PROJECT: BEE INVADERS

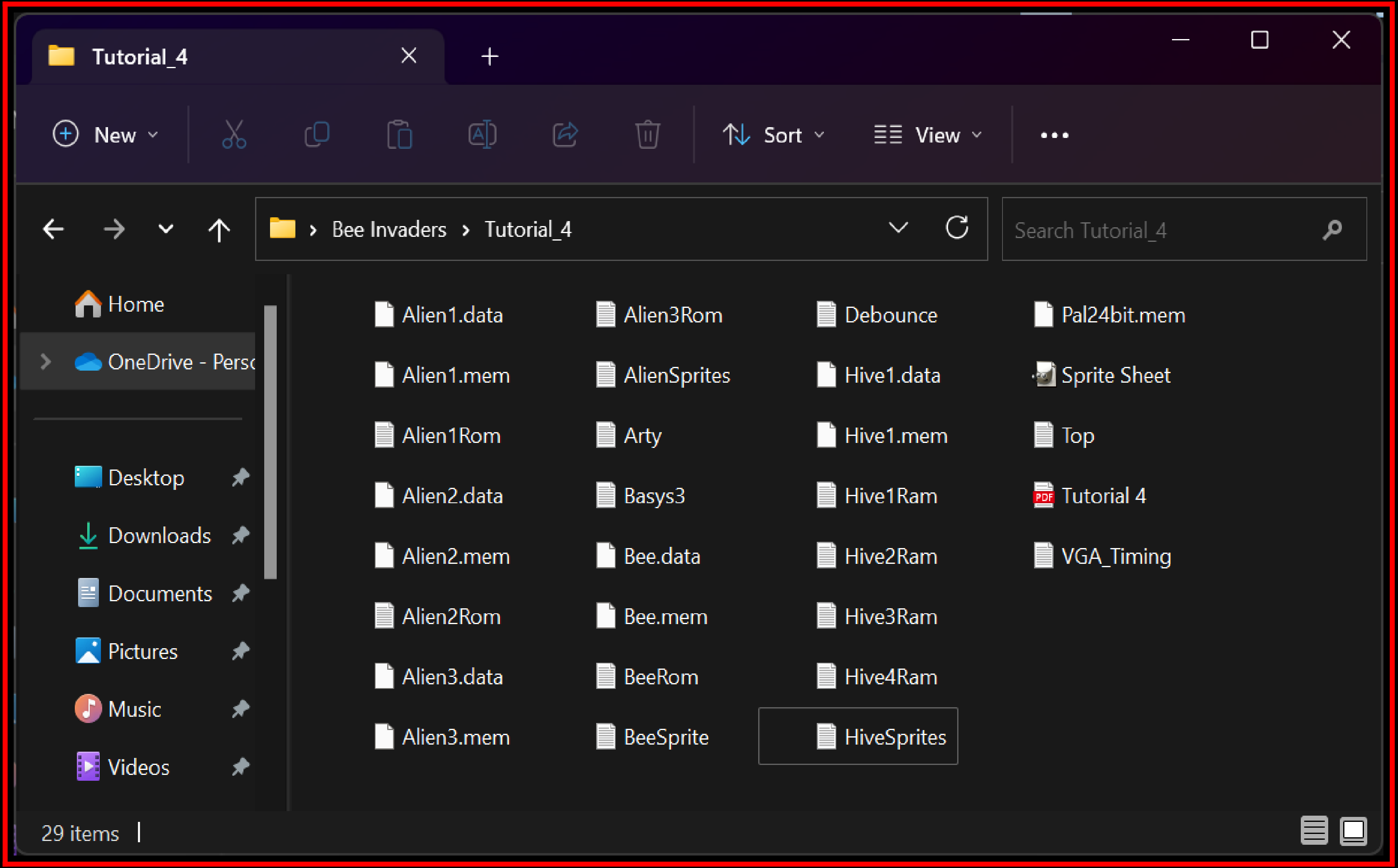
This Tutorial Is For The
Basys3 FPGA Board Or The Arty A7-35 FPGA Board With A VGA Pmod Connected
But Can Be Adapted To Other FPGA Boards
A Modern Version Of The Popular Arcade Game
Space Invaders

Tutorial 4 - Moving The Aliens & Display The Hives On The Screen

CONTENTS

(A) USING GIMP TO GENERATE THE GRAPHICS FOR THE HIVE

01 In the folder “Bee Invaders” create a folder called “Tutorial_4” and extract the files from the downloaded file “Tutorial_4 Files.zip” to this folder

