a single interface for both the memories, the only difference is in the modport configuration, where it can be distinguished between a read-only memory and a read-write memory (see Appendix B).
- Debug interface: it is an interface that will be removed during the synthesis, its only purpose is to made visible the control signals of the CU in order to check if the instruction-dependent properties are covered (see Appendix I).

2.1.1 Functional Coverage

Different coverage metrics are defined to assess that the design has been adequately exercised. These include functional coverage (has every functionality of the design been exercised?)

Figure 2.2: Functional coverage

program dependent also memory are never fully tested (at least the address)

2.2 Universal Verification Methodology

The Universal Verification Methodology (UVM) is a standardized methodology for verifying integrated circuit designs. UVM is derived mainly from the OVM (Open Verification Methodology). The UVM class library brings much automation to the SystemVerilog language such as sequences and data automation features (packing, copy, compare), and unlike the previous methodologies it is developed independently by the simulator vendors.

It exploits the OOP paradigm, therefore for each one of the entities that can be seen in Figure 2.3, they represent a class with a specific function.

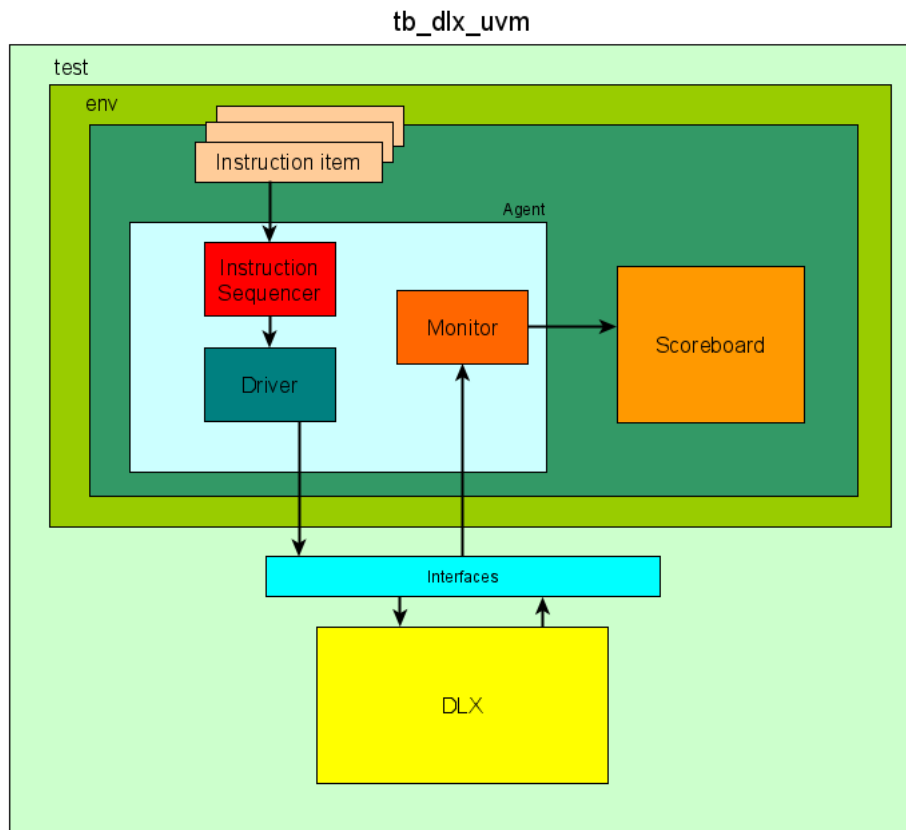


Figure 2.3: UVM testbench architecture

Each class in Figure 2.3 inherits the functions and tasks of the relative UVM related class. For this specific case, the UVM classes function are:

- **Instruction item**, it is the basic instruction for the microprocessor plus some additional function, such as its conversion to string, the retrieve of the only opcode and/or the opcode ALU function. It is important to mention that it includes the random variables for the opcode, opcode alu function, r_d , rs_1 , rs_2 , immediate and jump address (which are randomized when calling the relative function in instruction sequence) plus the constraint on the register, such as the one that the r_0 cannot be a destination register. Moreover, depending on the current opcode, it composes the instruction accordingly, i.e. the jump address is not needed when composing an add instruction and viceversa, even if all the variables are randomized everytime.
- **Instruction sequence**, it creates a given number of random instruction item.

- Instruction sequencer, it only gives the instruction item from the instruction sequence to the driver one by one.
- Driver, it retrieves the next instruction item from the sequencer and gives it to the DUT . It basically behaves as the IIRAM of Figure 2.1.
- Monitor, this class is only in charge of sampling the Debug signals from the DUV and its current instruction.
- Agent, since it is active it is in charge of creating the sequencer,driver and monitor classes and connects the driver port to the export port of the sequencer.
- Scoreboard, it stores for each executed instruction if it passes the test or not and how many time it has been executed. It also checks if the correct signals(sampled from the Debug interface) have been asserted for the specific instruction. For example, *add r₁,r₃,r₄*, it will access to both the port of register file and then it will compute the addition between the accessed values and as last step it will write back the value in the register file. The scoreboard stores the signals from when the instruction is given to the microprocessor up to the 5-th clock cycle and then it compares the signals with an internal signature.
- Environment, it instantias the agent and the scoreboard and connects the analysis port of the scoreboard to the output port of the agent.
- Test, it is only in charge of instantiate the environment class, it also applies a preliminary reset to all systems and then it creates the sequence of random instructions.
- tb_dlx_uvm, it is the top level module which is in charge of instantiating the DUV, the interfaces. It internconnects the interfaces with DUV and starts the test (see Appendix ??).

CHAPTER 3

A Top down view of the architecture

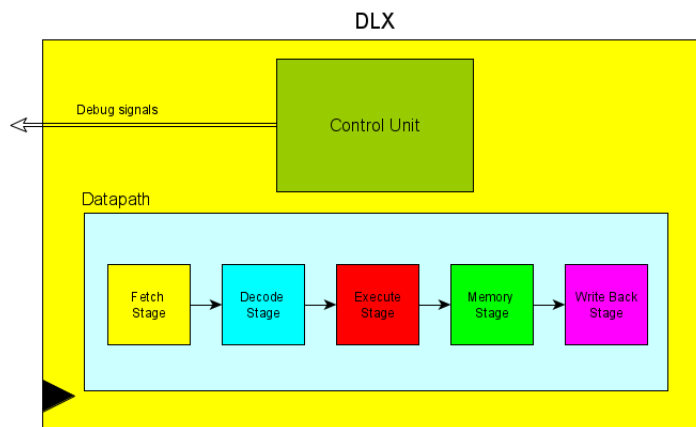


Figure 3.1: DLX top level entity

3.1 Control Unit

Figure 3.2: State Diagram

3.2 Datapath

Datapath



Figure 3.3: Datapath

CHAPTER 4

Synthesis

The synthesis of the design has been achieved by a script (Appendix K) which contains also the proposed synthesis algorithms. In addition, the script is also in charge of adjusting the environment variables and folders needed for the synthesis and later for the physical design script.

The synthesis has been done through an inductive approach. As first step, a simple design without any constraints has been synthesized and evaluated. For moving inside the design space, the next step has been using as constrained on the clock different percentage values of the non-constrained synthesized design clock. Different percentage has been used, from 1% up to 20% (reduciton of clock frequency wrt to the non-constrained synthesized clock). Moreover, in this case as synthesis strategy *compile_ultra* has been used for pushing more effort in general optimizaitons. The estimation of the area as much as possible to a real microprocessor has been achieved by the usage of Scan Flip Flops instead of the normal Flip Flops (avialable in the used library).

As next degree of freedom, in the design space, all the previous designs with different clock constraints have been synthesized putting a minimum area constraint.

4.1 Results

The results in terms of area, latency and area are collected and presented as graphs.

As first design space, the latency-area graph can be seen in Figure 4.1: add a latency area graph

Figure 4.1: Design space: Area vs Latency

where

Moreover, a further exention of the previous design space may be the power consumption (where also constrains can be added). In Figure 4.2 it is presented the power consumption of the constraints on area and latency.

Figure 4.2: Design space: Area vs Latency vs Power

CHAPTER 5

Physical Design

The physical design of the unit has been achieved by the usage of a script (Appendix L). As for the synthesis, this script is in charge of preparing the environment and start the real script for the physical design.

This step is very well known as a computing intensive step, even more then the synthesis since the granularity of details is bigger than the one in the synthesis. Therefore, for boosting-up the performance the script automatically sets the usage of six threads instead of only one.

Nevertheless the variety in the design space, only a subset of them has been choosen for being placed on a die. In particular the unconstrained desing, the minimum area and a 10% less of the clock frequency and only the 10% less of the clock frequency designs. It is worth to mention that the physical design does not use the RTL description but it uses the gate-level netlist of the RTL, produced by the synthesis.

5.1 Results

In the following pages, results are presented as images of the design on the same die.



Figure 5.1: Ameba view of unconstrained design

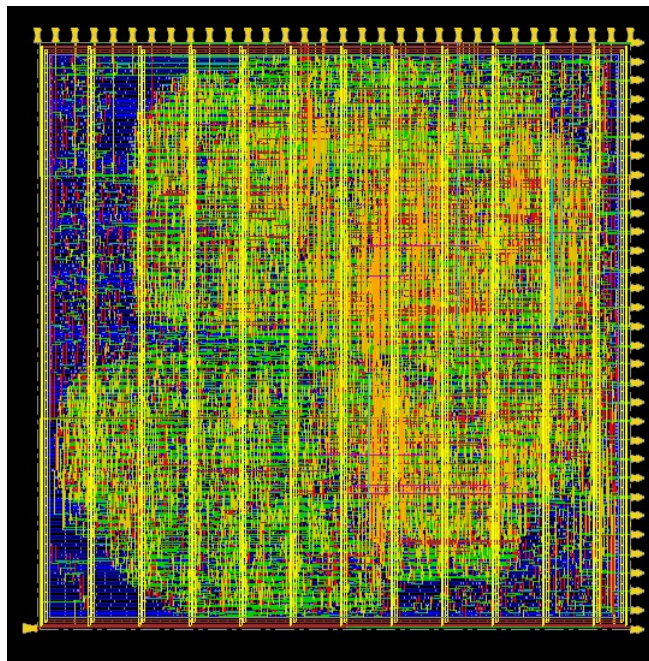


Figure 5.2: Placement of unconstrained design

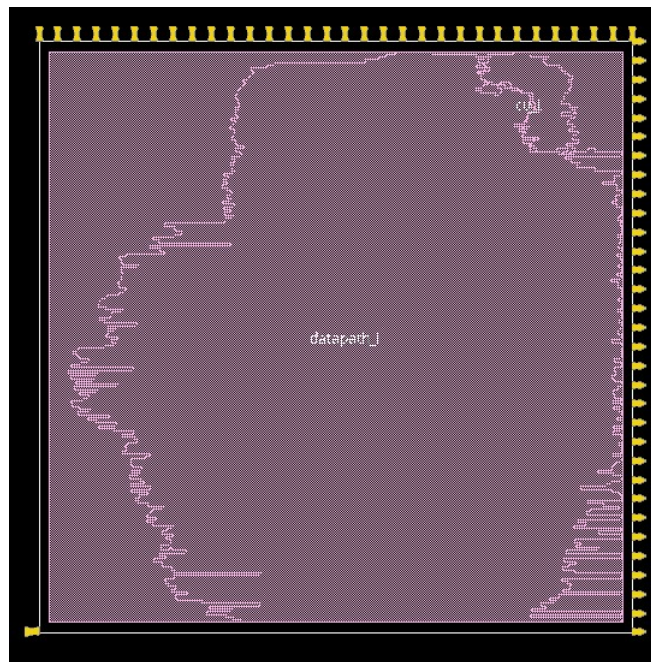


Figure 5.3: Ameba view of design with 10% less on clock frequency

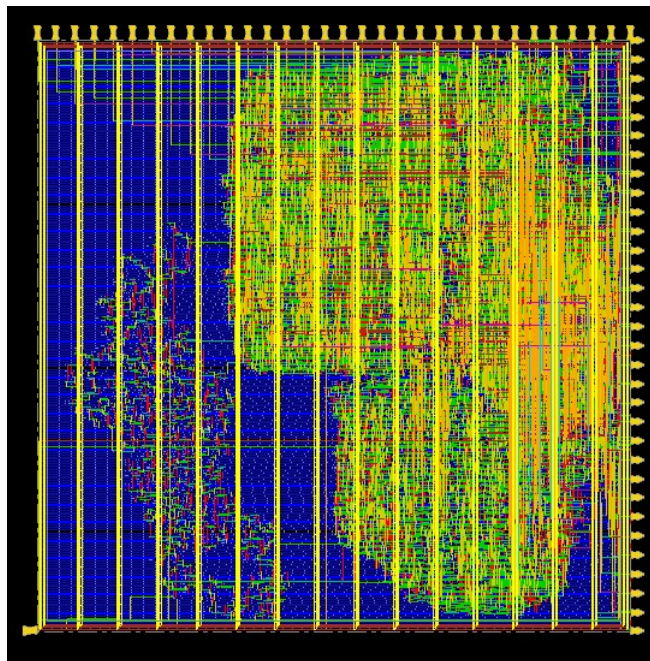


Figure 5.4: Placement of design with 10% less on clock frequency

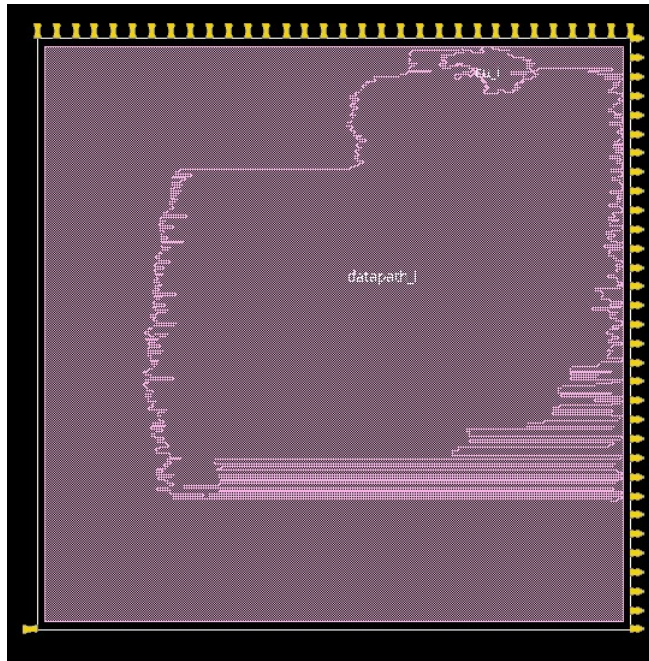


Figure 5.5: Ameba view of design with 1% less on clock frequency and minimum area

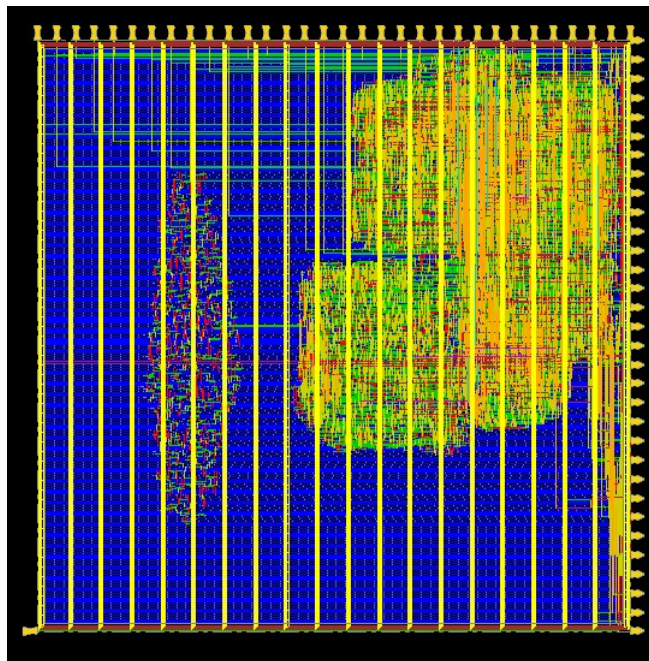


Figure 5.6: Placement of design with 1% less on clock frequency and minimum area

APPENDIX A

DLX testbench in System Verilog

```
//
//                                     \\ \\ Sapere Aude ///
//
// -----

// Copyright (c) 2014-2020 All rights reserved
//
// -----

// Author : Angione Francesco s262620@studenti.polito.it
//          franout@Github.com
// File   : tb_dlx.sv
// Create : 2020-07-21 19:00:18
// Revise : 2020-08-21 20:02:24
// Editor : sublime text3, tab size (4)
// Description: top level test bench for DLX functional verification
//              testing
//              Simple architecture :
//              - Driver :
//              iram
//              - Monitor :
//              dram and debug signals
//
// -----

`timescale 1ns/1ps
`include "./003-global_defs.svh"
`include "./004-implemented_instructions.svh"
`include "./memories/005-memory_interfaces.svh"
```



```

program automatic test_dlx_top(input logic clk, output logic rst,
    input cu_state_t curr_state,

                                input logic [
                                    'IRAM_WORD_SIZE
                                    -1:0]
                                current_instruction
                                );

// it may be encapsulated into a class which extends the covergroup
// class and implements manually all the methods ( new, sample, start
// and stop etc. )
covergroup instruction_cover with function sample(
    instructions_opcode opcode,    instructions_regtype_opcode
    func) ;
    option.name                = "instruction_cover";
    option.comment              = "cover_group_for_all_the_implemented
        _instruction_in_004-implemented_instructions.svh";
    option.per_instance        = 1;
    option.goal                 = 100;
    option.weight               = 90;

    instru_opcode: coverpoint opcode{
        bins regtype={i_regtype};
        bins immttype[] = {i_addi,i_andi,i_lw,i_nop,i_sgei,
            i_slei,i_slli,i_snei,i_srli,i_subi,i_sw,i_ori,
            i_xori};
        bins jump[]={i_j, i_jal};
        bins branch[]={i_beqz,i_benz}; // bnez beqz
    }

    instru_opcode_func: coverpoint func{
        bins alu_add = {i_add};
        bins alu_and = {i_and};
        bins alu_or = {i_or};
        bins alu_sll = {i_sll};
        bins alu_srl = {i_srl};
        bins alu_sub = {i_sub};
        bins alu_xor = {i_xor};
        bins alu_sne = {i_sne};
        bins alu_sle = {i_sle};
        bins alu_sge = {i_sge};
        bins alu_mul = {i_mul};
    }

endgroup : instruction_cover

```

```

default clocking test_clk_prog @( posedge clk);
endclocking

instructions_opcode current_opcode;
instructions_regtype_opcode current_opcode_func;

        // type_t'(x) cast x to type_t
assign  current_opcode=instructions_opcode'(current_instruction[
    'IRAM_WORD_SIZE-1:'IRAM_WORD_SIZE-'OP_CODE_SIZE]);
assign  current_opcode_func= (instructions_regtype_opcode'(
    current_instruction['OP_CODE_SIZE-1:0]));

sequence end_seq;
    @(test_clk_prog)
        ((current_instruction==='Z || current_instruction==='x
            ||current_instruction===i_j)[*12]);
endsequence;

task automatic print_current_instruction (instructions_opcode
    opcode, instructions_regtype_opcode func);
    begin
        if (opcode===i_regtype ) begin
            $display("current_instruction_opcode_%h
                -->%s",current_instruction,
                enum_wrap_instruction#(
                    instructions_regtype_opcode)::name
                    (func));
        end else begin
            $display("current_instruction_%h-->%s
                ",current_instruction,
                enum_wrap_instruction#(
                    instructions_opcode)::name(opcode)
                );
        end
    end
endtask : print_current_instruction

initial begin
    instruction_cover cg_instruction = new(); //
        instantiate the covegroupd
    // Set the database name sets the filename of the
        coverage database into which coverage
    //information is saved at the end of a simulation run.
    $set_coverage_db_name("tb_dlx_coverage_instructions");

