Digital Logic & Design - Final Project Report

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CAR SMASH

1 Introduction

1.1 Aim:

To depict the function of Car game using Verilog HDL, BASYS 3 Board, and Xilinx Vivado.

1.2 About The Game:

This project aims to develop a fast-paced, real-time car racing game using an FPGA. Designed for two players, the game features cars at the bottom of a three-lane road. Players must navigate their cars left or right to avoid randomly generated obstacles falling from the top. At least one lane will always remain clear, ensuring challenging gameplay. Both players start with three lives, losing one upon collision with an obstacle. The player who survives the longest wins.

1.3 Layout of the game design:

- Design a 3-lane road displayed on the screen.
- Two cars, controlled by two players, are positioned at the bottom of the screen.
- Input from a keyboard (WASD keys for Player 1 and arrow keys for Player 2) allows players to move their cars to avoid obstacles.
- Obstacles are randomly generated in the three lanes every 3 seconds, with at least one lane always being clear.
- If a car collides with an obstacle, the player loses one life. Both players start with 3 lives.
- The game continues until one player has no lives remaining. At this point, the game transitions to the Game Over state, and the other player is declared the winner.
- A reset button allows us to return to main screen, from where the game can be restarted.
- The game loop includes car movement, obstacle generation, collision detection, and life tracking, ensuring continuous and challenging gameplay.

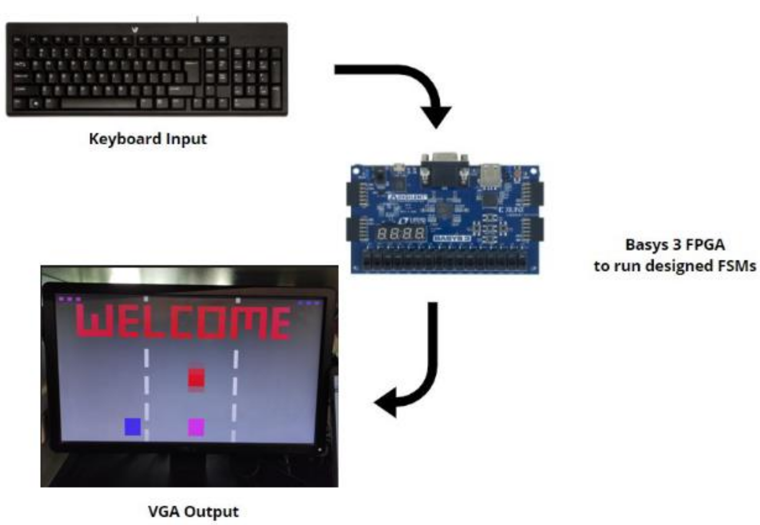


Figure 1: Game Layout

1.4 User Flow Diagram

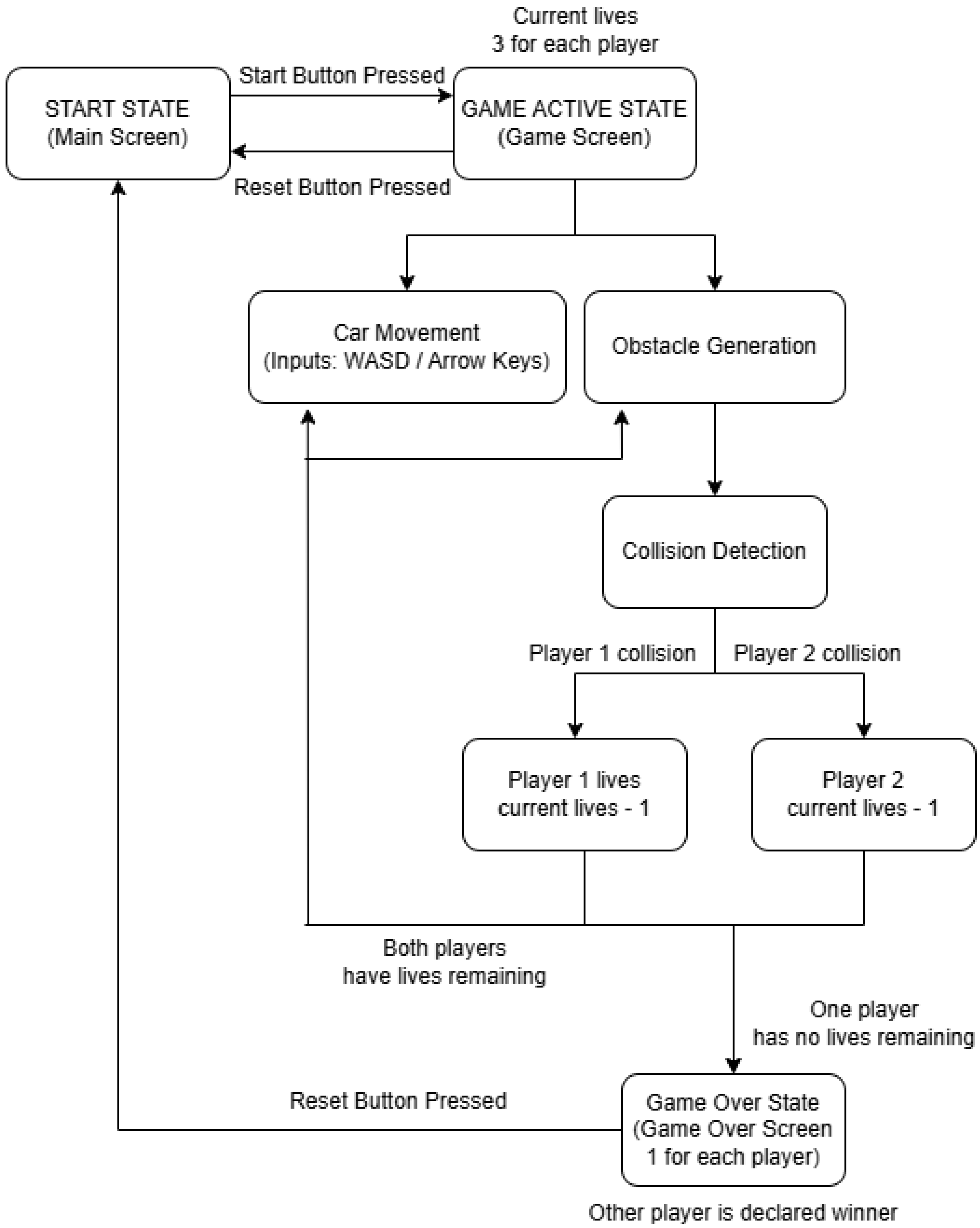


Figure 2: User Flow Diagram

The user flow diagram above provides an overview of the framework embedded within the game. After starting the game, the player will be able to view the following:

The user flow diagram above provides an overview of the framework embedded within the game. After starting the game, the player will be able to view the following:

- **Two cars** (blue and pink boxes) at the bottom of the screen, representing the players' positions. Each car moves based on the input keys.
- **Randomly generated obstacles** (red boxes) falling from the top of the screen in one of the three lanes.
- **Current lives** (displayed as 3 for each player initially).
- **Game screen** with continuous obstacle generation and car movement.

The player moves their car using the keyboard:

- Player 1 uses WASD.
- Player 2 uses arrow keys.

If a player's car collides with an obstacle, the corresponding player's lives decrease by 1. The game continues until one of the players loses all lives. At this point:

- The game transitions to the **Game Over State**, where the other player is declared the winner.

To restart the game, the reset button is pressed on the keyboard. This takes us back to the main screen, and reinitializes all variables, including the lives of both players. When the player presses the play button, the game restarts with 3 lives for each player.

2 Description of Modules

2.1 keyboard_input

Figure 3

- The `keyboard_input` module is designed to handle PS/2 keyboard inputs and translate them into actionable signals for gameplay. It processes the keyboard clock (`kclk`) and data (`kdata`) to detect key presses and releases. Key states are updated for two players, represented by `keys_1` and `keys_2`, which correspond to movement directions.

- Using a state machine implemented with a counter, the module captures keyboard data byte-by-byte, synchronizing to the keyboard's clock using debounced signals. Press and release events are identified and mapped to specific actions, such as directional movement for players or control signals like start and restart.

- This implementation uses internal flags and temporary registers to manage state changes efficiently and ensure accurate processing of key events. The use of D-FlipFlops ensures reliable storage of data and state transitions within the module.

2.2 obstacle_generator

- It uses a Linear Feedback Shift Register (LFSR) to create random horizontal positions (`obs_x`) for obstacles.
- The vertical position (`obs_y`) increments at a constant rate, simulating the downward movement of obstacles. When an obstacle reaches the bottom of the screen, the module resets the vertical position and generates a new random horizontal position.