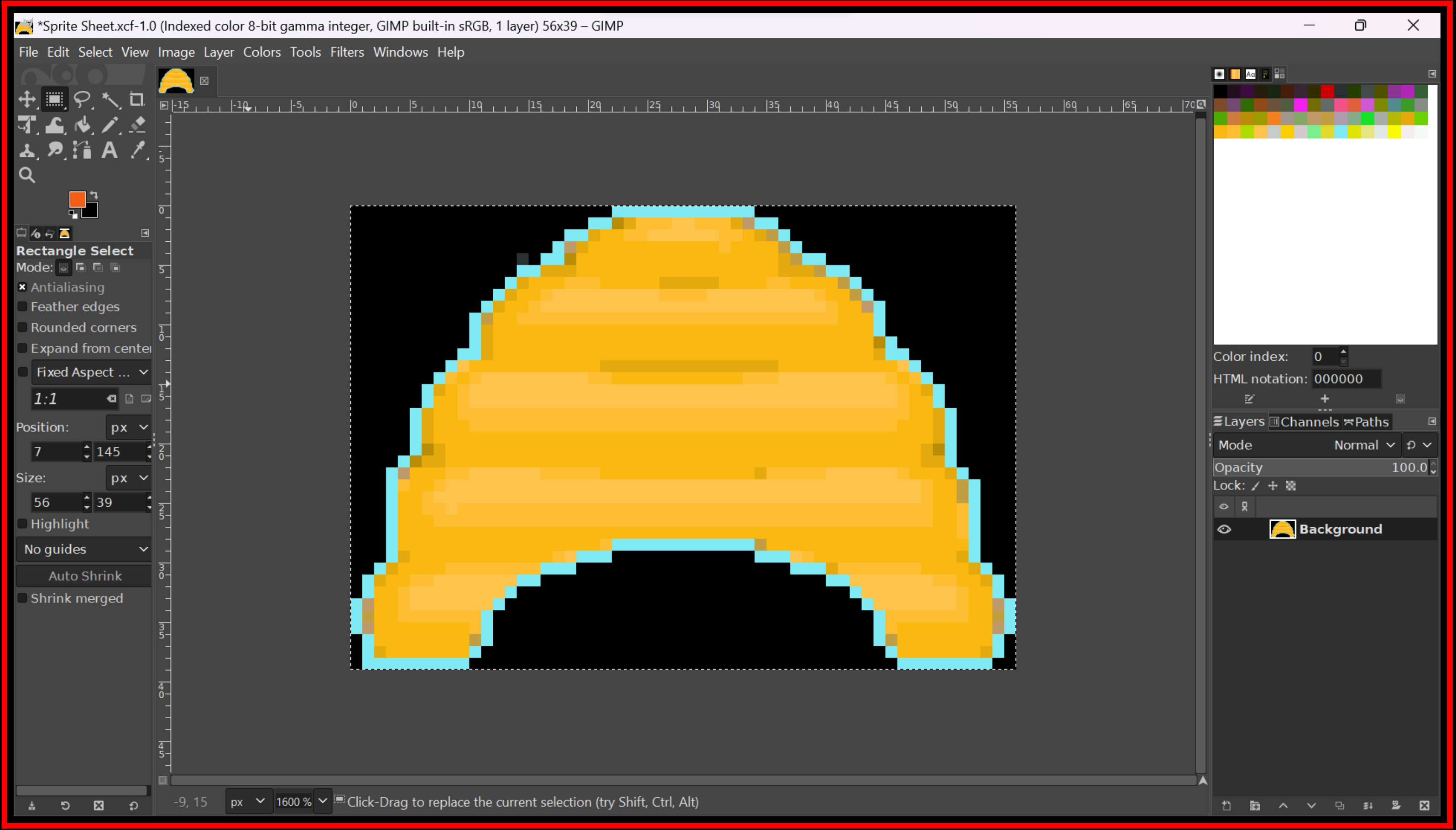


Alien1.data	Alien3Rom	Debounce	Pal24bit.mem
Alien1.mem	AlienSprites	Hive1.data	Sprite Sheet
Alien1Rom	Arty	Hive1.mem	Top
Alien2.data	Basys3	Hive1Ram	Tutorial 4
Alien2.mem	Bee.data	Hive2Ram	VGA_Timing
Alien2Rom	Bee.mem	Hive3Ram	
Alien3.data	BeeRom	Hive4Ram	
Alien3.mem	BeeSprite	HiveSprites	

29 items

02 The files for the Hives are in the files which were extracted in Step 01, so jump to section (B) if you do not wish to see how the files were made in Gimp

Open "Sprite Sheet.xcf" in the "Tutorial_4" folder with Gimp, convert it to 64 colours (Image → Mode → Indexed), set the maximum number of colours to 64 and make sure that Remove unused and duplicate colors from colormap is not selected, then select "Convert". Zoom in on the Hive character and using the "rectangle select tool" select around the Hive (this should be a rectangle 56 x 39 pixels) and crop it



*Sprite Sheet.xcf-1.0 (Indexed color 8-bit gamma integer, GIMP built-in sRGB, 1 layer) 56x39 – GIMP

Rectangle Select
Mode:
Antialiasing
Feather edges
Rounded corners
Expand from center
Fixed Aspect ratio
1:1
Position: px 7 145
Size: px 56 39
Highlight
No guides
Auto Shrink
Shrink merged

Color index: 0
HTML notation: 000000

Mode Normal
Opacity 100.0
Background

-9, 15 px 1600 % Click-Drag to replace the current selection (try Shift, Ctrl, Alt)

File Edit Select View Image Layer Colors Tools Filters Windows Help
Layers Channels Paths
Lock:

03

The image needs to be saved as a Raw Data File, do this using File → Export As → Raw image data. Call the file “Hive1.data”

Using HxD Hex Editor (or similar) load the file “Hive1.data”, select all the data and copy it

Then paste the data into a Notepad file and save it as “Hive1.mem”

(B) CREATING THE PROJECT IN VIVADO

01 Follow the instructions in "Tutorial 1" to create a new project in the "Tutorial_4" folder in Vivado but call it "BeeInvaders_WIP"

Add these design sources from the "Tutorial 4" folder:

Top.v	Bee.mem	Hive2Ram.v
VGA_Timing.v	Alien1.mem	Hive3Ram.v
BeeSprite.v	Alien2.mem	Hive4Ram.v
AlienSprites.v	Alien3.mem	Hive1.mem
BeeRom.v	Pal24bit.mem	
Alien1Rom.v	Debounce.v	
Alien2Rom.v	HiveSprites.v	
Alien3Rom.v	Hive1Ram.v	

Add a constraints file from the "Tutorial 4" folder:

Basys3.xdc	for the Basys3 board
Arty.xdc	for the Arty A7-35 board

Create the 25.2MHz pixel clock as we did in "Tutorial 1"

For this to work on the Arty A7-35 all you need to do is replace this line in "Top.v":

```
.reset(btn_rst_n),      // reset button is active high
```

With:

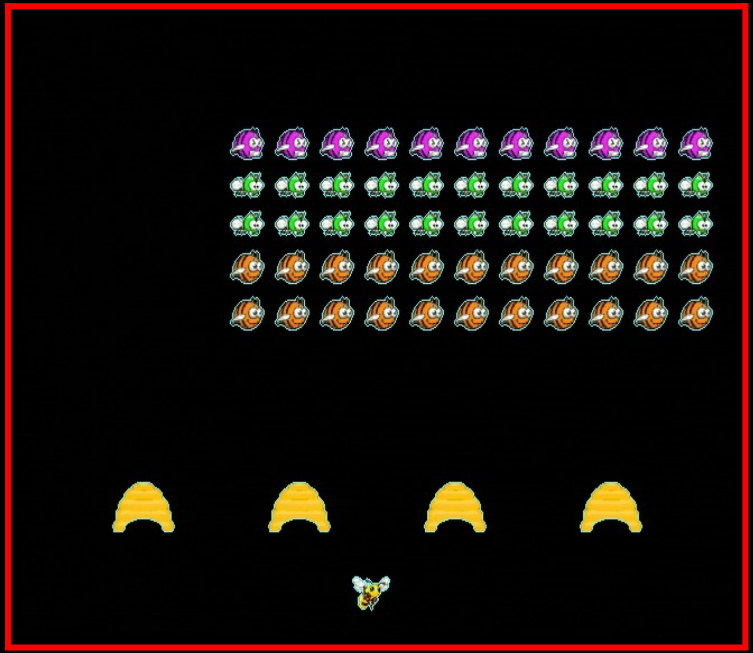
```
.reset(!btn_rst_n),      // reset button is active low
```

02

Click on “Run Synthesis” and when the window “Synthesis Completed” appears ensure “Run implementation” is selected and click “OK”. When the “Implementation Completed” window appears select “Generate Bitstream” and click “OK”

Now select “Open Hardware Manager” and click “OK”. Next click “Open Target” and select “Auto Connect”. Now click “Program Device”. When the “Program Device” box appears make sure the “Bitsteam file” path is correct and then click “Program”.