```

```

$display("@%0dns Starting Test Program in System Verilog", $time);
$display("Reset",);
rst=0;
##3;
rst=1;
cg_instruction.start();
cg_instruction.set_inst_name("instruction_coverage_group_tb_top_dlx");
fork
    forever begin
        wait($changed(current_instruction))
        print_current_instruction(
            current_opcode, current_opcode_func
        );
        cg_instruction.sample(current_opcode,
            current_opcode_func); // sample
            the covergroup
        ##2;
    end
join_none
// wait until the end of the program in iram
forever begin
    wait (end_seq.triggered)
    if(end_seq.triggered) begin
        $display("Program in IRAM has ended @ %d",
            $time());
        cg_instruction.stop();
        // Display the coverage
        $display("Total coverage of instructions %e",
            cg_instruction.get_coverage());
        $finish();
    end else begin
        ##10; // execute 10 more cc
    end
end
end
end

```

```

endprogram : test_dlx_top

```

```

module tb_dlx ();
    localparam clock_period= 10ns;
    // it needs the absolute path

    logic rst;
    logic clk;

```

```

logic [$clog2('CU_STATES)-1:0] curr_state_debug_i;
cu_state_t curr_state_debug;
logic [7:0] csr;
logic DEBUG_iram_ready_cu;
logic DEBUG_iram_enable_cu;
logic DEBUG_signed_notsigned;
logic DEBUG_compute_sext;
logic DEBUG_jump_sext;
logic DEBUG_write_rf;
logic [1:0] DEBUG_evaluate_branch;
logic DEBUG_alu_cin;
logic DEBUG_alu_overflow;
logic DEBUG_zero_mul_detect;
logic DEBUG_mul_exeception;
logic DEBUG_dram_ready_cu;
logic DEBUG_dram_r_nw_cu;
logic DEBUG_enable_rf;
logic DEBUG_read_rf_p1;
logic DEBUG_read_rf_p2;
logic DEBUG_rtype_itypen;
logic DEBUG_update_pc_branch;
logic DEBUG_dram_enable_cu;
logic [0:0] DEBUG_sel_val_a;
logic [0:0] DEBUG_sel_val_b;
logic [0:0] DEBUG_select_wb;
logic [3:0] DEBUG_alu_op_type_i;
TYPE_OP_ALU_sv DEBUG_alu_op_type;

assign curr_state_debug=cu_state_t'(curr_state_debug_i);
assign DEBUG_alu_op_type=TYPE_OP_ALU_sv'(DEBUG_alu_op_type_i);

initial begin
    clk = '0;
    forever #(clock_period/2) clk = ~clk;
end

// Specify the default clocking
default clocking test_dlx @ (posedge clk);
endclocking // clock

initial begin
    $display("Attention!!",);
    $display("Starting simulated execution of the DLX",);
    $display("Starting an amazing and very fancy testbench
        in System Verilog",);
end

`include "./006-property_def.svh"

```

```
//
//
/////////

///// instantiate property and coverage groupd defined in
property_def.svh ///
//
/////////

instructions_regtype_opcode ireg_instr;
instructions_opcode imm_instr,jump_instr,lw_instr,sw_instr,
    b_instr;
// cast from bit to typedef of instruction
always_comb begin : proc_cast
    // type_t'(x) cast x to type_t
    ireg_instr=instructions_regtype_opcode'(iram_if.DATA[
        'OP_CODE_SIZE-1:0]);
    imm_instr=instructions_opcode'(iram_if.DATA[
        'IRAM_WORD_SIZE-1:'IRAM_WORD_SIZE-'OP_CODE_SIZE]);
    jump_instr=instructions_opcode'(iram_if.DATA[
        'IRAM_WORD_SIZE-1:'IRAM_WORD_SIZE-'OP_CODE_SIZE]);
    lw_instr=instructions_opcode'(iram_if.DATA[
        'IRAM_WORD_SIZE-1:'IRAM_WORD_SIZE-'OP_CODE_SIZE]);
    sw_instr=instructions_opcode'(iram_if.DATA[
        'IRAM_WORD_SIZE-1:'IRAM_WORD_SIZE-'OP_CODE_SIZE]);
    b_instr=instructions_opcode'(iram_if.DATA[
        'IRAM_WORD_SIZE-1:'IRAM_WORD_SIZE-'OP_CODE_SIZE']);
end

// property instantiation
instruction_check_property_ireg : cover property (
    instruction_check_ireg);

instruction_check_property_i : cover property(instruction_check_i)
;

instruction_check_property_jump : cover property(
    instruction_check_jump);

instruction_check_property_lw : cover property(
    instruction_check_lw) ;

instruction_check_property_sw : cover property(
    instruction_check_sw) ;

instruction_check_property_b : cover property(instruction_check_b)
;
```

```

multiplication_stall_check_property : cover property(
    multiplication_stall) ;

//////////
// instantiate the components //////////
//////////

// Instruction memory
// instantiate the interface
mem_interface #(.ADDRESS_SIZE('IRAM_ADDRESS_SIZE),
                .WORD_SIZE('IRAM_WORD_SIZE))
iram_if (.clk(clk));

// instantiate the dut and connect the interface
romem #(.FILE_PATH    ('PATH_TO_IMEM),
        .WORD_SIZE    ('IRAM_WORD_SIZE),
        .ADDRESS_SIZE('IRAM_ADDRESS_SIZE/2),
        .DATA_DELAY   (2))
        iram
        (.mif(iram_if.ro));

mem_interface #(.ADDRESS_SIZE('DRAM_ADDRESS_SIZE),
                .WORD_SIZE('DRAM_WORD_SIZE))
dram_if (.clk(clk));
// Data memory
rwmem #(
    .FILE_PATH        ('PATH_TO_DMEM_FINAL),
    .FILE_PATH_INIT   ('PATH_TO_DMEM),
    .WORD_SIZE         ('DRAM_WORD_SIZE),
    .ADDRESS_SIZE      ('DRAM_ADDRESS_SIZE/2),
    .DATA_DELAY        (2))
dram ( .memif(dram_if.rw));

//DLX top level entity
DLX #(
    .IR_SIZE('IRAM_WORD_SIZE),
    .PC_SIZE('IRAM_ADDRESS_SIZE)
) dlx_uut (
    // verbose assignment of the interfaces signals
    // Inputs
    .CLK                                (clk),
    .RST                                (rst),
    // Instruction memory interface
    .IRAM_ADDRESS                       (iram_if.ADDRESS),
    .IRAM_ENABLE                        (iram_if.ENABLE),
    .IRAM_READY                         (iram_if.DATA_READY),

```

```

    .IRAM_DATA                (iram_if.DATA),
    // Data memory Interface
    .DRAM_ADDRESS             (dram_if.ADDRESS),
    .DRAM_ENABLE              (dram_if.ENABLE),
    .DRAM_READNOTWRITE        (dram_if.READNOTWRITE),
    .DRAM_READY               (dram_if.DATA_READY),
    .DRAM_DATA                (dram_if.INOUT_DATA)
    // simulation debug signals
    //synthesis_translate off
,
    .STATE_CU                 (curr_state_debug_i),
    .csr                      (csr),
    //all the control unit signals
    //used for system verilog verification
    .DEBUG_iram_ready_cu      (DEBUG_iram_ready_cu),
    .DEBUG_iram_enable_cu     (DEBUG_iram_enable_cu),
    .DEBUG_signed_notsigned   (DEBUG_signed_notsigned),
    .DEBUG_compute_sext       (DEBUG_compute_sext),
    .DEBUG_jump_sext          (DEBUG_jump_sext),
    .DEBUG_write_rf           (DEBUG_write_rf),
    .DEBUG_evaluate_branch    (DEBUG_evaluate_branch),
    .DEBUG_alu_cin            (DEBUG_alu_cin),
    .DEBUG_alu_overflow        (DEBUG_alu_overflow),
    .DEBUG_zero_mul_detect    (DEBUG_zero_mul_detect),
    .DEBUG_mul_exeception     (DEBUG_mul_exeception),
    .DEBUG_dram_ready_cu      (DEBUG_dram_ready_cu),
    .DEBUG_dram_r_nw_cu       (DEBUG_dram_r_nw_cu),
    .DEBUG_enable_rf          (DEBUG_enable_rf),
    .DEBUG_read_rf_p1         (DEBUG_read_rf_p1),
    .DEBUG_read_rf_p2         (DEBUG_read_rf_p2),
    .DEBUG_rtype_itypen       (DEBUG_rtype_itypen),
    .DEBUG_sel_val_a          (DEBUG_sel_val_a),
    .DEBUG_sel_val_b          (DEBUG_sel_val_b),
    .DEBUG_update_pc_branch   (DEBUG_update_pc_branch),
    .DEBUG_select_wb          (DEBUG_select_wb),
    .DEBUG_alu_op_type         (DEBUG_alu_op_type_i),
    .DEBUG_dram_enable_cu     (DEBUG_dram_enable_cu)
    //synthesis_translate on
);

//assign same reset signal to both interfaces
assign iram_if.rst=rst;
assign dram_if.rst=rst;

test_dlx_top test_prog(.clk(clk),
                        .rst(rst),
                        .curr_state(
                            curr_state_debug),

```

```
        .current_instruction(  
            iram_if.DATA));  
  
endmodule
```

APPENDIX B

Memories interfaces

```
'ifndef __MEMORY_INTERFACES__VH
'define __MEMORY_INTERFACES__VH

'timescale 1ns/1ps

interface mem_interface
    #(parameter ADDRESS_SIZE=16,
      WORD_SIZE=32)
    ( input wire clk);

    logic rst; // reset active low
    logic [ADDRESS_SIZE-1:0] ADDRESS;
    logic ENABLE;
    wire DATA_READY;
    wire [WORD_SIZE-1:0] DATA;
    logic READNOTWRITE;
    wire [WORD_SIZE-1:0] INOUT_DATA;

    // for umv tb
    logic [WORD_SIZE-1:0] DATA_UVM;
    logic [WORD_SIZE-1:0] INOUT_DATA_UVM;

    clocking ram_interface @(posedge clk);
        input #1 ADDRESS,ENABLE; // sampled after 1 time resoltuon
            see 'timescale
        output #1 DATA_READY,DATA;
    endclocking

    // automatic bind the cover points to the address
    covergroup address_cov () @ (posedge ENABLE iff rst);
        addr : coverpoint ADDRESS {
            option.auto_bin_max = 10; // max number of bins
```

```

    }
    endgroup

    // explicitly bind the coverpoint
    covergroup memory_rw @ (posedge READNOTWRITE or negedge
        READNOTWRITE);
        read_write : coverpoint READNOTWRITE {
            bins read = {0};
            bins write = {1};
        }
    endgroup
    //=====
    // instantiate cover group

    address_cov cov_address = new();
    memory_rw cov_rw = new();

modport rw (input ADDRESS, ENABLE, READNOTWRITE, rst, clk, inout
    INOUT_DATA, output DATA_READY); // read write memory interface
modport ro (input ADDRESS, ENABLE, rst, clk, output DATA_READY, DATA);
    // read only memory interface

endinterface

`endif//__MEMORY_INTERFACES__VH

```

APPENDIX C

Global Definitions

```
//
//                                     \\ \\ Sapere Aude ///
//
//
-----

// Copyright (c) 2014-2020 All rights reserved
//
-----

// Author : Angione Francesco s262620@studenti.polito.it
//          franout@Github.com
// File    : global_defs.svh
// Create  : 2020-07-27 17:47:25
// Revise  : 2020-07-27 17:47:25
// Editor  : sublime text3, tab size (4)
// Description: util global definition (mirror of 000-globals.vhd)
//
-----

`ifndef __GLOBAL_DEFS__SVH
`define __GLOBAL_DEFS__SVH

`define NUMBIT 32 // number of bits for the architecture
`define RF_REGS 32 // number of regisster in the register file
`define IRAM_WORD_SIZE 32
`define IRAM_SIZE 2**32-1
`define IRAM_ADDRESS_SIZE 32
`define DRAM_WORD_SIZE 32
`define DRAM_SIZE 2**32-1
`define DRAM_ADDRESS_SIZE 32

`define CU_STATES 3
```

```

`define  ENDIANESS                "big"; // for memory access
`define  OPCODE_LENGTH            6 // length in the
    instruction
`define  REGISTER_ADDRESS_FIELD_LENGTH  5 // length in the
    instruction
`define  IMMEDIATE_LENGTH          16 // for I-type instructions
`define  ALU_FUNCTION_LENGTH        11 // for R-type instructions
`define  JUMP_ADDRESS_LENGTH        26 // for J-type instruction
`define  OP_CODE_SIZE  6 // OPCODE field size
`define  FUNC_SIZE      11 // FUNC field size
`define  TOT_CU_SIGN  22 // number of total signal (I/O) of control
    unit

typedef enum bit[$clog2('CU_STATES)-1:0]{hang_error,fetch, decode }
    cu_state_t;

typedef enum  bit  [3:0]{ADD=4'h0,

                                SUB=4'h1,
                                MULT=4'h2,
                                BITAND=4'h3,
                                BITOR=4'h4,
                                BITXOR=4'h5,
                                FUNCLSL=4'h6,
                                FUNCLSR=4'h7,
                                GE=4'h8,
                                LE=4'h9,
                                NE=4'ha}
                                TYPE_OP_ALU_sv ;
                                // cause error in
                                importing the enum
                                from vhdl

// uncomment using vivado simulator 'cause some sv system call are not
    supported from vivavo simulator
//`define VIVADO_SIM 1 // comment using questa sim simulator

// iram and dram content path
`define PATH_TO_DMEN_FINAL "/home/ms20.50/Desktop/DLX_project/hardware
    /dlx/test_bench/memories/dram_out.txt"
`define PATH_TO_DMEN "/home/ms20.50/Desktop/DLX_project/hardware/dlx/
    test_bench/memories/dram.txt"
`define PATH_TO_IMEM "/home/ms20.50/Desktop/DLX_project/hardware/dlx/
    test_bench/memories/sbst_dump.txt"

// debug interfae for simulation purposes

```

```
interface DEBUG_interface ();
    logic iram_ready_cu;
    logic iram_enable_cu;
    logic signed_notsigned;
    logic compute_sext;
    logic jump_sext;
    logic write_rf;
    logic [1:0] evaluate_branch;
    logic alu_cin;
    logic alu_overflow;
    logic zero_mul_detect;
    logic mul_exeception;
    logic dram_ready_cu;
    logic dram_r_nw_cu;
    logic enable_rf;
    logic read_rf_p1;
    logic read_rf_p2;
    logic rtype_itypen;
    logic [0:0] sel_val_a;
    logic [0:0] sel_val_b;
    logic update_pc_branch;
    logic [0:0] select_wb;
    logic dram_enable_cu;
    logic [7:0] csr;
    logic rst;
    logic [$clog2('CU_STATES)-1:0] curr_state_debug;
    logic [3:0] alu_operation;

endinterface

`endif // __GLOBAL_DEFS__SVH
```

APPENDIX D

Implemented Instructions

```
//
//                                     \\ \\ Sapere Aude ///
//
//
-----

// Copyright (c) 2014-2020 All rights reserved
//
-----

// Author : Angione Francesco s262620@studenti.polito.it
//          franout@Github.com
// File   : implemented_instructions.svh
// Create : 2020-07-22 20:15:37
// Revise : 2020-07-22 20:15:37
// Editor : sublime text3, tab size (4)
// Description: List of current implemented instruction in the CU of
//              the DLX
//
-----

`ifndef __implemented_instructions__svh
`define __implemented_instructions__svh

`define IMPLEMENTED_INSTR 28

typedef bit[5:0] bit_instr;

typedef enum bit_instr {
    i_regtype=6'h00,
    i_addi= 6'h08,
    i_andi= 6'h0c,
    i_beqz= 6'h04,
```

```

    i_benz= 6'h05,
    i_j= 6'h02,
    i_jal= 6'h03,
    i_lw= 6'h23,
    i_nop=6'h15,
    i_sgei= 6'h1d,
    i_slei= 6'h1c,
    i_slli= 6'h14,
    i_snei= 6'h19,
    i_srli= 6'h16,
    i_subi=6'h0a,
    i_sw= 6'h2b,
    i_ori=6'h0d,
    i_xori=6'h0e
} instructions_opcode;

typedef enum bit_instr {
    i_add=6'h20,
    i_and= 6'h24,
    i_or= 6'h25,
    i_sll= 6'h04,
    i_srl= 6'h06,
    i_sub= 6'h22,
    i_xor= 6'h26,
    i_sne= 6'h29,
    i_sle= 6'h2c,
    i_sge= 6'h2d,
    i_mul=6'h3f
} instructions_regtype_opcode; // in the function field

/*for printing instruction name*/
virtual class enum_wrap_instruction#(type T);
    static function string name(T obj);
        return obj.name();
    endfunction
endclass

//General instructions
/*j j,0x02 jal j,0x03 beqz b,0x04 bnez b,0x05 bfpt b0,0x06 bfpf b0
,0x07 addi i,0x08
addui i,0x09 subi i,0x0a subui i,0x0b andi i,0x0c ori i,0x0d xori
i,0x0e
lhi i1,0x0frfe n,0x10 trap t,0x11 jr jr,0x12 jalr jr,0x13slli i,0
x14nop n,0x15srli i,0x16 srai i,0x17 seqi i,0x18 snei i,0x19
slti i,0x1a sgti i,0x1b slei i,0x1c sgei i,0x1d lb l,0x20 lh l,0x21lw
l,0x23lbu l,0x24lhu l,0x25
lf l,0x26ld l,0x27sb s,0x28sh s,0x29sw s,0x2bsf s,0x2esd s,0x2fitlb n

```

```

    ,0x38sltui i,0x3a sgtui i,0x3b sleui i,0x3c sgeui i,0x3d
*/

// Register-register instructions
/*sll r,0x04 srl r,0x06sra r,0x07 add r,0x20 addu r,0x21sub r,0x22subu
    r,0x23
and r,0x24 or r,0x25xor r,0x26 seq r,0x28 sne r,0x29 slt r,0x2a sgt r
    ,0x2b sle r,0x2c sge r,0x2dmovi2s r2,0x30 movs2i r2,0x31 movf r2,0
    x32
movd r2,0x33 movfp2i r2,0x34 movi2fp r2,0x35 movi2t r,0x36 movt2i r,0
    x37 sltu r,0x3a sgtu r,0x3b sleu r,0x3c sgeu r,0x3d
*/

//Floating-point instruction
/*addf f,0x00 subf f,0x01multf f,0x02divf f,0x03addd f,0x04subd f,0
    x05multd f,0x06divd f,0x07
cvtf2d fd,0x08cvtf2i fd,0x09cvt2d fd,0x0acvt2i fd,0x0bcvti2f fd,0
    x0ccvti2d fd,0x0dmult f,0x0e
div f,0x0f eqf f2,0x10 nef f2,0x11 ltf f2,0x12 gtf f2,0x13 lef f2,0x14
    gef f2,0x15 multu f,0x16
divu f,0x17 eqd f2,0x18 ned f2,0x19 ltd f2,0x1a gtd f2,0x1b led f2,0
    x1c ged f2,0x1d
*/

‘endif // __implemented_instructions__svh