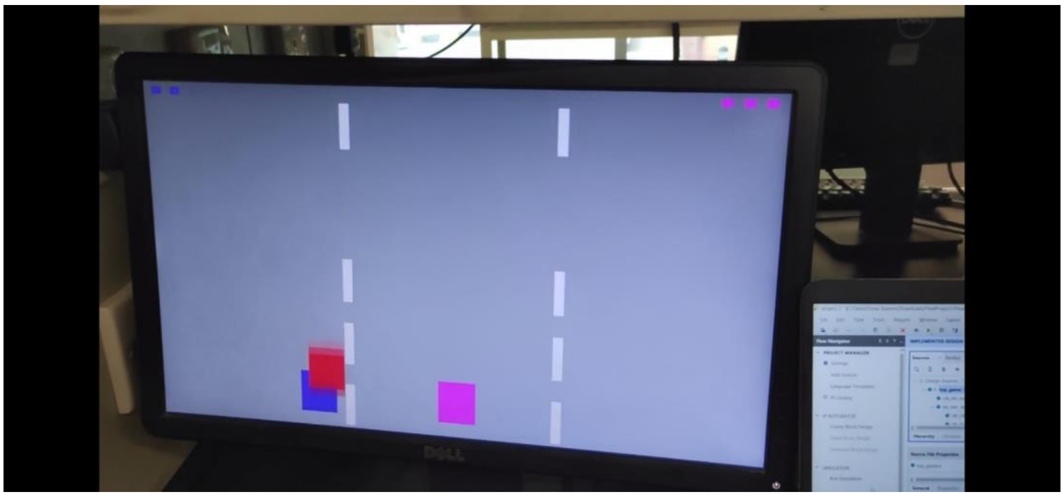
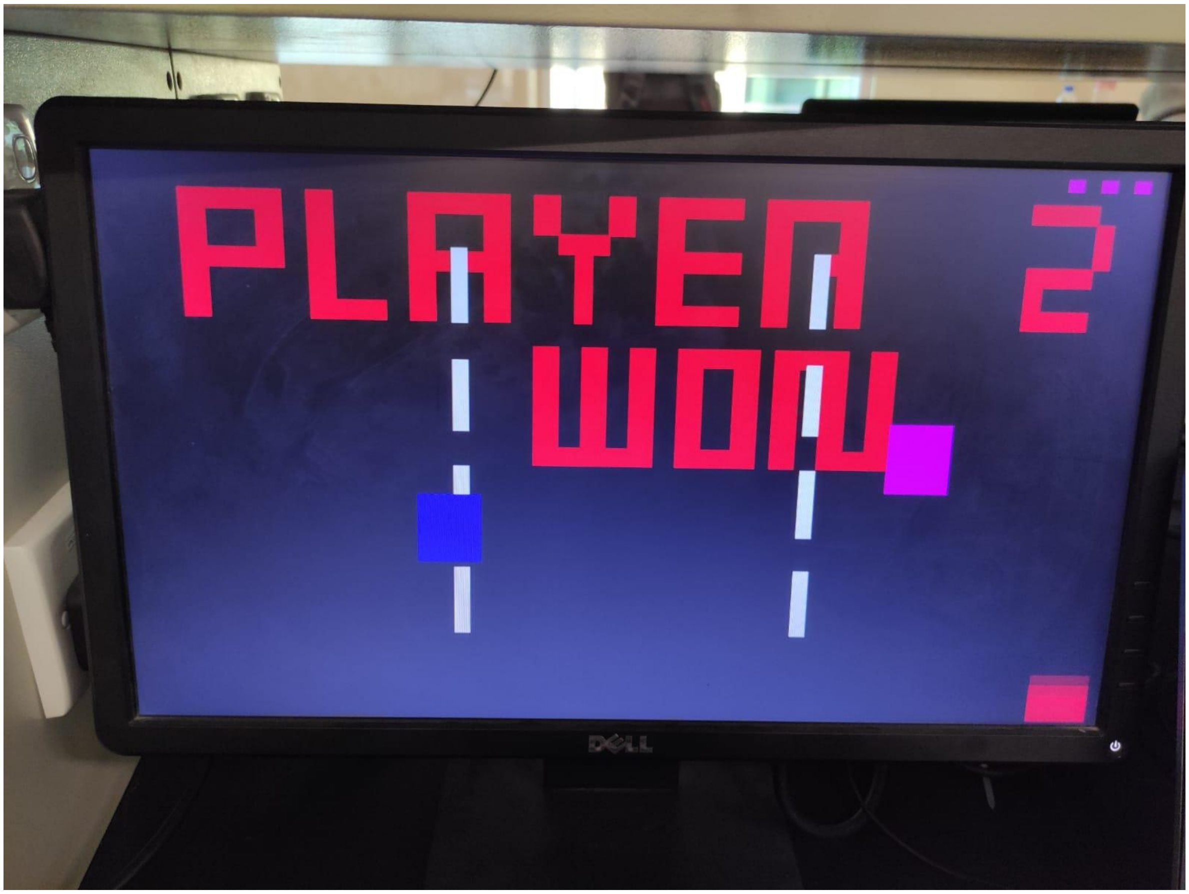


Figure 5

2.3 vga_controller

- The module generates horizontal (`vga_hsync`) and vertical (`vga_vsync`) synchronization signals for a standard 640x480 resolution at 60 Hz refresh rate.
- Uses parameters for horizontal and vertical timing, including the active display area, front porch, sync pulse, and back porch timings.
- Implements smooth scrolling for road effects using `road_offset` that updates every frame, managed by `road_clk`.
- Displays required screen ("WELCOME" or "PLAYER 1/2 WON") based on `game_state` input. Each letter is defined by a set of pixel conditions for its segments.
- Text is displayed in red against a black background (showing both inactive states).
- For each pixel the color is determined based on `h_count` and `v_count`, which give the current coordinates on the display.
- Resets internal counters (`h_count`, `v_count`, and `road_offset`) to initial states when the reset button is pressed and `rst` signal is activated and checked.

2.4 top_game



- The `top_game` module serves as the central controller for the car racing game on the Basys 3 FPGA board. It takes inputs such as the clock signal, reset, and keyboard signals (`ps2_clk` and `ps2_data`) and processes them using the `keyboard_input` module to generate key codes for player movement and game control. It coordinates the game logic, including player movements, obstacle generation, and collision detection.
- The game state transitions are managed using a Moore Finite State Machine, enabling dynamic gameplay with start and restart functionalities.

2.5 debouncer

- The `debouncer` module ensures that the input signal is stable and free from noise or glitches before it is processed.
- If the input signal fluctuates, the module waits until the signal remains consistent for a specified period, as defined by COUNT_MAX, before updating the output. This guarantees that only valid, stable signals are passed on to the next module.

2.6 clk_divider

- The `clk_divider` module is designed to generate and manage the clock signal by dividing the input clock frequency.
- It uses a counter to track clock cycles, toggling the output clock signal (`clk_out`) whenever the counter reaches a specified division value (`div_value`). This ensures that the output clock operates at a frequency determined by the division factor, providing a consistent and reliable slower clock signal for other modules.

2.7 Output Block

1. Overview

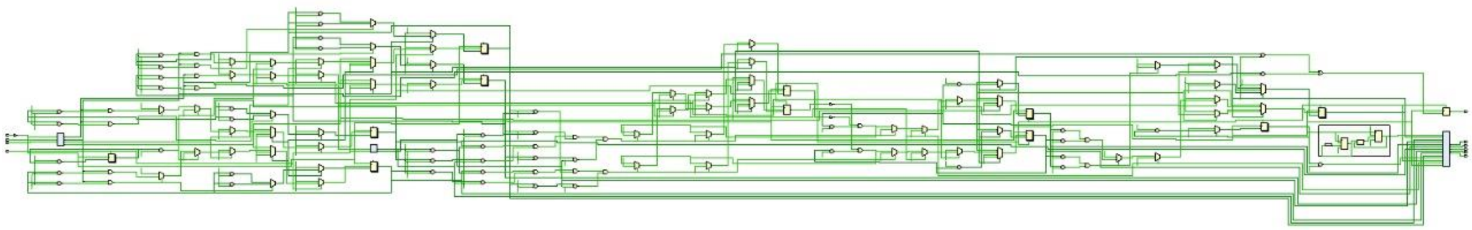


FIGURE 1: This picture shows the schematic for our top Game module. Next we will show a module view of the top game module

2. Modular View

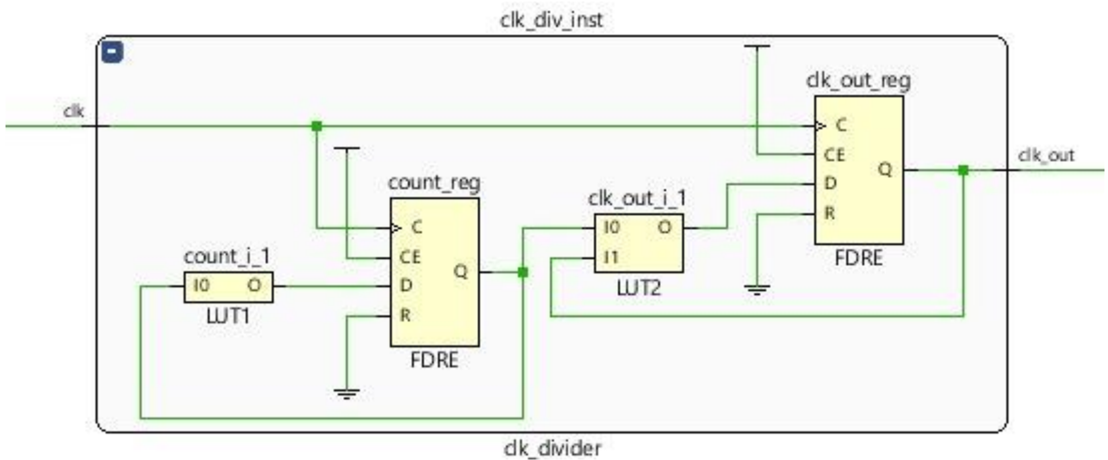


Figure 2 : Clock divider
A clock divider module that generates an output clock signal (clk_out) by dividing the input clock signal (clk) frequency by a parameterized value (div_value).

