6.111 Final Project Report – Bahrudin Trbalic

ChessAi

Abstract

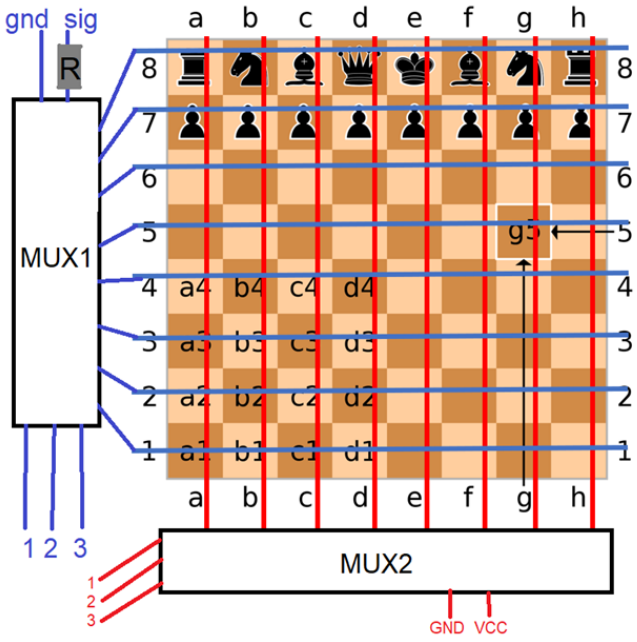
The goal of this project is to create chess board that acts as an opponent who can be played against with little to no human computer interaction. Physically it consists of a chess board with 64 LED indicator lights, a set of standard chess pieces modified with magnets on the bottom and wiring underneath the board to read off piece positions. On the FPGA we implemented an FSM to check the validity of all moves and to relay moves made by the human to a computer running a python script that determines the opponent's move. It also included a connection between the computer and the LEDs to provide useful signaling and indications of the opponent's move.

INTRODUCTION

Many people love to play chess but nowadays it's hard to find people to play with – especially for the senior and more experienced population. A subgroup of those people either don't own or don't know how to use a computer, so they cannot play chess online. We decided to build a physical chess board that brings the joy of moving the figures with your hands and the pleasure and flexibility of playing against a computer. The whole system is composed of a figure state detection module (module 1), an FSM that checks the validity of movements and tracks the progress of the game, communication modules with an external computer and an LED system that displays movements the computer wants to do.

MODULE 1 - The position of figures

As we always need to know the position of every figure, we will build a module to help us do so. We will have 8 horizontal (blue) and 8 vertical (red) wires running under the board with hall sensors connected to the grid formed by the wires. A hall sensor is a digital device that signals the presence/absence of strong magnetic fields in its proximity. Whenever a figure (with a magnet placed on the bottom) is placed on a square, it will produce a signal that is channeled to the FPGA. The horizontal and vertical lines will be connected to 2 multiplexers that will select which lines to analyze. The setup is shown in the figure below. MUX2 will individually supply the lines a-h with a high signal. At the same time, MUX1 will run through lines 1-8 and output a high signal if there is a figure on the corresponding square and a low signal otherwise. Since each mux is connected to 8 wires, we need only 3 bits to control each of them. Since only one hall sensor is powered at a time, only the signal from that particular sensor is relevant to the FPGA. We have determined that disconnected hall sensors (either from the positive or ground source) have a high impedance at their output so that they don't interfere with each other.



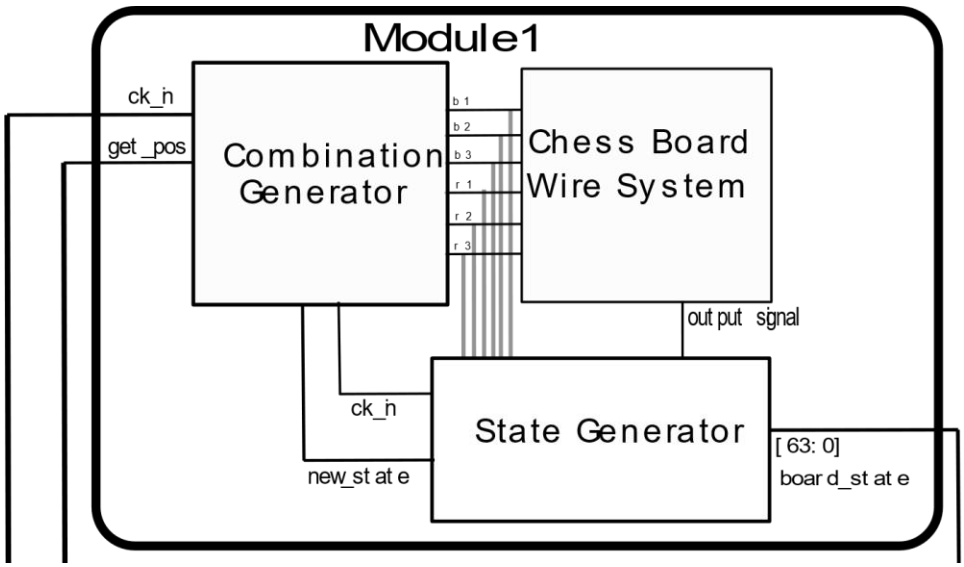
A counter implemented in software runs through 64 permutations activating and deactivating vertical and horizontal wires. The corresponding high and low signal was used by another module that generated a 64-bit long number that shows which squares of the chess board have figures on them. The challenging part here was to synchronize the arrival of the debounced signal received from the hall sensor with the update of the figure state. I solved the problem by always updating the previous square with the readily available signal. That solution worked fine for all of the squares except the starting one (at 0,0 position) since it did not have a predecessor. To solve that problem, I had to make sure that the LED wire system selection algorithm waits for the duration of the debounce for the initial state.

By testing various time constants, we have determined that an individual hall sensor should be powered for at least 0.4ms (SQUARE_WAIT) to produce reliable signals. Thus, the latency of this module is 64xSQUARE_WAIT ≈ 25ms (time spent

looking at every square) This module can have a large latency (<10ms) since faster state updates are not crucial to the whole system, taking into consideration the speed of possible figure movements.

Shown below is a detailed block diagram of the connection between the output ports from the FPGA to the wire system powering the hall sensors. For further implementations I would recommend designing a PCB instead of manually manufacturing the wire system. It required around 700 soldering points and around 5m of wire to get the system running. Mistakes in the manufacturing process were inevitable so that we had to struggle with faulty hall sensors and weak connections, which slowed down our progress and made it impossible to achieve the intended goal of having a fully functional board.

This module can only detect the presence/absence of figures on each square. In order to track different figures, we need an FSM to keep a record of the state of the game.



Chess Game FSM
Includes: Keeps track of figures, detects changes, tests legality of moves, communicates with other modules and looks out for the winner

While the essentials of chess basically only requires an FSM which keeps track of when a piece disappears and where it reappears, there are many subtleties in both the rules and how the moves are enacted which will need to be considered since we want as little of the computation to be done on the off board computer as possible.

First the FSM needs to ensure that the move order is preserved. This means that if a black piece is picked up after another black piece and before a timer runs out (in the case of capturing or castling) a warning signal is flashed on the LED's.

Next, once the piece has been placed, the FSM must ensure that the move was a valid one. Naively, this should be an easy task, but again, chess is a complex game with complex rules. Pawns can only move forward once...unless they've reached the other side...or they can move twice if they're on the second row...well except if an opponent could capture them in the intermediate position (en peasant). There are a lot of these oddities which will need to be accounted for in the FSM.