```

APPENDIX E

Properties definitions

```
//
//                                     \\ \\ Sapere Aude ///
//
//
-----

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//
-----

// Author : Angione Francesco s262620@studenti.polito.it
//          franout@Github.com
// File   : property_def.svh
// Create : 2020-08-01 16:14:31
// Revise : 2020-08-01 16:14:31
// Editor : sublime text3, tab size (4)
// Description: Defintion of all property and sequences for the DLX
//            top level entity
//
-----

`ifndef __PROPERTY_DEF_SVH
`define __PROPERTY_DEF_SVH

`include "../003-global_defs.svh"
`include "../004-implemented_instructions.svh"

    // property definition
    property multiplication_stall;
        @(test_dlx)
            disable iff(!rst && !DEBUG_zero_mul_detect && !
                DEBUG_mul_exeception )
                (ireg_instr==i_mul) |-> !
                    DEBUG_iram_enable_cu[*9]; // no
```

```

                                fetching for 9 cc
endproperty;

/* sequence for reg type instructions*/
sequence ireg_decode;
    ##1  DEBUG_enable_rf && DEBUG_read_rf_p1 && DEBUG_read_rf_p2
        && DEBUG_rtype_itypen && !DEBUG_compute_sext && !
        DEBUG_jump_sext;
endsequence ;

sequence ireg_execute(cin);
    ##1 !DEBUG_sel_val_a[0] && !DEBUG_sel_val_b[0] && (
        DEBUG_alu_cin===cin) && !DEBUG_evaluate_branch[1] && !
        DEBUG_evaluate_branch[0] && DEBUG_signed_notsigned ;
endsequence;

sequence ireg_memory;
    ##1 !DEBUG_dram_enable_cu ;
endsequence ;

sequence ireg_wb;
    ##1 DEBUG_write_rf && DEBUG_select_wb[0];
endsequence ;
/*sequence for immediate instruction */
sequence itype_decode;
    ##1  DEBUG_enable_rf && DEBUG_read_rf_p1 && !DEBUG_read_rf_p2
        && !DEBUG_rtype_itypen && DEBUG_compute_sext && !
        DEBUG_jump_sext;
endsequence ;

sequence itype_execute;
    ##1 !DEBUG_sel_val_a[0] && DEBUG_sel_val_b[0] && !
        DEBUG_evaluate_branch[1] && !DEBUG_evaluate_branch[0] &&
        DEBUG_signed_notsigned ;
endsequence ;

sequence itype_memory;
    ##1 !DEBUG_dram_enable_cu ;
endsequence ;

sequence itype_wb;
    ##1 DEBUG_write_rf && DEBUG_select_wb[0];
endsequence ;
/*sequence for lw*/
sequence lw_decode;
    ##1  DEBUG_enable_rf && DEBUG_read_rf_p1 && !DEBUG_read_rf_p2
        && !DEBUG_rtype_itypen && DEBUG_compute_sext && !
        DEBUG_jump_sext;
endsequence ;

```

```

sequence lw_execute;
    ##1 !DEBUG_sel_val_a[0] && DEBUG_sel_val_b[0] && !
        DEBUG_alu_cin && !DEBUG_evaluate_branch[1] && !
        DEBUG_evaluate_branch[0] && DEBUG_signed_otsigned ;
endsequence ;

sequence lw_memory;
    ##1 DEBUG_dram_enable_cu && DEBUG_dram_r_nw_cu;
endsequence ;

sequence lw_wb;
    ##1 DEBUG_write_rf && !DEBUG_select_wb[0];
endsequence ;

/*sequence for sw*/
sequence sw_decode;
    ##1 DEBUG_enable_rf && DEBUG_read_rf_p1 && DEBUG_read_rf_p2
        && !DEBUG_rtype_itypen && DEBUG_compute_sext && !
        DEBUG_jump_sext;
endsequence ;

sequence sw_execute;
    ##1 !DEBUG_sel_val_a[0] && DEBUG_sel_val_b[0] && !
        DEBUG_alu_cin && !DEBUG_evaluate_branch[1] && !
        DEBUG_evaluate_branch[0] && DEBUG_signed_otsigned ;
endsequence ;

sequence sw_memory;
    ##1 DEBUG_dram_enable_cu && !DEBUG_dram_r_nw_cu;
endsequence ;

sequence sw_wb;
    ##1 !DEBUG_write_rf ;
endsequence ;

/*sequence for b*/
sequence b_decode;
    ##1 DEBUG_enable_rf && DEBUG_read_rf_p1 && !DEBUG_read_rf_p2
        && !DEBUG_rtype_itypen && DEBUG_compute_sext && !
        DEBUG_jump_sext;
endsequence ;

sequence beqz_execute;

    ##1 DEBUG_sel_val_a[0] && DEBUG_sel_val_b[0] && !
        DEBUG_alu_cin && !DEBUG_evaluate_branch[1] &&
        DEBUG_evaluate_branch[0] && DEBUG_signed_otsigned ;

```

```

endsequence ;

sequence benz_execute;
    // i_benz
    ##1 DEBUG_sel_val_a[0] && DEBUG_sel_val_b[0] && !
        DEBUG_alu_cin && DEBUG_evaluate_branch[1] && !
        DEBUG_evaluate_branch[0] && DEBUG_signed_notsigned ;
endsequence;
sequence b_memory;
    ##1 !DEBUG_dram_enable_cu ;
endsequence ;

sequence b_wb;
    ##1 !DEBUG_write_rf ;
endsequence;
/*sequence for jump instruction*/
sequence ijump_decode;
    ##1 !DEBUG_enable_rf && !DEBUG_read_rf_p1 && !
        DEBUG_read_rf_p2 && !DEBUG_rtype_itypen &&
        DEBUG_compute_sext && DEBUG_jump_sext;
endsequence ;

sequence ijumpal_decode;
    ##1 !DEBUG_enable_rf && !DEBUG_read_rf_p1 && !DEBUG_read_rf_p2
        && !DEBUG_rtype_itypen && DEBUG_compute_sext &&
        DEBUG_jump_sext;
endsequence;

sequence ijump_execute;
    ##1 DEBUG_sel_val_a[0] && DEBUG_sel_val_b[0] && !DEBUG_alu_cin
        && !DEBUG_evaluate_branch[1] && DEBUG_evaluate_branch[0]
        && DEBUG_signed_notsigned ;
endsequence ;

sequence ijump_memory;
    ##1 !DEBUG_dram_enable_cu ;
endsequence ;

sequence ijump_wb;
    ##1 !DEBUG_write_rf;
endsequence ;

sequence ial_wb;
    ##1 DEBUG_write_rf && DEBUG_select_wb[0];
endsequence ;

property instruction_check_ireg;
    @(test_dlx)
    // iram enable cu is for the fetch stage

```

```

disable iff (!rst && ireg_instr!=0)
    // reg type
    if(ireg_instr===i_sub)
        DEBUG_iram_enable_cu |-> ireg_decode
        |-> ireg_execute(1) |->
        ireg_memory |-> ireg_wb
    else
        DEBUG_iram_enable_cu |-> ireg_decode
        |-> ireg_execute(0) |->
        ireg_memory |-> ireg_wb
endproperty;

property instruction_check_jump;
    @(test_dlx)
        disable iff(!rst && (jump_instr!=i_j||
        jump_instr!=i_jal))
    if (jump_instr===i_jal )
        DEBUG_iram_enable_cu |->
        ijumpal_decode |-> ijump_execute
        |-> ijump_memory |-> ijal_wb
    else
        DEBUG_iram_enable_cu |-> ijump_decode |->
        ijump_execute |-> ijump_memory |-> ijump_wb;
endproperty;

property instruction_check_lw;
    @(test_dlx)
        disable iff(!rst && lw_instr!=i_lw )
        DEBUG_iram_enable_cu |-> lw_decode |->
        lw_execute |-> lw_memory |->
        lw_wb;
endproperty;

property instruction_check_sw;
    @(test_dlx)
        disable iff(!rst && sw_instr!=i_sw)
        DEBUG_iram_enable_cu |-> sw_decode |->
        sw_execute |-> sw_memory |-> sw_wb;
endproperty;

property instruction_check_b;
    @(test_dlx)
        disable iff(!rst && ( b_instr!=i_beqz||
        b_instr!=i_benz ))
        if ( b_instr===i_beqz )
            DEBUG_iram_enable_cu |->
            b_decode |->

```

```

        beqz_execute |->
        b_memory |->  b_wb
    else
        DEBUG_iram_enable_cu |->
        b_decode |->
        benz_execute |->
        b_memory |->  b_wb;

    endproperty;

property instruction_check_i;
    @(test_dlx)
        disable iff(!rst  && ( b_instr!=i_beqz||
        b_instr!=i_benz )  && sw_instr!=i_sw  &&
        sw_instr!=i_lw
        && (jump_instr!=i_j||
        jump_instr!=i_jal) &&
        ireg_instr!=0)
        DEBUG_iram_enable_cu |-> itype_decode |->
        itype_execute |->  itype_memory |->  itype_wb; //
        itype
    endproperty;

`endif //__PROPERTY_DEF_SVH

```

APPENDIX F

UVM Top testbench

```
//  
//                                     \\ \\ Sapere Aude ///  
//  
//  
-----  
  
// Copyright (c) 2014-2020 All rights reserved  
//  
-----  
  
// Author : Angione Francesco s262620@studenti.polito.it  
//          franout@Github.com  
// File   : tb_dlx_uvm.sv  
// Create : 2020-30-08 19:00:18  
// Revise : 2020-08-21 20:02:24  
// Editor : sublime text3, tab size (4)  
// Description: top level test bench for DLX functional verification  
//              testing  
//                                     UVM architecture  
//  
-----  
  
'timescale 1ns/1ps  
'include "./003-global_defs.svh"  
'include "./004-implemented_instructions.svh"  
'include "./memories/005-memory_interfaces.svh"  
  
import uvm_pkg::*;  
  
'include <uvm_macros.svh>  
'include <uvm_pkg.sv>  
  
// including uvm classes in a bottom up order
```

```

`include "./uvm_class_def/dlx_sequence_item.sv"
`include "./uvm_class_def/dlx_sequence.sv"
`include "./uvm_class_def/dlx_sequencer.sv"
`include "./uvm_class_def/dlx_driver.sv"
`include "./uvm_class_def/dlx_monitor.sv"
`include "./uvm_class_def/dlx_scoreboard.sv"
`include "./uvm_class_def/dlx_env.sv"
`include "./uvm_class_def/dlx_test.sv"

module tb_dlx_uvm ();
    localparam clock_period= 10ns;
    // it needs the absolute path

    logic clk;

    initial begin
        clk = '0;
        forever #(clock_period/2) clk = ~clk;
    end

    // Specify the default clocking
    default clocking test_dlx @ (posedge clk);
    endclocking // clock

    initial begin
        $display("Attention!!",);
        $display("Starting simulated execution of the DLX_
            usign UVM architecture",);
    end

    ///////////////////////////////////////////////////
    // instantiate the components //
    ///////////////////////////////////////////////////

    // instantiate the interface
    mem_interface #(.ADDRESS_SIZE('IRAM_ADDRESS_SIZE),
        .WORD_SIZE('IRAM_WORD_SIZE))
    iram_if (.clk(clk));

    mem_interface #(.ADDRESS_SIZE('DRAM_ADDRESS_SIZE),
        .WORD_SIZE('DRAM_WORD_SIZE))
    dram_if (.clk(clk));

    DEBUG_interface dbg_if ();

    dlx_wrapper uut_uuv (.clk(clk),
        .rst (dbg_if.rst), // active
        low

```



```

        .mif_ro(iram_if), // memory
        interface clocked by clk
        .mif_rw(dram_if), // memory
        interface clocked by clk
        .dbg_if(dbg_if));

assign iram_if.DATA= iram_if.ENABLE ? iram_if.DATA_UVM : '0;
assign dram_if.INOUT_DATA= dram_if.ENABLE ? dram_if.INOUT_DATA_UVM : '
z;

    initial begin
        // set interfaces
        uvm_config_db#( virtual DEBUG_interface)::set(null,"*", "dbg_if"
            ,dbg_if);
        uvm_config_db#( virtual mem_interface #(.ADDRESS_SIZE(
            'IRAM_ADDRESS_SIZE),
            .WORD_SIZE('IRAM_WORD_SIZE)) )::set(null,"*", "iram_if"
            ,iram_if);
        uvm_config_db#( virtual mem_interface #(.ADDRESS_SIZE(
            'DRAM_ADDRESS_SIZE),
            .WORD_SIZE('DRAM_WORD_SIZE)) )::set(null,"*", "dram_if"
            ,dram_if);
        $dumpfile("dump.vcd"); $dumpvars; //enabling the wave dump
    end
    initial begin
        $display("Test is starting....");
        run_test("test"); // start the test
        $display("And finished! D");
    end

end

endmodule

```

APPENDIX G

Top level entity of DLX

```
--
-- -----
-- Title       : DLX top
-- Project     : DLX for Microelectronic Systems
--
-- -----

-- File        : a-DLX.vhd
-- Author      : Francesco Angione <s262620@studenti.polito.it>
--              franout@github.com
-- Company     : Politecnico di Torino, Italy
-- Created     : Wed Jul 22 22:58:15 2020
-- Last update : Sat Sep  5 22:31:23 2020
-- Platform    : Default Part Number
-- Standard    : VHDL-2008
--
-- -----

-- Copyright (c) 2020 Politecnico di Torino, Italy
--
-- -----

-- Description: top level entity of dlx without memories
--
-- -----

library IEEE;
use IEEE.std_logic_1164.all;

use work.globals.all;
use work.constants.all;
```

```

entity DLX is
  generic (
    IR_SIZE : integer := 32; -- Instruction Register Size
    PC_SIZE : integer := 32  -- Program Counter Size
  );
  port (
    -- Inputs
    CLK : in std_logic; -- Clock
    RST : in std_logic; -- Reset:Active-low
    -- Instruction memory interface
    IRAM_ADDRESS : out std_logic_vector( iram_address_size- 1 downto
      0);
    IRAM_ENABLE   : out std_logic;
    IRAM_READY    : in  std_logic;
    IRAM_DATA     : in  std_logic_vector(instr_length-1 downto 0);
    -- Data memory Interface
    DRAM_ADDRESS  : out  std_logic_vector(dram_address_size-1
      downto 0);
    DRAM_ENABLE   : out  std_logic;
    DRAM_READNOTWRITE : out  std_logic;
    DRAM_READY    : in   std_logic;
    DRAM_DATA     : inout std_logic_vector(data_size-1 downto 0)
    --
    -----

    -- cpu status signals in case of exception or hang
    -----
    --
    -----

    -- simulation debug signals and verification purposes
    --synopsys translate_off
    ;
    STATE_CU : out std_logic_vector(f_log2(tot_state)-1 downto 0);
    csr      : out std_logic_vector(7 downto 0);
    -- all the control unit signals
    -- used for system verilog verification
    DEBUG_iram_ready_cu      : out std_logic;
    DEBUG_iram_enable_cu    : out std_logic;
    DEBUG_signed_notsigned  : out std_logic;
    DEBUG_compute_sext      : out std_logic;
    DEBUG_jump_sext         : out std_logic;
    DEBUG_write_rf          : out std_logic;
    DEBUG_evaluate_branch   : out std_logic_vector(1 downto 0);
    DEBUG_alu_cin           : out std_logic;
    DEBUG_alu_overflow      : out std_logic;
    DEBUG_zero_mul_detect   : out std_logic;

```

```

    DEBUG_mul_exception      : out std_logic;
    DEBUG_dram_ready_cu      : out std_logic;
    DEBUG_dram_r_nw_cu       : out std_logic;
    DEBUG_enable_rf          : out std_logic;
    DEBUG_read_rf_p1         : out std_logic;
    DEBUG_read_rf_p2         : out std_logic;
    DEBUG_rtype_itypen       : out std_logic;
    DEBUG_update_pc_branch   : out std_logic;
    DEBUG_sel_val_a          : out std_logic_vector(0 downto 0);
    DEBUG_sel_val_b          : out std_logic_vector(0 downto 0);
    DEBUG_select_wb          : out std_logic_vector(0 downto 0);
    DEBUG_alu_op_type        : out std_logic_vector(3 downto 0);
    DEBUG_dram_enable_cu     : out std_logic;
    --synopsys translate_on
);
end DLX;

architecture dlx_rtl of DLX is

    -- control unit
    component control_unit is
        generic (
            PC_SIZE : integer := 32;
            RF_REGS : integer := 32; -- number of register in register file
            IR_SIZE : integer := 32; -- Instruction Register Size
            CW_SIZE : integer := 15  -- Control Word Size
        );
        port (
            clk : in std_logic;
            rst : in std_logic; -- active low
                                -- for fetch stage
            iram_enable_cu      : out std_logic;
            iram_ready_cu       : in  std_logic;
            curr_instruction_to_cu : in  std_logic_vector(IR_SIZE-1 downto
                0);
            stall_pip          : out std_logic;
                                -- for decode stage
            enable_rf : out std_logic; -- used as enable for sign26
                                -- extention when equal to 0
            read_rf_p1 : out std_logic; -- if read_rf_p1/2 are both zero it
                                -- is a jal instruction write address -> 31
            read_rf_p2 : out std_logic;

            rtype_itypen : out std_logic;
            compute_sext : out std_logic;
            jump_sext    : out std_logic;
                                -- for execute stage
            alu_op_type   : out std_logic_vector(3 downto 0); --

```

```

    TYPE_OP_ALU ; for compatibility with sv
sel_val_a      : out std_logic_vector(0 downto 0 );
sel_val_b      : out std_logic_vector(0 downto 0 );
signed_notsigned : out std_logic;
alu_cin        : out std_logic;
evaluate_branch : out std_logic_vector(1 downto 0); -- msb for
    evaluate branch negated(!=0) lsb for evaluate branch (==0)
                                                    -- from
                                                    execute
                                                    stage

alu_overflow : in std_logic;
-- exception control logic for multiplication
zero_mul_detect : in std_logic;
mul_exeception : in std_logic;
-- for memory stage
dram_enable_cu : out std_logic;
dram_r_nw_cu   : out std_logic;
dram_ready_cu  : in  std_logic;
update_pc_branch : out std_logic;
-- for write back stage
write_rf : out std_logic;
select_wb : out std_logic_vector(0 downto 0)
-- simulation debug signals
--synopsys translate_off
;
STATE_CU : out std_logic_vector(f_log2(tot_state)-1 downto 0);
csr       : out std_logic_vector(7 downto 0)
--synopsys translate_on
);
end component control_unit;

-- Datapath
component DATAPATH is
generic (
    N : integer := 32;
    RF_REGS : integer := 32; -- number of registers in register file
    component
    IR_SIZE : integer := 32; -- Instruction register size
    PC_SIZE : integer := 32 -- Program Counter Size
);
port (
    clk : in std_logic;
    rst : in std_logic;
    -- iram interface
    IRAM_ADDRESS : out std_logic_vector( iram_address_size- 1 downto
        0);
    IRAM_ENABLE : out std_logic;
    IRAM_READY : in  std_logic;
    IRAM_DATA : in  std_logic_vector(IR_SIZE-1 downto 0);

```

```

-- dram interface
DRAM_ADDRESS      : out    std_logic_vector(dram_address_size-1
      downto 0);
DRAM_ENABLE       : out    std_logic;
DRAM_READNOTWRITE : out    std_logic;
DRAM_READY        : in     std_logic;
DRAM_DATA         : inout  std_logic_vector(data_size-1 downto 0)
      ;
-- control unit interface, signals from/to control unit
-- for fetch stage
iram_enable_cu    : in     std_logic;
iram_ready_cu     : out    std_logic;
stall             : in     std_logic;
curr_instruction_to_cu : out std_logic_vector(PC_SIZE-1 downto
      0);
-- for decode stage
enable_rf        : in     std_logic;
read_rf_p1       : in     std_logic;
read_rf_p2       : in     std_logic;
write_rf         : in     std_logic;
rtype_itypen     : in     std_logic; -- =='1' rtype instruccion =='0'
      itype instructnions
jump_sext        : in     std_logic;
compute_sext     : in     std_logic;
-- for execute stage
alu_op_type       : in     std_logic_vector(3 downto 0); --
      TYPE_OP_ALU ; for compatibility with sv
sel_val_a         : in     std_logic_vector(0 downto 0 );
sel_val_b         : in     std_logic_vector(0 downto 0 );
alu_cin          : in     std_logic;
signed_notsigned  : in     std_logic;
evaluate_branch   : in     std_logic_vector(1 downto 0);
-- from execute stage
alu_overflow      : out    std_logic;
-- exception control logic for multiplication
zero_mul_detect  : out    std_logic;
mul_exeception    : out    std_logic;
-- for memory stage
dram_enable_cu    : in     std_logic;
dram_r_nw_cu      : in     std_logic;
dram_ready_cu     : out    std_logic;
update_pc_branch  : in     std_logic;
-- for write back stage
select_wb         : in     std_logic_vector(0 downto 0)

);
end component DATAPATH;