You should see on your VGA monitor the 55 Aliens moving slowly across the screen and the 4 Hives



(C) THE CODE FOR THIS TUTORIAL

This is the code from the file “Top.v”

```
//----------------------------------------------
// Top.v module
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//----------------------------------------------

`default_nettype none
`timescale 1ns / 1ps

// Setup Top module
module Top (
    input  wire clk_100m,                    // 100 MHz clock
    input  wire btn_rst_n,                   // reset button
    output wire vga_hsync,                   // VGA horizontal sync
    output wire vga_vsync,                   // VGA vertical sync
    output reg [3:0] vga_r,                  // 4-bit VGA red
    output reg [3:0] vga_g,                  // 4-bit VGA green
    output reg [3:0] vga_b,                  // 4-bit VGA blue
    input wire btnR,                         // Right button
    input wire btnL                          // Left button
    );

    // Instantiate VGA_Clock
    reg reset;                               // Reset Button
    wire clk_pix;                            // 25.2Mhz Pixel clock
    wire clk_pix_locked;                     // Pixel clock locked?

    VGA_Clock clock_pix_inst (
       .clk_100m(clk_100m),
       .reset(btn_rst_n),                    // reset button is active high
       .clk_pix(clk_pix),
       .clk_pix_locked(clk_pix_locked)
    );

    // Instantiate VGA_Timing
    localparam CORDW = 10;                   // screen coordinate width in bits
   reg rst_pix;
    wire [CORDW-1:0] sx, sy;
    wire hsync;
    wire vsync;
    wire de;
    VGA_Timing display_inst (
        .clk_pix(clk_pix),
        .rst_pix(!clk_pix_locked),           // wait for clock lock
        .sx(sx),
        .sy(sy),
        .hsync(hsync),
        .vsync(vsync),
        .de(de)
    );
```

```
// Instantiate BeeSprite
wire [1:0] BeeSpriteOn;                 // 1=on, 0=off
wire [7:0] dout;                        // pixel value from Bee.mem
BeeSprite BeeDisplay (
    .clk_pix(clk_pix),
    .sx(sx),
    .sy(sy),
    .de(de),
    .BeeSpriteOn(BeeSpriteOn),
    .btnR(btnR),
    .btnL(btnL),
    .dataout(dout)
);

// Instantiate AlienSprites
wire [1:0] Alien1SpriteOn;              // 1=on, 0=off
wire [1:0] Alien2SpriteOn;              // 1=on, 0=off
wire [1:0] Alien3SpriteOn;              // 1=on, 0=off
wire [7:0] Alien1dout;                  // pixel value from Alien1.mem
wire [7:0] Alien2dout;                  // pixel value from Alien2.mem
wire [7:0] Alien3dout;                  // pixel value from Alien3.mem
AlienSprites AlienDisplay (
    .clk_pix(clk_pix),
    .sx(sx),
    .sy(sy),
    .de(de),
    .Alien1SpriteOn(Alien1SpriteOn),
    .Alien2SpriteOn(Alien2SpriteOn),
    .Alien3SpriteOn(Alien3SpriteOn),
    .A1dout(Alien1dout),
    .A2dout(Alien2dout),
    .A3dout(Alien3dout)
);

// instantiate HiveSprites
wire [1:0] Hive1SpriteOn;               // 1=on, 0=off
wire [1:0] Hive2SpriteOn;               // 1=on, 0=off
wire [1:0] Hive3SpriteOn;               // 1=on, 0=off
wire [1:0] Hive4SpriteOn;               // 1=on, 0=off
wire [7:0] H1dataout;                   // pixel value from Hive1
wire [7:0] H2dataout;                   // pixel value from Hive2
wire [7:0] H3dataout;                   // pixel value from Hive3
wire [7:0] H4dataout;                   // pixel value from Hive4
HiveSprites HDisplay (
    .clk_pix(clk_pix),
    .sx(sx),
    .sy(sy),
    .de(de),
    .Hive1SpriteOn(Hive1SpriteOn),
    .Hive2SpriteOn(Hive2SpriteOn),
    .Hive3SpriteOn(Hive3SpriteOn),
    .Hive4SpriteOn(Hive4SpriteOn),
    .H1dout(H1dataout),
    .H2dout(H2dataout),
    .H3dout(H3dataout),
    .H4dout(H4dataout)
);

// Load colour palette
reg [7:0] palette [0:191];              // 8 bit values from the 192 hex entries in the colour palette
reg [7:0] COL = 0;                      // background colour palette value
```

```
initial begin
    $readmemh("pal24bit.mem", palette); // load 192 hex values into "palette"
end

// VGA Output
assign vga_hsync = hsync;
assign vga_vsync = vsync;
always @ (posedge clk_pix)
begin
    if(de)
        begin
            if (BeeSpriteOn==1)
                begin
                    vga_r <= (palette[(dout*3)])>>4;             // RED bits(7:4) from colour palette
                    vga_g <= (palette[(dout*3)+1])>>4;           // GREEN bits(7:4) from colour palette
                    vga_b <= (palette[(dout*3)+2])>>4;           // BLUE bits(7:4) from colour palette
                end
            else
            if (Alien1SpriteOn==1)
                begin
                    vga_r <= (palette[(Alien1dout*3)])>>4;       // RED bits(7:4) from colour palette
                    vga_g <= (palette[(Alien1dout*3)+1])>>4;     // GREEN bits(7:4) from colour palette
                    vga_b <= (palette[(Alien1dout*3)+2])>>4;     // BLUE bits(7:4) from colour palette
                end
            else
            if (Alien2SpriteOn==1)
                begin
                    vga_r <= (palette[(Alien2dout*3)])>>4;       // RED bits(7:4) from colour palette
                    vga_g <= (palette[(Alien2dout*3)+1])>>4;     // GREEN bits(7:4) from colour palette
                    vga_b <= (palette[(Alien2dout*3)+2])>>4;     // BLUE bits(7:4) from colour palette
                end
            else
            if (Alien3SpriteOn==1)
                begin
                    vga_r <= (palette[(Alien3dout*3)])>>4;       // RED bits(7:4) from colour palette
                    vga_g <= (palette[(Alien3dout*3)+1])>>4;     // GREEN bits(7:4) from colour palette
                    vga_b <= (palette[(Alien3dout*3)+2])>>4;     // BLUE bits(7:4) from colour palette
                end
            else
            if (Hive1SpriteOn==1)
                begin
                    vga_r <= (palette[(H1dataout*3)])>>4;        // RED bits(7:4) from colour palette
                    vga_g <= (palette[(H1dataout*3)+1])>>4;      // GREEN bits(7:4) from colour palette
                    vga_b <= (palette[(H1dataout*3)+2])>>4;      // BLUE bits(7:4) from colour palette
                end
            else
            if (Hive2SpriteOn==1)
                begin
                    vga_r <= (palette[(H2dataout*3)])>>4;        // RED bits(7:4) from colour palette
                    vga_g <= (palette[(H2dataout*3)+1])>>4;      // GREEN bits(7:4) from colour palette
                    vga_b <= (palette[(H2dataout*3)+2])>>4;      // BLUE bits(7:4) from colour palette
                end
            else
            if (Hive3SpriteOn==1)
                begin
                    vga_r <= (palette[(H3dataout*3)])>>4;        // RED bits(7:4) from colour palette
                    vga_g <= (palette[(H3dataout*3)+1])>>4;      // GREEN bits(7:4) from colour palette
                    vga_b <= (palette[(H3dataout*3)+2])>>4;      // BLUE bits(7:4) from colour palette
                end
            else
            if (Hive4SpriteOn==1)
                begin
```

```
                    vga_r <= (palette[(H4dataout*3)])>>4;       // RED bits(7:4) from colour palette
                    vga_g <= (palette[(H4dataout*3)+1])>>4;     // GREEN bits(7:4) from colour palette
                    vga_b <= (palette[(H4dataout*3)+2])>>4;     // BLUE bits(7:4) from colour palette
                end
            else
                begin
                    vga_r <= (palette[(COL*3)])>>4;             // RED bits(7:4) from colour palette
                    vga_g <= (palette[(COL*3)+1])>>4;           // GREEN bits(7:4) from colour palette
                    vga_b <= (palette[(COL*3)+2])>>4;           // BLUE bits(7:4) from colour palette
                end
        end
    else
        begin
            vga_r <= 0; // set RED, GREEN & BLUE
            vga_g <= 0; // to "0" when x,y outside of
            vga_b <= 0; // the active display area
        end
    end
endmodule
```