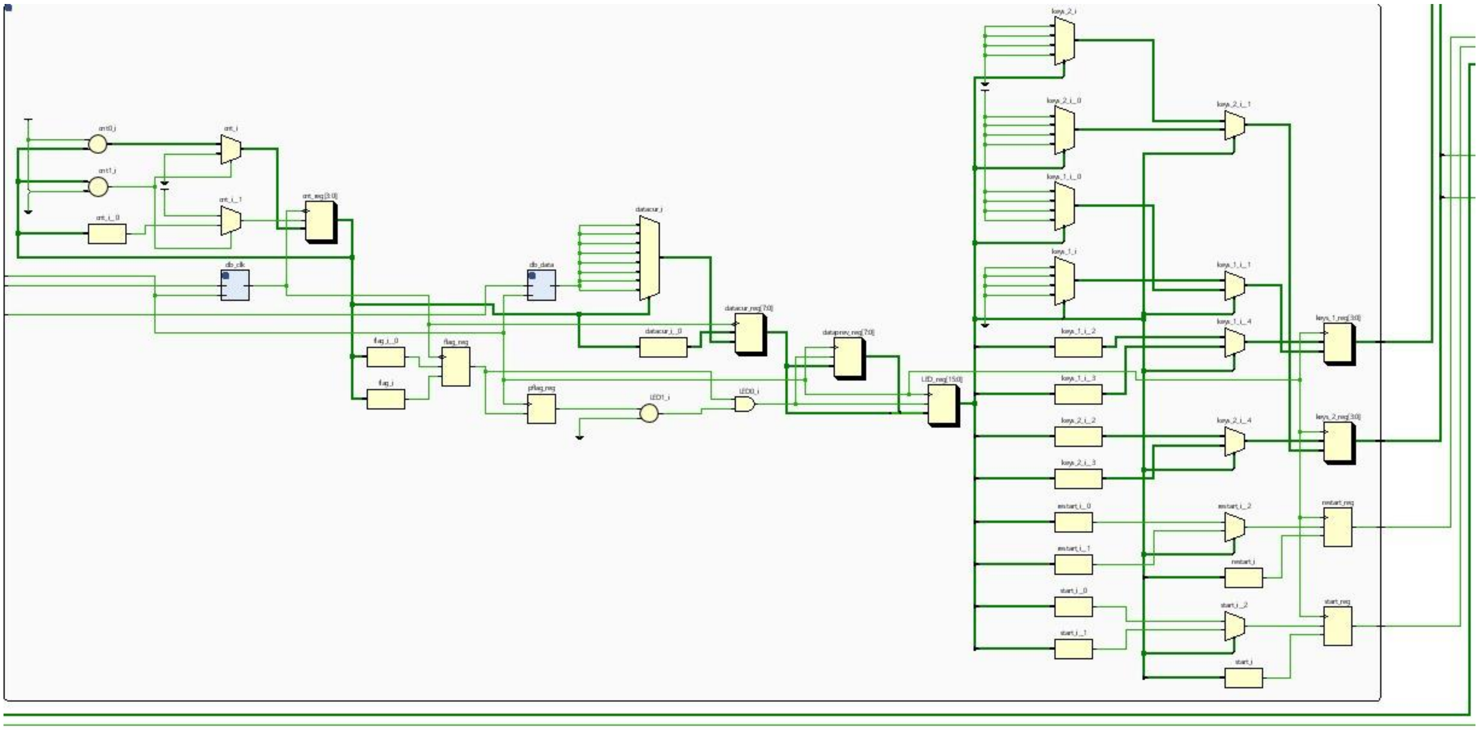


Figure 3:
A PS/2 keyboard input module that decodes key presses and releases for two players' directional controls (Player 1: Arrow keys, Player 2: W, S, A, D), as well as Start (Enter) and Restart (Space) signals.

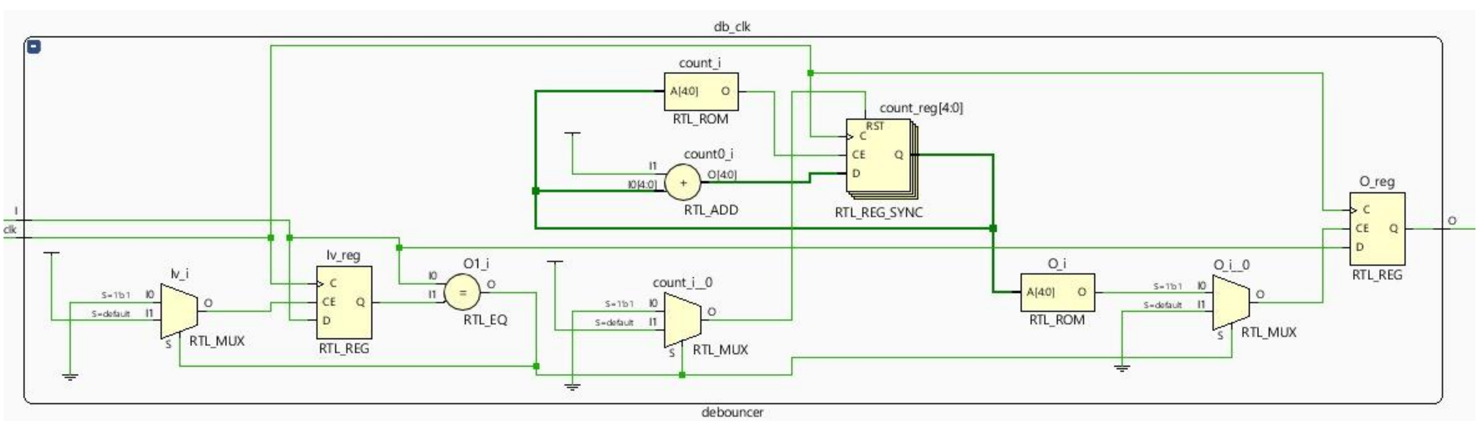


Figure 4: A debouncer module that stabilizes an input signal (I) by eliminating glitches using a counter-based delay, producing a clean output signal (O).

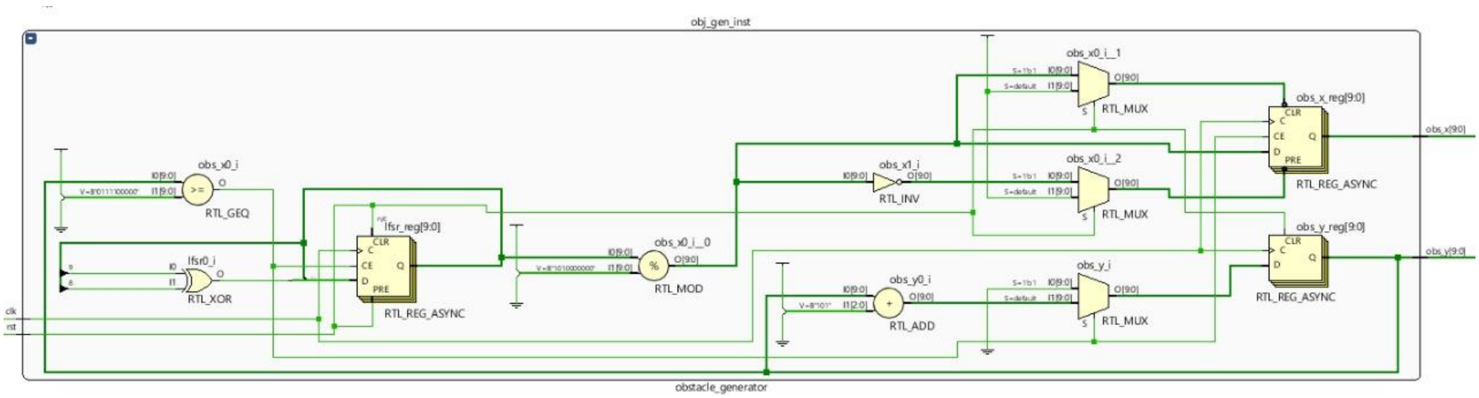


Figure 5: An obstacle generator module that uses an LFSR-based randomizer to generate horizontal positions (obs_x) and vertically moves obstacles (obs_y) down the screen, resetting upon reaching the bottom

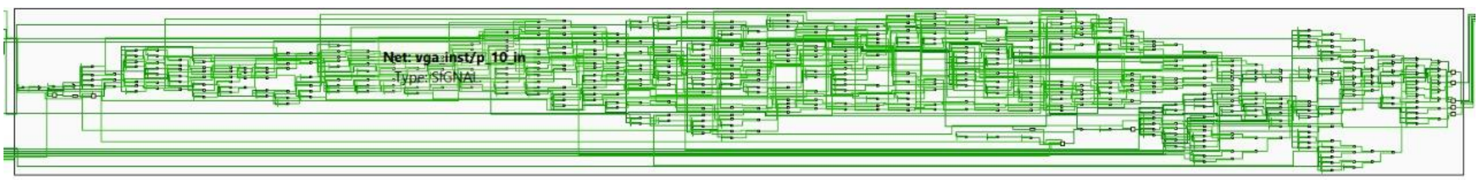


Figure 6: the vga_controller module is an extensive implementation of a VGA display logic system, including specific designs for game states with visual text representation ("WELCOME," "PLAYER 1," "PLAYER 2," etc.) on the screen.