```

```

-----
-- Internconnection Signals Declaration
-----

signal  iram_ready_cu_i, iram_enable_cu_i, signed_notsigned_i,
compute_sext_i, write_rf_i, alu_cin_i, jump_sext_i, update_pc_branch_i,
alu_overflow_i, zero_mul_detect_i, mul_exeception_i, stall_i,
dram_ready_cu_i, dram_r_nw_cu_i, enable_rf_i, read_rf_p1_i, read_rf_p2_i
    , rtype_itypen_i,
dram_enable_cu_i                : std_logic;
signal evaluate_branch_i        : std_logic_vector(1
    downto 0);
signal curr_instruction_to_cu_i  : std_logic_vector(
    PC_SIZE-1 downto 0);
signal sel_val_a_i, sel_val_b_i , select_wb_i : std_logic_vector(0
    downto 0);
signal alu_op_type_i            : std_logic_vector(3
    downto 0); --TYPE_OP_ALU ; for compatibility with sv

begin -- DLX

-- Control Unit Instantiation
cu_i : control_unit
    generic map (
        PC_SIZE => PC_SIZE,
        RF_REGS => register_in_rf,
        IR_SIZE => instr_length,
        CW_SIZE => tot_cu_sign
    )
    port map (
        clk                => clk,
        rst                => rst,
        iram_enable_cu     => iram_enable_cu_i,
        iram_ready_cu      => iram_ready_cu_i,
        curr_instruction_to_cu => curr_instruction_to_cu_i,
        stall_pip          => stall_i,
        -- for decode stage
        enable_rf          => enable_rf_i,
        read_rf_p1         => read_rf_p1_i,
        read_rf_p2         => read_rf_p2_i,
        write_rf           => write_rf_i,
        rtype_itypen       => rtype_itypen_i,
        jump_sext          => jump_sext_i,
        compute_sext       => compute_sext_i,
        -- for execute stage
        alu_op_type        => alu_op_type_i ,
        sel_val_a          => sel_val_a_i ,

```

```

sel_val_b      => sel_val_b_i ,
evaluate_branch => evaluate_branch_i ,
signed_notsigned => signed_notsigned_i ,
-- from execute stage
alu_cin        => alu_cin_i ,
alu_overflow   => alu_overflow_i ,
zero_mul_detect => zero_mul_detect_i ,
mul_exeception => mul_exeception_i ,
-- for memory stage
dram_enable_cu => dram_enable_cu_i ,
dram_r_nw_cu   => dram_r_nw_cu_i ,
dram_ready_cu  => dram_ready_cu_i ,
update_pc_branch => update_pc_branch_i ,
-- for write back stage
select_wb      => select_wb_i
-- simulation debug signals
--synopsys translate_off
,
STATE_CU      => STATE_CU ,
csr           => csr
--synopsys translate_on

);

-- Datapath instantiation
datapath_i : DATAPATH generic map (
    N          => data_size ,
    RF_REGS    => register_in_rf , -- number of registers in register
        file component
    IR_SIZE    => IR_SIZE ,         -- Instruction register size
    PC_SIZE    => PC_SIZE          -- Program Counter Size
)
port map (
    clk => clk ,
    rst => rst ,
    -- iram interface
    IRAM_ADDRESS => IRAM_ADDRESS ,
    IRAM_ENABLE  => IRAM_ENABLE ,
    IRAM_READY   => IRAM_READY ,
    IRAM_DATA    => IRAM_DATA ,
    -- dram interface
    DRAM_ADDRESS    => DRAM_ADDRESS ,
    DRAM_ENABLE     => DRAM_ENABLE ,
    DRAM_READNOTWRITE => DRAM_READNOTWRITE ,
    DRAM_READY      => DRAM_READY ,
    DRAM_DATA       => DRAM_DATA ,
    -- control unit interface, signals from/to control unit
    -- for fetch stage
    iram_enable_cu    => iram_enable_cu_i ,

```



```

    iram_ready_cu      => iram_ready_cu_i ,
    stall              => stall_i ,
    curr_instruction_to_cu => curr_instruction_to_cu_i ,
    -- for decode stage
    enable_rf          => enable_rf_i ,
    read_rf_p1         => read_rf_p1_i ,
    read_rf_p2         => read_rf_p2_i ,
    write_rf           => write_rf_i ,
    jump_sext          => jump_sext_i ,
    rtype_itypen       => rtype_itypen_i ,
    compute_sext       => compute_sext_i ,
    -- for execute stage
    alu_op_type        => alu_op_type_i ,
    sel_val_a          => sel_val_a_i ,
    sel_val_b          => sel_val_b_i ,
    evaluate_branch    => evaluate_branch_i ,
    signed_notsigned   => signed_notsigned_i ,
    -- from execute stage
    alu_cin            => alu_cin_i ,
    alu_overflow       => alu_overflow_i ,
    zero_mul_detect    => zero_mul_detect_i ,
    mul_exeception     => mul_exeception_i ,
    -- for memory stage
    dram_enable_cu     => dram_enable_cu_i ,
    dram_r_nw_cu       => dram_r_nw_cu_i ,
    dram_ready_cu      => dram_ready_cu_i ,
    update_pc_branch   => update_pc_branch_i ,
    -- for write back stage
    select_wb          => select_wb_i
);

--synopsys translate_off
DEBUG_iram_ready_cu    <= iram_ready_cu_i;
DEBUG_iram_enable_cu   <= iram_enable_cu_i;
DEBUG_signed_notsigned <= signed_notsigned_i;
DEBUG_compute_sext     <= compute_sext_i;
DEBUG_jump_sext        <= jump_sext_i;
DEBUG_write_rf         <= write_rf_i;
DEBUG_evaluate_branch  <= evaluate_branch_i;
DEBUG_alu_cin          <= alu_cin_i;
DEBUG_alu_overflow     <= alu_overflow_i;
DEBUG_zero_mul_detect  <= zero_mul_detect_i;
DEBUG_mul_exeception   <= mul_exeception_i;
DEBUG_dram_ready_cu    <= dram_ready_cu_i;
DEBUG_dram_r_nw_cu     <= dram_r_nw_cu_i;
DEBUG_enable_rf        <= enable_rf_i;
DEBUG_read_rf_p1       <= read_rf_p1_i;
DEBUG_read_rf_p2       <= read_rf_p2_i;
DEBUG_rtype_itypen     <= rtype_itypen_i;

```

```
DEBUG_dram_enable_cu    <= dram_enable_cu_i;
DEBUG_update_pc_branch <= update_pc_branch_i;
DEBUG_sel_val_a         <= sel_val_a_i ;
DEBUG_sel_val_b         <= sel_val_b_i ;
DEBUG_select_wb         <= select_wb_i;
DEBUG_alu_op_type       <= alu_op_type_i; --TYPE_OP_ALU ; for
    compatibility with sv

--synopsys translate_on

end dlx_rtl;
```

APPENDIX H

Globals package

```
--
-- -----
-- Title       : globals
-- Project      : DLX for Microelectronic Systems
--
-- -----

-- File         : 000-globals.vhd
-- Author        : Francesco Angione <s262620@studenti.polito.it>
--               franout@github.com
-- Company       : Politecnico di Torino, Italy
-- Created       : Wed Jul 22 22:56:54 2020
-- Last update   : Sun Aug 30 22:58:17 2020
-- Platform      : Default Part Number
-- Standard      : VHDL-2008
--
-- -----

-- Copyright (c) 2020 Politecnico di Torino, Italy
--
-- -----

-- Description: global constants, functions and definitions for the
--             dlx
--
-- -----

library ieee;
use ieee.std_logic_1164.all;
use work.constants.all; -- it contains f_log2 function
```

```

package globals is

    -- function for transforming from big endian to little endian
    function b2l_endian (a : in std_logic_vector)
        return std_logic_vector;

    -- function for transforming from little endian to big endian
    function l2b_endian(a : in std_logic_vector)
        return std_logic_vector;

    -- function for calculating the log2 of an integer
    --function f_log2 ( x: integer ) return integer; it is in the
        constants package from the labs

    --
    -----

    -- for debug purposes
    --synthesis_translate off
    constant tot_state : integer := 3;
    --synthesis_translate on
    --
    -----

    -- definition for instruction
    constant endianness                : string := "big"; -- for
        memory access
    constant instr_length               : integer := 32;    --
        number of bits for an instruction
    constant opcode_length             : integer := 6;      --
        length in the instruction
    constant register_address_field_length : integer := 5;  --
        length in the instruction
    constant immediate_length          : integer := 16;     -- for
        I-type instructions
    constant alu_function_length        : integer := 11;    -- for
        R-type instructions
    constant jump_address_length        : integer := 26;    -- for
        J-type instruction
    constant OP_CODE_SIZE               : integer := 6;     --
        OPCODE field size
    constant FUNC_SIZE                  : integer := 11;    -- FUNC
        field size
    constant tot_cu_sign                : integer := 22;    --
        number of total signal (I/O) of control unit

    -- definition for data
    constant data_size : integer := 32;

```

```

-- definition for register file
constant register_in_rf : integer := 32;

-- definition for memories size
--      constant dram_size      : integer := 2**32-1;
constant dram_address_size : integer := 32; --f_log2(dram_size);
--      constant
--      iram_size
--      : integer :=
--      2**32-1;
constant iram_address_size : integer := 32; --f_log2(iram_size);

-- R-TYPE -> register to register operation
-- I-TYPE -> register and an immediate of ALU operation or load/
-- store memory operations
-- from lab defined in alu_types.vhd package
type TYPE_OP_ALU is (ADD, SUB, MULT, BITAND, BITOR, BITXOR,
    FUNCLSL, FUNCLSR, GE, LE, NE);

-- see also implemented_instruction.svh in ./test_bench
-- removed as attribute encoding for being compliant with
-- synthesis and remove warning
--type instruction is (
--      i_regtype,i_addi ,i_andi ,i_beqz ,i_benz ,i_j ,i_jal
--      ,i_lw ,i_nop
--      ,i_ori ,i_sgei ,i_slei ,i_slli ,i_snei ,
--      i_srli ,i_subi ,i_sw ,i_xori
--      );
--type ireg_instruction_funcode is(i_add,i_mul,i_and ,i_or,i_sge ,
--      i_sle,i_sll ,i_sne,i_srl,i_sub,i_xor);

-- for being complaint with synthesis
constant i_regtype : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "00"&x"0";
constant i_addi : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "00"&x"8";
constant i_andi : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "00"&x"c";
constant i_beqz : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "00"&x"4";
constant i_benz : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "00"&x"5";
constant i_j : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "00"&x"2";
constant i_jal : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=

```

```

    "00"&x"3";
constant i_lw      : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "10"&x"3";
constant i_nop     : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "01"&x"5";
constant i_ori     : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "00"&x"d";
constant i_sgei    : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "01"&x"d";
constant i_slei    : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "01"&x"c";
constant i_slli    : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "01"&x"4";
constant i_snei    : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "01"&x"9";
constant i_srli    : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "01"&x"6";
constant i_subi    : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "00"&x"a";
constant i_sw      : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "10"&x"b";
constant i_xori    : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "00"&x"e";

--- function opcode definition
constant i_add : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "10"&x"0";
constant i_mul : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "11"&x"f";
constant i_and : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "10"&x"4";
constant i_or  : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "10"&x"5";
constant i_sge : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "10"&x"d";
constant i_sle : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "10"&x"c";
constant i_sll : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "00"&x"4";
constant i_sne : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "10"&x"9";
constant i_srl : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "00"&x"6";
constant i_sub : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "10"&x"2";
constant i_xor : std_logic_vector(OP_CODE_SIZE-1 downto 0) :=
    "10"&x"6";

end globals;
```

```
package body globals is

    -- function for transforming from big endian to little endian
    function b2l_endian (a : in std_logic_vector)
        return std_logic_vector is
        variable result      : std_logic_vector(a'RANGE);
        constant cNumBytes   : natural := a'length / 8;

    begin
        for i in 0 to cNumBytes-1 loop
            for j in 7 downto 0 loop
                result(8*i + j) := a(8*(cNumBytes-1-i) + j);
            end loop; -- j
        end loop;    -- i

        return result;
    end; -- function b2l_endian

    -- function for transforming from little endian to big endian it
    -- is actually the same function
    function l2b_endian(a : in std_logic_vector)
        return std_logic_vector is
        variable result      : std_logic_vector(a'RANGE);
        constant cNumBytes   : natural := a'length / 8;

    begin
        for i in 0 to cNumBytes-1 loop
            for j in 7 downto 0 loop
                result(8*i + j) := a(8*(cNumBytes-1-i) + j);
            end loop; -- j
        end loop;    -- i

        return result;
    end; -- function l2b_endian

end package body globals;
```

APPENDIX I

Globals components package from labs

```
--
-- -----
-- Title       : global component
-- Project     : DLX for Microelectronic Systems
--
-- -----
-- File        : 001-global_components.vhd
-- Author      : Francesco Angione <s262620@studenti.polito.it>
--              franout@github.com
-- Company     : Politecnico di Torino, Italy
-- Created     : Wed Jul 22 22:56:15 2020
-- Last update : Sun Aug 30 22:58:11 2020
-- Platform    : Default Part Number
-- Standard    : VHDL-2008
--
-- -----
-- Copyright (c) 2020 Politecnico di Torino, Italy
--
-- -----
-- Description: package which contains all basic components from the
--              labs of MS
--              the component files are in the folder
--              ./global_components.package
--              Suggestion: Open the folder of the dlx
--              with Sublime Text v3 in order
--              to see the declaration
--              for each component when selected with the mouse
--
-- -----
```



```

library ieee;
use ieee.std_logic_1164.all;
use work.globals.all;
use work.constants.all; -- for avoiding compilation error
use work.alu_types.all;

package global_components is
  -- dummy alu declaration
  component ALU is
    generic (N : integer := numBit);
    port ( FUNC : IN TYPE_OP;
          DATA1, DATA2 : IN std_logic_vector(N-1 downto
            0);
          OUTALU : OUT std_logic_vector(N-1 downto
            0));
  end component ALU;

  --- a multiplexer for selection among a generic number of
  signals glued together
  component MUX_zbit_nbit IS
    Generic ( N : integer := NUMBIT;
              -- number of bit for
              every signal
              Z : integer := 3);
    --
    log2 of the number of signals in input,
    basically it is the length of the
    selection signal
    Port ( inputs : In std_logic_vector(0 TO ((2**Z)*(N))
      -1 ); -- one single input with the concatenation
      of all input signals
          SEL : In std_logic_vector(Z-1 downto 0);
          Y : Out std_logic_vector(N-1 downto 0));
  end component MUX_zbit_nbit;

  -- register n bit
  component reg_nbit IS
    generic ( n : INTEGER := numbit);
    port (clk,reset : in std_logic;
          d : in std_logic_vector(N-1 DOWNT0 0);
          Q : out std_logic_vector(N-1 downto 0));
  end component reg_nbit;

  -- windowed register file s
  component wrf is
    generic ( NBITREG : natural := 64;
              M : natural := 8; -- number of global
              registers

```

```

-- F and N must be power of
-- two
N : natural := 4; -- number of registers in
-- each in/out/local section
F : natural := 8); -- number of windows
port ( CLK : IN std_logic;
      RESET      : IN  std_logic;
      ENABLE     : IN  std_logic;
      RD1        : IN  std_logic;
      RD2        : IN  std_logic;
      WR         : IN  std_logic;
      ADD_WR      : IN  std_logic_vector(f_log2(2**
      f_log2(3*N) + M)-1 downto 0); -- the most
      -- significant part of the address identifies
      -- the global registers from the local one
      ADD_RD1     : IN  std_logic_vector(f_log2(2**
      f_log2(3*N) + M)-1 downto 0);
      ADD_RD2     : IN  std_logic_vector(f_log2(2**
      f_log2(3*N) + M)-1 downto 0);
      DATAIN     : IN  std_logic_vector(NBITREG-1
      downto 0);
      OUT1        : OUT std_logic_vector(NBITREG-1
      downto 0);
      OUT2        : OUT std_logic_vector(NBITREG-1
      downto 0);
      SUB_CALL    : IN  std_logic;
      SUB_RET     : IN  std_logic;
      FILL        : OUT std_logic;
      SPILL       : OUT std_logic;
      DATA_MEM_IN : IN  std_logic_vector(NBITREG-1
      downto 0);
      DATA_MEM_OUT : OUT std_logic_vector(NBITREG-1
      downto 0);
      READY       : OUT std_logic); -- signal for
      -- the CU that defines when no memory
      -- operations are being performed
end component wrf;

-- register file
component register_file is
  generic ( NBITREG : natural := 64;
            NBITADD : natural := 5);
  port ( CLK : IN std_logic;
        RESET : IN  std_logic;
        ENABLE : IN  std_logic;
        RD1 : IN  std_logic;
        RD2 : IN  std_logic;
        WR : IN  std_logic;
        ADD_WR : IN  std_logic_vector(NBITADD-1

```

```

        downto 0);
    ADD_RD1 : IN  std_logic_vector(NBITADD-1
        downto 0);
    ADD_RD2 : IN  std_logic_vector(NBITADD-1
        downto 0);
    DATAIN : IN  std_logic_vector(NBITREG-1
        downto 0);
    OUT1     : OUT std_logic_vector(NBITREG-1
        downto 0);
    OUT2     : OUT std_logic_vector(NBITREG-1
        downto 0));
end component register_file;

-- p4 adder
-- hierarchy:
-- sparse tree carry generator:
-- propagate and generate network
-- general propagate and generate block
-- general generate block
-- sum generator:
-- carry select block:
-- ripple carry adder x2:
-- full adder
component p4_adder IS
    GENERIC ( NBIT : integer := 8 ); -- number of bits
        for the adder
    PORT( a,b      : IN std_logic_vector(NBIT -1 DOWNT0 0
        );
        cin  : IN  std_logic;
        s    : OUT std_logic_vector(NBIT-1 DOWNT0 0);
        cout : OUT std_logic);
END component p4_adder;

-- mux 2x1 on nbit
component mux21_nbit IS
    Generic (N : integer := NUMBIT);
    Port ( A : In std_logic_vector(N-1 downto 0) ;
        B : In std_logic_vector(N-1 downto 0);
        SEL : In std_logic;
        Y : Out std_logic_vector(N-1 downto 0));
end component mux21_nbit;

-- behavioural full adder
component FA is
    Port ( A : In std_logic;
        B : In std_logic;
        Ci : In std_logic;
        S : Out std_logic;
        Co : Out std_logic);

```

```
end component FA;

-- basic encoder
component encoder IS
    PORT (y : IN std_logic_vector(2 DOWNTO 0);
          sel : OUT std_logic_vector(2 DOWNTO 0));
END component encoder;

-- top level entity of the booth multiplier
component boothmul IS
    GENERIC(N : integer := 32);
    PORT( multiplier, multiplicand : IN std_logic_vector(N
        -1 DOWNTO 0);
          result : OUT std_logic_vector(2*N-1 DOWNTO 0))
        ;
END component boothmul;

-- behavioural adder
component adder IS
    GENERIC ( NBIT : integer := 8 ); -- number of bits
        for the adder
    PORT( a,b : IN std_logic_vector(NBIT-1 DOWNTO 0 )
        ;
          cin : IN std_logic;
          s : OUT std_logic_vector(NBIT DOWNTO 0));
END component adder;

end package global_components;

package body global_components is

end package body global_components;
```

