2025 Digital IC Design Homework 2

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Functional Simulation Result

Pattern1	Pattern2	Pattern3	Pattern4	Pattern5
Pass	Pass	Pass	Pass	Pass

Pattern 1

```
VSIM 2> run -all
# All data have been generated successfully!
#
#                    ////////////////////////
#                    /                      /       |__||
#                    /  Congratulations !!  /      / O.O  |
#                    /                      /    /_____   |
#                    /  Simulation PASS !!  /   /^ ^ ^ \  |
#                    /                      /  |^ ^ ^ ^ |w|
#                    ////////////////////////   \m___m__|_|
#
#
# ** Note: $finish    : E:/GG/Code/DIC_HW/HW2/file/testfixture.sv(162)
#    Time: 1315 ns  Iteration: 0  Instance: /testfixture
```

Pattern 2

```
VSIM 5> run -all
# All data have been generated successfully!
#
#                    ////////////////////////
#                    /                      /       |__||
#                    /  Congratulations !!  /      / O.O  |
#                    /                      /    /_____   |
#                    /  Simulation PASS !!  /   /^ ^ ^ \  |
#                    /                      /  |^ ^ ^ ^ |w|
#                    ////////////////////////   \m___m__|_|
#
#
# ** Note: $finish    : E:/GG/Code/DIC_HW/HW2/file/testfixture.sv(162)
#    Time: 1565 ns  Iteration: 0  Instance: /testfixture
```

Pattern 3

```
VSIM 8> run -all
# All data have been generated successfully!
#
#                    ////////////////////////
#                    /                      /       |__||
#                    /  Congratulations !!  /      / O.O  |
#                    /                      /    /_____   |
#                    /  Simulation PASS !!  /   /^ ^ ^ \  |
#                    /                      /  |^ ^ ^ ^ |w|
#                    ////////////////////////   \m___m__|_|
#
#
# ** Note: $finish    : E:/GG/Code/DIC_HW/HW2/file/testfixture.sv(162)
#    Time: 1685 ns  Iteration: 0  Instance: /testfixture
```

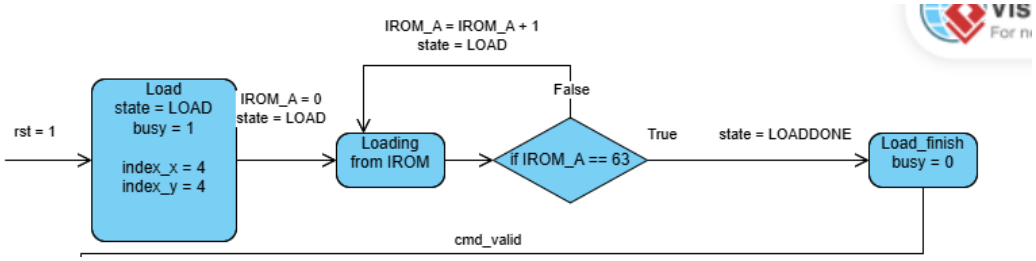
Pattern 4

```
VSIM 11> run -all
# All data have been generated successfully!
#
#                    //////////////////////////
#                    /                       /       |__||
#                    /  Congratulations !!   /      / O.O  |
#                    /                       /    /_____   |
#                    /  Simulation PASS !!   /   /^ ^ ^ \  |
#                    /                       /  |^ ^ ^ ^ |w|
#                    //////////////////////////   \m___m__|_|
#
#
# ** Note: $finish    : E:/GG/Code/DIC_HW/HW2/file/testfixture.sv(162)
#    Time: 1805 ns  Iteration: 0  Instance: /testfixture
```

Pattern 5

```
VSIM 13> run -all
# All data have been generated successfully!
#
#                    //////////////////////////
#                    /                       /       |__||
#                    /  Congratulations !!   /      / O.O  |
#                    /                       /    /_____   |
#                    /  Simulation PASS !!   /   /^ ^ ^ \  |
#                    /                       /  |^ ^ ^ ^ |w|
#                    //////////////////////////   \m___m__|_|
#
#
# ** Note: $finish    : E:/GG/Code/DIC_HW/HW2/file/testfixture.sv(162)
#    Time: 2345 ns  Iteration: 0  Instance: /testfixture
```