2.8 Input-Output-Control Block

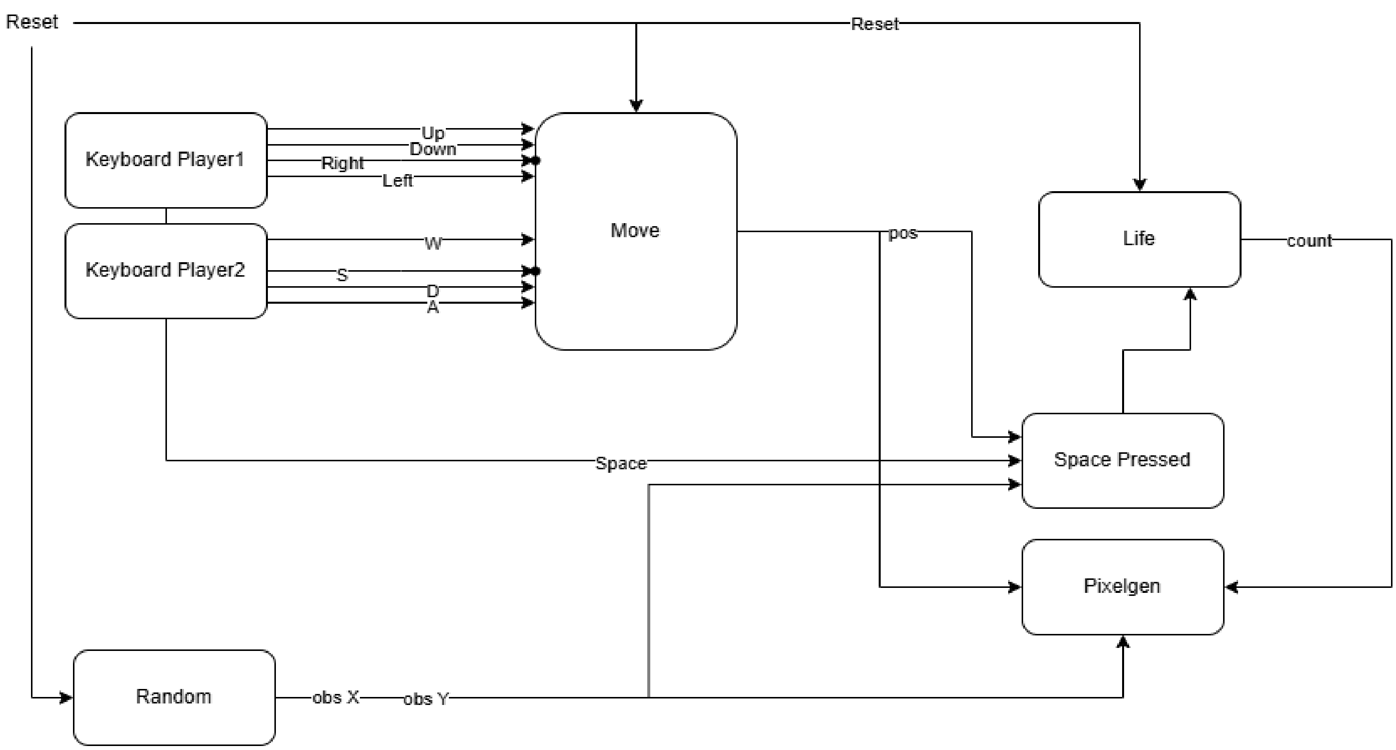


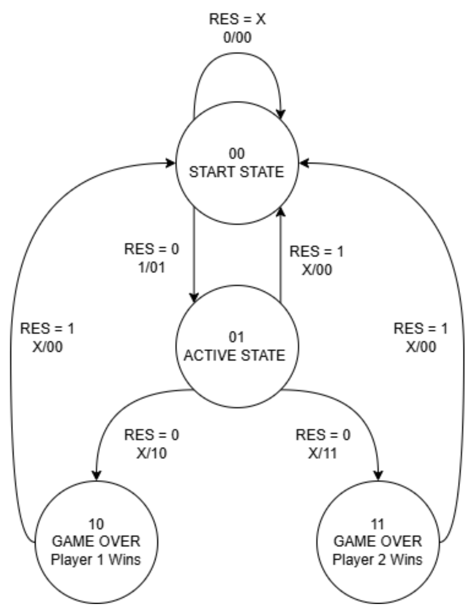
Figure 18

The Input-Output-Control block above shows how inputs transform to outputs in a racing game for two participants. Keyboard Player1 and Player2 to control movement through arrow keys and WASD displayed in Move module which shows the position of the players “pos”. The life Module counts lives (count) and alters them after a collision. For certain game events, the Space Pressed module is used for identifying space bar operations. The Pixelgen module generates visual outputs based on player positions and obstacle coordinates (obs X, obs Y) from the Random module. Combined, these modules help in the processing of game logic, visuals and interactions.

▪ FSM Design Procedure

1. top_game Module:

- **State Assignment and Diagram**



- **State Transition Table**

Present States		Input	RES	Next States	
A(t)	B(t)	X	Y	A(t+1)	B(t+1)
0	0	0	0	0	0
0	0	0	1	0	0
0	0	1	0	0	1
0	0	1	1	0	0
0	1	0	0	1	X
0	1	0	1	0	0
0	1	1	0	1	X
0	1	1	1	0	0
1	0	0	0	1	0
1	0	0	1	0	0
1	0	1	0	1	0
1	0	1	1	0	0
1	1	0	0	1	1
1	1	0	1	0	0
1	1	1	0	1	1
1	1	1	1	0	0

- **State Equations**

$$A(t+1) = RES' \cdot (A(t) \cdot B(t)' + X \cdot B(t))$$
$$B(t+1) = RES' \cdot (Y + A(t)' \cdot B(t) \cdot X)$$

(The vga_controller module relies on the game_state input, which is generated and controlled by the top_game module)

▪ Detailed Input Module Overview

- Input Device: Keyboard

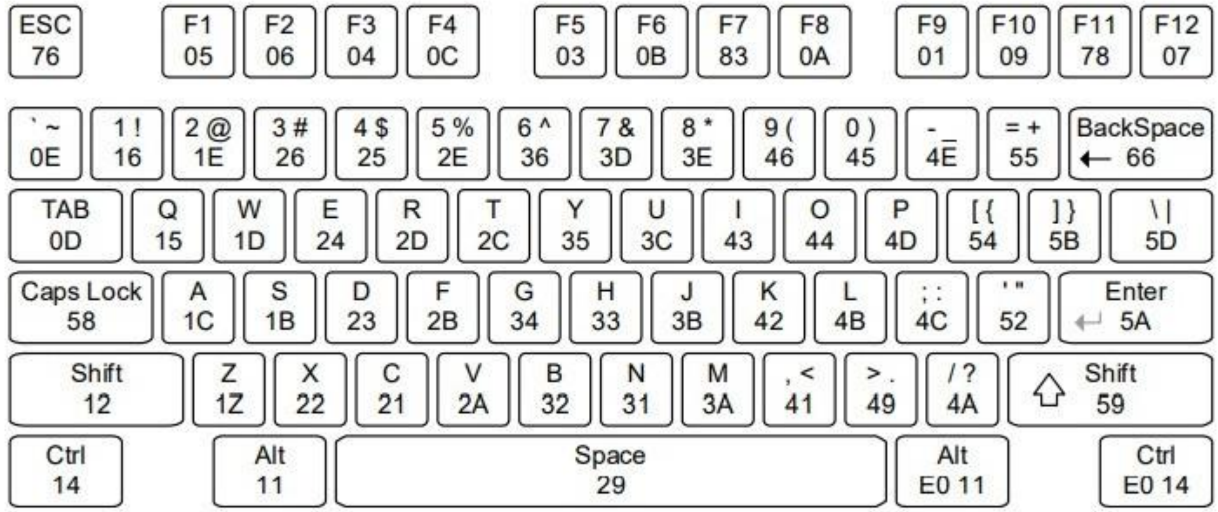


Figure 19

- Input Description:

PS2 Receiver module is used to shift-in keycodes from a keyboard plugged into the PS2 port 2 wires are used to transmit data, which are called PS2DATA and PS2CLOCK. When you press the button on the keyboard, the micro-controller inside the keyboard sends bits of information on DATA wire. Each bit is accompanied by a falling CLOCK edge signal, meaning that you must only read the data when CLOCK signal falls down and not the other time.

The first bit is START bit, then there are 8 bits for DATA0-7, then a PARITY bit and finally STOP bit Now looking broader, when a button is pressed, the keyboard sends one packet of 11 bits to tell which button was pressed. you only need to keep DATA0-7 bits and get rid of the rest. If the key is pressed and held then it starts repeatedly send the same packet. Finally if you release the button it sends another 2 packets, telling that the button was released and which button was released.

Whenever the user presses a key on a keyboard connected to the USB HID port (J2, labeled "USB"), a scan code is sent to the Basys3 through a PS/2 interface. This scan code is read and transmitted to the computer via the USB-UART bridge. When the key is released, a scan code of 0xF0XX is transmitted, indicating that the key with PS/2 code "XX" has been released.