APPENDIX J

Simulation script

```
#!/usr/bin/bash

path_to_file="./hardware/dlx/"
## using questasim
source /software/scripts/init_questa10.7c

if [ -z $1 ]; then
    echo "usage ./simulation.sh sbst.asm"
    exit
fi

path_to_hex_test_program="$1"

if [ ! -f $path_to_hex_test_program ] ; then
    echo "Input software file for IRAM not defined"
    exit
fi

echo "Moving the hex files into the memories folders"
cp "$path_to_hex_test_program" ../"$path_to_file"test_bench/memories/

echo "Starting initialization of simulation environment"
cd ..
if [ -d "./work" ] ;then
    rm -rf work
fi

vlib ./work # it also creates the folder
echo "Simulation ready to go!"
echo "Start hierarchical compilation"
echo "Compiling labs units"
vcom -2008 -check_synthesis -autoorder ${path_to_file}
    global_components.package/*.vhd
vcom -2008 -check_synthesis ${path_to_file}000-globals.vhd
```

```
vcom -2008 -check_synthesis ${path_to_file}001-global_components.vhd
# vlog for verilog -incr(mental) compilation
# vcom for vhdl-2008 and drc for synthesis (basic)

#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    adder.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    alu.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    alu_type.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    boothmul.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    complement2.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    constants.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    csb.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    encoder.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    fa.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    fd.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    gsb.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    mux.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    p4_adder.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    pgsb.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    rca.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    reg_nbit.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    registerfile.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    stcg.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    sum_gen.vhd
#vcom -2008 -check_synthesis ${path_to_file}global_components.package/
#    pg.vhd

echo "Compiling memories"
vlog -incr ${path_to_file}test_bench/003-global_defs.svh
```

```

vlog -incr ${path_to_file}test_bench/004-implemented_instructions.svh
vlog -incr ${path_to_file}test_bench/006-property_def.svh
vlog -incr ${path_to_file}test_bench/memories/tb_memories.sv
vlog -incr ${path_to_file}test_bench/memories/005-memory_interfaces.
    svh
vlog -incr ${path_to_file}test_bench/memories/romem.sv
vlog -incr ${path_to_file}test_bench/memories/rwmem.sv

echo "Compiling stages, control unit and datapath"
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.e-
    Write_back.stage.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.a-
    Fetch.stage.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.b-
    Decode.stage.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.d.
    Memory.stage.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.b-
    Decode.stage/a.b.b.a-sign_extension.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage/a.b.c.a-check_branch_logic.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage/a.b.c.b-general_alu.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage/a.b.c.c-boothmul_pipelined.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage/a.b.c.c-boothmul_pipelined.core/a.b.c.a-mux.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage/a.b.c.c-boothmul_pipelined.core/a.b.c.b-adder.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage/a.b.c.c-boothmul_pipelined.core/a.b.c.c-complement2.
    vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage/a.b.c.c-boothmul_pipelined.core/a.b.c.d-encoder.vhd
vcom -2008 -check_synthesis ${path_to_file}a.a-control_unit.vhd
vcom -2008 -check_synthesis ${path_to_file}a-DLX.vhd

echo "Compiling top level testbench for DLX"
vlog -incr ${path_to_file}test_bench/tb_dlx.sv

echo "Starting simulation of dlx top level entity"
## suppress novopt error and metavalue warnings
vsim -suppress 12110 -suppress 8664 -novopt work.tb_dlx -do ./scripts
    /dlx_tb.do

```

```

echo "Do you want to see the DLX' tb with the Universal Verification
Methodology architecture? y/n"
read answer
if [ answer=="y" ] ; then
export UVM_VERSION="1.1d"
vlog +incdir+/software/mentor/questa10.7c/questasim/uvm-"$UVM_VERSION"
    ../verilog_src/uvm-"$UVM_VERSION"/src -incr ${path_to_file}
    test_bench/uvm_class_def/dlx_sequence_item.sv
vlog +incdir+/software/mentor/questa10.7c/questasim/uvm-"$UVM_VERSION"
    ../verilog_src/uvm-"$UVM_VERSION"/src -incr ${path_to_file}
    test_bench/uvm_class_def/dlx_sequence.sv
vlog +incdir+/software/mentor/questa10.7c/questasim/uvm-"$UVM_VERSION"
    ../verilog_src/uvm-"$UVM_VERSION"/src -incr ${path_to_file}
    test_bench/uvm_class_def/dlx_sequencer.sv
vlog +incdir+/software/mentor/questa10.7c/questasim/uvm-"$UVM_VERSION"
    ../verilog_src/uvm-"$UVM_VERSION"/src -incr ${path_to_file}
    test_bench/uvm_class_def/dlx_driver.sv
vlog +incdir+/software/mentor/questa10.7c/questasim/uvm-"$UVM_VERSION"
    ../verilog_src/uvm-"$UVM_VERSION"/src -incr ${path_to_file}
    test_bench/uvm_class_def/dlx_monitor.sv
vlog +incdir+/software/mentor/questa10.7c/questasim/uvm-"$UVM_VERSION"
    ../verilog_src/uvm-"$UVM_VERSION"/src -incr ${path_to_file}
    test_bench/uvm_class_def/dlx_scoreboard.sv
vlog +incdir+/software/mentor/questa10.7c/questasim/uvm-"$UVM_VERSION"
    ../verilog_src/uvm-"$UVM_VERSION"/src -incr ${path_to_file}
    test_bench/uvm_class_def/dlx_env.sv
vlog +incdir+/software/mentor/questa10.7c/questasim/uvm-"$UVM_VERSION"
    ../verilog_src/uvm-"$UVM_VERSION"/src -incr ${path_to_file}
    test_bench/uvm_class_def/dlx_test.sv
vlog +incdir+/software/mentor/questa10.7c/questasim/uvm-"$UVM_VERSION"
    ../verilog_src/uvm-"$UVM_VERSION"/src -incr ${path_to_file}
    test_bench/dlx_wrapper.sv
vlog +incdir+/software/mentor/questa10.7c/questasim/uvm-"$UVM_VERSION"
    ../verilog_src/uvm-"$UVM_VERSION"/src -incr ${path_to_file}
    test_bench/tb_dlx_uvm.sv
vsim -c -sv_lib /software/mentor/questa10.7c/questasim/uvm-"
    $UVM_VERSION"/linux_x86_64/uvm_dpi +UVM_STACKTRACE -suppress 8664
    work.tb_dlx_uvm -do ./scripts/dlx_uvm_tb.do
else
echo "Ok! you are missing a lot of fancy, amazing and astonishing
things"
fi
rm -rf ./work

```

APPENDIX K

Synthesis script

```
#!/usr/bin/bash
echo "Starting synthesis setup"
cd ..
export path_to_file=$PWD"/hardware/dlx/"
cd project/

if [ -d "./synthesis" ] ;then
    cp -r ./synthesis ./synthesis.old
    echo "Previous synthesis run can be found in synthesis.old folder"
    rm -rf ./synthesis
fi
mkdir synthesis
cd synthesis
mkdir report
mkdir output_netlist
cp ../../scripts/.synopsys_dc.setup ./
cp ../../scripts/synthesis.tcl ./
source /software/scripts/init_synopsys_64.18
mkdir work
echo "Starting Design Vision executing synthesis.tcl script"
design_vision -f synthesis.tcl -no_gui
```

TCL script:

```
#####
### analyzing and checking vhdl netlist ###
#####
puts "Starting top down compilation"
set designer "Franco - Francesco Angione"
```

```
set company "Microelectronic_Systems@Polito"
## maybe for vhdl2008 support
#set_property file_type {VHDL 2008} [get_files {{D:/uni/2018-2019/
  Microelectronic_systems/dlx_project/hardware/dlx/
  global_components.package/pg.vhd}}]
## path_to_file variable comes from bash script
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/constants.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/alu_type.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)000-globals.vhd"
analyze -library WORK -format vhd1 "$env(path_to_file)001
  -global_components.vhd"

puts "Compiling_labs_units"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/wrf.vhd"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/adder.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/alu.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/boothmul.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/complement2.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/encoder.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/fa.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/fd.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/gsb.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/mult_gm.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/mux.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/mux21.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/mux21_nbit.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/p4_adder.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/pgsb.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/rca.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
  global_components.package/csb.vhd_"
```

```

analyze -library WORK -format vhd1 "$env(path_to_file)
    global_components.package/reg_nbit.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
    global_components.package/registerfile.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
    global_components.package/stcg.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
    global_components.package/sum_gen.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
    global_components.package/pg.vhd"

puts "Compiling stages, control unit and datapath"
analyze -library WORK -format vhd1 "$env(path_to_file)a.b-DataPath.vhd
    _"
analyze -library WORK -format vhd1 "$env(path_to_file)
    a.b-DataPath.core/a.b.e-Write_back.stage.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
    a.b-DataPath.core/a.b.a-Fetch.stage.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
    a.b-DataPath.core/a.b.b-Decode.stage.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
    a.b-DataPath.core/a.b.c-Execute.stage.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
    a.b-DataPath.core/a.b.d.Memory.stage.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
    a.b-DataPath.core/a.b.b-Decode.stage/a.b.b.a-sign_extension.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
    a.b-DataPath.core/a.b.c-Execute.stage/
    a.b.c.a-check_branch_logic.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
    a.b-DataPath.core/a.b.c-Execute.stage/a.b.c.b-general_alu.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
    a.b-DataPath.core/a.b.c-Execute.stage/
    a.b.c.c-boothmul_pipelined.vhd_"
analyze -library WORK -format vhd1 "$env(path_to_file)
    a.b-DataPath.core/a.b.c-Execute.stage/
    a.b.c.c-boothmul_pipelined.core/a.b.c.a-mux.vhd"
analyze -library WORK -format vhd1 "$env(path_to_file)
    a.b-DataPath.core/a.b.c-Execute.stage/
    a.b.c.c-boothmul_pipelined.core/a.b.c.b-adder.vhd"
analyze -library WORK -format vhd1 "$env(path_to_file)
    a.b-DataPath.core/a.b.c-Execute.stage/
    a.b.c.c-boothmul_pipelined.core/a.b.c.c-complement2.vhd"
analyze -library WORK -format vhd1 "$env(path_to_file)
    a.b-DataPath.core/a.b.c-Execute.stage/
    a.b.c.c-boothmul_pipelined.core/a.b.c.d-encoder.vhd"
analyze -library WORK -format vhd1 "$env(path_to_file)
    a.a-control_unit.vhd_"
analyze -autoread -library WORK -format vhd1 "$env(path_to_file)

```

```

a-DLX.vhd_"

#####
##### elaborating the top entity #####
#####
puts "Elaborating_top_level_entity"
elaborate -update dlx -architecture dlx_rtl -library WORK -parameters
    "IR_SIZE=32,PC_SIZE=32"
current_design "DLX_IR_SIZE32_PC_SIZE32"

# define a clock name
set clockName "clk"
create_clock -name $clockName

#####
# first compilation, without constraints #
#####
puts "Synthesis_without_constraints"
compile
# reporting timing and power after the first synthesis without
constraints #
report_timing -nworst 10 > ./report/
    timing10worst_report_dlx_irsize32_pcsz32_nopt.rpt ; # 10 worse
paths
report_timing > ./report/timing_report_dlx_irsize32_pcsz32b_nopt.rpt
report_area > ./report/area_report_dlx_irsize32_pcsz32_nopt.rpt
report_power > ./report/power_report_dlx_irsize32_pcsz32_nopt.rpt
report_clock > ./report/report_clock_dlx_irsize32_pcsz32_nopt.rpt

write -hierarchy -format ddc -output ./output_netlist/
    dlx_irsize32_pcsz32_nopt.ddc
write -hierarchy -format vhdl -output ./output_netlist/
    dlx_irsize32_pcsz32_nopt.vhdl
write -hierarchy -format verilog -output ./output_netlist/
    dlx_irsize32_pcsz32_nopt.v
write_sdc ./output_netlist/dlx_irsize32_pcsz32_nopt.sdc

puts "Synthesis_push_as_much_as_possible_the_clock_frequency_i.e._
    until_the_slack_is_positive"
# forces a combinational max delay of REQUIRED_TIME from each of the
inputs
# to each of the output, that is a delay lower than the one found
after
# the first compilation step #
# often this is the working clock period of your system #
# set a 20% lower required time( float ) than maxpath
set MAX_PATH_c [ get_timing_paths -delay_type max -nworst 1
    -include_hierarchical_pins ]

```

```

#calculating the value of max_path in ns
set mp_1 [list]
foreach_in_collection path $MAX_PATH_c {
    set mpi 0.0
    foreach_in_collection point [ get_attribute $path points ] {
        set mpi [ expr $mpi + [ get_attribute $point arrival ] ]
    }
lappend mp_1 $mpi
}

# since the path is critical there is only one object into the list
set REQUIRED_TIME [ expr $mp_1*0.80 ]
#####
### clock constraints ###
#####
create_clock -name $clockName -period $REQUIRED_TIME
set_max_delay $REQUIRED_TIME -from [all_inputs] -to [all_outputs]
set_fix_hold $clockName

set max_transition_time 0.08
set_max_transition $max_transition_time [all_outputs]
set_min_delay 0.03 -from [all_inputs] -to [all_outputs]
set_input_delay 0.07 -clock $clockName [all_inputs]
set_output_delay 0.07 -clock $clockName [all_outputs]

# optimize
# enable the scan insetion and evaluation of impact
compile_ultra -scan
# save report
report_timing > ./report/
    timing_report_dlx_irsiz32_pcsiz32_opt_20.rpt
report_area > ./report/area_report_dlx_irsiz32_pcsiz32_opt_20.rpt
report_power > ./report/power_report_dlx_irsiz32_pcsiz32_opt_20.rpt
report_clock > ./report/report_clock_dlx_irsiz32_pcsiz32_opt_20.rpt
# saving files
write -hierarchy -format ddc -output ./output_netlist/
    dlx_irsiz32_pcsiz32_topt_20.ddc
write -hierarchy -format vhd1 -output ./output_netlist/
    dlx_irsiz32_pcsiz32_topt_20.vhd1
write -hierarchy -format verilog -output ./output_netlist/
    dlx_irsiz32_pcsiz32_topt_20.v

#set a 10% lower required time( float ) than maxpath
set REQUIRED_TIME [ expr $mp_1*0.90 ]
#####
### clock constraints ###
#####
create_clock -name $clockName -period $REQUIRED_TIME

```

```

set_max_delay $REQUIRED_TIME -from [all_inputs] -to [all_outputs]
set_fix_hold $clockName

set max_transition_time 0.08
set_max_transition $max_transition_time [all_outputs]
set_min_delay 0.03 -from [all_inputs] -to [all_outputs]
set_input_delay 0.07 -clock $clockName [all_inputs]
set_output_delay 0.07 -clock $clockName [all_outputs]

# optimize
compile_ultra -scan
# save report
report_timing > ./report/
    timing_report_dlx_irsiz32_pcsiz32_opt_10.rpt
report_area > ./report/area_report_dlx_irsiz32_pcsiz32_opt_10.rpt
report_power > ./report/power_report_dlx_irsiz32_pcsiz32_opt_10.rpt
report_clock > ./report/report_clock_dlx_irsiz32_pcsiz32_opt_10.rpt

# saving files
write -hierarchy -format ddc -output ./output_netlist/
    dlx_irsiz32_pcsiz32_topt_10.ddc
write -hierarchy -format vhdl -output ./output_netlist/
    dlx_irsiz32_pcsiz32_topt_10.vhdl
write -hierarchy -format verilog -output ./output_netlist/
    dlx_irsiz32_pcsiz32_topt_10.v
write_sdc ./output_netlist/dlx_irsiz32_pcsiz32_10.sdc

#set a 1% lower required time( float ) than maxpath
set REQUIRED_TIME [ expr $mp_1*0.99 ]
#####
### clock constraints ###
#####
create_clock -name $clockName -period $REQUIRED_TIME
set_max_delay $REQUIRED_TIME -from [all_inputs] -to [all_outputs]
set_fix_hold $clockName

set max_transition_time 0.08
set_max_transition $max_transition_time [all_outputs]
set_min_delay 0.03 -from [all_inputs] -to [all_outputs]
set_input_delay 0.07 -clock $clockName [all_inputs]
set_output_delay 0.07 -clock $clockName [all_outputs]

# optimize
compile_ultra -scan
# save report
report_timing > ./report/timing_report_dlx_irsiz32_pcsiz32_opt_1.rpt
report_area > ./report/area_report_dlx_irsiz32_pcsiz32_opt_1.rpt
report_power > ./report/power_report_dlx_irsiz32_pcsiz32_opt_1.rpt

```

```

report_clock > ./report/report_clock_dlx_irsiz32_pcsiz32_opt_1.rpt

# saving files
write -hierarchy -format ddc -output ./output_netlist/
    dlx_irsiz32_pcsiz32_topt_1.ddc
write -hierarchy -format vhdl -output ./output_netlist/
    dlx_irsiz32_pcsiz32_topt_1.vhdl
write -hierarchy -format verilog -output ./output_netlist/
    dlx_irsiz32_pcsiz32_topt_1.v

# put constraint on finding the minimum possible area for this design
set_max_area 0.0
puts "Synthesis push as much as possible the clock frequency i.e.
    until the slack is positive and push as much as possible the area"

# since the path is critical there is only one object into the list
set REQUIRED_TIME [ expr $mp_1*0.80 ]

#####
### clock constraints ###
#####
create_clock -name $clockName -period $REQUIRED_TIME
set_max_delay $REQUIRED_TIME -from [all_inputs] -to [all_outputs]
set_fix_hold $clockName

set max_transition_time 0.08
set_max_transition $max_transition_time [all_outputs]
set_min_delay 0.03 -from [all_inputs] -to [all_outputs]
set_input_delay 0.07 -clock $clockName [all_inputs]
set_output_delay 0.07 -clock $clockName [all_outputs]

# optimize
compile_ultra -scan
# save report
report_timing > ./report/
    timing_report_dlx_irsiz32_pcsiz32_opt_20_minarea.rpt
report_area > ./report/
    area_report_dlx_irsiz32_pcsiz32_opt_20_minarea.rpt
report_power > ./report/
    power_report_dlx_irsiz32_pcsiz32_opt_20_minarea.rpt
report_clock > ./report/
    report_clock_dlx_irsiz32_pcsiz32_opt_20_minarea.rpt

# saving files
write -hierarchy -format ddc -output ./output_netlist/
    dlx_irsiz32_pcsiz32_topt_20_minarea.ddc
write -hierarchy -format vhdl -output ./output_netlist/

```

```

    dlx_irsize32_pcsizes32_topt_20_minarea.vhdl
write -hierarchy -format verilog -output ./output_netlist/
    dlx_irsize32_pcsizes32_topt_20_minarea.v

#set a 10% lower required time( float )  than maxpath
set REQUIRED_TIME [ expr $mp_1*0.90 ]

#####
### clock constraints ###
#####
create_clock -name $clockName -period $REQUIRED_TIME
set_max_delay $REQUIRED_TIME -from [all_inputs] -to [all_outputs]
set_fix_hold $clockName

set max_transition_time 0.08
set_max_transition $max_transition_time [all_outputs]
set_min_delay 0.03 -from [all_inputs] -to [all_outputs]
set_input_delay 0.07 -clock $clockName [all_inputs]
set_output_delay 0.07 -clock $clockName [all_outputs]

# optimize
compile_ultra -scan
# save report
report_timing > ./report/
    timing_report_dlx_irsize32_pcsizes32_opt_10_minarea.rpt
report_area > ./report/
    area_report_dlx_irsize32_pcsizes32_opt_10_minarea.rpt
report_power > ./report/
    power_report_dlx_irsize32_pcsizes32_opt_10_minarea.rpt
report_clock > ./report/
    report_clock_dlx_irsize32_pcsizes32_opt_10_minarea.rpt

# saving files
write -hierarchy -format ddc -output ./output_netlist/
    dlx_irsize32_pcsizes32_topt_10_minarea.ddc
write -hierarchy -format vhd1 -output ./output_netlist/
    dlx_irsize32_pcsizes32_topt_10_minarea.vhdl
write -hierarchy -format verilog -output ./output_netlist/
    dlx_irsize32_pcsizes32_topt_10_minarea.v

#set a 1% lower required time( float )  than maxpath
set REQUIRED_TIME [ expr $mp_1*0.99 ]

#####
### clock constraints ###
#####
create_clock -name $clockName -period $REQUIRED_TIME
set_max_delay $REQUIRED_TIME -from [all_inputs] -to [all_outputs]