This is the code from the file "VGA_Timing.v"

```
//------------------------------------------------
// VGA_Timing.v module
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//------------------------------------------------

`default_nettype none
`timescale 1ns / 1ps


module VGA_Timing (
       input  wire clk_pix,   // pixel clock
       input  wire rst_pix,   // reset in pixel clock domain
       output reg [9:0] sx,   // horizontal screen position
       output reg [9:0] sy,   // vertical screen position
       output wire hsync,     // horizontal sync
       output wire vsync,     // vertical sync
       output wire de         // data enable (low in blanking interval)
       );

       // horizontal timings
       parameter HA_END = 639;           // end of active pixels
       parameter HS_STA = HA_END + 16;   // sync starts after front porch
       parameter HS_END = HS_STA + 96;   // sync ends
       parameter LINE   = 799;           // last pixel on line (after back porch)

       // vertical timings
       parameter VA_END = 479;           // end of active pixels
       parameter VS_STA = VA_END + 10;   // sync starts after front porch
       parameter VS_END = VS_STA + 2;    // sync ends
       parameter SCREEN = 524;           // last line on screen (after back porch)

       assign hsync = ~(sx >= HS_STA && sx < HS_END);  // invert: negative polarity
       assign vsync = ~(sy >= VS_STA && sy < VS_END);  // invert: negative polarity
       assign de = (sx <= HA_END && sy <= VA_END);
```

```
        // calculate horizontal and vertical screen position
        always @(posedge clk_pix) begin
            if (sx == LINE) begin  // last pixel on line?
                sx <= 0;
                sy <= (sy == SCREEN) ? 0 : sy + 1;  // last line on screen?
            end else begin
                sx <= sx + 1;
            end
            if (rst_pix) begin
                sx <= 0;
                sy <= 0;
            end
        end
    endmodule
```

This is the code from the file “BeeSprite.v”

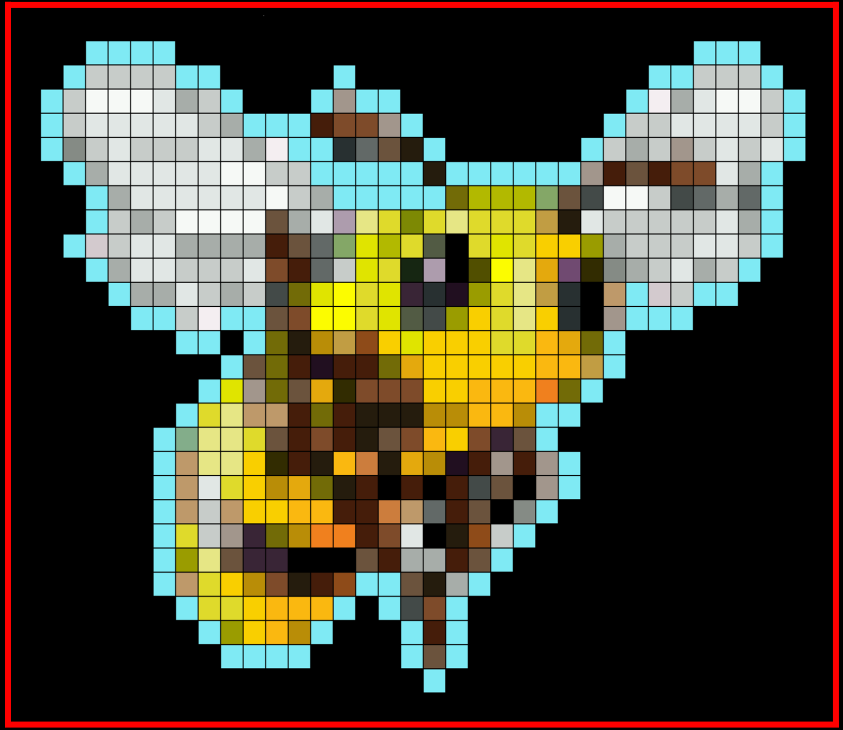
```
//--------------------------------------------
// BeeSprite.v Module
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//--------------------------------------------
`timescale 1ns / 1ps

// Setup BeeSprite module
module BeeSprite(
    input wire clk_pix,
    input wire [9:0] sx,
    input wire [9:0] sy,
    input wire de,
    output reg [1:0] BeeSpriteOn,   // 1=on, 0=off
    input wire btnR,                // right button
    input wire btnL,                // left button
    output wire [7:0] dataout
    );

    // instantiate BeeRom code
    reg [9:0] address;              // 2^10 or 1024, need 34 x 27 = 918
    BeeRom BeeVRom (
        .address(address),
        .clk_pix(clk_pix),
        .dataout(dataout)
    );

    // Instantiate Debounce
    wire sig_right;
    wire sig_left;

    Debounce deb_right (
        .clk_pix(clk_pix),
        .btn(btnR),
        .out(sig_right)
    );

    Debounce deb_left (
        .clk_pix(clk_pix),
        .btn(btnL),
        .out(sig_left)
    );

    // setup character positions and sizes
    reg [9:0] BeeX = 297;           // Bee X start position
    reg [8:0] BeeY = 433;           // Bee Y start position
    localparam BeeWidth = 34;       // Bee width in pixels
    localparam BeeHeight = 27;      // Bee height in pixels

    always @ (posedge clk_pix)
    begin
        // if sx,sy are within the confines of the Bee character, switch the Bee On and
        if(de)
            begin
                if(sx==BeeX-2 && sy==BeeY)                  // Initially sx = 295 (297 - 2) = 1 pixel
                    begin
                        address <= 0;                       // Initially address = 0
                        BeeSpriteOn <=1;
                    end
                if((sx>BeeX-2) && (sx<BeeX+BeeWidth-1) && (sy>BeeY-1) && (sy<BeeY+BeeHeight)) // Thereafter sx = 296 to 329 = 33 pixels
                    begin
                        address <= address +1;              // Secondly address = (296 + 2 - 297) + (0 * 34) = 1
                        BeeSpriteOn <=1;
                    end
                else
                    BeeSpriteOn <=0;
            end
        // if left or right button pressed, move the Bee
        if (sx==640 && sy==480)                             // check for movement once every frame
            begin
                if (sig_right == 1 && BeeX<640-BeeWidth)    // Check for right button
                    BeeX<=BeeX+1;
                else
                if (sig_left == 1 && BeeX>2)                // Check for left button
                    BeeX<=BeeX-1;
            end
    end
endmodule
```