LCD_CTRL Finite-State Machine Design:



我把有限狀態機拆成多個 **submachine,** 第一部分是 **load** 區域，只有處理完 **load(state = LOADDONE)**才能讀取/執行指令。**rst** 進來之後，**state** 設為 **LOAD** 先維持住 **Load** 狀態，每次 **clk** 遞增 **IROM_A**，讀取 **IROM_Q**，存到 **LCD controller** 的 **memory**。直到 **IROM_A==63**，也會讀取 **IROM_Q**，再下一個 **clk** 之後才會改變狀態為 **LOADDONE**。說明 **Load** 結束

```
always @(posedge clk) begin
    if (state == LOAD) begin
        memory[IROM_A] <= IROM_Q;
    end
end

always @(posedge clk or posedge rst) begin
    if (rst) begin
        IROM_rd   <= 1'b1;  // 复位后立刻开始读 IROM
        IROM_A    <= 6'd0;  // 地址从 0 开始
        state     <= LOAD;
        busy      <= 1'b1;
        done      <= 1'b0;
        index_x   <= 4;
        index_y   <= 4;
    end else begin
        case (state)
            LOAD: begin
                // 存入 memory
                if (IROM_A == 6'd63) begin
                    IROM_rd <= 1'b0;  // 读取完成
                    state   <= LOADDONE;  // 进入下一个阶段
                    busy  <= 1'b0;
                end else begin
                    IROM_A <= IROM_A + 1;  // 地址递增
                end
            end

            LOADDONE: begin
                IROM_A <= 6'd0;
            end
        endcase
    end
end
```