```



```
set_fix_hold $clockName

set max_transition_time 0.08
set_max_transition $max_transition_time [all_outputs]
set_min_delay 0.03 -from [all_inputs] -to [all_outputs]
set_input_delay 0.07 -clock $clockName [all_inputs]
set_output_delay 0.07 -clock $clockName [all_outputs]

# optimize
compile_ultra -scan
# save report
report_timing > ./report/
    timing_report_dlx_irsized32_pcsized32_opt_1_minarea.rpt
report_area > ./report/
    area_report_dlx_irsized32_pcsized32_opt_1_minarea.rpt
report_power > ./report/
    power_report_dlx_irsized32_pcsized32_opt_1_minarea.rpt
report_clock > ./report/
    report_clock_dlx_irsized32_pcsized32_opt_1_minarea.rpt

# saving files
write -hierarchy -format ddc -output ./output_netlist/
    dlx_irsized32_pcsized32_topt_1_minarea.ddc
write -hierarchy -format vhd1 -output ./output_netlist/
    dlx_irsized32_pcsized32_topt_1_minarea.vhd1
write -hierarchy -format verilog -output ./output_netlist/
    dlx_irsized32_pcsized32_topt_1_minarea.v
write_sdc ./output_netlist/dlx_irsized32_pcsized32_1_minarea.sdc

exit
```

APPENDIX L

Physical Design script

```
#!/usr/bin/bash
echo "Starting physical design"
cd ..

export path_to_file_synthesis=$PWD"/project/synthesis/"

gui_option=$1
if [[ "$gui_option" != "no_gui" && "$gui_option" != "gui" ]] ;
then
    echo "---> wrong parameter! Usage is ./physical_design.sh gui/
    no_gui<---"
    exit
fi
cd project/
echo "Starting physical design setup"

if [ -d "./physical_design" ] ;then
    cp -r ./physical_design ./physical_design.old
    echo "Previous physical design run can be found in
    physical_design.old folder"
    rm -rf ./physical_design
fi
mkdir ./physical_design
cd ./physical_design
cp ../../scripts/physical_design.tcl ./
cp ../../scripts/Default_nopt.view ./
cp ../../scripts/Default_10.view ./
cp ../../scripts/Default_1_minarea.view ./
mkdir report
mkdir output_netlist
mkdir images_nopt
mkdir images_10
mkdir images_1_minarea
```

```

source /software/scripts/init_innovus17.11
# launch innovus
echo "Startig_Innovus_executing_physical_design.tcl_script_with_
    $gui_option"
if [ "$gui_option" == "gui" ] ; then
innovus -files physical_design.tcl
else
innovus -files physical_design.tcl -no_gui
fi

exit

```

TCL script:

```

puts "Configuring_Innovus"
setMultiCpuUsage -cpuAutoAdjust {true} -localCpu 6
set_global _enable_mmmc_by_default_flow $CTE::mmmc_default
suppressMessage ENCEXT-2799
loadWorkspace -name Physical
set defHierChar /
set delaycal_input_transition_delay 0.1ps
set fpIsMaxIoHeight 0
set init_gnd_net {gnd}
set init_mmmc_file {Default_nopt.view}
set init_oa_search_lib {}
set init_pwr_net {vdd}
set init_verilog "$env(path_to_file_synthesis)output_netlist/
    dlx_irsiz32_pcsiz32_nopt.v"
set init_lef_file /software/dk/nangate45/lef/
    NangateOpenCellLibrary.lef
set lsgOCPGainMult 1.000000
set LEF_DIR /software/dk/nangate45/lef
set LEF_list [list ${LEF_DIR}/NangateOpenCellLibrary.lef]
set init_lef_file "${LEF_list}"
set LIB_DIR /software/dk/nangate45/liberty
set MyTimingLibNom ${LIB_DIR}/
    NangateOpenCellLibrary_typical_ecsm_nowlm.lib
set MyTimingLibSlow ${LIB_DIR}/NangateOpenCellLibrary_slow_ecsm.lib
set MyTimingLibFast ${LIB_DIR}/NangateOpenCellLibrary_fast_ecsm.lib
set MycapTable $LEF_DIR/captables/NCSU_FreePDK_45nm.capTbl
puts "Floorplanning_Innovus"
init_design
getIoFlowFlag
setIoFlowFlag 0
floorPlan -site FreePDK45_38x28_10R_NP_162NW_340 -r 1 0.6 5 5 5 5
getIoFlowFlag

```

```

## for gui run
uiSetTool select
getIoFlowFlag
fit
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0

puts "Power planning and routing Innovus"

setAddRingMode -ring_target default -extend_over_row 0 -ignore_rows 0
    -avoid_short 0 -skip_crossing_trunks none -stacked_via_top_layer
    metal10 -stacked_via_bottom_layer metal1
    -via_using_exact_crossover_size 1 -orthogonal_only true
    -skip_via_on_pin { standardcell } -skip_via_on_wire_shape {
    noshape }
#addRing -nets {} -type core_rings -follow core -layer {top metal1
    bottom metal1 left metal2 right metal2} -width {top 1.8 bottom 1.8
    left 1.8 right 1.8} -spacing {top 1.8 bottom 1.8 left 1.8 right 1
    .8} -offset {top 1.8 bottom 1.8 left 1.8 right 1.8} -center 0
    -extend_corner {} -threshold 0 -jog_distance 0
    -snap_wire_center_to_grid None
setAddRingMode -ring_target default -extend_over_row 0 -ignore_rows 0
    -avoid_short 0 -skip_crossing_trunks none -stacked_via_top_layer
    metal10 -stacked_via_bottom_layer metal1
    -via_using_exact_crossover_size 1 -orthogonal_only true
    -skip_via_on_pin { standardcell } -skip_via_on_wire_shape {
    noshape }
addRing -nets {gnd vdd} -type core_rings -follow core -layer {top
    metal9 bottom metal9 left metal10 right metal10} -width {top 0.8
    bottom 0.8 left 0.8 right 0.8} -spacing {top 0.8 bottom 0.8 left 0
    .8 right 0.8} -offset {top 1.8 bottom 1.8 left 1.8 right 1.8}
    -center 1 -extend_corner {} -threshold 0 -jog_distance 0
    -snap_wire_center_to_grid None

```

```

set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
setAddStripeMode -ignore_block_check false -break_at none
    -route_over_rows_only false -rows_without_stripes_only false
    -extend_to_closest_target none -stop_at_last_wire_for_area false
    -partial_set_thru_domain false -ignore_nondefault_domains false
    -trim_antenna_back_to_shape none -spacing_type edge_to_edge
    -spacing_from_block 0 -stripe_min_length 0 -stacked_via_top_layer
    metal10 -stacked_via_bottom_layer metal1
    -via_using_exact_crossover_size false -split_vias false
    -orthogonal_only true -allow_jog { padcore_ring block_ring }
addStripe -nets {vdd gnd} -layer metal10 -direction vertical -width 0
    .8 -spacing 0.8 -set_to_set_distance 20 -start_from left
    -start_offset 15 -switch_layer_over_obs false
    -max_same_layer_jog_length 2 -padcore_ring_top_layer_limit metal10
    -padcore_ring_bottom_layer_limit metal1
    -block_ring_top_layer_limit metal10 -block_ring_bottom_layer_limit
    metal1 -use_wire_group 0 -snap_wire_center_to_grid None
    -skip_via_on_pin { standardcell } -skip_via_on_wire_shape {
    noshape }

setSrouteMode -viaConnectToShape { noshape }
sroute -connect { blockPin padPin padRing corePin floatingStripe }
    -layerChangeRange { metal1(1) metal10(10) } -blockPinTarget {
    nearestTarget } -padPinPortConnect { allPort oneGeom }
    -padPinTarget { nearestTarget } -corePinTarget { firstAfterRowEnd
    } -floatingStripeTarget { blockring padring ring stripe ringpin
    blockpin followpin } -allowJogging 1 -crossoverViaLayerRange {
    metal1(1) metal10(10) } -nets { gnd vdd } -allowLayerChange 1
    -blockPin useLef -targetViaLayerRange { metal1(1) metal10(10) }

```

```

puts "PinAssignment"

getPinAssignMode -pinEditInBatch -quiet
setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    CLK
setPinAssignMode -pinEditInBatch false
setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    RST
setPinAssignMode -pinEditInBatch false

# iram
setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    IRAM_ENABLE
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    IRAM_READY
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -spreadDirection clockwise -side Top -layer 1
    -spreadType side -pin {{IRAM_ADDRESS[0]} {IRAM_ADDRESS[1]} {
    IRAM_ADDRESS[2]} {IRAM_ADDRESS[3]} {IRAM_ADDRESS[4]} {IRAM_ADDRESS
    [5]} {IRAM_ADDRESS[6]} {IRAM_ADDRESS[7]} {IRAM_ADDRESS[8]} {
    IRAM_ADDRESS[9]} {IRAM_ADDRESS[10]} {IRAM_ADDRESS[11]} {
    IRAM_ADDRESS[12]} {IRAM_ADDRESS[13]} {IRAM_ADDRESS[14]} {
    IRAM_ADDRESS[15]} {IRAM_ADDRESS[16]} {IRAM_ADDRESS[17]} {
    IRAM_ADDRESS[18]} {IRAM_ADDRESS[19]} {IRAM_ADDRESS[20]} {
    IRAM_ADDRESS[21]} {IRAM_ADDRESS[22]} {IRAM_ADDRESS[23]} {
    IRAM_ADDRESS[24]} {IRAM_ADDRESS[25]} {IRAM_ADDRESS[26]} {
    IRAM_ADDRESS[27]} {IRAM_ADDRESS[28]} {IRAM_ADDRESS[29]} {
    IRAM_ADDRESS[30]} {IRAM_ADDRESS[31]}}
setPinAssignMode -pinEditInBatch true

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -spreadDirection clockwise -side Top -layer 2
    -spreadType side -pin {{IRAM_DATA[0]} {IRAM_DATA[1]} {IRAM_DATA
    [2]} {IRAM_DATA[3]} {IRAM_DATA[4]} {IRAM_DATA[5]} {IRAM_DATA[6]} {
    IRAM_DATA[7]} {IRAM_DATA[8]} {IRAM_DATA[9]} {IRAM_DATA[10]} {
    IRAM_DATA[11]} {IRAM_DATA[12]} {IRAM_DATA[13]} {IRAM_DATA[14]} {

```

```

    IRAM_DATA[15]} {IRAM_DATA[16]} {IRAM_DATA[17]} {IRAM_DATA[18]} {
    IRAM_DATA[19]} {IRAM_DATA[20]} {IRAM_DATA[21]} {IRAM_DATA[22]} {
    IRAM_DATA[23]} {IRAM_DATA[24]} {IRAM_DATA[25]} {IRAM_DATA[26]} {
    IRAM_DATA[27]} {IRAM_DATA[28]} {IRAM_DATA[29]} {IRAM_DATA[30]} {
    IRAM_DATA[31]}}
setPinAssignMode -pinEditInBatch true

# dram
setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    DRAM_ENABLE
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    DRAM_READNOTWRITE
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    DRAM_READY
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -spreadDirection clockwise -side Right -layer 1
    -spreadType side -pin {{DRAM_ADDRESS[0]} {DRAM_ADDRESS[1]} {
    DRAM_ADDRESS[2]} {DRAM_ADDRESS[3]} {DRAM_ADDRESS[4]} {DRAM_ADDRESS
    [5]} {DRAM_ADDRESS[6]} {DRAM_ADDRESS[7]} {DRAM_ADDRESS[8]} {
    DRAM_ADDRESS[9]} {DRAM_ADDRESS[10]} {DRAM_ADDRESS[11]} {
    DRAM_ADDRESS[12]} {DRAM_ADDRESS[13]} {DRAM_ADDRESS[14]} {
    DRAM_ADDRESS[15]} {DRAM_ADDRESS[16]} {DRAM_ADDRESS[17]} {
    DRAM_ADDRESS[18]} {DRAM_ADDRESS[19]} {DRAM_ADDRESS[20]} {
    DRAM_ADDRESS[21]} {DRAM_ADDRESS[22]} {DRAM_ADDRESS[23]} {
    DRAM_ADDRESS[24]} {DRAM_ADDRESS[25]} {DRAM_ADDRESS[26]} {
    DRAM_ADDRESS[27]} {DRAM_ADDRESS[28]} {DRAM_ADDRESS[29]} {
    DRAM_ADDRESS[30]} {DRAM_ADDRESS[31]}}
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -spreadDirection clockwise -side Right -layer 2
    -spreadType side -pin {{DRAM_DATA[0]} {DRAM_DATA[1]} {DRAM_DATA
    [2]} {DRAM_DATA[3]} {DRAM_DATA[4]} {DRAM_DATA[5]} {DRAM_DATA[6]} {
    DRAM_DATA[7]} {DRAM_DATA[8]} {DRAM_DATA[9]} {DRAM_DATA[10]} {
    DRAM_DATA[11]} {DRAM_DATA[12]} {DRAM_DATA[13]} {DRAM_DATA[14]} {
    DRAM_DATA[15]} {DRAM_DATA[16]} {DRAM_DATA[17]} {DRAM_DATA[18]} {

```

```

    DRAM_DATA[19]} {DRAM_DATA[20]} {DRAM_DATA[21]} {DRAM_DATA[22]} {
    DRAM_DATA[23]} {DRAM_DATA[24]} {DRAM_DATA[25]} {DRAM_DATA[26]} {
    DRAM_DATA[27]} {DRAM_DATA[28]} {DRAM_DATA[29]} {DRAM_DATA[30]} {
    DRAM_DATA[31]}}
setPinAssignMode -pinEditInBatch false

## for gui run
setDrawView fplan
fit
dumpToGIF ./images_nopt/DLX_IR_SIZE32_PC_SIZE32_nopt_fplan_postpin
setDrawView ameba
fit
dumpToGIF ./images_nopt/DLX_IR_SIZE32_PC_SIZE32_nopt_ameba_postpin
setDrawView place
fit
dumpToGIF ./images_nopt/DLX_IR_SIZE32_PC_SIZE32_nopt_place_postpin

puts "Cell␣placing␣Innovus"
placeDesign
setOptMode -fixCap true -fixTran true -fixFanoutLoad false
optDesign -postCTS
optDesign -postCTS -hold
getFillerMode -quiet
addFiller -cell FILLCELL_X8 FILLCELL_X32 FILLCELL_X4 FILLCELL_X2
          FILLCELL_X16 FILLCELL_X1 -prefix FILLER

## for gui run
setDrawView fplan
fit
dumpToGIF ./images_nopt/DLX_IR_SIZE32_PC_SIZE32_nopt_fplan_prerouting
setDrawView ameba
fit
dumpToGIF ./images_nopt/DLX_IR_SIZE32_PC_SIZE32_nopt_ameba_prerouting
setDrawView place
fit
dumpToGIF ./images_nopt/DLX_IR_SIZE32_PC_SIZE32_nopt_place_prerouting

puts "Signal␣routing␣␣Innovus"

setNanoRouteMode -quiet -timingEngine {}
setNanoRouteMode -quiet -routeWithSiPostRouteFix 0
setNanoRouteMode -quiet -drouteStartIteration default
setNanoRouteMode -quiet -routeTopRoutingLayer default
setNanoRouteMode -quiet -routeBottomRoutingLayer default
setNanoRouteMode -quiet -drouteEndIteration default
setNanoRouteMode -quiet -routeWithTimingDriven false
setNanoRouteMode -quiet -routeWithSiDriven false
routeDesign -globalDetail

```



```

setAnalysisMode -analysisType onChipVariation
setOptMode -fixCap true -fixTran true -fixFanoutLoad false
optDesign -postRoute
optDesign -postRoute -hold
saveDesign DLX_IR_SIZE32_PC_SIZE32_nopt_saved
reset_parasitics
extractRC
redirect -quiet {set honorDomain [getAnalysisMode -honorClockDomains]}
    > /dev/null
timeDesign -postRoute -pathReports -drvReports -slackReports -numPaths
    50 -prefix DLX_IR_SIZE32_PC_SIZE32_nopt_postroute -outDir
    timingReports
get_time_unit
report_timing -machine_readable -max_paths 10000 -max_slack 0.75
    -path_exceptions all > DLX_IR_SIZE32_PC_SIZE32_nopt.mtarpt
load_timing_debug_report -name default_report
    DLX_IR_SIZE32_PC_SIZE32_nopt.mtarpt

puts "Verification"
verifyConnectivity -type all -error 1000 -warning 50
setVerifyGeometryMode -area { 0 0 0 0 } -minWidth true -minSpacing
    true -minArea true -sameNet true -short true -overlap true
    -offRGrid false -offMGrid true -mergedMGridCheck true -minHole
    true -implantCheck true -minimumCut true -minStep true
    -viaEnclosure true -antenna false -insuffMetalOverlap true
    -pinInBlkg false -diffCellViol true -sameCellViol false
    -padFillerCellsOverlap true -routingBlkgPinOverlap true
    -routingCellBlkgOverlap true -regRoutingOnly false
    -stackedViasOnRegNet false -wireExt true -useNonDefaultSpacing
    false -maxWidth true -maxNonPrefLength -1 -error 1000
verifyGeometry
setVerifyGeometryMode -area { 0 0 0 0 }
get_verify_drc_mode -disable_rules -quiet
get_verify_drc_mode -quiet -area
get_verify_drc_mode -quiet -layer_range
get_verify_drc_mode -check_implant -quiet
get_verify_drc_mode -check_implant_across_rows -quiet
get_verify_drc_mode -check_ndr_spacing -quiet
get_verify_drc_mode -check_only -quiet
get_verify_drc_mode -check_same_via_cell -quiet
get_verify_drc_mode -exclude_pg_net -quiet
get_verify_drc_mode -ignore_trial_route -quiet
get_verify_drc_mode -max_wrong_way_halo -quiet
get_verify_drc_mode -use_min_spacing_on_block_obs -quiet
get_verify_drc_mode -limit -quiet
set_verify_drc_mode -disable_rules {} -check_implant true
    -check_implant_across_rows false -check_ndr_spacing false
    -check_same_via_cell false -exclude_pg_net false
    -ignore_trial_route false -report

```

```

DLX_IR_SIZE32_PC_SIZE32_nopt.drc.rpt -limit 1000
verify_drc

## dump images of various stages * congestion * density floor
placement      route_all * route_C4    * route_C5    * route_C6    *
route_M1 * route_M2      route_M3    * specialroute    *
violations
## for gui run
setDrawView fplan
fit
dumpToGIF ./images_nopt/DLX_IR_SIZE32_PC_SIZE32_nopt_fplan
setDrawView ameba
fit
dumpToGIF ./images_nopt/DLX_IR_SIZE32_PC_SIZE32_nopt_ameba
setDrawView place
fit
dumpToGIF ./images_nopt/DLX_IR_SIZE32_PC_SIZE32_nopt_place
dumpPictures -dir ./images_nopt/ -prefix [dbGet top.name] -fullScreen
saveFPlan ./DLX_IR_SIZE32_PC_SIZE32_nopt_floorplan
reportGateCount -level 5 -limit 100 -outfile
DLX_IR_SIZE32_PC_SIZE32_nopt.gateCount
saveNetlist DLX_IR_SIZE32_PC_SIZE32_nopt.v
all_hold_analysis_views
all_setup_analysis_views
write_sdf -ideal_clock_network DLX_IR_SIZE32_PC_SIZE32_nopt.sdf

puts "Starting with optimized design with a lower slack"

set defHierChar /
set delaycal_input_transition_delay 0.1ps
set fpIsMaxIoHeight 0
set init_gnd_net {gnd}
set init_mmmc_file Default_10.view
set init_oa_search_lib {}
set init_pwr_net {vdd}
set init_verilog "$env(path_to_file_synthesis)output_netlist/
dlx_irsiz32_pcsiz32_topt_10.v"
set init_lef_file /software/dk/nangate45/lef/
NangateOpenCellLibrary.lef
set lsg0CPGainMult 1.000000
set LEF_DIR /software/dk/nangate45/lef
set LEF_list [list ${LEF_DIR}/NangateOpenCellLibrary.lef]
set init_lef_file "${LEF_list}"
set LIB_DIR /software/dk/nangate45/liberty
set MyTimingLibNom ${LIB_DIR}/
NangateOpenCellLibrary_typical_ecsm_nowlm.lib
set MyTimingLibSlow ${LIB_DIR}/NangateOpenCellLibrary_slow_ecsm.lib
set MyTimingLibFast ${LIB_DIR}/NangateOpenCellLibrary_fast_ecsm.lib