▪ Known Issues & Drawbacks

- Lane Movement speed not aligned with speed of obstacles
- When we go back to main screen after resetting from active state, lives do not reset until game starts again

▪ References

https://digilent.com/reference/_media/basys3:basys3_rm.pdf

▪ GitHub Link

Source code available at: https://github.com/hamzaraza123/DLD-PROJECT---CAR-SMASH.git

- **Configurations**

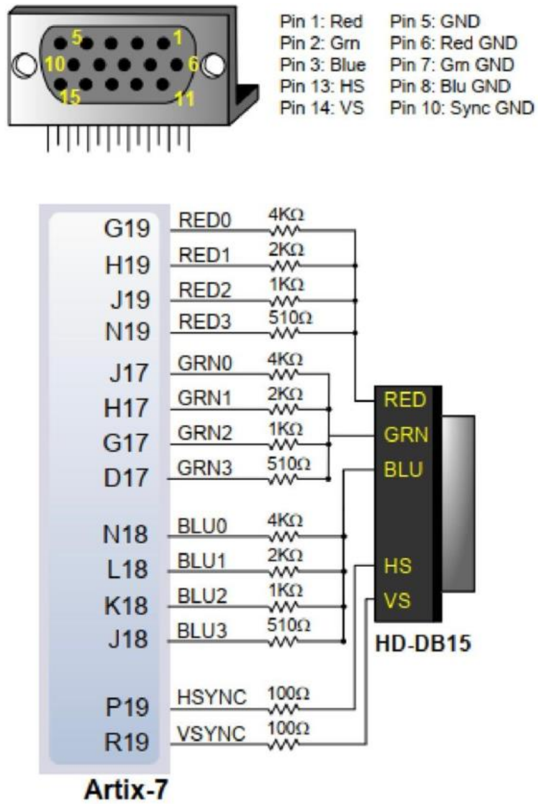


Figure 20

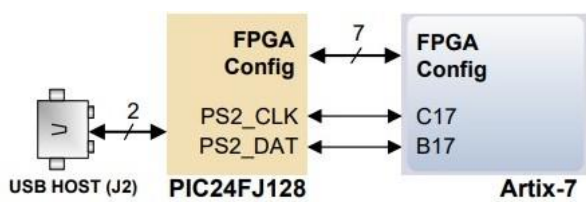


Figure 21

The connections between the FT2232HQ and the Artix-7 are shown in Fig. 6.

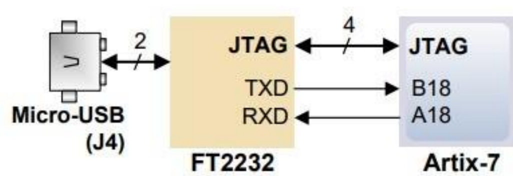


Figure 22

▪ Addendum (Main Module Codes for Reference):

1. top_game

```
module top_game (
  input clk,
  input rst,
  input ps2_clk,
  input ps2_data,
  output [3:0] vga_r, vga_g, vga_b,
  output vga_hsync, vga_vsync,
  output led
);

  localparam STEP_SIZE = 3;
  localparam SCREEN_WIDTH = 640;
  localparam SCREEN_HEIGHT = 480;

  wire clk25MHz;
  wire slow_clk;
  wire road_clk;
  wire [3:0] keys_1, keys_2;
  wire start, restart;
  reg [9:0] player1_x, player1_y;
  reg [9:0] player2_x, player2_y;
  wire [9:0] obstacle_x, obstacle_y;
  reg [1:0] game_state; // 0: Idle, 1: Playing, 2: Game
Over
  reg [1:0] player1_lives, player2_lives;

  // Collision flags to ensure lives decrement only once
per collision
  reg player1_collision_flag;
  reg player2_collision_flag;

  wire player1_collision = (player1_x < obstacle_x +
40) &&
                (player1_x + 40 > obstacle_x) &&
                (player1_y < obstacle_y + 60) &&
                (player1_y + 60 > obstacle_y);

  wire player2_collision = (player2_x < obstacle_x +
40) &&
                (player2_x + 40 > obstacle_x) &&
                (player2_y < obstacle_y + 60) &&
                (player2_y + 60 > obstacle_y);

  clk_divider clk_div_inst (.clk(clk),
.clk_out(clk25MHz));

  reg [20:0] slow_clk_counter;
  assign slow_clk = (slow_clk_counter == 0);
  always @(posedge clk or posedge rst) begin
    if (rst)
      slow_clk_counter <= 0;
    else if (slow_clk_counter == 3333333)
      slow_clk_counter <= 0;
```

```
    else
      slow_clk_counter <= slow_clk_counter + 1;
  end

  reg [20:0] road_clk_counter;
  parameter ROAD_CLK_DIV = 52_083;  // Adjust for
desired frequency
  assign road_clk = (road_clk_counter == 0);

  always @(posedge clk or posedge rst) begin
    if (rst)
      road_clk_counter <= 0;
    else if (road_clk_counter == ROAD_CLK_DIV)
      road_clk_counter <= 0;
    else
      road_clk_counter <= road_clk_counter + 1;
  end

  keyboard_input kb_inst (
    .clk(clk),
    .kclk(ps2_clk),
    .kdata(ps2_data),
    .keys_1(keys_1),
    .keys_2(keys_2),
    .start(start),
    .restart(restart)
  );

  reg led_reg;
  always @(posedge clk or posedge rst) begin
    if (rst)
      led_reg <= 0;
    else
      led_reg <= (keys_1 != 4'b0000 || keys_2 !=
4'b0000);
  end
  assign led = led_reg;

  always @(posedge clk or posedge rst) begin
    if (rst) begin
      game_state <= 0;
      player1_lives <= 2'd3;
      player2_lives <= 2'd3;
      player1_collision_flag <= 0;
      player2_collision_flag <= 0;
    end else begin
      case (game_state)
        0: if (start) begin
          game_state <= 1;
          player1_lives <= 2'd3;
          player2_lives <= 2'd3;
          player1_x <= 160;
          player1_y <= 400;
          player2_x <= 320;
          player2_y <= 400;
          player1_collision_flag <= 0;
```

```
          player2_collision_flag <= 0;
        end
        1: begin
          if (restart)
            game_state <= 0;
          else if (slow_clk) begin
            // Player 1 movement
            // Player 1 movement
            if (keys_1[0] && player1_y > 60)
// Prevent moving above top
              player1_y <= player1_y - STEP_SIZE;
            if (keys_1[1] && player1_y <
SCREEN_HEIGHT - 60)    // Prevent moving below
bottom
              player1_y <= player1_y + STEP_SIZE;
            if (keys_1[2] && player1_x > 1)
// Prevent moving left of left edge
              player1_x <= player1_x - STEP_SIZE;
            if (keys_1[3] && player1_x <
SCREEN_WIDTH - 40)     // Prevent moving past right
edge
              player1_x <= player1_x + STEP_SIZE;

            // Player 2 movement
            if (keys_2[0] && player2_y > 60)
// Prevent moving above top
              player2_y <= player2_y - STEP_SIZE;
            if (keys_2[1] && player2_y <
SCREEN_HEIGHT - 60)    // Prevent moving below
bottom
              player2_y <= player2_y + STEP_SIZE;
            if (keys_2[2] && player2_x > 1)
// Prevent moving left of left edge
              player2_x <= player2_x - STEP_SIZE;
            if (keys_2[3] && player2_x <
SCREEN_WIDTH - 40)     // Prevent moving past right
edge
              player2_x <= player2_x + STEP_SIZE;


            // Collision handling for Player 1
            if (player1_collision) begin
              if (!player1_collision_flag &&
player1_lives > 2'd0) begin
                player1_lives <= player1_lives - 2'd1;
                player1_collision_flag <= 1; // Set
flag to avoid repeated decrement
              end
            end else begin
              player1_collision_flag <= 0; // Reset
flag when no collision
            end

            // Collision handling for Player 2
            if (player2_collision) begin
              if (!player2_collision_flag &&
```

```
player2_lives > 2'd0) begin
                        player2_lives <= player2_lives - 2'd1;
                        player2_collision_flag <= 1; // Set
flag to avoid repeated decrement
                     end
                  end else begin
                     player2_collision_flag <= 0; // Reset
flag when no collision
                  end
                if(player2_lives==0 && player1_lives !=0)
                     game_state<=3;
                else if(player1_lives==0 &&
player2_lives!=0)
                     game_state<=2;
            end
          end
            2: begin
         if(restart)
            game_state<=0;
               if(start)
                  game_state<=1;
      end

            3: begin
            if(restart)
               game_state<=0;
                  if(start)
                     game_state<=1;

         end
   endcase
   end
end

   obstacle_generator obj_gen_inst (
      .clk(slow_clk),
      .rst(rst),
      .obs_x(obstacle_x),
      .obs_y(obstacle_y)
   );

   vga_controller vga_inst (
      .clk25MHz(clk25MHz),
      .slow_clk(slow_clk),
      .sys_clk(clk),
      .road_clk(road_clk),
      .rst(rst),
      .game_state(game_state), // Pass game state to
VGA for display logic
      .p1_x(player1_x),
      .p1_y(player1_y),
      .p2_x(player2_x),
      .p2_y(player2_y),
      .obs_x(obstacle_x),
      .obs_y(obstacle_y),
      .player1_lives(player1_lives),
```

```
    .player2_lives(player2_lives),
    .vga_r(vga_r),
    .vga_g(vga_g),
    .vga_b(vga_b),
    .vga_hsync(vga_hsync),
    .vga_vsync(vga_vsync)
  );

endmodule
```

2. clk_divider

```
`timescale 1ns / 1ps

module clk_divider (clk, clk_out);
parameter div_value = 1;
input clk;
output clk_out;
reg clk_out; reg count;
initial
begin
clk_out = 0; count = 0;
end
always @(posedge clk)
begin
if (count == div_value)
count <= 0; // reset count
else
count <= count + 1; // count up
end
always @(posedge clk)
begin
if (count == div_value)
clk_out <= ~clk_out; //toggle
end
endmodule
```