Once the movement has been verified by the FPGA, it will update the state of all the pieces accordingly then send the most recent move to the computer (over UART?) and wait for a response.

External Computer Attachment - Response of the opponent
Includes: communication with the computer + python script
Example: send:c2c4: returns: d2d4

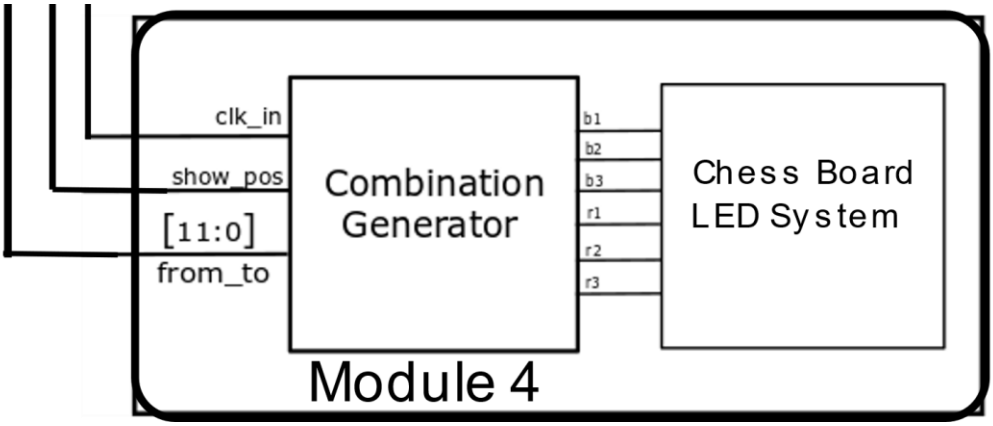
Due to the complexity of chess gameplay and how much research and effort has been put into making decent chess AI on standard PC architectures, we have decided to leave the opponent move generation to a separate computer running some sort of standard chess library in python. This python script will simply receive moves generated by our system's FSM and respond to them with optimal opponent moves over UART and an improvised communication channel over a teensy. It is straightforward to implement the communication over UART from the FPGA to the computer: we need to send 12bits (6bits for the initial position, 6bits for the final position) over the already available UART protocol. As the maximum number of bits UART can transmit at one time is 8 bits, we had

to divide the 12bit long signal into two 6bit signals, appended with bits to indicate the order in which they were sent.

The communication from the computer to the FPGA is more complicated. I have used serial communication between the computer and a teensy to control its digital pins. Those digital pins (7 of them) were connected to the jc digital inputs of the FPGA. The first bit indicated weather we are sending the initial or final position of the intended movement and the remaining six bits were used to transmit the coordinates of the positions the chess figures should move.

MODULE 4 - Opponent's movement signaling via LED's

Since this game is meant to be played against a computer - but on hardware, the simplest way for the computer to control the chess figures is to signal where the figures should be moved (by the player) via means of lighting up LEDs embedded in the chess board. Similar to the Module 1, we have an additional set of 8 horizontal and 8 vertical wires running under the board. They are able to individually power each of the 64 LEDs. Two LEDs turned on and off periodically signal the intended movement: the one from where the figure is to be moved and the second one to where it should be moved. Again, a pair of 8-bit mux-es will be used to turn on/off individual LEDs.

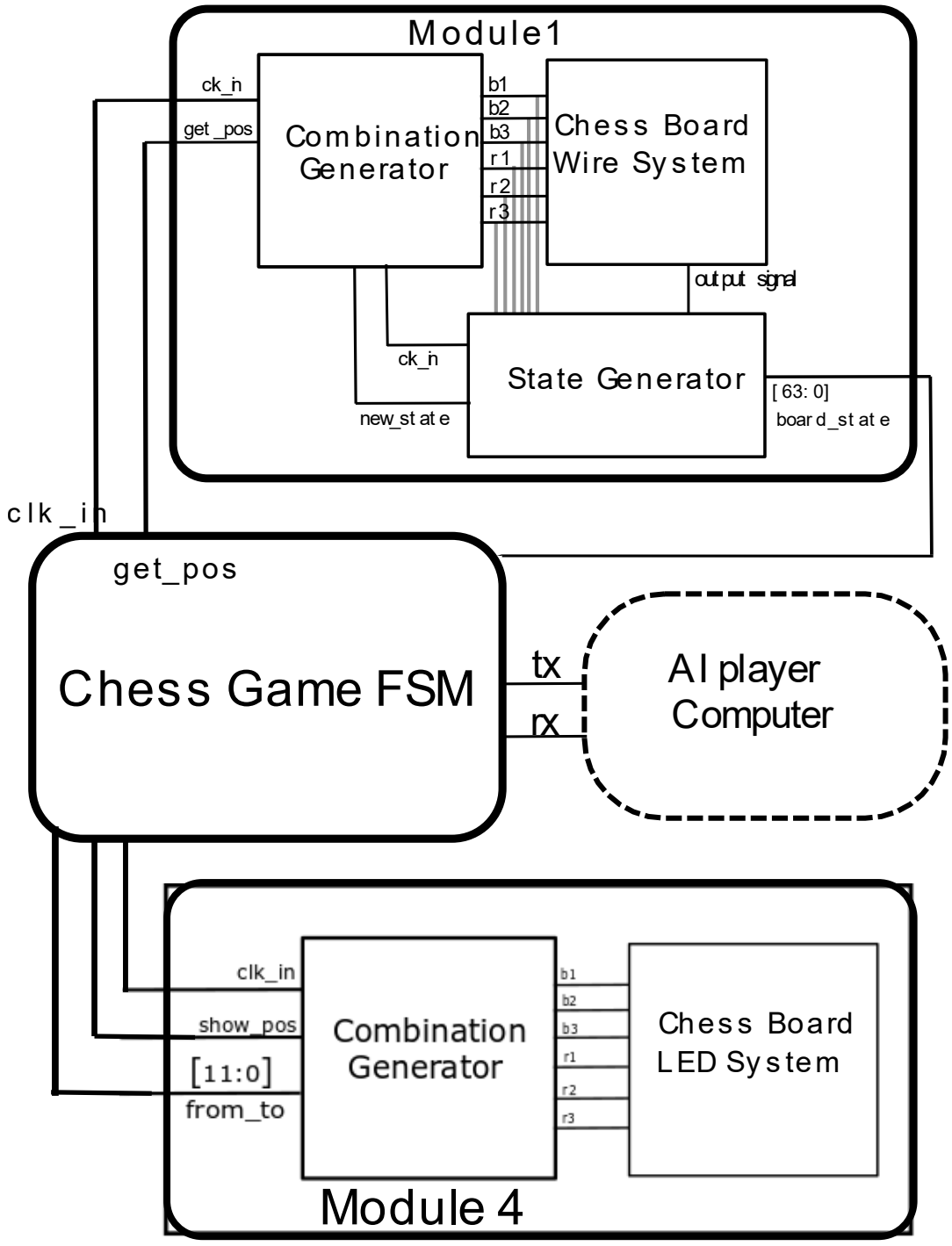


One input to this module is the **show_pos** signal to start displaying the needed movement of the figures. The **from_to** signal is a 12-bit long signal. First 6 bits are designated to signal the coordinate of the "from" LED while the last 6 bits are to signal the "to" LED. The two LED's will turn on and off alternatively until the player moves the figure.