```

```

set MycapTable $LEF_DIR/captables/NCSU_FreePDK_45nm.capTbl

puts "Floorplanning□Innovus"

init_design
getIoFlowFlag
setIoFlowFlag 0
floorPlan -site FreePDK45_38x28_10R_NP_162NW_340 -r 1 0.6 5 5 5 5
getIoFlowFlag
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0

puts "Power□planning□and□routing□Innovus"

setAddRingMode -ring_target default -extend_over_row 0 -ignore_rows 0
    -avoid_short 0 -skip_crossing_trunks none -stacked_via_top_layer
    metal10 -stacked_via_bottom_layer metal1
    -via_using_exact_crossover_size 1 -orthogonal_only true
    -skip_via_on_pin { standardcell } -skip_via_on_wire_shape {
    noshape }
#addRing -nets {} -type core_rings -follow core -layer {top metal1
    bottom metal1 left metal2 right metal2} -width {top 1.8 bottom 1.8
    left 1.8 right 1.8} -spacing {top 1.8 bottom 1.8 left 1.8 right 1
    .8} -offset {top 1.8 bottom 1.8 left 1.8 right 1.8} -center 0
    -extend_corner {} -threshold 0 -jog_distance 0
    -snap_wire_center_to_grid None
setAddRingMode -ring_target default -extend_over_row 0 -ignore_rows 0
    -avoid_short 0 -skip_crossing_trunks none -stacked_via_top_layer
    metal10 -stacked_via_bottom_layer metal1
    -via_using_exact_crossover_size 1 -orthogonal_only true
    -skip_via_on_pin { standardcell } -skip_via_on_wire_shape {
    noshape }

```

```

addRing -nets {gnd vdd} -type core_rings -follow core -layer {top
    metal9 bottom metal9 left metal10 right metal10} -width {top 0.8
    bottom 0.8 left 0.8 right 0.8} -spacing {top 0.8 bottom 0.8 left 0
    .8 right 0.8} -offset {top 1.8 bottom 1.8 left 1.8 right 1.8}
    -center 1 -extend_corner {} -threshold 0 -jog_distance 0
    -snap_wire_center_to_grid None
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
setAddStripeMode -ignore_block_check false -break_at none
    -route_over_rows_only false -rows_without_strips_only false
    -extend_to_closest_target none -stop_at_last_wire_for_area false
    -partial_set_thru_domain false -ignore_nondefault_domains false
    -trim_antenna_back_to_shape none -spacing_type edge_to_edge
    -spacing_from_block 0 -stripe_min_length 0 -stacked_via_top_layer
    metal10 -stacked_via_bottom_layer metal1
    -via_using_exact_crossover_size false -split_vias false
    -orthogonal_only true -allow_jog { padcore_ring block_ring }
addStripe -nets {vdd gnd} -layer metal10 -direction vertical -width 0
    .8 -spacing 0.8 -set_to_set_distance 20 -start_from left
    -start_offset 15 -switch_layer_over_obs false
    -max_same_layer_jog_length 2 -padcore_ring_top_layer_limit metal10
    -padcore_ring_bottom_layer_limit metal1
    -block_ring_top_layer_limit metal10 -block_ring_bottom_layer_limit
    metal1 -use_wire_group 0 -snap_wire_center_to_grid None
    -skip_via_on_pin { standardcell } -skip_via_on_wire_shape {
    noshape }

setSroutemode -viaConnectToShape { noshape }
sroute -connect { blockPin padPin padRing corePin floatingStripe }
    -layerChangeRange { metal1(1) metal10(10) } -blockPinTarget {
    nearestTarget } -padPinPortConnect { allPort oneGeom }
    -padPinTarget { nearestTarget } -corePinTarget { firstAfterRowEnd
    } -floatingStripeTarget { blockring padring ring stripe ringpin

```

```

    blockpin followpin } -allowJogging 1 -crossoverViaLayerRange {
    metal1(1) metal10(10) } -nets { gnd vdd } -allowLayerChange 1
    -blockPin useLef -targetViaLayerRange { metal1(1) metal10(10) }

puts "␣Pin␣assignment␣"

getPinAssignMode -pinEditInBatch -quiet
setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    CLK
setPinAssignMode -pinEditInBatch false
setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    RST
setPinAssignMode -pinEditInBatch false

# iram
setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    IRAM_ENABLE
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    IRAM_READY
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -spreadDirection clockwise -side Top -layer 1
    -spreadType side -pin {{IRAM_ADDRESS[0]} {IRAM_ADDRESS[1]} {
    IRAM_ADDRESS[2]} {IRAM_ADDRESS[3]} {IRAM_ADDRESS[4]} {IRAM_ADDRESS
    [5]} {IRAM_ADDRESS[6]} {IRAM_ADDRESS[7]} {IRAM_ADDRESS[8]} {
    IRAM_ADDRESS[9]} {IRAM_ADDRESS[10]} {IRAM_ADDRESS[11]} {
    IRAM_ADDRESS[12]} {IRAM_ADDRESS[13]} {IRAM_ADDRESS[14]} {
    IRAM_ADDRESS[15]} {IRAM_ADDRESS[16]} {IRAM_ADDRESS[17]} {
    IRAM_ADDRESS[18]} {IRAM_ADDRESS[19]} {IRAM_ADDRESS[20]} {
    IRAM_ADDRESS[21]} {IRAM_ADDRESS[22]} {IRAM_ADDRESS[23]} {
    IRAM_ADDRESS[24]} {IRAM_ADDRESS[25]} {IRAM_ADDRESS[26]} {
    IRAM_ADDRESS[27]} {IRAM_ADDRESS[28]} {IRAM_ADDRESS[29]} {
    IRAM_ADDRESS[30]} {IRAM_ADDRESS[31]}}
setPinAssignMode -pinEditInBatch true

setPinAssignMode -pinEditInBatch true

```

```

editPin -fixOverlap 1 -spreadDirection clockwise -side Top -layer 2
    -spreadType side -pin {{IRAM_DATA[0]} {IRAM_DATA[1]} {IRAM_DATA
[2]} {IRAM_DATA[3]} {IRAM_DATA[4]} {IRAM_DATA[5]} {IRAM_DATA[6]} {
IRAM_DATA[7]} {IRAM_DATA[8]} {IRAM_DATA[9]} {IRAM_DATA[10]} {
IRAM_DATA[11]} {IRAM_DATA[12]} {IRAM_DATA[13]} {IRAM_DATA[14]} {
IRAM_DATA[15]} {IRAM_DATA[16]} {IRAM_DATA[17]} {IRAM_DATA[18]} {
IRAM_DATA[19]} {IRAM_DATA[20]} {IRAM_DATA[21]} {IRAM_DATA[22]} {
IRAM_DATA[23]} {IRAM_DATA[24]} {IRAM_DATA[25]} {IRAM_DATA[26]} {
IRAM_DATA[27]} {IRAM_DATA[28]} {IRAM_DATA[29]} {IRAM_DATA[30]} {
IRAM_DATA[31]}}
setPinAssignMode -pinEditInBatch true

# dram
setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    DRAM_ENABLE
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    DRAM_READNOTWRITE
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    DRAM_READY
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -spreadDirection clockwise -side Right -layer 1
    -spreadType side -pin {{DRAM_ADDRESS[0]} {DRAM_ADDRESS[1]} {
DRAM_ADDRESS[2]} {DRAM_ADDRESS[3]} {DRAM_ADDRESS[4]} {DRAM_ADDRESS
[5]} {DRAM_ADDRESS[6]} {DRAM_ADDRESS[7]} {DRAM_ADDRESS[8]} {
DRAM_ADDRESS[9]} {DRAM_ADDRESS[10]} {DRAM_ADDRESS[11]} {
DRAM_ADDRESS[12]} {DRAM_ADDRESS[13]} {DRAM_ADDRESS[14]} {
DRAM_ADDRESS[15]} {DRAM_ADDRESS[16]} {DRAM_ADDRESS[17]} {
DRAM_ADDRESS[18]} {DRAM_ADDRESS[19]} {DRAM_ADDRESS[20]} {
DRAM_ADDRESS[21]} {DRAM_ADDRESS[22]} {DRAM_ADDRESS[23]} {
DRAM_ADDRESS[24]} {DRAM_ADDRESS[25]} {DRAM_ADDRESS[26]} {
DRAM_ADDRESS[27]} {DRAM_ADDRESS[28]} {DRAM_ADDRESS[29]} {
DRAM_ADDRESS[30]} {DRAM_ADDRESS[31]}}
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -spreadDirection clockwise -side Right -layer 2

```

```

-spreadType side -pin {{DRAM_DATA[0]} {DRAM_DATA[1]} {DRAM_DATA
[2]} {DRAM_DATA[3]} {DRAM_DATA[4]} {DRAM_DATA[5]} {DRAM_DATA[6]} {
DRAM_DATA[7]} {DRAM_DATA[8]} {DRAM_DATA[9]} {DRAM_DATA[10]} {
DRAM_DATA[11]} {DRAM_DATA[12]} {DRAM_DATA[13]} {DRAM_DATA[14]} {
DRAM_DATA[15]} {DRAM_DATA[16]} {DRAM_DATA[17]} {DRAM_DATA[18]} {
DRAM_DATA[19]} {DRAM_DATA[20]} {DRAM_DATA[21]} {DRAM_DATA[22]} {
DRAM_DATA[23]} {DRAM_DATA[24]} {DRAM_DATA[25]} {DRAM_DATA[26]} {
DRAM_DATA[27]} {DRAM_DATA[28]} {DRAM_DATA[29]} {DRAM_DATA[30]} {
DRAM_DATA[31]}}
setPinAssignMode -pinEditInBatch false

## for gui run
setDrawView fplan
fit
dumpToGIF ./images_10/DLX_IR_SIZE32_PC_SIZE32_10_fplan_postpin
setDrawView ameba
fit
dumpToGIF ./images_10/DLX_IR_SIZE32_PC_SIZE32_10_ameba_postpin
setDrawView place
fit
dumpToGIF ./images_10/DLX_IR_SIZE32_PC_SIZE32_10_place_postpin

puts "Cell_placing_Innovus"
placeDesign
setOptMode -fixCap true -fixTran true -fixFanoutLoad false
optDesign -postCTS
optDesign -postCTS -hold
getFillerMode -quiet
addFiller -cell FILLCELL_X8 FILLCELL_X32 FILLCELL_X4 FILLCELL_X2
        FILLCELL_X16 FILLCELL_X1 -prefix FILLER

## for gui run
setDrawView fplan
fit
dumpToGIF ./images_10/DLX_IR_SIZE32_PC_SIZE32_10_fplan_prerouting
setDrawView ameba
fit
dumpToGIF ./images_10/DLX_IR_SIZE32_PC_SIZE32_10_ameba_prerouting
setDrawView place
fit
dumpToGIF ./images_10/DLX_IR_SIZE32_PC_SIZE32_10_place_prerouting
puts "Signal_routing_Innovus"

setNanoRouteMode -quiet -timingEngine {}
setNanoRouteMode -quiet -routeWithSiPostRouteFix 0
setNanoRouteMode -quiet -drouteStartIteration default

```

```

setNanoRouteMode -quiet -routeTopRoutingLayer default
setNanoRouteMode -quiet -routeBottomRoutingLayer default
setNanoRouteMode -quiet -drouteEndIteration default
setNanoRouteMode -quiet -routeWithTimingDriven false
setNanoRouteMode -quiet -routeWithSiDriven false
routeDesign -globalDetail
setAnalysisMode -analysisType onChipVariation
setOptMode -fixCap true -fixTran true -fixFanoutLoad false
optDesign -postRoute
optDesign -postRoute -hold
saveDesign DLX_IR_SIZE32_PC_SIZE32_10_saved
reset_parasitics
extractRC
redirect -quiet {set honorDomain [getAnalysisMode -honorClockDomains]}
    > /dev/null
timeDesign -postRoute -pathReports -drvReports -slackReports -numPaths
    50 -prefix DLX_IR_SIZE32_PC_SIZE32_10_postroute -outDir
    timingReports
get_time_unit
report_timing -machine_readable -max_paths 10000 -max_slack 0.75
    -path_exceptions all > DLX_IR_SIZE32_PC_SIZE32_10.mtarpt
load_timing_debug_report -name default_report
    DLX_IR_SIZE32_PC_SIZE32_10.mtarpt

puts "Verification"
verifyConnectivity -type all -error 1000 -warning 50
setVerifyGeometryMode -area { 0 0 0 0 } -minWidth true -minSpacing
    true -minArea true -sameNet true -short true -overlap true
    -offRGrid false -offMGrid true -mergedMGridCheck true -minHole
    true -implantCheck true -minimumCut true -minStep true
    -viaEnclosure true -antenna false -insuffMetalOverlap true
    -pinInBlkg false -diffCellViol true -sameCellViol false
    -padFillerCellsOverlap true -routingBlkgPinOverlap true
    -routingCellBlkgOverlap true -regRoutingOnly false
    -stackedViasOnRegNet false -wireExt true -useNonDefaultSpacing
    false -maxWidth true -maxNonPrefLength -1 -error 1000
verifyGeometry
setVerifyGeometryMode -area { 0 0 0 0 }
get_verify_drc_mode -disable_rules -quiet
get_verify_drc_mode -quiet -area
get_verify_drc_mode -quiet -layer_range
get_verify_drc_mode -check_implant -quiet
get_verify_drc_mode -check_implant_across_rows -quiet
get_verify_drc_mode -check_ndr_spacing -quiet
get_verify_drc_mode -check_only -quiet
get_verify_drc_mode -check_same_via_cell -quiet
get_verify_drc_mode -exclude_pg_net -quiet
get_verify_drc_mode -ignore_trial_route -quiet
get_verify_drc_mode -max_wrong_way_halo -quiet

```



```

get_verify_drc_mode -use_min_spacing_on_block_obs -quiet
get_verify_drc_mode -limit -quiet
set_verify_drc_mode -disable_rules {} -check_implant true
    -check_implant_across_rows false -check_ndr_spacing false
    -check_same_via_cell false -exclude_pg_net false
    -ignore_trial_route false -report
    DLX_IR_SIZE32_PC_SIZE32_10.drc.rpt -limit 1000
verify_drc

setDrawView fplan
fit
dumpToGIF ./images_10/DLX_IR_SIZE32_PC_SIZE32_10_fplan
setDrawView ameba
fit
dumpToGIF ./images_10/DLX_IR_SIZE32_PC_SIZE32_10_ameba
setDrawView place
fit
dumpToGIF ./images_10/DLX_IR_SIZE32_PC_SIZE32_10_place
dumpPictures -dir ./images_nopt/ -prefix [dbGet top.name] -fullScreen
saveFPlan ./DLX_IR_SIZE32_PC_SIZE32_10_floorplan

dumpPictures -dir ./images_10/ -prefix [dbGet top.name] -fullScreen
reportGateCount -level 5 -limit 100 -outfile
    DLX_IR_SIZE32_PC_SIZE32_10.gateCount
saveFPlan ./DLX_IR_SIZE32_PC_SIZE32_10_floorplan
saveNetlist DLX_IR_SIZE32_PC_SIZE32_10.v
all_hold_analysis_views
all_setup_analysis_views
write_sdf -ideal_clock_network DLX_IR_SIZE32_PC_SIZE32_10.sdf

puts "Starting with optimized design with a lower slack and area"

set defHierChar /
set delaycal_input_transition_delay 0.1ps
set fpIsMaxIoHeight 0
set init_gnd_net {gnd}
set init_mmmc_file Default_10.view
set init_oa_search_lib {}
set init_pwr_net {vdd}
set init_verilog "$env(path_to_file_synthesis)output_netlist/
    dlx_irsizesize32_pcsize32_topt_1_minarea.v"
set init_lef_file /software/dk/nangate45/lef/
    NangateOpenCellLibrary.lef

```

```

set lsgOCPGainMult 1.000000
set LEF_DIR /software/dk/nangate45/lef
set LEF_list [list ${LEF_DIR}/NangateOpenCellLibrary.lef]
set init_lef_file "${LEF_list}"
set LIB_DIR /software/dk/nangate45/liberty
set MyTimingLibNom ${LIB_DIR}/
    NangateOpenCellLibrary_typical_ecsm_nowlm.lib
set MyTimingLibSlow ${LIB_DIR}/NangateOpenCellLibrary_slow_ecsm.lib
set MyTimingLibFast ${LIB_DIR}/NangateOpenCellLibrary_fast_ecsm.lib

set MycapTable $LEF_DIR/captables/NCSU_FreePDK_45nm.capTbl

puts "Floorplanning␣Innovus"

init_design
getIoFlowFlag
setIoFlowFlag 0
floorPlan -site FreePDK45_38x28_10R_NP_162NW_340 -r 1 0.6 5 5 5 5
getIoFlowFlag
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0

puts "Power␣planning␣and␣routing␣Innovus"

setAddRingMode -ring_target default -extend_over_row 0 -ignore_rows 0
    -avoid_short 0 -skip_crossing_trunks none -stacked_via_top_layer
    metal10 -stacked_via_bottom_layer metal1
    -via_using_exact_crossover_size 1 -orthogonal_only true
    -skip_via_on_pin { standardcell } -skip_via_on_wire_shape {
    noshape }
#addRing -nets {} -type core_rings -follow core -layer {top metal1
    bottom metal1 left metal2 right metal2} -width {top 1.8 bottom 1.8
    left 1.8 right 1.8} -spacing {top 1.8 bottom 1.8 left 1.8 right 1

```

```

    .8} -offset {top 1.8 bottom 1.8 left 1.8 right 1.8} -center 0
    -extend_corner {} -threshold 0 -jog_distance 0
    -snap_wire_center_to_grid None
setAddRingMode -ring_target default -extend_over_row 0 -ignore_rows 0
    -avoid_short 0 -skip_crossing_trunks none -stacked_via_top_layer
    metal10 -stacked_via_bottom_layer metal1
    -via_using_exact_crossover_size 1 -orthogonal_only true
    -skip_via_on_pin { standardcell } -skip_via_on_wire_shape {
    noshape }
addRing -nets {gnd vdd} -type core_rings -follow core -layer {top
    metal9 bottom metal9 left metal10 right metal10} -width {top 0.8
    bottom 0.8 left 0.8 right 0.8} -spacing {top 0.8 bottom 0.8 left 0
    .8 right 0.8} -offset {top 1.8 bottom 1.8 left 1.8 right 1.8}
    -center 1 -extend_corner {} -threshold 0 -jog_distance 0
    -snap_wire_center_to_grid None
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
set sprCreateIeRingOffset 1.0
set sprCreateIeRingThreshold 1.0
set sprCreateIeRingJogDistance 1.0
set sprCreateIeRingLayers {}
set sprCreateIeStripeWidth 10.0
set sprCreateIeStripeThreshold 1.0
setAddStripeMode -ignore_block_check false -break_at none
    -route_over_rows_only false -rows_without_stripes_only false
    -extend_to_closest_target none -stop_at_last_wire_for_area false
    -partial_set_thru_domain false -ignore_nondefault_domains false
    -trim_antenna_back_to_shape none -spacing_type edge_to_edge
    -spacing_from_block 0 -stripe_min_length 0 -stacked_via_top_layer
    metal10 -stacked_via_bottom_layer metal1
    -via_using_exact_crossover_size false -split_vias false
    -orthogonal_only true -allow_jog { padcore_ring block_ring }
addStripe -nets {vdd gnd} -layer metal10 -direction vertical -width 0
    .8 -spacing 0.8 -set_to_set_distance 20 -start_from left
    -start_offset 15 -switch_layer_over_obs false
    -max_same_layer_jog_length 2 -padcore_ring_top_layer_limit metal10
    -padcore_ring_bottom_layer_limit metal1
    -block_ring_top_layer_limit metal10 -block_ring_bottom_layer_limit
    metal1 -use_wire_group 0 -snap_wire_center_to_grid None