3. keyboard_input

```
module keyboard_input(
   input clk,        // Clock signal
   input kclk,       // Keyboard clock
   input kdata,      // Keyboard data
   output reg [3:0] keys_1 = 0, // Player 1 directions (Up, Down, Left, Right)
   output reg [3:0] keys_2 = 0, // Player 2 directions (W, S, A, D)
   output reg start = 0,       // Start signal
   output reg restart = 0      // Restart signal
);
   // Internal registers
   reg [7:0] datacur = 0;      // Current data byte
   reg [7:0] dataprev = 0;     // Previous data byte
   reg [15:0] LED = 0;         // Temporary storage for key states
   reg [3:0] cnt = 0;          // State machine counter
   reg flag = 0;               // Data ready flag
   reg oflag = 0;              // Output flag for state change
   reg pflag = 0;              // Previous flag state

   // Debounced clock and data signals
   wire kclkf, kdataf;

   // Debouncer instances for clock and data
   debouncer #(
      .COUNT_MAX(19),
      .COUNT_WIDTH(5)
   ) db_clk (
      .clk(clk),
      .I(kclk),
      .O(kclkf)
```

```
);
debouncer #(
   .COUNT_MAX(19),
   .COUNT_WIDTH(5)
) db_data (
   .clk(clk),
   .I(kdata),
   .O(kdataf)
);

// State machine for receiving PS/2 data
always @(negedge(kclkf)) begin
   case (cnt)
      0: ; // Start bit
      1: datacur[0] <= kdataf;
      2: datacur[1] <= kdataf;
      3: datacur[2] <= kdataf;
      4: datacur[3] <= kdataf;
      5: datacur[4] <= kdataf;
      6: datacur[5] <= kdataf;
      7: datacur[6] <= kdataf;
      8: datacur[7] <= kdataf;
      9: flag <= 1'b1; // Data byte ready
      10: flag <= 1'b0; // Reset flag
   endcase
   if (cnt <= 9)
      cnt <= cnt + 1;
   else if (cnt == 10)
      cnt <= 0;
end

// Process received data and update key states
always @(posedge clk) begin
   if (flag == 1'b1 && pflag == 1'b0) begin
      LED <= {dataprev, datacur}; // Store current and previous data
      oflag <= 1'b1;
      dataprev <= datacur;
   end else
      oflag <= 1'b0;

   pflag <= flag;

   // Handle key release (break code 0xF0)
   if (LED[15:8] == 8'hF0) begin
      // Player 1 key release
      case (LED[7:0])
         8'h75: keys_1[0] <= 1'b0; // Arrow Up
         8'h72: keys_1[1] <= 1'b0; // Arrow Down
         8'h6B: keys_1[2] <= 1'b0; // Arrow Left
         8'h74: keys_1[3] <= 1'b0; // Arrow Right
         // Player 2 key release
         8'h1D: keys_2[0] <= 1'b0; // W
         8'h1B: keys_2[1] <= 1'b0; // S
         8'h1C: keys_2[2] <= 1'b0; // A
         8'h23: keys_2[3] <= 1'b0; // D
         // Start and Restart key release
```

```
        8'h5A: start <= 1'b0; // Enter
        8'h29: restart <= 1'b0; // Space
      endcase
    end else begin
      // Player 1 key press
      case (LED[7:0])
        8'h75: keys_1[0] <= 1'b1; // Arrow Up
        8'h72: keys_1[1] <= 1'b1; // Arrow Down
        8'h6B: keys_1[2] <= 1'b1; // Arrow Left
        8'h74: keys_1[3] <= 1'b1; // Arrow Right
      endcase
      // Player 2 key press
      case (LED[7:0])
        8'h1D: keys_2[0] <= 1'b1; // W
        8'h1B: keys_2[1] <= 1'b1; // S
        8'h1C: keys_2[2] <= 1'b1; // A
        8'h23: keys_2[3] <= 1'b1; // D
      endcase
      // Start and Restart key press
      case (LED[7:0])
        8'h5A: start <= 1'b1; // Enter
        8'h29: restart <= 1'b1; // Space
      endcase
    end
  end
endmodule
```

4. debouncer

```
module debouncer(
   input clk,
   input I,
   output reg O
   );
   parameter COUNT_MAX=255, COUNT_WIDTH=8;
   reg [COUNT_WIDTH-1:0] count;
   reg Iv=0;
   always@(posedge clk)
      if (I == Iv) begin
         if (count == COUNT_MAX)
            O <= I;
         else
            count <= count + 1'b1;
      end else begin
         count <= 'b0;
         Iv <= I;
      end

Endmodule
```

5. obstacle_generator

```
module obstacle_generator (
   input clk, rst,
   output reg [9:0] obs_x, obs_y
);
   reg [9:0] lfsr = 10'b1010101010;  // Initial LFSR value

   parameter V_PIXELS = 480;
   parameter H_PIXELS = 640;

   always @(posedge clk or posedge rst) begin
      if (rst) begin
         obs_x <= lfsr % H_PIXELS;
         obs_y <= 0;
         lfsr <= 10'b1010101010;  // Reset LFSR
      end else begin
         if (obs_y >= V_PIXELS) begin
            obs_y <= 0;
            lfsr <= {lfsr[8:0], lfsr[9] ^ lfsr[8]};  // Updated tap for 10-bit LFSR
            obs_x <= lfsr % H_PIXELS;  // Random x-coordinate
         end else begin
            obs_y <= obs_y + 5;  // Move down
         end
      end
   end
endmodule
```

6. vga_controller

```
module vga_controller (
   input clk25MHz,
// 25 MHz clock (for VGA)
   input slow_clk,
   input sys_clk,
   input road_clk,
   input rst,             //
Reset
   input [9:0] p1_x, p1_y,
// Player 1 car position
   input [9:0] p2_x, p2_y,
// Player 2 car position
   input [9:0] obs_x, obs_y,
// Obstacle position
   input [1:0] game_state,
// Game state (optional for
future use)
   input [1:0] player1_lives,
// Player 1 remaining lives
   input [1:0] player2_lives,
// Player 2 remaining lives
   output reg [3:0] vga_r,
vga_g, vga_b, // VGA color
signals
   output reg vga_hsync,
vga_vsync      // VGA sync
signals
);

   // VGA parameters
(640x480 resolution, 60Hz
refresh rate)
   parameter H_PIXELS =
640;
   parameter V_PIXELS =
480;
   parameter
H_FRONT_PORCH = 16;
   parameter
H_SYNC_PULSE = 96;
   parameter
H_BACK_PORCH = 48;
   parameter
V_FRONT_PORCH = 10;
   parameter
V_SYNC_PULSE = 2;
   parameter
V_BACK_PORCH = 33;
   localparam
SCREEN_WIDTH = 640;
   localparam
SCREEN_HEIGHT = 480;

   // Counters for
horizontal and vertical
pixel positions
   reg [9:0] h_count = 0;
   reg [9:0] v_count = 0;
```

```
   // Road marking
variables
   reg [9:0] road_offset =
0;  // Vertical scrolling
effect
   reg [9:0]
road_marking_y;

   // Horizontal and
vertical sync generation
   always @(posedge
clk25MHz or posedge rst)
begin
       if (rst) begin
           h_count <= 0;
           v_count <= 0;
       end else begin
           if (h_count ==
(H_PIXELS +
H_FRONT_PORCH +
H_SYNC_PULSE +
H_BACK_PORCH - 1))
begin
               h_count <= 0;
               if (v_count ==
(V_PIXELS +
V_FRONT_PORCH +
V_SYNC_PULSE +
V_BACK_PORCH - 1))
                   v_count <= 0;
               else
                   v_count <=
v_count + 1;
           end else
               h_count <=
h_count + 1;
       end
   end

   // Sync pulse logic
   always @(posedge
clk25MHz) begin
       vga_hsync <=
(h_count < (H_PIXELS +
H_FRONT_PORCH)) ||
                    (h_count >=
(H_PIXELS +
H_FRONT_PORCH +
H_SYNC_PULSE));
       vga_vsync <= (v_count
< (V_PIXELS +
V_FRONT_PORCH)) ||
                    (v_count >=
(V_PIXELS +
V_FRONT_PORCH +
V_SYNC_PULSE));
   end

   // Road scrolling logic
(smooth increment)
   always @(posedge
road_clk or posedge rst)
```

```
begin
    if (rst)
        road_offset <= 0;
    else if (v_count ==
V_PIXELS - 1)  // Update
every frame
        road_offset <=
(road_offset - 4 +
V_PIXELS) % V_PIXELS;  //
Decrement to scroll down
  end

  // Corrected road
marking calculation
  always @(posedge
clk25MHz) begin
    road_marking_y <=
(v_count + road_offset) %
V_PIXELS;
  end

  // Pixel color assignment
  always @(posedge
clk25MHz) begin
    // Default
background: grey
    vga_r <= 4'h8;
    vga_g <= 4'h8;
    vga_b <= 4'h8;

    if ((h_count <
H_PIXELS) && (v_count <
V_PIXELS)) begin
        // Road Markings
(White stripes)
        if (game_state==0)
begin
            if (
            // W conditions
            (h_count >= 50
&& h_count <= 65 &&
v_count >= 30 && v_count
<= 130) || // Left bar of W
            (h_count >= 65
&& h_count <= 85 &&
v_count >= 110 &&
v_count <= 130) ||  //
bottom left bar of W
            (h_count >= 85
&& h_count <= 100 &&
v_count >= 60 && v_count
<= 130) || // Middle bar of
W
            (h_count >= 100
&& h_count <= 120 &&
v_count >= 110 &&
v_count <= 130) || //
bottom right bar of W
            (h_count >= 120
&& h_count <= 135 &&
v_count >= 30 && v_count
<= 130) ||  // right bar of
```