There are several special patterns displayed by the LED array when:

- An illegal move has been made LEDs will create an X sign
- The game has ended, the winner side of the board lights up

BLOCK DIAGRAM



```
`timescale 1ns / 1ps

module detectAndSignal(input            clk_100mhz,
                       input [15:0]       sw,
                       input [3:0]        jb,
                       input [6:0]        jc,
                       input [63:0]       image,
                       input              btnc,
                       input              btnd,

                       //output[63:0]       positions,
                       output logic [6:0]  ja,
                       output[15:0]       led,
                       output             led16_b,led16_r,led17_g,led17_r,led17_b
                       );

    parameter TIMECONST = 10_000;
    parameter SCAN_DELAY = 256*TIMECONST;
    parameter SCAN_DELAY_MULT = 8;
    logic figure;
    logic reset=0;
    logic sig_ready;
    logic board_state_ready=0;
    debounce db1(.reset_in(reset),.clock_in(clk_100mhz),.noisy_in(~jb[0]),.clean_out(figure),.ready(sig_ready));

    logic wrong_move;
    //assign wrong_move = sw[15];

    logic [11:0] from_to = 12'b101_111_100_110;
    logic [11:0] computer_out = 12'b101_111_100_110;

    logic win_a;
    assign win_a = sw[14];

    logic win_b;
    assign win_b = sw[13];
    logic[63:0] positions = 64'b0;
    logic[63:0] final_positions = 64'b0;

    logic[31:0] counter = 0;//hold counter
    logic[31:0] count = 0;
    logic[4:0] counterx=0;
    logic[4:0] countery=0;

    logic scan_enable=0;
    logic zero_pos;
    logic[31:0] led_timer_big;


    always_ff@(posedge clk_100mhz) begin
    //this part scans the board and detects the figures
     if (counter<SCAN_DELAY*{sw[9:0],1'b1}*(1+sw[11:10]*SCAN_DELAY_MULT)) begin
```

```
        if (~scan_enable) counter <= counter+1;
          end
        else begin
          scan_enable<=1;
          counter <=0;
          end

 if (scan_enable&(count<TIMECONST*{sw[9:0],1'b1}))   //
   begin
   count <= count+1;              //
   end
 else                          //
 begin   count <= 0;
   if (counterx==7) begin          //
            counterx <=0;      //
            countery <= countery+1;//
            end
   else
     counterx <= counterx+1;
   if (countery==8)
     begin
     final_positions<=positions;
     board_state_ready<=1;
     countery <= 0;
     end
   else
     board_state_ready<=0;

   if (countery==8)
      begin
      scan_enable <= 0;      //
      end

   else begin
     ja[2:0] <= {counterx}[2:0];  //
     ja[5:3] <= {countery}[2:0];  //
     end
end

//this part builds the scan output
if (~scan_enable &(counter<(SCAN_DELAY)*{sw[9:0],1'b1}
                          *(1+sw[11:10]*SCAN_DELAY_MULT))
           &(counter>(99*SCAN_DELAY/100)*{sw[9:0],1'b1}
                          *(1+sw[11:10]*SCAN_DELAY_MULT)))
    begin
    ja[2:0] <= {3'b000}[2:0];
    ja[5:3] <= {3'b000}[2:0];
    zero_pos <=1;
    end
else if(zero_pos&~scan_enable)
   begin
   zero_pos <=0;
```

```
    positions[0]<=figure;
    end

 if (sig_ready&scan_enable&(counterx+countery*8>1))
    begin
    positions[counterx+countery*8-1]= countery < 2 ? 1 : figure;
    end

//------------------------------------------------------------------------------
//this part displays the input
//it is blocked by the scan_enable signal
//------------------------------------------------------------------------------
led_timer_big <= (SCAN_DELAY/100)*{sw[9:0],1'b1}*(1+sw[11:10]*SCAN_DELAY_MULT);
if (wrong_move) begin  // draw an X if there is a wrong move
   if (~scan_enable &(counter<15*led_timer_big))
     begin ja[2:0] <= {3'b010}[2:0];
         ja[5:3] <= {3'b010}[2:0];end
   else if (~scan_enable &(counter<30*led_timer_big))
     begin ja[2:0] <= {3'b010}[2:0];
         ja[5:3] <= {3'b100}[2:0]; end
  else if (~scan_enable &(counter<45*led_timer_big))
     begin ja[2:0] <= {3'b100}[2:0];
         ja[5:3] <= {3'b010}[2:0]; end
  else if (~scan_enable &(counter<60*led_timer_big))
     begin ja[2:0] <= {3'b100}[2:0];
         ja[5:3] <= {3'b100}[2:0]; end
  else if (~scan_enable &(counter<79*led_timer_big))
     begin ja[2:0] <= {3'b011}[2:0];
         ja[5:3] <= {3'b011}[2:0]; end
      end

else if(win_a) begin // if a wins then the first row
  if (~scan_enable &(counter<15*led_timer_big))
     begin ja[2:0] <= {3'b010}[2:0];
         ja[5:3] <= {3'b000}[2:0];end
   else if (~scan_enable &(counter<30*led_timer_big))
     begin ja[2:0] <= {3'b011}[2:0];
         ja[5:3] <= {3'b000}[2:0]; end
  else if (~scan_enable &(counter<45*led_timer_big))
     begin ja[2:0] <= {3'b100}[2:0];
         ja[5:3] <= {3'b000}[2:0]; end
  else if (~scan_enable &(counter<60*led_timer_big))
     begin ja[2:0] <= {3'b101}[2:0];
         ja[5:3] <= {3'b000}[2:0]; end
  else if (~scan_enable &(counter<79*led_timer_big))
     begin ja[2:0] <= {3'b110}[2:0];
         ja[5:3] <= {3'b000}[2:0]; end
      end
  else if(win_b) begin // if b wins
     if (~scan_enable &(counter<15*led_timer_big))
     begin ja[2:0] <= {3'b010}[2:0];
         ja[5:3] <= {3'b111}[2:0];end
```

```
      else if (~scan_enable &(counter<30*led_timer_big))
       begin ja[2:0] <= {3'b011}[2:0];
           ja[5:3] <= {3'b111}[2:0]; end
       else if (~scan_enable &(counter<45*led_timer_big))
       begin ja[2:0] <= {3'b100}[2:0];
           ja[5:3] <= {3'b111}[2:0]; end
        else if (~scan_enable &(counter<60*led_timer_big))
       begin ja[2:0] <= {3'b101}[2:0];
           ja[5:3] <= {3'b111}[2:0]; end
       else if (~scan_enable &(counter<79*led_timer_big))
       begin ja[2:0] <= {3'b110}[2:0];
           ja[5:3] <= {3'b111}[2:0]; end
        end

       //-=-=-=--=-=-=-=-=-=-=-=-=-=-=-=-=-=
 else begin // Display required move
     if (~scan_enable &(counter<40*led_timer_big))
       begin
       ja[2:0] <= from_to[2:0];
       ja[5:3] <= from_to[5:3];
       end
     else if (~scan_enable &(counter<80*led_timer_big))
       begin
       ja[2:0] <= from_to[8:6];
       ja[5:3] <= from_to[11:9];
       end
     end

  end


assign led16_b = ~jb[0];
assign led17_r = wrong_move;
assign led17_g = final_positions[7];
assign led17_b = final_positions[0];
assign led[15:0]=final_positions[63:48];
//-=-=-=-=--=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=
//SERIAL PART
logic clean;
logic old_clean;
logic sig_readdy2;

always_ff @(posedge clk_100mhz)begin
   old_clean <= clean;  //for rising edge detection
   if (jc[0])
      from_to[2:0] <=jc[3:1];
   else if (~jc[0])
      from_to[5:3] <=jc[6:4];
end

debounce my_deb(.clock_in(clk_100mhz),
            .reset_in(btnd),
```

```
                .noisy_in(btnc),
                .clean_out(clean),
                .ready(sig_readdy2));

   serial_tx my_tx(.clk_in(clk_100mhz),
                .rst_in(btnd),
                .trigger_in(clean&~old_clean),
                .val_in(computer_out),//should be data to computer
                .data_out(ja[6]));


  // Communication with the fsm
  // input: final_positions
  // output:


  chess_fsm my_fsm(
  .clk_100mhz(clk_100mhz),
  .rst_in(btnd),
  .player_first(1),
  .board_state(final_positions),
  .board_state_ready(board_state_ready),

  .opponents_move(computer_out),
  .from_to(from_to),
  .invalid_state(wrong_move));

endmodule



module debounce (input reset_in, clock_in, noisy_in,
              output reg clean_out,reg ready);

  reg [19:0] count;
  reg new_input;

  always_ff @(posedge clock_in)
    if (reset_in) begin
       new_input <= noisy_in;
       clean_out <= noisy_in;
       count <= 0;
       ready <=0; end
    else if (noisy_in != new_input) begin new_input<=noisy_in; count <= 0;
       ready <=0;
       end
    else if (count == 1000) begin clean_out <= new_input;
        ready <=1;
        end
    else begin count <= count+1;
       ready <=0;
       end
```

```
endmodule

module serial_tx(   input          clk_in,
                    input          rst_in,
                    input          trigger_in,
                    input [7:0]     val_in,
                    output logic    data_out);
   parameter   DIVISOR = 868; //treat this like a constant!!

   logic [9:0]        shift_buffer; //10 bits...interesting
   logic [31:0]       count;
   logic [8:0]        count2 =0;
   logic              started=0;
   always @(posedge clk_in)begin
      if (trigger_in) begin
         count<=0;
         started<=1;
         count2 <=0;
         shift_buffer<={1'b1,val_in,1'b0};
         data_out<=1;
                  end
      if (rst_in) begin
                  count<=0;
                  shift_buffer<={1'b1,val_in,1'b0};
                  started<=0;
                  count2 <=0;
                  end
      else if (started) begin
         if (count<DIVISOR)
            count<=count+1;
         else if(count2==11)
            started<=0;
         else begin
            count<=0;
            count2 <=count2+1;
            data_out<=shift_buffer[0];
            shift_buffer<={shift_buffer[0],shift_buffer[7:1]};
            end
         end
   end
endmodule


//FSM MODULE

module chess_fsm(
   input clk_100mhz,