This is the code from the file “BeeRom.v”

```
//--------------------------------------------
// BeeRom.v Module
// Single Port ROM
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//--------------------------------------------
`timescale 1ns / 1ps

// Setup BeeRom module
module BeeRom(
    input wire [9:0] address, // (9:0) or 2^10 or 1024, need 34 x 27 = 918
    input wire clk_pix,
    output reg [7:0] dataout // (7:0) 8 bit pixel value from Bee.mem
    );

    (*ROM_STYLE="block"*) reg [7:0] memory_array [0:917]; // 8 bit values for 918 pixels of Bee (34 x 27)

    initial
    begin
        $readmemh("Bee.mem", memory_array);
    end

    always@(posedge clk_pix)
            dataout <= memory_array[address];
endmodule
```

This is the data from the file "Bee.mem" - Sprite Size 34 x 27 pixels

```
00 00 39 39 39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 39 00 00 00 39 34 34 34 34 39 39 00 00 00 00 00 39 00 00 00 00 00
00 00 00 00 00 00 00 00 39 39 34 34 34 39 00 39 34 3F 3F 3F 3C 2C 34 39 00 00 00 39 25 39 39 00 00 00 00 00 00 00 00 00 00 39 3E 2C 3C 3F 3F 34 39 39 34 3C 3C
3C 3C 3C 34 2C 39 39 39 05 10 10 25 39 00 00 00 00 00 00 00 00 39 34 34 3C 3C 3C 3C 34 39 39 1F 34 3C 34 34 34 3C 3C 2C 3E 39 39 09 18 14 03 39 00 00 00 00 00
00 39 34 2C 34 25 34 3C 34 3C 39 00 39 2C 3C 3C 3C 3C 3C 3F 3F 34 34 39 39 39 39 39 03 39 39 39 39 39 39 25 05 14 05 10 10 3C 2C 39 00 00 00 39 2C 3C 3C 3C 3C
3C 3C 3F 34 2C 39 39 39 39 39 17 2D 2D 2D 26 14 0B 3F 3F 34 0B 18 2C 18 39 00 00 00 39 34 2C 34 3F 3F 3F 3F 14 2C 3C 29 3B 38 1C 38 3B 38 38 38 28 03 3C 34 34
34 34 34 3C 2C 39 00 00 39 36 34 3C 3C 2C 2C 2C 2C 05 14 18 26 3A 2D 38 15 00 38 3A 38 35 35 23 2C 34 34 34 3C 3C 34 39 00 00 00 39 2C 3C 3C 34 34 34 3C 10 05
18 34 3A 38 04 29 00 0C 3D 3B 2E 11 07 1F 2C 34 3C 2C 34 39 00 00 00 00 00 39 2C 2C 3C 34 2C 34 0B 17 3A 3D 38 3A 06 09 01 23 38 3B 28 09 00 27 39 36 34 39 39
00 00 00 00 00 00 00 39 39 34 3E 39 39 14 10 3D 3D 38 3A 15 0B 23 35 38 3B 35 09 00 25 39 39 39 00 00 00 00 00 00 00 00 00 00 00 39 39 00 39 17 03 22 28 13 35
3A 35 35 35 38 38 30 2E 17 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 14 17 05 01 05 05 17 2E 35 35 35 35 35 30 30 28 39 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 39 3A 25 17 14 2E 07 10 10 10 35 35 30 30 30 24 17 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 38 3B 27 27 05 17 05 03 03 03 22 22 30
30 22 39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 2A 3B 3B 38 14 05 10 05 03 14 10 30 35 10 06 14 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
39 27 3B 3B 35 07 05 03 30 21 03 2E 22 01 05 25 05 25 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 27 3C 38 35 22 2E 17 03 05 00 05 00 05 0B 14 00 25 39
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 27 34 27 35 35 30 30 05 05 21 27 18 05 14 00 1F 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 38 34 25
06 17 22 24 24 05 10 3C 00 03 13 34 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 23 3B 14 06 06 00 00 00 14 05 2C 2C 05 14 39 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 39 27 38 35 22 10 03 05 13 39 39 14 03 2C 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 38 38 35 30 30 30
39 00 39 0B 10 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 23 35 30 22 39 00 00 00 39 05 39 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 39 39 39 39 00 00 00 00 39 14 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
```



This is the code from the file “Debounce.v”

```
//----------------------------------------------
// Debounce.v Module
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//----------------------------------------------
`timescale 1ns / 1ps

// Setup Debounce module
module Debounce (
    input wire clk_pix,              // Clock signal to synchronize the button input
    input wire btn,
    output wire out
  );

  reg [19:0] ctr_d;                  // 20 bit counter to increment when button is pressed or released
  reg [19:0] ctr_q;                  // 20 bit counter to increment when button is pressed or released
  reg [1:0] sync_d;                  // button flip-flop for synchronization
  reg [1:0] sync_q;                  // button flip-flop for synchronization

  assign out = ctr_q == {20{1'b1}}; // if ctr_q = 11111111111111111111

  always @(*)
  begin
    sync_d[0] = btn;
    sync_d[1] = sync_q[0];
    ctr_d = ctr_q + 1'b1;

    if (ctr_q == {20{1'b1}})
      ctr_d = ctr_q;

    if (!sync_q[1])
      ctr_d = 20'd0;
  end

  always @(posedge clk_pix)
  begin
    ctr_q <= ctr_d;
    sync_q <= sync_d;
  end
endmodule
```