W

```
        // E conditions
        (h_count >= 150
&& h_count <= 165 &&
v_count >= 30 && v_count
<= 130) || // Left vertical
bar of E
        (h_count >= 165
&& h_count <= 195 &&
v_count >= 30 && v_count
<= 45) || // Top bar of E
        (h_count >= 165
&& h_count <= 195 &&
v_count >= 72 && v_count
<= 88) || // Middle bar of
E
        (h_count >= 165
&& h_count <= 195 &&
v_count >= 115 &&
v_count <= 130) || //
Bottom bar of E

        // L conditions
        (h_count >= 210
&& h_count <= 225 &&
v_count >= 30 && v_count
<= 130) || // Left vertical
bar of L
        (h_count >= 225
&& h_count <= 260 &&
v_count >= 115 &&
v_count <= 130) || //
Bottom bar of L

        // C conditions
        (h_count >= 275
&& h_count <= 290 &&
v_count >= 30 && v_count
<= 130) || // Left Bar of C
        (h_count >= 290
&& h_count <= 325 &&
v_count >= 30 && v_count
<= 45) || // Top Bar of C
        (h_count >= 290
&& h_count <= 325 &&
v_count >= 115 &&
v_count <= 130) || //
Bottom Bar of C

        // O conditions
        (h_count >= 340
&& h_count <= 355 &&
v_count >= 30 && v_count
<= 130) || // Left Bar of O
        (h_count >= 355
&& h_count <= 390 &&
v_count >= 30 && v_count
<= 45) || // Top Bar of O
        (h_count >= 355
&& h_count <= 390 &&
v_count >= 115 &&
```

```
v_count <= 130) || //
Bottom Bar of O
             (h_count >= 390
&& h_count <= 405 &&
v_count >= 30 && v_count
<= 130) || // Right Bar of
O

             // M conditions
             (h_count >= 420
&& h_count <= 435 &&
v_count >= 30 && v_count
<= 130) || // Left Bar of M
             (h_count >= 435
&& h_count <= 455 &&
v_count >= 30 && v_count
<= 45) || // Top Left Bar of
M
             (h_count >= 455
&& h_count <= 470 &&
v_count >= 30 && v_count
<= 100) || // Middle Bar of
M
             (h_count >= 470
&& h_count <= 490 &&
v_count >= 30 && v_count
<= 45) || // Top Right Bar
of M
             (h_count >= 490
&& h_count <= 505 &&
v_count >= 30 && v_count
<= 130) || // Right Bar of
M

             // E conditions
(again for second E)
             (h_count >= 520
&& h_count <= 535 &&
v_count >= 30 && v_count
<= 130) || // Left vertical
bar of E
             (h_count >= 535
&& h_count <= 560 &&
v_count >= 30 && v_count
<= 45) || // Top bar of E
             (h_count >= 535
&& h_count <= 560 &&
v_count >= 72 && v_count
<= 88) || // Middle bar of
E
             (h_count >= 535
&& h_count <= 560  &&
v_count >= 115 &&
v_count <= 130)  //
Bottom bar of E


          ) begin
             // Text color (light
pink)
             vga_r <= 4'hF;    //
High vga_r intensity
```

```
            vga_g <= 4'h0;  //
High vga_g intensity
            vga_b <= 4'h0;   //
High vga_b intensity (light
pink)
         end else begin
            // Background
color (black)
            vga_r <= 4'h0;
// No vga_r intensity
            vga_g <= 4'h0;  //
No vga_g intensity
            vga_b <= 4'h0;   //
No vga_b intensity
         end
       end else
if(game_state==2)begin

         if (
            // P conditions
            (h_count >= 50
&& h_count <= 65 &&
v_count >= 30 && v_count
<= 130) || // Left bar of P
            (h_count >= 65
&& h_count <= 95 &&
v_count >= 30 && v_count
<= 45) ||  // Top bar of P
            (h_count >= 65
&& h_count <= 95 &&
v_count >= 75 && v_count
<= 90) || // Middle bar of
P
            (h_count >= 95
&& h_count <= 110 &&
v_count >= 30 && v_count
<= 90) || // Right bar of P

            // L conditions
            (h_count >= 125
&& h_count <= 140 &&
v_count >= 30 && v_count
<= 130) || // Left vertical
bar of L
            (h_count >= 140
&& h_count <= 170 &&
v_count >= 115 &&
v_count <= 130) || //
Bottom bar of L

            // A Conditions
            (h_count >= 185
&& h_count <= 200 &&
v_count >= 30 && v_count
<= 130) || // Left Bar of A
            (h_count >= 200
&& h_count <= 230 &&
v_count >= 30 && v_count
<= 45) || // Top Bar of A
            (h_count >= 200
&& h_count <= 230 &&
v_count >= 75 && v_count
```

<= 90) || // Middle Bar of A
(h_count >= 230 && h_count <= 245 && v_count >= 30 && v_count <= 130) || // Right Bar of A

// Y Conditions
(h_count >= 260 && h_count <= 275 && v_count >= 30 && v_count <= 60) || // Left Bar of Y
(h_count >= 275 && h_count <= 305 && v_count >= 60 && v_count <= 75) || // Middle Horizontal Bar of Y
(h_count >= 305 && h_count <= 320 && v_count >= 30 && v_count <= 60) || // Right Bar of A
(h_count >= 285 && h_count <= 295 && v_count >= 75 && v_count <= 130) || // Middle Vertical Bar of A

// E conditions
(h_count >= 335 && h_count <= 350 && v_count >= 30 && v_count <= 130) || // Left vertical bar of E
(h_count >= 350 && h_count <= 385 && v_count >= 30 && v_count <= 45) || // Top bar of E
(h_count >= 350 && h_count <= 385 && v_count >= 72 && v_count <= 88) || // Middle bar of E
(h_count >= 350 && h_count <= 385 && v_count >= 115 && v_count <= 130) || // Bottom bar of E