   input rst_in,
   input player_first,
   input [63:0] board_state,
   input board_state_ready,
```

```
output logic opponents_move,
output logic [7:0] from_to,
output logic invalid_state
);

//ai_comms ai_uart(.from_to_player(),.sent_val());

logic game_started = 1'b0;
logic orientation = ~player_first;
// Orientation 0:
// Black (opponent)
// White (player)

// Orientation 1:
// Black (player)
// White (opponent)
logic player_move;
logic [63:0] prev_board_state;
logic [3:0] chess_fsm [63:0];
// 0XXX Player 1XXX Opponent
// X000 Empty
// X001 Pawn
// X010 Rook
// X011 Knight
// X100 Bishop
// X101 Queen
// X110 King
// X111 Pawn -> XXXX
logic [2:0] game_state;
// 0XX Player, 1XX Opponent
// X00 X's Move
// X01 Moving
// X10 Attacking
// X11 Castling
logic invalid_state = 1'b0;
logic [3:0] lifted1_type;
logic [5:0] lifted1_loc;
logic [3:0] lifted2_type;
logic [5:0] lifted2_loc;

logic [5:0] player_king_loc;
logic [5:0] opponent_king_loc;

function valid_move;
   input [63:0] prev_board_state; //Moving piece shouldn't exist
   input [2:0] piece_type;
   input [5:0] old_loc;
   input [5:0] new_loc;
   input attacking;
   begin
      reg [5:0] bigger_loc;
```

```
        reg [5:0] smaller_loc;
        reg [5:0] difference;
        reg moving_up;
        reg [2:0] old_loc_col;
        reg hits_right_in_1;
        reg hits_left_in_1;
        reg hits_right_in_2;
        reg hits_left_in_2;
        if (new_loc > old_loc) begin
          bigger_loc = new_loc;
          smaller_loc = old_loc;
          moving_up = 1'b1;
        end else begin
          bigger_loc = old_loc;
          smaller_loc = new_loc;
          moving_up = 1'b0;
        end
        difference = bigger_loc - smaller_loc;
        old_loc_col = old_loc % 8;
        hits_right_in_1 = old_loc_col == 0;
        hits_left_in_1 = old_loc_col == 7;
        hits_right_in_2 = old_loc_col == 1;
        hits_left_in_2 = old_loc_col == 6;
        case (piece_type)
          3'b000: begin //Empty moves (complete)
            valid_move = 1'b0;
          end
          3'b001: begin //Pawn moves (complete)
            //Pawn moves up if vvv else, pawn moves down
            if (orientation ^ player_move) begin //player on bottom moving up, or opponent on bottom moving up
              if (~moving_up) begin
                valid_move = 1'b0;
              end else begin
                if (attacking) begin //Pawn is attacking
                  if ((difference == 7 && ~hits_right_in_1) || (difference == 9 && ~hits_left_in_1)) begin
                    valid_move = 1'b1;
                  end else begin
                    valid_move = 1'b0;
                  end
                end else begin //Pawn is not attacking
                  if (new_loc == old_loc + 8 || (old_loc < 16 && new_loc == old_loc + 16)) begin //Pawn moved
correctly
                    valid_move = 1'b1;
                  end else begin //Pawn moved incorrectly
                    valid_move = 1'b0;
                  end
                end
              end
            end else begin //Pawn should be moving down -----
              if (moving_up) begin
                valid_move = 1'b0;
              end else begin
```

```
                if (attacking) begin //Pawn is attacking
                    if ((difference == 7 && ~hits_left_in_1) || (difference == 9 && ~hits_right_in_1)) begin
                        valid_move = 1'b1;
                    end else begin
                        valid_move = 1'b0;
                    end
                end else begin //Pawn is not attacking
                    if (new_loc == old_loc - 8 || (old_loc >= 48 && new_loc == old_loc - 16)) begin //Pawn moved
correctly
                        valid_move = 1'b1;
                    end else begin //Pawn moved incorrectly
                        valid_move = 1'b0;
                    end
                end
            end
        end
        3'b010: begin //Rook moves (complete)
            if (difference % 8 == 0) begin
                valid_move = 1'b1;
                if (moving_up) begin //Piece collision detection
                    for (int i = 0; i < 8; i++) begin
                        if (prev_board_state[8*i + (new_loc % 8)] & 8*i + (new_loc % 8) > old_loc & 8*i + (new_loc % 8) <
new_loc) begin
                            valid_move = 1'b0;
                        end
                    end
                end else begin
                    for (int i = 0; i < 8; i++) begin
                        if (prev_board_state[8*i + (new_loc % 8)] & 8*i + (new_loc % 8) > new_loc & 8*i + (new_loc % 8)
< old_loc) begin
                            valid_move = 1'b0;
                        end
                    end
                end
            end else begin
                valid_move = 1'b1;
                if (new_loc > old_loc) begin
                    for (int i = 0; i < 8; i++) begin //Piece collision detection
                        if (prev_board_state[new_loc - (new_loc % 8) + i] & new_loc - (new_loc % 8) + i > old_loc &
new_loc - (new_loc % 8) + i < new_loc) begin
                            valid_move = 1'b0;
                        end
                    end
                end else begin
                    for (int i = 0; i < 8; i++) begin //Piece collision detection
                        if (prev_board_state[new_loc - (new_loc % 8) + i] & new_loc - (new_loc % 8) + i < old_loc &
new_loc - (new_loc % 8) + i > new_loc) begin
                            valid_move = 1'b0;
                        end
                    end
                end
```

```
      if (old_loc >= 8 & new_loc >= 8) begin
        if (old_loc < new_loc) begin
          old_loc = old_loc - (old_loc - (old_loc%8));
          new_loc = new_loc - (old_loc - (old_loc%8));
        end else begin
          old_loc = old_loc - (new_loc - (new_loc%8));
          new_loc = new_loc - (new_loc - (new_loc%8));
        end
      end
      if (old_loc < 8 & new_loc < 8 & valid_move != 1'b0) begin
        valid_move = 1'b1;
      end else begin
        valid_move = 1'b0;
      end
    end
  end
  3'b011: begin //Knight moves (complete)
    if (difference == 6 & ((moving_up & ~hits_right_in_2) | (~moving_up & ~hits_left_in_2)) |
      difference == 10 & ((moving_up & ~hits_left_in_2) | (~moving_up & ~hits_right_in_2)) |
      difference == 15 & ((moving_up & ~hits_right_in_1) | (~moving_up & ~hits_left_in_1)) |
      difference == 17 & ((moving_up & ~hits_left_in_1) | (~moving_up & ~hits_right_in_1)) ) begin
      valid_move = 1'b1;
    end else begin
      valid_move = 1'b0;
    end
  end
  3'b100: begin //Bishop moves (complete)
    valid_move = 1'b0; //Should be default value here
    for (int i = 1; i < 8 - old_loc_col; i++) begin //Check for validity on columns to left
      if ((new_loc == old_loc + 9*i) || (new_loc == old_loc - 7*i)) begin
        valid_move = 1'b1;
      end
    end
    for (int j = 1; j <= old_loc_col; j++) begin //Check for validity on columns to right
      if ((new_loc == old_loc - 9*j) || (new_loc == old_loc + 7*j)) begin
        valid_move = 1'b1;
      end
    end
    if (valid_move) begin //Piece collision detection
      if (moving_up) begin
        if (difference % 9 == 0) begin //Northwest
          for (int k = 1; k < 8 - old_loc_col; k++) begin //Check for validity on columns to left
            if (prev_board_state[old_loc + 9*k]) begin
              valid_move = 1'b0;
            end
          end
        end else begin //Northeast
          for (int k = 1; k <= old_loc_col; k++) begin //Check for validity on columns to right
            if (prev_board_state[old_loc + 7*k]) begin
              valid_move = 1'b0;
            end
          end
```

```
        end
      end else begin
        if (difference % 9 == 0) begin //Southeast
          for (int k = 1; k <= old_loc_col; k++) begin //Check for validity on columns to right
            if (prev_board_state[old_loc - 9*k]) begin
              valid_move = 1'b0;
            end
          end
        end else begin //Southwest
          for (int k = 1; k < 8 - old_loc_col; k++) begin //Check for validity on columns to left
            if (prev_board_state[old_loc - 7*k]) begin
              valid_move = 1'b0;
            end
          end
        end
      end
    end
  end
  3'b101: begin //Queen moves (combine bishop and rook code)
    valid_move = 1'b0; //Should be default value here
    //vvv Bishop check vvv
    for (int i = 1; i < 8 - old_loc_col; i++) begin //Check for validity on columns to left
      if ((new_loc == old_loc + 9*i) || (new_loc == old_loc - 7*i)) begin
        valid_move = 1'b1;
      end
    end
    for (int j = 1; j <= old_loc_col; j++) begin //Check for validity on columns to right
      if ((new_loc == old_loc - 9*j) || (new_loc == old_loc + 7*j)) begin
        valid_move = 1'b1;
      end
    end
    if (valid_move) begin //Piece collision detection
      if (moving_up) begin
        if (difference % 9 == 0) begin //Northwest
          for (int k = 1; k < 8 - old_loc_col; k++) begin //Check for validity on columns to left
            if (prev_board_state[old_loc + 9*k]) begin