==========

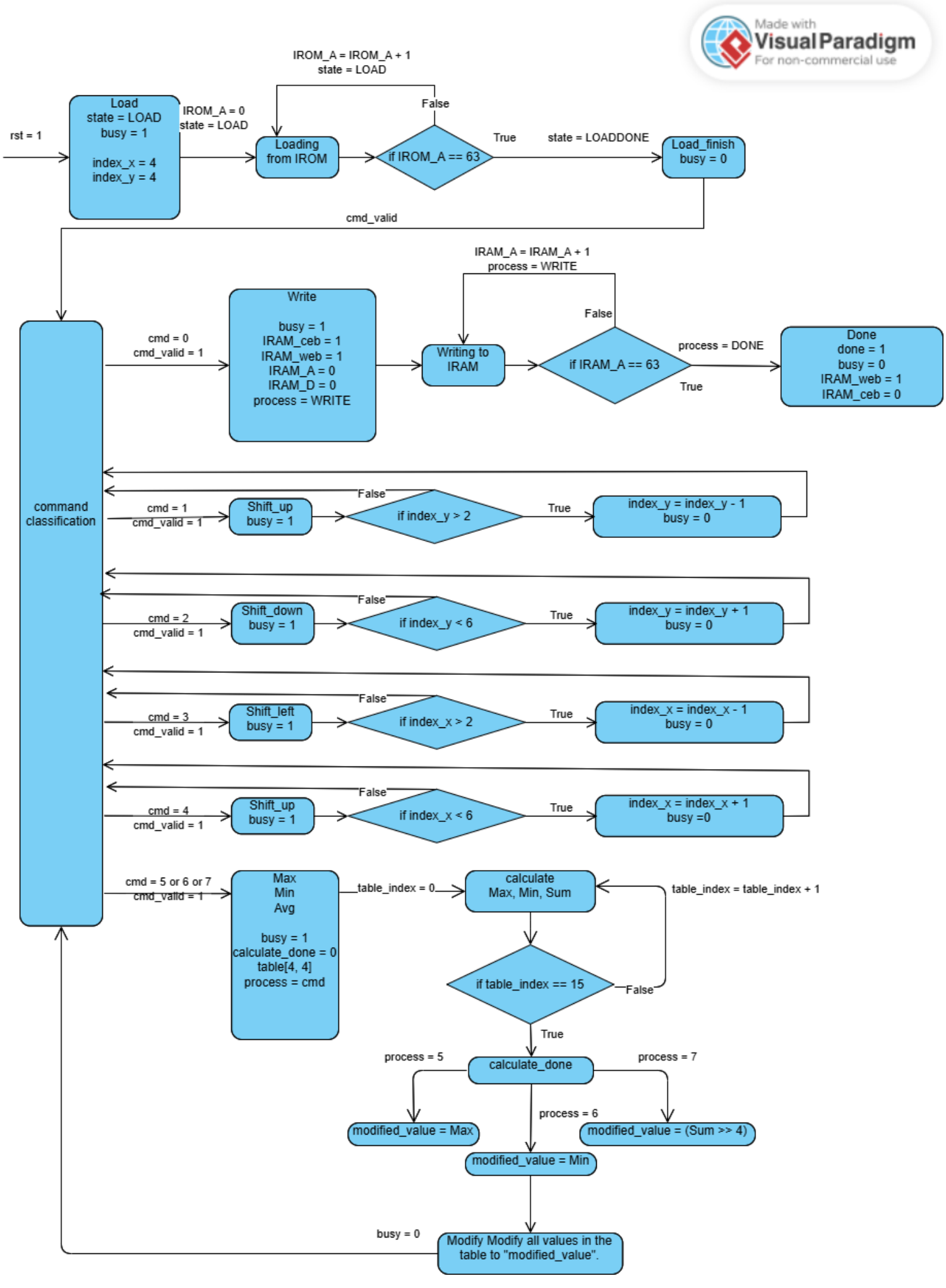
cmd 和 cmd_valid 進來時，有一個 command classification 分類 cmd 當遇到 Write/Max/Min/Avg 會 hold cmd 與初始化 4 * 4 的 table。遇到 shift 就簡單的變化 index_x 與 index_y。

```
always @(posedge clk) begin
    if (cmd_valid && state == LOADDONE && !busy) begin
        busy  <= 1'b1;
        done  <= 1'b0;
        count <= 6'd0;

        case (cmd)
            WRITE: begin
                IRAM_ceb <= 1'b1;
                IRAM_web <= 1'b0;
                IRAM_A   <= 6'd0;
                IRAM_D   <= 8'd0;
                process  <= WRITE;
            end


            SHIFT_UP: begin
                if (index_y > 2) begin
                    index_y <= index_y - 1;
                end
                process = SHIFT_UP;
            end

            SHIFT_DOWN: begin
                if (index_y < 6) begin
                    index_y <= index_y + 1;
                end
                process = SHIFT_DOWN;
            end

            SHIFT_LEFT: begin
                if (index_x > 2) begin
                    index_x <= index_x - 1;
                end
                process = SHIFT_LEFT;
            end

            SHIFT_RIGHT: begin
                if (index_x < 6) begin
                    index_x <= index_x + 1;
                end
                process = SHIFT_RIGHT;
            end

            MAX, MIN, AVG: begin
                region_memory = {
                    memory[8 * index_y + index_x - 18], memory[8 * index_y + index_x - 17],
                    memory[8 * index_y + index_x - 16], memory[8 * index_y + index_x - 15],
                    memory[8 * index_y + index_x - 10], memory[8 * index_y + index_x - 9],
                    memory[8 * index_y + index_x - 8 ], memory[8 * index_y + index_x - 7],
                    memory[8 * index_y + index_x - 2 ], memory[8 * index_y + index_x - 1],
                    memory[8 * index_y + index_x     ], memory[8 * index_y + index_x + 1],
                    memory[8 * index_y + index_x + 6 ], memory[8 * index_y + index_x + 7],
                    memory[8 * index_y + index_x + 8 ], memory[8 * index_y + index_x + 9]
                };
                cmd_count <= 4'd0;
                process = cmd;
                calculate_done = 1'b0;

            end
            default: begin
            end
        endcase
    end
end
```