This is the code from the file “AlienSprites.v”

```
//-----------------------------------------------
// AlienSprites.v module
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//-----------------------------------------------
`timescale 1ns / 1ps

// Setup AlienSprites Module
module AlienSprites(
    input wire clk_pix,                 // 25MHz pixel clock
    input wire [9:0] sx,                // current x position
    input wire [9:0] sy,                // current y position
    input wire de,                      // high during active pixel drawing
    output reg [1:0] Alien1SpriteOn,    // 1=on, 0=off
    output reg [1:0] Alien2SpriteOn,    // 1=on, 0=off
    output reg [1:0] Alien3SpriteOn,    // 1=on, 0=off
    output wire [7:0] A1dout,           // 8 bit pixel value from Alien1.mem
    output wire [7:0] A2dout,           // 8 bit pixel value from Alien2.mem
    output wire [7:0] A3dout            // 8 bit pixel value from Alien3.mem
    );

// instantiate Alien1Rom code
    reg [9:0] A1address;                // 2^10 or 1024, need 31 x 26 = 806
    Alien1Rom Alien1VRom (
        .A1address(A1address),
        .clk_pix(clk_pix),
        .A1dout(A1dout)
    );

// instantiate Alien2Rom code
    reg [9:0] A2address;                // 2^10 or 1024, need 31 x 21 = 651
    Alien2Rom Alien2VRom (
        .A2address(A2address),
        .clk_pix(clk_pix),
        .A2dout(A2dout)
    );

// instantiate Alien3Rom code
    reg [9:0] A3address;                // 2^10 or 1024, need 31 x 27 = 837
    Alien3Rom Alien3VRom (
        .A3address(A3address),
        .clk_pix(clk_pix),
        .A3dout(A3dout)
    );

// setup character positions and sizes
    reg [9:0] A1X = 135;                // Alien1 X start position
    reg [8:0] A1Y = 85;                 // Alien1 Y start position
    localparam A1Width = 31;            // Alien1 width in pixels
    localparam A1Height = 26;           // Alien1 height in pixels
    reg [9:0] A2X = 135;                // Alien2 X start position
    reg [8:0] A2Y = 120;                // Alien2 Y start position
    localparam A2Width = 31;            // Alien2 width in pixels
    localparam A2Height = 21;           // Alien2 height in pixels
    reg [9:0] A3X = 135;                // Alien3 X start position
    reg [8:0] A3Y = 180;                // Alien3 Y start position
    localparam A3Width = 31;            // Alien3 width in pixels
    localparam A3Height = 27;           // Alien3 height in pixels

    reg [9:0] AoX = 0;                  // Offset for X Position of next Alien in row
    reg [8:0] AoY = 0;                  // Offset for Y Position of next row of Aliens
    reg [9:0] AcounterW = 0;            // Counter to check if Alien width reached
    reg [9:0] AcounterH = 0;            // Counter to check if Alien height reached
    reg [3:0] AcolCount = 11;           // Number of horizontal aliens in all columns
    reg [1:0] Adir = 2;                 // direction of aliens: 2=right, 1=left
    reg [2:0] delaliens = 0;            // counter to slow alien movement
    reg [2:0] delloop = 5;              // counter end value for delaliens

    always @ (posedge clk_pix)
    begin
        if (de)
            begin
                // check if sx,sy are within the confines of the Alien characters
                // Alien1
                if (sx==A1X+AoX-2 && sy==A1Y+AoY)
                    begin
                        A1address <= 0;
                        Alien1SpriteOn <=1;
                        AcounterW<=0;
                    end
                if ((sx>A1X+AoX-2) && (sx<A1X+A1Width+AoX) && (sy>A1Y+AoY-1) && (sy<A1Y+A1Height+AoY))
                    begin
                        A1address <= A1address + 1;
                        AcounterW <= AcounterW + 1;
                        Alien1SpriteOn <=1;
                        if (AcounterW==A1Width-1)
                            begin
                                AcounterW <= 0;
                                AoX <= AoX + 40;
                                if(AoX<(AcolCount-1)*40)
                            A1address <= A1address - (A1Width-1);
                         else
                         if(AoX==(AcolCount-1)*40)
                            AoX<=0;
                        end
                    end
                else
                    Alien1SpriteOn <=0;

                // Alien2
                if (sx==A2X+AoX-2 && sy==A2Y+AoY)
                    begin
                        A2address <= 0;
                        Alien2SpriteOn <=1;
                        AcounterW<=0;
                    end
                if ((sx>A2X+AoX-2) && (sx<A2X+A2Width+AoX) && (sy>A2Y+AoY-1) && (sy<A2Y+AoY+A2Height))
                    begin
                        A2address <= A2address + 1;
                        AcounterW <= AcounterW + 1;
                        Alien2SpriteOn <=1;
                        if (AcounterW==A2Width-1)
                            begin
                                AcounterW <= 0;
                                AoX <= AoX + 40;
                                if(AoX<(AcolCount-1)*40)
                            A2address <= A2address - (A2Width-1);
                         else
                         if(AoX==(AcolCount-1)*40)
```

```
                              begin
                         AoX<=0;
                         AcounterH <= AcounterH + 1;
                         if(AcounterH==A2Height-1)
                                     begin
                                   AcounterH<=0;
                                   AoY <= AoY + 30;
                                   if(AoY==30)
                                       begin
                                          AoY<=0;
                                          AoX<=0;
                                          end
                               end
                              end
                      end
              end
          else
              Alien2SpriteOn <=0;

          // Alien3
          if (sx==A3X+AoX-2 && sy==A3Y+AoY)
              begin
                  A3address <= 0;
                  Alien3SpriteOn <=1;
                  AcounterW<=0;
                  AcounterH<=0;
              end
          if ((sx>A3X+AoX-2) && (sx<A3X+AoX+A3Width) && (sy>A3Y+AoY-1) && (sy<A3Y+AoY+A3Height))
              begin
                  A3address <= A3address + 1;
                  AcounterW <= AcounterW + 1;
                  Alien3SpriteOn <=1;
                  if (AcounterW==A3Width-1)
                      begin
                          AcounterW <= 0;
                          AoX <= AoX + 40;
                          if(AoX<(AcolCount-1)*40)
                      A3address <= A3address - (A3Width-1);
                   else
                   if(AoX==(AcolCount-1)*40)
                              begin
                         AoX<=0;
                         AcounterH <= AcounterH + 1;
                         if(AcounterH==A3Height-1)
                                     begin
                                   AcounterH<=0;
                                   AoY <= AoY + 36;
                                   if(AoY==36)
                                       begin
                                          AoY<=0;
                                          AoX<=0;
                                          end
                               end
                      end
                   end
              end
          else
              Alien3SpriteOn <=0;
      end
  else
  // slow down the alien movement / move aliens left or right
  if (sx==640 && sy==480)
```

```
            begin
                delaliens<=delaliens+1;
                if (delaliens>delloop)
                    begin
                        delaliens<=0;
                        if (Adir==2)
                            begin
                                A1X<=A1X+1;
                                A2X<=A2X+1;
                                A3X<=A3X+1;
                                if (A1X+A1Width+((AcolCount-1)*40)>636)
                                    Adir<=1;
                            end
                        else
                        if (Adir==1)
                            begin
                                A1X<=A1X-1;
                                A2X<=A2X-1;
                                A3X<=A3X-1;
                                if (A1X<4)
                                    Adir<=2;
                            end
                    end
            end
    end
endmodule
```