              valid_move = 1'b0;
            end
          end
        end else begin //Northeast
          for (int k = 1; k <= old_loc_col; k++) begin //Check for validity on columns to right
            if (prev_board_state[old_loc + 7*k]) begin
              valid_move = 1'b0;
            end
          end
        end
      end else begin
        if (difference % 9 == 0) begin //Southeast
          for (int k = 1; k <= old_loc_col; k++) begin //Check for validity on columns to right
            if (prev_board_state[old_loc - 9*k]) begin
              valid_move = 1'b0;
            end
```

```
                    end
                  end else begin //Southwest
                    for (int k = 1; k < 8 - old_loc_col; k++) begin //Check for validity on columns to left
                      if (prev_board_state[old_loc - 7*k]) begin
                        valid_move = 1'b0;
                      end
                    end
                  end
                end
                //vvv Rook check vvv
                if (~valid_move) begin //Failed to find valid bishop route
                  if (difference % 8 == 0) begin
                    valid_move = 1'b1;
                    if (moving_up) begin //Piece collision detection
                      for (int i = 0; i < 8; i++) begin
                        if (prev_board_state[8*i + (new_loc % 8)] & 8*i + (new_loc % 8) > old_loc & 8*i + (new_loc % 8)
< new_loc) begin
                          valid_move = 1'b0;
                        end
                      end
                    end else begin
                      for (int i = 0; i < 8; i++) begin
                        if (prev_board_state[8*i + (new_loc % 8)] & 8*i + (new_loc % 8) > new_loc & 8*i + (new_loc %
8) < old_loc) begin
                          valid_move = 1'b0;
                        end
                      end
                    end
                  end else begin
                    valid_move = 1'b1;
                    if (new_loc > old_loc) begin
                      for (int i = 0; i < 8; i++) begin //Piece collision detection
                        if (prev_board_state[new_loc - (new_loc % 8) + i] & new_loc - (new_loc % 8) + i > old_loc &
new_loc - (new_loc % 8) + i < new_loc) begin
                          valid_move = 1'b0;
                        end
                      end
                    end else begin
                      for (int i = 0; i < 8; i++) begin //Piece collision detection
                        if (prev_board_state[new_loc - (new_loc % 8) + i] & new_loc - (new_loc % 8) + i < old_loc &
new_loc - (new_loc % 8) + i > new_loc) begin
                          valid_move = 1'b0;
                        end
                      end
                    end
                    if (old_loc >= 8 & new_loc >= 8) begin
                      if (old_loc < new_loc) begin
                        old_loc = old_loc - (old_loc - (old_loc%8));
                        new_loc = new_loc - (old_loc - (old_loc%8));
                      end else begin
                        old_loc = old_loc - (new_loc - (new_loc%8));
```

```
                    new_loc = new_loc - (new_loc - (new_loc%8));
                  end
                end
                if (old_loc < 8 & new_loc < 8 & valid_move != 1'b0) begin
                  valid_move = 1'b1;
                end else begin
                  valid_move = 1'b0;
                end
              end
            end

          end
          3'b110: begin //King moves (complete)
            if (difference == 1 & ((moving_up & ~hits_left_in_1) | (~moving_up & ~hits_right_in_1)) | //Moved to
right (not hitting edge) or Moved to left (not hitting edge)
              difference == 7 & ((moving_up & ~hits_right_in_1) | (~moving_up & ~hits_left_in_1)) |
              difference == 8 |
              difference == 9 & ((moving_up & ~hits_left_in_1) | (~moving_up & ~hits_right_in_1)) ) begin
              valid_move = 1'b1;
            end else begin
              valid_move = 1'b0;
            end
          end
          3'b111: begin //Transitioning Pawn moves (Knight and Queen ability (will get upgraded by FSM after
first move))
            valid_move = 1'b0; //Should be default value here
            //vvv Bishop check vvv
            for (int i = 1; i < 8 - old_loc_col; i++) begin //Check for validity on columns to left
              if ((new_loc == old_loc + 9*i) || (new_loc == old_loc - 7*i)) begin
                valid_move = 1'b1;
              end
            end
            for (int j = 1; j <= old_loc_col; j++) begin //Check for validity on columns to right
              if ((new_loc == old_loc - 9*j) || (new_loc == old_loc + 7*j)) begin
                valid_move = 1'b1;
              end
            end
            if (valid_move) begin //Piece collision detection
              if (moving_up) begin
                if (difference % 9 == 0) begin //Northwest
                  for (int k = 1; k < 8 - old_loc_col; k++) begin //Check for validity on columns to left
                    if (prev_board_state[old_loc + 9*k]) begin
                      valid_move = 1'b0;
                    end
                  end
                end else begin //Northeast
                  for (int k = 1; k <= old_loc_col; k++) begin //Check for validity on columns to right
                    if (prev_board_state[old_loc + 7*k]) begin
                      valid_move = 1'b0;
                    end
                  end
                end
```

```
                end else begin
                    if (difference % 9 == 0) begin //Southeast
                        for (int k = 1; k <= old_loc_col; k++) begin //Check for validity on columns to right
                            if (prev_board_state[old_loc - 9*k]) begin
                                valid_move = 1'b0;
                            end
                        end
                    end else begin //Southwest
                        for (int k = 1; k < 8 - old_loc_col; k++) begin //Check for validity on columns to left
                            if (prev_board_state[old_loc - 7*k]) begin
                                valid_move = 1'b0;
                            end
                        end
                    end
                end
            end
            //vvv Rook check vvv
            if (~valid_move) begin //Failed to find valid bishop route
                if (difference % 8 == 0) begin
                    valid_move = 1'b1;
                    if (moving_up) begin //Piece collision detection
                        for (int i = 0; i < 8; i++) begin
                            if (prev_board_state[8*i + (new_loc % 8)] & 8*i + (new_loc % 8) > old_loc & 8*i + (new_loc % 8)
< new_loc) begin
                                valid_move = 1'b0;
                            end
                        end
                    end else begin
                        for (int i = 0; i < 8; i++) begin
                            if (prev_board_state[8*i + (new_loc % 8)] & 8*i + (new_loc % 8) > new_loc & 8*i + (new_loc %
8) < old_loc) begin
                                valid_move = 1'b0;
                            end
                        end
                    end
                end else begin
                    valid_move = 1'b1;
                    if (new_loc > old_loc) begin
                        for (int i = 0; i < 8; i++) begin //Piece collision detection
                            if (prev_board_state[new_loc - (new_loc % 8) + i] & new_loc - (new_loc % 8) + i > old_loc &
new_loc - (new_loc % 8) + i < new_loc) begin
                                valid_move = 1'b0;
                            end
                        end
                    end else begin
                        for (int i = 0; i < 8; i++) begin //Piece collision detection
                            if (prev_board_state[new_loc - (new_loc % 8) + i] & new_loc - (new_loc % 8) + i < old_loc &
new_loc - (new_loc % 8) + i > new_loc) begin
                                valid_move = 1'b0;
                            end
                        end
                    end
```

```
                if (old_loc >= 8 & new_loc >= 8) begin
                  if (old_loc < new_loc) begin
                    old_loc = old_loc - (old_loc - (old_loc%8));
                    new_loc = new_loc - (old_loc - (old_loc%8));
                  end else begin
                    old_loc = old_loc - (new_loc - (new_loc%8));
                    new_loc = new_loc - (new_loc - (new_loc%8));
                  end
                end
                if (old_loc < 8 & new_loc < 8 & valid_move != 1'b0) begin
                  valid_move = 1'b1;
                end else begin
                  valid_move = 1'b0;
                end
              end
            end
            //vvv Knight check vvv (only works because we don't use old_loc or new_loc anymore
            if (difference == 6 & ((moving_up & ~hits_right_in_2) | (~moving_up & ~hits_left_in_2)) |
              difference == 10 & ((moving_up & ~hits_left_in_2) | (~moving_up & ~hits_right_in_2)) |