==========

接著就是執行長的指令(Write/Min/Max/Avg)， “process” 變數會儲存 hold cmd。Write 時，每個 clk，一步一步的將 LCD memory 的值傳給 IRAM，Write 完即回傳 Done。Min/Max/Avg 時，針對 4*4 的 table，一步一步運算，最後再寫回去 LCD memory，完成後 busy = 0。Shift 已經處理完了，所以就 busy = 0

```
// process
always @(posedge clk) begin
    if (busy) begin
        case (process)
            WRITE: begin
                IRAM_A = IRAM_A + 1;
                IRAM_D <= memory[IRAM_A];
                if(IRAM_A == 6'd63) begin
                    process <= DONE;
                end
            end

            SHIFT_UP, SHIFT_DOWN, SHIFT_LEFT, SHIFT_RIGHT: begin
                process = NONE;
            end

            MAX, MIN, AVG: begin
                if(!calculate_done) begin
                    if (cmd_count == 4'd0) begin
                        max_value <= region_memory[cmd_count*8 +: 8];
                        min_value <= region_memory[cmd_count*8 +: 8];
                        sum <= region_memory[cmd_count*8 +: 8];
                    end
                    else begin
                        if (region_memory[cmd_count*8 +: 8] > max_value)
                            max_value <= region_memory[cmd_count*8 +: 8];
                        if (region_memory[cmd_count*8 +: 8] < min_value)
                            min_value <= region_memory[cmd_count*8 +: 8];
                        sum <= sum + region_memory[cmd_count*8 +: 8];
                    end

                    cmd_count <= cmd_count + 1;
                    if (cmd_count == 4'd15) begin
                        calculate_done = 1'b1;
                    end
                end
                else begin
                    modified_value = (process == MAX) ? max_value : (process == MIN) ? min_value : sum >> 4;
                    {
                        memory[8 * index_y + index_x - 18], memory[8 * index_y + index_x - 17],
                        memory[8 * index_y + index_x - 16], memory[8 * index_y + index_x - 15],
                        memory[8 * index_y + index_x - 10], memory[8 * index_y + index_x - 9],
                        memory[8 * index_y + index_x - 8 ], memory[8 * index_y + index_x - 7],
                        memory[8 * index_y + index_x - 2 ], memory[8 * index_y + index_x - 1],
                        memory[8 * index_y + index_x     ], memory[8 * index_y + index_x + 1],
                        memory[8 * index_y + index_x + 6 ], memory[8 * index_y + index_x + 7],
                        memory[8 * index_y + index_x + 8 ], memory[8 * index_y + index_x + 9]
                    } = {16{modified_value}};
                    process = NONE;
                end
            end

            DONE: begin
                done <= 1'b1;
                busy <= 1'b0;
                IRAM_web <= 1'b1;
                IRAM_ceb <= 1'b0;
            end

            NONE: begin
                done <= 1'b0;
                busy <= 1'b0;
                IRAM_web <= 1'b1;
                IRAM_ceb <= 1'b0;
                process = NONE;
            end
        endcase
    end
```


Made with VisualParadigm For non-commercial use
IROM_A = IROM_A + 1
state = LOAD
False
rst = 1
Load
state = LOAD
busy = 1
index_x = 4
index_y = 4
IROM_A = 0
state = LOAD
Loading from IROM
if IROM_A == 63
True
state = LOADDONE
Load_finish
busy = 0
cmd_valid
IRAM_A = IRAM_A + 1
process = WRITE
False
Write
busy = 1
IRAM_ceb = 1
IRAM_web = 1
IRAM_A = 0
IRAM_D = 0
process = WRITE
cmd = 0
cmd_valid = 1
Writing to IRAM
if IRAM_A == 63
process = DONE
True
Done
done = 1
busy = 0
IRAM_web = 1
IRAM_ceb = 0
command classification
cmd = 1
cmd_valid = 1
Shift_up
busy = 1
False
if index_y > 2
True
index_y = index_y - 1
busy = 0
cmd = 2
cmd_valid = 1
Shift_down
busy = 1
False
if index_y < 6
True
index_y = index_y + 1
busy = 0
cmd = 3
cmd_valid = 1
Shift_left
busy = 1
False
if index_x > 2
True
index_x = index_x - 1
busy = 0
cmd = 4
cmd_valid = 1
Shift_up
busy = 1
False
if index_x < 6
True
index_x = index_x + 1
busy =0
cmd = 5 or 6 or 7
cmd_valid = 1
Max
Min
Avg
busy = 1
calculate_done = 0
table[4, 4]
process = cmd
table_index = 0
calculate Max, Min, Sum
table_index = table_index + 1
if table_index == 15
False
True
process = 5
calculate_done
process = 7
process = 6
modified_value = Max
modified_value = (Sum >> 4)
modified_value = Min
busy = 0
Modify Modify all values in the table to "modified_value".