This is the code from the file “Alien1Rom.v”

```
//------------------------------------------------
// Alien1Rom.v Module
// Single Port ROM
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//------------------------------------------------
`timescale 1ns / 1ps

// Setup Alien1Rom module
module Alien1Rom(
    input wire [9:0] A1address, // (9:0) or 2^10 or 1024, need 31 x 26 = 806
    input wire clk_pix,
    output reg [7:0] A1dout     // (7:0) 8 bit pixel value from Alien1.mem
    );

    (*ROM_STYLE="block"*) reg [7:0] A1memory_array [0:805]; // 8 bit values for 806 pixels of Alien1 (31 x 26)

    initial
    begin
        $readmemh("Alien1.mem", A1memory_array);
    end

    always @ (posedge clk_pix)
            A1dout <= A1memory_array[A1address];
endmodule
```

This is the code from the file "Alien2Rom.v"

```
//---------------------------------------------
// Alien2Rom.v Module
// Single Port ROM
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//---------------------------------------------
`timescale 1ns / 1ps

// Setup Alien2Rom module
module Alien2Rom(
    input wire [9:0] A2address, // (9:0) or 2^10 or 1024, need 31 x 21 = 651
    input wire clk_pix,
    output reg [7:0] A2dout     // (7:0) 8 bit pixel value from Alien2.mem
    );

    (*ROM_STYLE="block"*) reg [7:0] A2memory_array [0:650]; // 8 bit values for 651 pixels of Alien2 (31 x 21)

    initial
    begin
        $readmemh("Alien2.mem", A2memory_array);
    end

    always @ (posedge clk_pix)
            A2dout <= A2memory_array[A2address];
endmodule
```

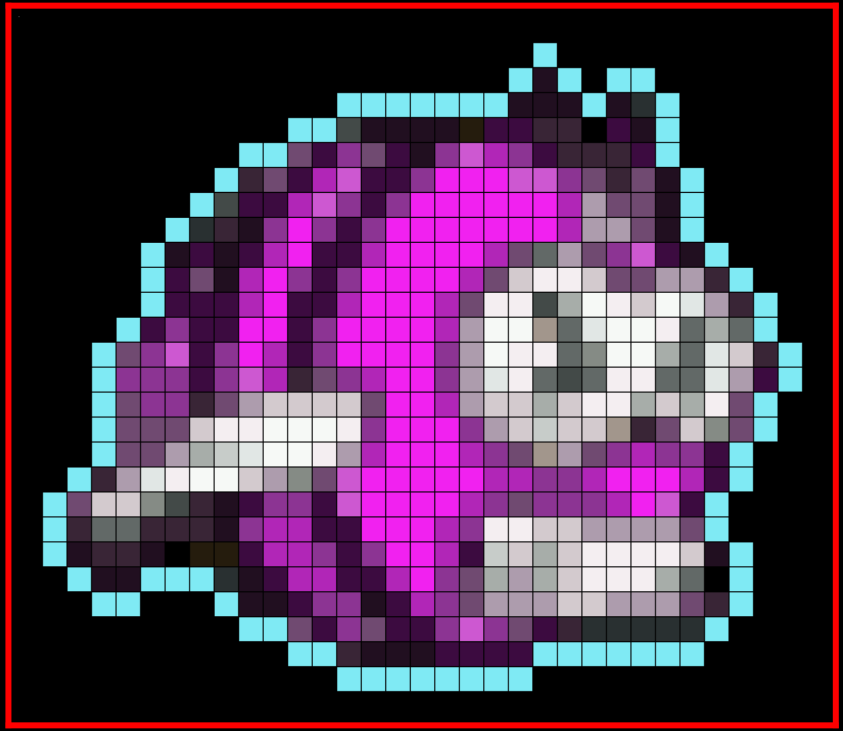
This is the code from the file "Alien3Rom.v"

```
//---------------------------------------------
// Alien3Rom.v Module
// Single Port ROM
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//---------------------------------------------
`timescale 1ns / 1ps

// Setup Alien3Rom module
module Alien3Rom(
    input wire [9:0] A3address, // (9:0) or 2^10 or 1024, need 31 x 27 = 837
    input wire clk_pix,
    output reg [7:0] A3dout     // (7:0) 8 bit pixel value from Alien3.mem
    );

    (*ROM_STYLE="block"*) reg [7:0] A3memory_array [0:836]; // 8 bit values for 837 pixels of Alien3 (31 x 27)

    initial
    begin
        $readmemh("Alien3.mem", A3memory_array);
    end

    always @ (posedge clk_pix)
```

```
            A3dout <= A3memory_array[A3address];
endmodule
```