              difference == 15 & ((moving_up & ~hits_right_in_1) | (~moving_up & ~hits_left_in_1)) |
              difference == 17 & ((moving_up & ~hits_left_in_1) | (~moving_up & ~hits_right_in_1)) ) begin
              valid_move = 1'b1;
            end
          end
        endcase
      end
    endfunction

    always_ff @(posedge clk_100mhz) begin
      if (rst_in) begin
        game_started <= 1'b0;
      end else begin
        if (board_state_ready) begin //Only run game logic on valid board_states
          if (game_started) begin //usual logic fsm
            if (board_state != prev_board_state) begin //Something has changed on the board, and the board was
valid prior
              if (~invalid_state) begin
                automatic reg [63:0] board_change = board_state ^ prev_board_state;
                automatic reg [5:0] loc_change; //Where the change was detected
                automatic reg update_state = 1'b1;
                for (int i = 63; i > 0; i--) begin
                  if (board_change[i]) begin
                    loc_change = i;
                  end
                end

                case (game_state)
                  3'b000: begin //Player Move
                    if (board_state[loc_change]) begin //A piece was placed down (WE DON'T CURRENTLY
SUPPORT PIECE PLACE PRIOR TO PROMOTION)
                      invalid_state <= 1'b1;
                      update_state = 1'b0;
```

```
                    end else begin
                        lifted1_type <= chess_fsm[loc_change]; //Which piece was lifted first
                        lifted1_loc <= loc_change; //Where was it lifted from
                        if (chess_fsm[loc_change][3]) begin //An opponent's piece was lifted
                            game_state <= 3'b010; //Player is attacking
                        end else begin //A player's piece was lifted
                            game_state <= 3'b001; //Player is moving
                        end
                    end
                end
                3'b001: begin //Player is moving
                    if (loc_change == lifted1_loc) begin //Piece was placed back down in same spot. Go back to
player's turn
                        game_state <= 3'b000;
                        lifted1_type <= 4'b0000;
                    end else begin
                        if (board_state[loc_change]) begin  //A piece was placed down (Player has made their move)
                            //Test for move validity and check/checkmate. Otherwise, make the change and tell uart
about it
                            if (valid_move(prev_board_state,lifted1_type[2:0],lifted1_loc,loc_change,1'b0)) begin
                                //Virtually make the move (send game_state to valid_move w/ updated king_loc if
necessary)
                                //Make sure the king is safe
                                //  If he is, write to fsm + forward to uart
                                //  If not, enter invalid state
                                for (int i = 0; i < 64; i++) begin
                                    if (chess_fsm[i][3]) begin //Opponent's piece
                                        //If their exists an opponent piece which is capable of attacking the player's king,
this move is invalid
                                        if (valid_move(board_state, chess_fsm[i][2:0], i, lifted1_type[2:0] == 3'b110 ?
loc_change : player_king_loc, 1'b1)) begin
                                            invalid_state <= 1'b1;
                                            update_state = 1'b0;
                                        end
                                    end
                                end
                                if (update_state) begin //Player is not in check, and their move was valid
                                    if (lifted1_type[2:0] == 3'b110) begin //Update the king position if needed
                                        player_king_loc <= loc_change;
                                    end
                                    chess_fsm[lifted1_loc] <= 4'b0000; //Clear out the original piece location
                                    chess_fsm[loc_change] <= lifted1_type; //Fill in the new piece location
                                    //Send stuff to UART
                                    game_state <= 3'b000; //Change back to 3'b100
                                    lifted1_type <= 4'b0000;
                                    player_move <= 1'b0;
                                end
                            end else begin //Player made an invalid move
                                invalid_state <= 1'b1;
                                update_state = 1'b0;
                            end
                        end else begin //Player is either attacking or castling (piece was lifted)
```

```
                        if (chess_fsm[loc_change][3]) begin //They lifted an opponent piece, and are attacking
                            //Go ahead and put black in buffer 1 + switch
                            //With opponent in buffer 1, we can guarantee that buffer 2 will be empty if both pieces
aren't lifted
                            lifted2_type <= lifted1_type;
                            lifted2_loc <= lifted1_loc;
                            lifted1_type <= chess_fsm[loc_change];
                            lifted1_loc <= loc_change;
                            game_state <= 4'b010;
                        end else begin //They lifted another of their own pieces, must be castling
                            automatic reg king_1_orig = (lifted1_type == 4'b0110) & ((lifted1_loc == 3 & orientation
== 0) | (lifted1_loc == 59 & orientation == 1));
                            automatic reg king_2_orig = (chess_fsm[loc_change] == 4'b0110) & ((loc_change == 3 &
orientation == 0) | (loc_change == 59 & orientation == 1));
                            automatic reg rook_1_orig = (lifted1_type == 4'b0010) & (((lifted1_loc == 0 | lifted1_loc
== 7) & orientation == 0) | ((lifted1_loc == 56 | lifted1_loc == 63) & orientation == 1));
                            automatic reg rook_2_orig = (chess_fsm[loc_change] == 4'b0010) & (((loc_change == 0 |
loc_change == 7) & orientation == 0) | ((loc_change == 56 | loc_change == 63) & orientation == 1));
                            if ((king_1_orig & rook_2_orig) | (king_2_orig & rook_1_orig)) begin
                                lifted2_type <= chess_fsm[loc_change];
                                lifted2_loc <= loc_change;
                                game_state <= 3'b011;
                            end else begin
                                invalid_state <= 1'b1;
                                update_state = 1'b0;
                            end
                        end
                    end
                end
            end
            3'b010: begin //Player is attacking (Assumed that buffers are (opponent at 1 and player at 2)
                if (lifted2_type == 4'b0000) begin //entered by lifting a black piece
                    if (game_state[loc_change]) begin //A piece was placed down (better be same piece in same
spot)
                        if (loc_change == lifted1_loc) begin
                            lifted1_type <= 4'b0000;
                            game_state <= 3'b000;
                        end else begin
                            invalid_state <= 1'b1;
                            update_state = 1'b0;
                        end
                    end else begin //Another piece was lifted (better be their own piece)
                        if (chess_fsm[loc_change][3]) begin //Lifted another black piece
                            invalid_state <= 1'b1;
                            update_state = 1'b0;
                        end else begin //Lifted one of their own pieces
                            lifted2_type <= chess_fsm[loc_change];
                            lifted2_loc <= loc_change;
                        end
                    end
                end else begin //entered by lifting a white piece then a black piece (black still in spot 1)
```

```
                        if (game_state[loc_change]) begin //A piece was placed down (better be in same spot as
black)
                          if (loc_change == lifted1_loc) begin //Correct
                            if (valid_move(prev_board_state,lifted2_type[2:0],lifted2_loc,loc_change,1'b1)) begin
//Prev is both lifted (no collision)
                              //Virtually make the move (send game_state to valid_move w/ updated king_loc if
necessary)
                              //Make sure the king is safe
                              //  If he is, write to fsm + forward to uart
                              //  If not, enter invalid state
                              for (int i = 0; i < 64; i++) begin
                                if (chess_fsm[i][3]) begin //Opponent's piece
                                  //If their exists an opponent piece which is capable of attacking the player's king,
this move is invalid
                                  if (valid_move(board_state, chess_fsm[i][2:0], i, lifted2_type[2:0] == 3'b110 ?