```

```

-skip_via_on_pin { standardcell } -skip_via_on_wire_shape {
noshape }

setSroutemode -viaConnectToShape { noshape }
sroute -connect { blockPin padPin padRing corePin floatingStripe }
-layerChangeRange { metal1(1) metal10(10) } -blockPinTarget {
nearestTarget } -padPinPortConnect { allPort oneGeom }
-padPinTarget { nearestTarget } -corePinTarget { firstAfterRowEnd
} -floatingStripeTarget { blockring padring ring stripe ringpin
blockpin followpin } -allowJogging 1 -crossoverViaLayerRange {
metal1(1) metal10(10) } -nets { gnd vdd } -allowLayerChange 1
-blockPin useLef -targetViaLayerRange { metal1(1) metal10(10) }

puts "PinAssignment"

getPinAssignMode -pinEditInBatch -quiet
setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
CLK
setPinAssignMode -pinEditInBatch false
setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
RST
setPinAssignMode -pinEditInBatch false

# iram
setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
IRAM_ENABLE
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
IRAM_READY
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -spreadDirection clockwise -side Top -layer 1
-spreadType side -pin {{IRAM_ADDRESS[0]} {IRAM_ADDRESS[1]} {
IRAM_ADDRESS[2]} {IRAM_ADDRESS[3]} {IRAM_ADDRESS[4]} {IRAM_ADDRESS
[5]} {IRAM_ADDRESS[6]} {IRAM_ADDRESS[7]} {IRAM_ADDRESS[8]} {
IRAM_ADDRESS[9]} {IRAM_ADDRESS[10]} {IRAM_ADDRESS[11]} {
IRAM_ADDRESS[12]} {IRAM_ADDRESS[13]} {IRAM_ADDRESS[14]} {

```

```

    IRAM_ADDRESS[15]} {IRAM_ADDRESS[16]} {IRAM_ADDRESS[17]} {
    IRAM_ADDRESS[18]} {IRAM_ADDRESS[19]} {IRAM_ADDRESS[20]} {
    IRAM_ADDRESS[21]} {IRAM_ADDRESS[22]} {IRAM_ADDRESS[23]} {
    IRAM_ADDRESS[24]} {IRAM_ADDRESS[25]} {IRAM_ADDRESS[26]} {
    IRAM_ADDRESS[27]} {IRAM_ADDRESS[28]} {IRAM_ADDRESS[29]} {
    IRAM_ADDRESS[30]} {IRAM_ADDRESS[31]}}
setPinAssignMode -pinEditInBatch true

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -spreadDirection clockwise -side Top -layer 2
    -spreadType side -pin {{IRAM_DATA[0]} {IRAM_DATA[1]} {IRAM_DATA
    [2]} {IRAM_DATA[3]} {IRAM_DATA[4]} {IRAM_DATA[5]} {IRAM_DATA[6]} {
    IRAM_DATA[7]} {IRAM_DATA[8]} {IRAM_DATA[9]} {IRAM_DATA[10]} {
    IRAM_DATA[11]} {IRAM_DATA[12]} {IRAM_DATA[13]} {IRAM_DATA[14]} {
    IRAM_DATA[15]} {IRAM_DATA[16]} {IRAM_DATA[17]} {IRAM_DATA[18]} {
    IRAM_DATA[19]} {IRAM_DATA[20]} {IRAM_DATA[21]} {IRAM_DATA[22]} {
    IRAM_DATA[23]} {IRAM_DATA[24]} {IRAM_DATA[25]} {IRAM_DATA[26]} {
    IRAM_DATA[27]} {IRAM_DATA[28]} {IRAM_DATA[29]} {IRAM_DATA[30]} {
    IRAM_DATA[31]}}
setPinAssignMode -pinEditInBatch true

# dram
setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    DRAM_ENABLE
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    DRAM_READNOTWRITE
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -unit MICRON -spreadDirection clockwise -side
    Left -layer 1 -spreadType start -spacing 0.14 -start 0.0 0.0 -pin
    DRAM_READY
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -spreadDirection clockwise -side Right -layer 1
    -spreadType side -pin {{DRAM_ADDRESS[0]} {DRAM_ADDRESS[1]} {
    DRAM_ADDRESS[2]} {DRAM_ADDRESS[3]} {DRAM_ADDRESS[4]} {DRAM_ADDRESS
    [5]} {DRAM_ADDRESS[6]} {DRAM_ADDRESS[7]} {DRAM_ADDRESS[8]} {
    DRAM_ADDRESS[9]} {DRAM_ADDRESS[10]} {DRAM_ADDRESS[11]} {
    DRAM_ADDRESS[12]} {DRAM_ADDRESS[13]} {DRAM_ADDRESS[14]} {
    DRAM_ADDRESS[15]} {DRAM_ADDRESS[16]} {DRAM_ADDRESS[17]} {

```

```

    DRAM_ADDRESS[18]} {DRAM_ADDRESS[19]} {DRAM_ADDRESS[20]} {
    DRAM_ADDRESS[21]} {DRAM_ADDRESS[22]} {DRAM_ADDRESS[23]} {
    DRAM_ADDRESS[24]} {DRAM_ADDRESS[25]} {DRAM_ADDRESS[26]} {
    DRAM_ADDRESS[27]} {DRAM_ADDRESS[28]} {DRAM_ADDRESS[29]} {
    DRAM_ADDRESS[30]} {DRAM_ADDRESS[31]}}
setPinAssignMode -pinEditInBatch false

setPinAssignMode -pinEditInBatch true
editPin -fixOverlap 1 -spreadDirection clockwise -side Right -layer 2
    -spreadType side -pin {{DRAM_DATA[0]} {DRAM_DATA[1]} {DRAM_DATA
    [2]} {DRAM_DATA[3]} {DRAM_DATA[4]} {DRAM_DATA[5]} {DRAM_DATA[6]} {
    DRAM_DATA[7]} {DRAM_DATA[8]} {DRAM_DATA[9]} {DRAM_DATA[10]} {
    DRAM_DATA[11]} {DRAM_DATA[12]} {DRAM_DATA[13]} {DRAM_DATA[14]} {
    DRAM_DATA[15]} {DRAM_DATA[16]} {DRAM_DATA[17]} {DRAM_DATA[18]} {
    DRAM_DATA[19]} {DRAM_DATA[20]} {DRAM_DATA[21]} {DRAM_DATA[22]} {
    DRAM_DATA[23]} {DRAM_DATA[24]} {DRAM_DATA[25]} {DRAM_DATA[26]} {
    DRAM_DATA[27]} {DRAM_DATA[28]} {DRAM_DATA[29]} {DRAM_DATA[30]} {
    DRAM_DATA[31]}}
setPinAssignMode -pinEditInBatch false

## for gui run
setDrawView fplan
fit
dumpToGIF ./images_1_minarea/
    DLX_IR_SIZE32_PC_SIZE32_1_minarea_fplan_postpin
setDrawView ameba
fit
dumpToGIF ./images_1_minarea/
    DLX_IR_SIZE32_PC_SIZE32_1_minarea_ameba_postpin
setDrawView place
fit
dumpToGIF ./images_1_minarea/
    DLX_IR_SIZE32_PC_SIZE32_1_minarea_place_postpin

puts "Cell_placing_Innovus"
placeDesign
setOptMode -fixCap true -fixTran true -fixFanoutLoad false
optDesign -postCTS
optDesign -postCTS -hold
getFillerMode -quiet
addFiller -cell FILLCELL_X8 FILLCELL_X32 FILLCELL_X4 FILLCELL_X2
    FILLCELL_X16 FILLCELL_X1 -prefix FILLER
## for gui run
setDrawView fplan
fit
dumpToGIF ./images_1_minarea/
    DLX_IR_SIZE32_PC_SIZE32_1_minarea_fplan_prerouting
setDrawView ameba
fit

```

```

dumpToGIF ./images_1_minarea/
    DLX_IR_SIZE32_PC_SIZE32_1_minarea_ameba_prerouting
setDrawView place
fit
dumpToGIF ./images_1_minarea/
    DLX_IR_SIZE32_PC_SIZE32_1_minarea_place_prerouting

puts "Signal_routing_innovus"
setNanoRouteMode -quiet -timingEngine {}
setNanoRouteMode -quiet -routeWithSiPostRouteFix 0
setNanoRouteMode -quiet -drouteStartIteration default
setNanoRouteMode -quiet -routeTopRoutingLayer default
setNanoRouteMode -quiet -routeBottomRoutingLayer default
setNanoRouteMode -quiet -drouteEndIteration default
setNanoRouteMode -quiet -routeWithTimingDriven false
setNanoRouteMode -quiet -routeWithSiDriven false
routeDesign -globalDetail
setAnalysisMode -analysisType onChipVariation
setOptMode -fixCap true -fixTran true -fixFanoutLoad false
optDesign -postRoute
optDesign -postRoute -hold
saveDesign DLX_IR_SIZE32_PC_SIZE32_1_minarea_saved
reset_parasitics
extractRC
redirect -quiet {set honorDomain [getAnalysisMode -honorClockDomains]}
    > /dev/null
timeDesign -postRoute -pathReports -drvReports -slackReports -numPaths
    50 -prefix DLX_IR_SIZE32_PC_SIZE32_1_minarea_postroute -outDir
    timingReports
get_time_unit
report_timing -machine_readable -max_paths 10000 -max_slack 0.75
    -path_exceptions all > DLX_IR_SIZE32_PC_SIZE32_1_minarea.mtarpt
load_timing_debug_report -name default_report
    DLX_IR_SIZE32_PC_SIZE32_1_minarea.mtarpt

puts "Verification"
verifyConnectivity -type all -error 1000 -warning 50
setVerifyGeometryMode -area { 0 0 0 0 } -minWidth true -minSpacing
    true -minArea true -sameNet true -short true -overlap true
    -offRGrid false -offMGrid true -mergedMGridCheck true -minHole
    true -implantCheck true -minimumCut true -minStep true
    -viaEnclosure true -antenna false -insuffMetalOverlap true
    -pinInBlkg false -diffCellViol true -sameCellViol false
    -padFillerCellsOverlap true -routingBlkgPinOverlap true
    -routingCellBlkgOverlap true -regRoutingOnly false
    -stackedViasOnRegNet false -wireExt true -useNonDefaultSpacing
    false -maxWidth true -maxNonPrefLength -1 -error 1000
verifyGeometry
setVerifyGeometryMode -area { 0 0 0 0 }

```

```
get_verify_drc_mode -disable_rules -quiet
get_verify_drc_mode -quiet -area
get_verify_drc_mode -quiet -layer_range
get_verify_drc_mode -check_implant -quiet
get_verify_drc_mode -check_implant_across_rows -quiet
get_verify_drc_mode -check_ndr_spacing -quiet
get_verify_drc_mode -check_only -quiet
get_verify_drc_mode -check_same_via_cell -quiet
get_verify_drc_mode -exclude_pg_net -quiet
get_verify_drc_mode -ignore_trial_route -quiet
get_verify_drc_mode -max_wrong_way_halo -quiet
get_verify_drc_mode -use_min_spacing_on_block_obs -quiet
get_verify_drc_mode -limit -quiet
set_verify_drc_mode -disable_rules {} -check_implant true
    -check_implant_across_rows false -check_ndr_spacing false
    -check_same_via_cell false -exclude_pg_net false
    -ignore_trial_route false -report
    DLX_IR_SIZE32_PC_SIZE32_1_minarea.drc.rpt -limit 1000
verify_drc
fit
setDrawView fplan
dumpToGIF ./images_1_minarea/DLX_IR_SIZE32_PC_SIZE32_1_minarea_fplan
setDrawView ameba
fit
dumpToGIF ./images_1_minarea/DLX_IR_SIZE32_PC_SIZE32_1_minarea_ameba
setDrawView place
fit
dumpToGIF ./images_1_minarea/DLX_IR_SIZE32_PC_SIZE32_1_minarea_place
dumpPictures -dir ./images_nopt/ -prefix [dbGet top.name] -fullScreen
saveFPlan ./DLX_IR_SIZE32_PC_SIZE32_1_minarea_floorplan
dumpPictures -dir ./images_1_minarea/ -prefix [dbGet top.name]
    -fullScreen
reportGateCount -level 5 -limit 100 -outfile
    DLX_IR_SIZE32_PC_SIZE32_1_minarea.gateCount
saveFPlan ./DLX_IR_SIZE32_PC_SIZE32_1_minarea_floorplan
saveNetlist DLX_IR_SIZE32_PC_SIZE32_1_minarea.v
all_hold_analysis_views
all_setup_analysis_views
write_sdf -ideal_clock_network DLX_IR_SIZE32_PC_SIZE32_1_minarea.sdf
exit
```

APPENDIX M

Regression Test script

```
#!/usr/bin/bash
echo "#####"
echo "##_---->_Boot_regression_test_<----_##"
echo "#####"
path_to_file="./hardware/dlx/"

echo "Starting_initialization_of_simulation_environment"
## using questasim
source /software/scripts/init_questa10.7c
cd .. # go in parent folder
if [ -d "./work" ] ;then
    rm -rf work
fi
## add fsm debug
echo "Starting_regression_functional_tests"
vlib ./work # it also creates the folder
echo "Simulation_ready_to_go!"
echo "Start_hierarchical_compilation"
vcom -2008 -check_synthesis -autoorder ${path_to_file}
    global_components.package/constants.vhd
vcom -2008 -check_synthesis -autoorder ${path_to_file}
    global_components.package/alu_type.vhd
vcom -2008 -check_synthesis -autoorder ${path_to_file}000-globals.vhd
vcom -2008 -check_synthesis -autoorder ${path_to_file}001-
    global_components.vhd
# vlog for verilog -incr(mental) compilation
# vcom for vhdl-2008 and drc for synthesis (basic)

echo "Compiling_labs_units" ## compile the entire folder
vcom -2008 -check_synthesis -autoorder ${path_to_file}
    global_components.package/*.vhd

vcom -2008 ${path_to_file}test_bench/testbench_subunits_labs/
    tb_sum_gen.vhd
```

```

vcom -2008 ${path_to_file}test_bench/testbench_subunits_labs/
MULTIPLIER_tb.vhd
vcom -2008 ${path_to_file}test_bench/testbench_subunits_labs/tb_alu.
vhd
vcom -2008 ${path_to_file}test_bench/testbench_subunits_labs/tb_csb.
vhd
vcom -2008 ${path_to_file}test_bench/testbench_subunits_labs/tb_fd.
vhd
vcom -2008 ${path_to_file}test_bench/testbench_subunits_labs/
tb_mux21_generic.vhd
vcom -2008 ${path_to_file}test_bench/testbench_subunits_labs/
tb_p4adder.vhd
vcom -2008 ${path_to_file}test_bench/testbench_subunits_labs/tb_rca.
vhd
vcom -2008 ${path_to_file}test_bench/testbench_subunits_labs/
tb_registerfile.vhd
vcom -2008 ${path_to_file}test_bench/testbench_subunits_labs/
tb_registerfile_wrf.vhd
vcom -2008 ${path_to_file}test_bench/testbench_subunits_labs/tb_regN.
vhd
vcom -2008 ${path_to_file}test_bench/testbench_subunits_labs/tb_stcg.
vhd

```

```

echo "Compiling memories"

```

```

vlog -incr ${path_to_file}test_bench/003-global_defs.svh
vlog -incr ${path_to_file}test_bench/004-implemented_instructions.svh
vlog -incr ${path_to_file}test_bench/006-property_def.svh
vlog -incr ${path_to_file}test_bench/memories/tb_memories.sv
vlog -incr ${path_to_file}test_bench/memories/005-memory_interfaces.
svh
vlog -incr ${path_to_file}test_bench/memories/romem.sv
vlog -incr ${path_to_file}test_bench/memories/rwmem.sv

```

```

echo "Compiling stages, control unit and datapath"

```

```

vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.e-
Write_back.stage.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.a-
Fetch.stage.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.b-
Decode.stage.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
Execute.stage.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.d.
Memory.stage.vhd

```

```

vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.b-
    Decode.stage/a.b.b.a-sign_extension.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage/a.b.c.a-check_branch_logic.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage/a.b.c.b-general_alu.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage/a.b.c.c-boothmul_pipelined.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage/a.b.c.c-boothmul_pipelined.core/a.b.c.a-mux.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage/a.b.c.c-boothmul_pipelined.core/a.b.c.b-adder.vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage/a.b.c.c-boothmul_pipelined.core/a.b.c.c-complement2.
    vhd
vcom -2008 -check_synthesis ${path_to_file}a.b-DataPath.core/a.b.c-
    Execute.stage/a.b.c.c-boothmul_pipelined.core/a.b.c.d-encoder.vhd
vcom -2008 -check_synthesis ${path_to_file}a.a-control_unit.vhd
vcom -2008 -check_synthesis ${path_to_file}a-DLX.vhd

echo "Compiling testbenches subunits"
vlog -incr ${path_to_file}test_bench/testbench_subunits/
    tb_writeback_stage.sv
vlog -incr ${path_to_file}test_bench/testbench_subunits/tb_cu.sv
vlog -incr ${path_to_file}test_bench/testbench_subunits/
    tb_decode_stage.sv
vlog -incr ${path_to_file}test_bench/testbench_subunits/
    tb_execute_stage.sv
vlog -incr ${path_to_file}test_bench/testbench_subunits/tb_fetch_stage
    .sv
vlog -incr ${path_to_file}test_bench/testbench_subunits/
    tb_memory_stage.sv

echo "#####"
echo "####--> Starting regression test for every units <---####"
echo "#####"

if [ ! -z "$1" ] ; then
echo "Starting simulation for $1"
vsim -suppress 12110 -novopt work.tb_"$1" -do ./scripts/"$1"_tb.do

else
echo "Starting simulation of memory units"
vsim -suppress 12110 -novopt work.tb_memories -do ./scripts/
    memories_tb.do

```

```
echo "Starting simulation of fetch stage unit"
#suppress warning using the -novopt
vsim -suppress 12110 -novopt work.tb_fetch_stage -do ./scripts/
    fetch_stage_tb.do
echo "Starting simulation of decode stage unit"
vsim -suppress 12110 -novopt work.tb_decode_stage -do ./scripts/
    decode_stage_tb.do
echo "Starting simulation of execute stage unit"
vsim -suppress 12110 -novopt work.tb_execute_stage -do ./scripts/
    execute_stage_tb.do
echo "Starting simulation of memory stage unit"
vsim -suppress 12110 -novopt work.tb_memory_stage -do ./scripts/
    memory_stage_tb.do
echo "Starting simulation of writeback stage unit"
vsim -suppress 12110 -novopt work.tb_writeback_stage -do ./scripts/
    writeback_stage_tb.do
echo "Starting simulation of cu unit"
vsim -suppress 12110 -novopt work.tb_cu -do ./scripts/cu_tb.do
fi
echo "[PASS] -> Regression test passed, you can safely execute the
    simulation.sh script for testing the DLX top level entity"
rm -rf work
exit
```