// R Condition
(h_count >= 400 && h_count <= 415 && v_count >= 30 && v_count <= 130) || // Left Bar of R
(h_count >= 415 && h_count <= 445 && v_count >= 30 && v_count <= 45) || // Top Bar of R
(h_count >= 430 && h_count <= 445 && v_count >= 72 && v_count <= 88) || // Middle Bar of R

```
        (h_count >= 445
&& h_count <= 460 &&
v_count >= 30 && v_count
<= 130) || // Right Bar of R

        // 2 Conditions
        // Conditions for
drawing the number 2
        (h_count >= 560
&& h_count <= 600 &&
v_count >= 30 && v_count
<= 45) ||  // Top
horizontal bar of 2
        (h_count >= 600
&& h_count <= 610 &&
v_count >= 45 && v_count
<= 80) ||  // Top-right
vertical bar of 2
        (h_count >= 560
&& h_count <= 600 &&
v_count >= 80 && v_count
<= 95) ||  // Middle
horizontal bar of 2
        (h_count >= 560
&& h_count <= 570 &&
v_count >= 95 && v_count
<= 130) || // Bottom-left
vertical bar of 2
        (h_count >= 560
&& h_count <= 600 &&
v_count >= 115 &&
v_count <= 130)||    //
Bottom horizontal bar of 2

        // W conditions
        (h_count >= 260
&& h_count <= 275 &&
v_count >= 150 &&
v_count <= 250) || // Left
bar of W
        (h_count >= 275
&& h_count <= 290 &&
v_count >= 235 &&
v_count <= 250) ||  //
bottom left bar of W
        (h_count >= 290
&& h_count <= 305 &&
v_count >= 150 &&
v_count <= 250) || //
Middle bar of W
        (h_count >= 305
&& h_count <= 320 &&
v_count >= 235 &&
v_count <= 250) || //
bottom right bar of W
        (h_count >= 320
&& h_count <= 335 &&
v_count >= 150 &&
v_count <= 250) ||  //
right bar of W

        // O conditions
```

```
            (h_count >= 350
&& h_count <= 365 &&
v_count >= 150 &&
v_count <= 250) || // Left
Bar of O
            (h_count >= 365
&& h_count <= 385 &&
v_count >= 150 &&
v_count <= 165) || // Top
Bar of O
            (h_count >= 365
&& h_count <= 385 &&
v_count >= 235 &&
v_count <= 250) || //
Bottom Bar of O
            (h_count >= 385
&& h_count <= 400 &&
v_count >= 150 &&
v_count <= 250) || //
Right Bar of O

            // N Conditions
            (h_count >= 410
&& h_count <= 425 &&
v_count >= 150 &&
v_count <= 250) || // Left
Bar of N
            (h_count >= 425
&& h_count <= 440 &&
v_count >= 150 &&
v_count <= 165) || // Top-
left Bar of N
            (h_count >= 440
&& h_count <= 455 &&
v_count >= 150 &&
v_count <= 250) || //
Middle line-Bar of N
            (h_count >= 455
&& h_count <= 470 &&
v_count >= 235 &&
v_count <= 250) || //
Bottom-right Bar of N
            (h_count >= 470
&& h_count <= 485 &&
v_count >= 150 &&
v_count <= 250)  // Right
Bar of N



        )
         begin
            // Text color (light
pink)
            vga_r <= 4'hF;    //
High vga_r intensity
            vga_g <= 4'h0;  //
High vga_g intensity
            vga_b <= 4'h0;   //
High vga_b intensity (light
pink)
         end else begin
```

```
            // Background
color (black)
            vga_r <= 4'h0;
// No vga_r intensity
            vga_g <= 4'h0;  //
No vga_g intensity
            vga_b <= 4'h0;   //
No vga_b intensity
         end
      end

     else if(game_state==3)
begin
         if (
            // P conditions
            (h_count >= 50
&& h_count <= 65 &&
v_count >= 30 && v_count
<= 130) || // Left bar of P
            (h_count >= 65
&& h_count <= 95 &&
v_count >= 30 && v_count
<= 45) ||  // Top bar of P
            (h_count >= 65
&& h_count <= 95 &&
v_count >= 75 && v_count
<= 90) || // Middle bar of
P
            (h_count >= 95
&& h_count <= 110 &&
v_count >= 30 && v_count
<= 90) || // Right bar of P

            // L conditions
            (h_count >= 125
&& h_count <= 140 &&
v_count >= 30 && v_count
<= 130) || // Left vertical
bar of L
            (h_count >= 140
&& h_count <= 170 &&
v_count >= 115 &&
v_count <= 130) || //
Bottom bar of L

            // A Conditions
            (h_count >= 185
&& h_count <= 200 &&
v_count >= 30 && v_count
<= 130) || // Left Bar of A
            (h_count >= 200
&& h_count <= 230 &&
v_count >= 30 && v_count
<= 45) || // Top Bar of A
            (h_count >= 200
&& h_count <= 230 &&
v_count >= 75 && v_count
<= 90) || // Middle Bar of
A
            (h_count >= 230
&& h_count <= 245 &&
v_count >= 30 && v_count
```

```
<= 130) || // Right Bar of A

            // Y Conditions
            (h_count >= 260
&& h_count <= 275 &&
v_count >= 30 && v_count
<= 60) || // Left Bar of Y
            (h_count >= 275
&& h_count <= 305 &&
v_count >= 60 && v_count
<= 75) || // Middle
Horizontal Bar of Y
            (h_count >= 305
&& h_count <= 320 &&
v_count >= 30 && v_count
<= 60) || // Right Bar of A
            (h_count >= 285
&& h_count <= 295 &&
v_count >= 75 && v_count
<= 130) || // Middle
Vertical Bar of A

            // E conditions
            (h_count >= 335
&& h_count <= 350 &&
v_count >= 30 && v_count
<= 130) || // Left vertical
bar of E
            (h_count >= 350
&& h_count <= 385 &&
v_count >= 30 && v_count
<= 45) || // Top bar of E
            (h_count >= 350
&& h_count <= 385 &&
v_count >= 72 && v_count
<= 88) || // Middle bar of
E
            (h_count >= 350
&& h_count <= 385 &&
v_count >= 115 &&
v_count <= 130) || //
Bottom bar of E

            // R Condition
            (h_count >= 400
&& h_count <= 415 &&
v_count >= 30 && v_count
<= 130) || // Left Bar of R
            (h_count >= 415
&& h_count <= 445 &&
v_count >= 30 && v_count
<= 45) || // Top Bar of R
            (h_count >= 430
&& h_count <= 445 &&
v_count >= 72 && v_count
<= 88) || // Middle Bar of
R
            (h_count >= 445
&& h_count <= 460 &&
v_count >= 30 && v_count
<= 130) || // Right Bar of R
```

```
        // 1 Conditions
        (h_count >= 510
&& h_count <= 550 &&
v_count >= 115 &&
v_count <= 130) || //
Bottom Bar of 1
        (h_count >= 525
&& h_count <= 535 &&
v_count >= 30 && v_count
<= 115) || // Middle Bar of
1
        (h_count >= 520
&& h_count <= 525 &&
v_count >= 30 && v_count
<= 45) || // Top small Bar
of

        // W conditions
        (h_count >= 260
&& h_count <= 275 &&
v_count >= 150 &&
v_count <= 250) || // Left
bar of W
        (h_count >= 275
&& h_count <= 290 &&
v_count >= 235 &&
v_count <= 250) ||  //
bottom left bar of W
        (h_count >= 290
&& h_count <= 305 &&
v_count >= 150 &&
v_count <= 250) || //
Middle bar of W
        (h_count >= 305
&& h_count <= 320 &&
v_count >= 235 &&
v_count <= 250) || //
bottom right bar of W
        (h_count >= 320
&& h_count <= 335 &&
v_count >= 150 &&
v_count <= 250) ||  //
right bar of W

        // O conditions
        (h_count >= 350
&& h_count <= 365 &&
v_count >= 150 &&
v_count <= 250) || // Left
Bar of O
        (h_count >= 365
&& h_count <= 385 &&
v_count >= 150 &&
v_count <= 165) || // Top
Bar of O
        (h_count >= 365
&& h_count <= 385 &&
v_count >= 235 &&
v_count <= 250) || //
Bottom Bar of O
        (h_count >= 385
&& h_count <= 400 &&
```

```
v_count >= 150 &&
v_count <= 250) || //
Right Bar of O

            // N Conditions
            (h_count >= 410
&& h_count <= 425 &&
v_count >= 150 &&
v_count <= 250) || // Left
Bar of N
            (h_count >= 425
&& h_count <= 440 &&
v_count >= 150 &&
v_count <= 165) || // Top-
left Bar of N
            (h_count >= 440
&& h_count <= 455 &&
v_count >= 150 &&
v_count <= 250) || //
Middle line-Bar of N
            (h_count >= 455
&& h_count <= 470 &&
v_count >= 235 &&
v_count <= 250) || //
Bottom-right Bar of N
            (h_count >= 470
&& h_count <= 485 &&
v_count >= 150 &&
v_count <= 250)  // Right
Bar of N



         )
         begin
            // Text color (light
pink)
            vga_r <= 4'hF;    //
High vga_r intensity
            vga_g <= 4'h0;  //
High vga_g intensity
            vga_b <= 4'h0;   //
High vga_b intensity (light
pink)
         end else begin
            // Background
color (black)
            vga_r <= 4'h0;
// No vga_r intensity
            vga_g <= 4'h0;  //
No vga_g intensity
            vga_b <= 4'h0;   //
No vga_b intensity
         end
      end
         if
(((road_marking_y >= 20
&& road_marking_y < 80)
|| (road_marking_y >=
110 && road_marking_y <
170) ||
             (road_marking_y
```

```
>= 200 &&
road_marking_y < 260) ||
(road_marking_y >= 290
&& road_marking_y <
350)) &&
            ((h_count >= 210
&& h_count < 220) ||
(h_count >= 430 &&
h_count < 440))) begin
            vga_r <= 4'hF;
            vga_g <= 4'hF;
            vga_b <= 4'hF;
         end

         // Player 1 Car
(Blue)
         // Ensure player 1
rendering is within screen
boundaries
         if ((h_count >=
p1_x) && (h_count < (p1_x
+ 40)) &&
            (v_count >= p1_y)
&& (v_count < (p1_y + 60))
&&
            (p1_x <
SCREEN_WIDTH) && (p1_y
< SCREEN_HEIGHT)) begin
               vga_r <= 4'h0;
// Blue
               vga_g <= 4'h0;
               vga_b <= 4'hF;
         end

         // Ensure player 2
rendering is within screen
boundaries
         if ((h_count >=
p2_x) && (h_count < (p2_x
+ 40)) &&
            (v_count >= p2_y)
&& (v_count < (p2_y + 60))
&&
            (p2_x <
SCREEN_WIDTH) && (p2_y
< SCREEN_HEIGHT)) begin
               vga_r <= 4'hF;
// Purple
               vga_g <= 4'h0;
               vga_b <= 4'hF;
         end


         // Obstacle (Dark
Red)
         if ((h_count >=
obs_x) && (h_count <
(obs_x + 40)) &&
            (v_count >=
obs_y) && (v_count <
(obs_y + 60))) begin
            vga_r <= 4'hF;
```

```
            vga_g <= 4'h0;
            vga_b <= 4'h0;
          end

          // Player 1 Lives:
Red rectangles at the top-
left
          if ((h_count >= 10
&& h_count < 20 &&
player1_lives >= 1) ||
            (h_count >= 30
&& h_count < 40 &&
player1_lives >= 2) ||
            (h_count >= 50
&& h_count < 60 &&
player1_lives == 3)) begin
            if (v_count >= 10
&& v_count < 20) begin
              vga_r <= 4'h0;
// Red
              vga_g <= 4'h0;
              vga_b <= 4'hF;
            end
          end

          // Player 2 Lives:
Blue rectangles at the top-
right
          if ((h_count >= 580
&& h_count < 590 &&
player2_lives == 3) ||
            (h_count >= 600
&& h_count < 610 &&
player2_lives >= 2) ||
            (h_count >= 620
&& h_count < 630 &&
player2_lives >= 1)) begin
            if (v_count >= 10
&& v_count < 20) begin
              vga_r <= 4'hF;
// Blue
              vga_g <= 4'h0;
              vga_b <= 4'hF;
            end
          end
        end else begin
          // Outside active
display area
          vga_r <= 4'h0;
          vga_g <= 4'h0;
          vga_b <= 4'h0;
        end
    end

endmodule
```

```
);
debouncer #(
   .COUNT_MAX(19),
   .COUNT_WIDTH(5)
) db_data(
     .clk(clk),
     .I(kdata),
     .O(kdataf)
);
always@(negedge(kclkf))begin
     case(cnt)
     0:;//Start bit
     1:datacur[0]<=kdataf;
     2:datacur[1]<=kdataf;
     3:datacur[2]<=kdataf;
     4:datacur[3]<=kdataf;
     5:datacur[4]<=kdataf;
     6:datacur[5]<=kdataf;
     7:datacur[6]<=kdataf;
     8:datacur[7]<=kdataf;
     9:flag<=1'b1;
     10:flag<=1'b0;
     endcase
          if(cnt<=9) cnt<=cnt+1;
          else  if(cnt==10)  cnt<=0;
end
reg  pflag;
always@(posedge  clk)  begin
     if  (flag  ==  1'b1  && pflag  ==  1'b0)  begin
          keycode  <=  {dataprev,  datacur};
          oflag  <=  1'b1;
          dataprev <= datacur;
     end else
          oflag <= 'b0;
     pflag  <=  flag;
end
always@(posedge  kclk)  begin
if (keycode[7:0]== keycode[15:8]) begin
          lights<=  datacur;
     end else begin
          lights<=8'hf0;
     end
end
endmodule
```