loc_change : player_king_loc, 1'b1)) begin
                                    invalid_state <= 1'b1;
                                    update_state = 1'b0;
                                  end
                                end
                              end
                              if (update_state) begin //Player is not in check, and their move was valid
                                if (lifted2_type[2:0] == 3'b110) begin //Update the king position if needed
                                  player_king_loc <= loc_change;
                                end
                                chess_fsm[lifted2_loc] <= 4'b0000; //Clear out the original piece location
                                chess_fsm[loc_change] <= lifted2_type; //Fill in the new piece location
                                //Send stuff to UART
                                game_state <= 3'b000; //Change back to 3'b100
                                lifted1_type <= 4'b0000;
                                lifted2_type <= 4'b0000;
                                player_move <= 1'b0;
                              end
                            end else begin //Piece was moved improperly
                              invalid_state <= 1'b1;
                              update_state = 1'b0;
                            end
                          end else begin //Invalid
                            invalid_state <= 1'b1;
                            update_state = 1'b0;
                          end
                        end else begin //Really...A third piece. invalidated!
                          invalid_state <= 1'b1;
                          update_state = 1'b0;
                        end
                      end
                    end
                    3'b011: begin //Player is castling (Lift both pieces in question, then place them in the correct
spots [atomic move])
                      automatic reg castle_left = (orientation == 0 & (lifted1_loc == 7 | lifted2_loc == 7)) |
(orientation == 1 & (lifted1_loc == 63 | lifted2_loc == 63));
                      if (lifted2_type == 4'b0000) begin //Player has already placed one piece down
```

```
                        if (game_state[loc_change]) begin //Second piece is placed down
                            if ((orientation == 0 &  castle_left & loc_change == 5)  |
                                (orientation == 0 & ~castle_left & loc_change == 1)  |
                                (orientation == 1 &  castle_left & loc_change == 61) |
                                (orientation == 1 & ~castle_left & loc_change == 57)) begin //King was placed

                                if (valid_move(prev_board_state,4'b0010,lifted1_loc,loc_change,1'b0)) begin //Pretend
king is rook for validity checking (can move more than 1)
                                    chess_fsm[lifted1_loc] <= 4'b0000;
                                    chess_fsm[loc_change] <= 4'b0110;
                                    player_move <= 1'b0;
                                    game_state <= 3'b000; //Change back to 3'b100
                                    lifted1_type <= 4'b0000;
                                end else begin
                                    invalid_state <= 1'b1;
                                    update_state = 1'b0;
                                end
                            end else begin
                                if ((orientation == 0 &  castle_left & loc_change == 4)  |
                                    (orientation == 0 & ~castle_left & loc_change == 2)  |
                                    (orientation == 1 &  castle_left & loc_change == 60) |
                                    (orientation == 1 & ~castle_left & loc_change == 58)) begin //Rook was placed

                                    if (valid_move(prev_board_state,lifted1_type[2:0],lifted1_loc,loc_change,1'b0)) begin
                                        chess_fsm[lifted1_loc] <= 4'b0000;
                                        chess_fsm[loc_change] <= 4'b0010;
                                        player_move <= 1'b0;
                                        game_state <= 3'b000; //Change back to 3'b100
                                        lifted1_type <= 4'b0000;
                                    end else begin
                                        invalid_state <= 1'b1;
                                        update_state = 1'b0;
                                    end
                                end else begin //Placed them down in an invalid spot
                                    invalid_state <= 1'b1;
                                    update_state = 1'b0;
                                end
                            end
                        end else begin //Atomic operation. Once castling has begun, no re-lifting
                            invalid_state <= 1'b1;
                            update_state = 1'b0;
                        end
                    end else begin //Player has lifted both pieces at this point
                        if (game_state[loc_change]) begin //A piece was placed
                            if (loc_change == lifted1_loc | loc_change == lifted2_loc) begin //Piece was put back where
it started
                                if (loc_change == lifted1_loc) begin
                                    lifted1_loc <= lifted2_loc;
                                    lifted1_type <= lifted2_type;
                                end
                                lifted2_type <= 4'b0000;
                                game_state <= 3'b001;
```

```
                        end else begin //First piece was placed down
                            if ((orientation == 0 &  castle_left & loc_change == 5)  |
                                (orientation == 0 & ~castle_left & loc_change == 1)  |
                                (orientation == 1 &  castle_left & loc_change == 61) |
                                (orientation == 1 & ~castle_left & loc_change == 57)) begin //King was placed down
first (Pretend king is rook for validity)

                                if (lifted1_type == 4'b0110) begin //King is in 1 slot
                                    if (valid_move(prev_board_state,4'b0010,lifted1_loc,loc_change,1'b0)) begin
                                        chess_fsm[lifted1_loc] <= 4'b0000;
                                        chess_fsm[loc_change] <= 4'b0010;
                                    end else begin
                                        invalid_state <= 1'b1;
                                        update_state = 1'b0;
                                    end
                                    lifted1_loc <= lifted2_loc;
                                    lifted1_type <= lifted2_type;
                                end else begin //King is in 2 slot
                                    if (valid_move(prev_board_state,4'b0010,lifted2_loc,loc_change,1'b0)) begin
                                        chess_fsm[lifted2_loc] <= 4'b0000;
                                        chess_fsm[loc_change] <= 4'b0010;
                                    end else begin
                                        invalid_state <= 1'b1;
                                        update_state = 1'b0;
                                    end
                                end
                                lifted2_type <= 4'b0000;
                            end else begin
                                if ((orientation == 0 &  castle_left & loc_change == 4)  |
                                    (orientation == 0 & ~castle_left & loc_change == 2)  |
                                    (orientation == 1 &  castle_left & loc_change == 60) |
                                    (orientation == 1 & ~castle_left & loc_change == 58)) begin //Rook was placed down
first

                                    if (lifted1_type == 4'b0010) begin //Rook is in 1 slot
                                        if (valid_move(prev_board_state,lifted1_type[2:0],lifted1_loc,loc_change,1'b0))
begin
                                            chess_fsm[lifted1_loc] <= 4'b0000;
                                            chess_fsm[loc_change] <= 4'b0010;
                                        end else begin
                                            invalid_state <= 1'b1;
                                            update_state = 1'b0;
                                        end
                                        lifted1_loc <= lifted2_loc;
                                        lifted1_type <= lifted2_type;
                                    end else begin //Rook is in 2 slot
                                        if (valid_move(prev_board_state,lifted2_type[2:0],lifted2_loc,loc_change,1'b0))
begin
                                            chess_fsm[lifted2_loc] <= 4'b0000;
                                            chess_fsm[loc_change] <= 4'b0010;
                                        end else begin
                                            invalid_state <= 1'b1;
```

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                                update_state = 1'b0;
                              end
                            end
                            lifted2_type <= 4'b0000;
                          end else begin //Placed them down in an invalid spot
                            invalid_state <= 1'b1;
                          end
                        end
                        update_state = 1'b0; //Makes checking for move validity much easier
                      end
                    end else begin //Picked up a third piece. XD
                      invalid_state <= 1'b1;
                      update_state = 1'b0;
                    end
                  end
                end
                3'b100: begin //Opponent's turn
                end
                3'b101: begin //Opponent is moving
                end
                3'b110: begin //Opponent is attacking
                end
                3'b111: begin //Opponent is castling
                end
              endcase
              if (update_state) begin
                prev_board_state <= board_state;
              end
            end
          end else begin //States do match
            if (invalid_state) begin //Since we don't update prev_state when we detect invalid state, this means we have returned to the valid state
              invalid_state <= 1'b0;
            end
          end
        end else begin //Game has not started yet (reset has been pushed)
          automatic reg royal_rows_present = &board_state[63:56] & &board_state[7:0]; //The top/bottom rows are fully occupied
          automatic reg pawn_rows_present = &board_state[55:48] & &board_state[15:8]; //The pawn rows are fully occupied
          automatic reg other_rows_present = |board_state[47:16]; //There's something in the middle of the board
          if (royal_rows_present & pawn_rows_present & ~other_rows_present) begin //Valid starting state
            game_started <= 1'b1;
            prev_board_state <= board_state;
            if (player_first) begin
              game_state <= 3'b000; //Player's Move
              chess_fsm <= {{4'b1010},{4'b1011},{4'b1100},{4'b1101},{4'b1110},{4'b1100},{4'b1011},{4'b1010}, //Black opponent here
                            {4'b1001},{4'b1001},{4'b1001},{4'b1001},{4'b1001},{4'b1001},{4'b1001},{4'b1001},
                            {4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},
                            {4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},
```

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                        {4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},
                        {4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},
                        {4'b0001},{4'b0001},{4'b0001},{4'b0001},{4'b0001},{4'b0001},{4'b0001},{4'b0001},
                        {4'b0010},{4'b0011},{4'b0100},{4'b0101},{4'b0110},{4'b0100},{4'b0011},{4'b0010}};
//White player here
                    player_king_loc <= 3;
                    opponent_king_loc <= 59;
                    player_move <= 1'b1;
                  end else begin
                    game_state <= 3'b100; //Opponent's Move
                    chess_fsm <=
{{4'b0010},{4'b0011},{4'b0100},{4'b0101},{4'b0110},{4'b0100},{4'b0011},{4'b0010}, //Black player here
                        {4'b0001},{4'b0001},{4'b0001},{4'b0001},{4'b0001},{4'b0001},{4'b0001},{4'b0001},
                        {4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},
                        {4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},
                        {4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},
                        {4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},{4'b0000},
                        {4'b1001},{4'b1001},{4'b1001},{4'b1001},{4'b1001},{4'b1001},{4'b1001},{4'b1001},
                        {4'b1010},{4'b1011},{4'b1100},{4'b1101},{4'b1110},{4'b1100},{4'b1011},{4'b1010}};
//White opponent here
                    player_king_loc <= 59;
                    opponent_king_loc <= 3;
                    player_move <= 1'b0;
                  end
                end
              end
            end
          end
        end
endmodule

module ai_uart(
  input [7:0] from_to_player,
  input send_val,

  output [7:0] from_to_ai,
  output rcv_val
  );


endmodule
```