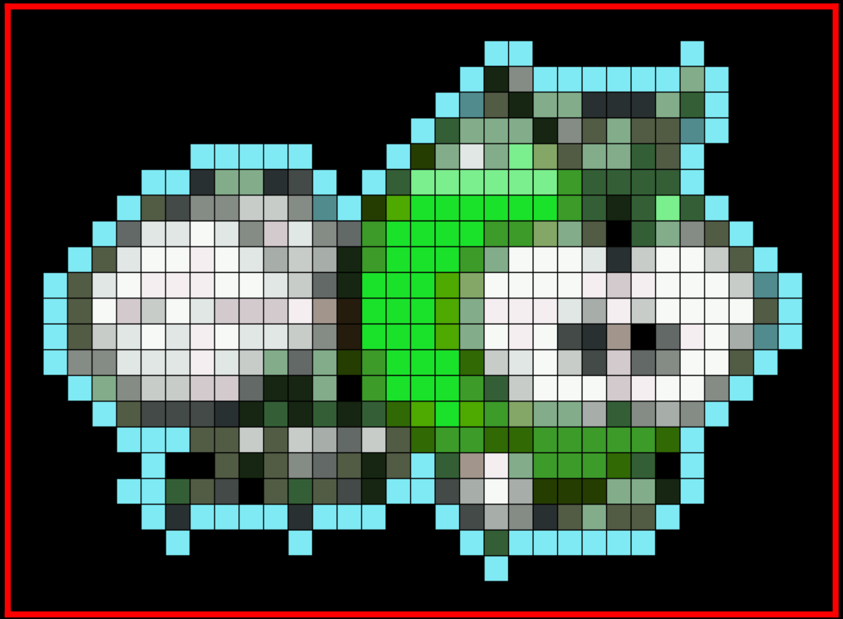
This is the data from the file "Alien1.mem" - Sprite Size 31 x 26 pixels

```
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 01 39
00 39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 39 39 39 39 39 01 01 01 39 01 09 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 0B
01 01 01 01 03 02 02 06 06 00 02 01 39 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 11 02 0D 11 02 01 0D 1B 0E 0D 02 06 06 06 02 39 00 00 00 00 00 00 00 00 00
00 00 00 39 06 11 02 0E 1B 02 02 0D 16 16 16 1B 1B 0D 11 06 11 01 39 00 00 00 00 00 00 00 00 00 00 39 0B 02 02 0E 1B 0D 02 0D 16 16 16 16 16 16 0E 29 11 11 01
39 00 00 00 00 00 00 00 00 00 39 09 06 01 0D 16 0D 02 0D 16 16 16 16 16 16 16 0E 29 29 11 01 39 00 00 00 00 00 00 00 00 39 01 02 01 02 0E 16 02 02 0E 16 16 16
16 0E 11 18 29 11 0D 1B 02 01 39 00 00 00 00 00 00 00 39 02 11 01 0E 16 0D 02 0D 16 16 16 16 0E 11 36 3E 3E 36 11 11 29 29 06 39 00 00 00 00 00 00 39 02 02 02
0E 16 02 02 0E 16 16 16 0E 11 3E 3E 0B 2C 3F 3E 36 3F 3C 29 06 39 00 00 00 00 39 02 0D 02 02 16 16 02 0D 16 16 16 16 0E 29 3F 3F 25 18 3C 3F 3F 3E 18 2C 18 39
00 00 00 39 11 0D 1B 02 0D 16 0E 02 0D 16 16 16 16 0D 29 3F 3E 3E 18 1F 3F 3F 2C 18 3C 36 06 39 00 00 39 0D 0D 0D 02 0D 1B 0E 06 11 0D 0E 16 16 0D 29 3C 3E 18
0B 18 3E 3E 18 18 3C 29 02 39 00 00 39 11 0D 0D 06 11 29 36 36 36 36 11 16 16 0E 29 36 36 2C 36 3E 3E 2C 36 2C 3E 11 39 00 00 00 39 11 11 11 36 3E 3E 3F 3F 3F
3E 0D 16 16 16 0D 29 36 34 36 36 25 06 11 36 1F 11 39 00 00 00 39 11 11 29 2C 34 3C 3F 3F 3E 29 0E 16 16 16 0E 0D 11 25 29 11 0D 0E 0D 0D 02 39 00 00 00 39 06
29 3C 3E 3F 3F 36 29 1F 11 1B 16 16 16 16 16 0E 0E 0D 0D 0E 16 16 16 0E 02 39 00 00 39 11 36 36 1F 0B 06 01 02 0D 0D 02 1B 16 16 16 16 0E 0D 11 0D 0D 0D 0E 16
1B 02 39 00 00 00 39 06 18 18 06 06 06 01 0D 0E 0E 02 02 16 16 16 0E 0D 3E 3E 36 36 29 29 29 29 11 39 00 00 00 39 01 06 06 01 00 03 03 02 0E 0E 0D 02 0D 16 16
0E 02 34 36 2C 36 3E 3E 3E 3E 36 01 39 00 00 00 39 01 01 39 39 39 09 01 02 0E 0E 02 02 0E 16 0D 11 2C 29 2C 36 3E 3E 3E 2C 18 00 39 00 00 00 00 39 39 00 00 00
39 01 01 02 0D 0D 01 02 0E 0D 11 29 29 29 36 36 29 29 29 11 06 39 00 00 00 00 00 00 00 00 00 00 39 39 11 02 0D 11 02 02 0D 1B 0D 11 02 06 09 09 09 09 09 39 00
00 00 00 00 00 00 00 00 00 00 00 00 39 39 06 01 01 01 02 02 02 02 39 39 39 39 39 39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 39 39 39 39 39 39
00 00 00 00 00 00 00 00 00 00 00
```



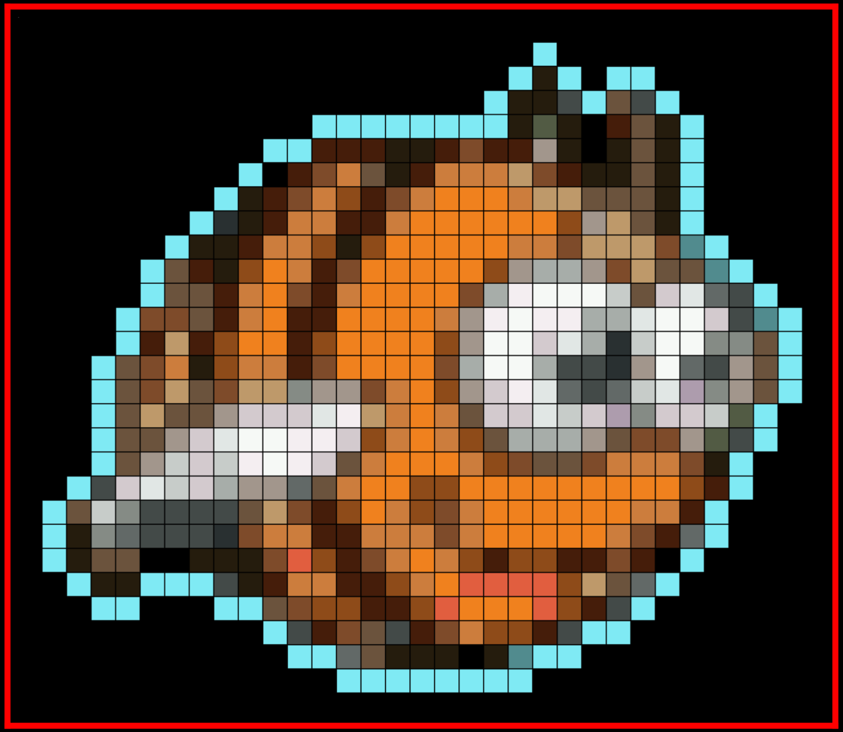
This is the data from the file "Alien2.mem" - Sprite Size 31 x 21 pixels

```
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 00 00 00 00 00 00 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 04 1F 39 39
39 39 39 39 2A 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 1D 15 04 2A 2A 09 09 09 2A 0F 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 39 0F 2A 2A 2A 04 1F 15 2A 15 15 1D 39 00 00 00 00 00 00 00 00 00 39 39 39 39 39 00 00 00 39 0A 2A 3C 2A 37 26 15 2A 2A 0F 15 39 00 00 00 00 00 00 00 00
39 39 09 2A 2A 09 0B 39 00 39 0F 37 37 37 37 37 37 1E 0F 0F 0F 0F 39 00 00 00 00 00 00 39 15 0B 1F 1F 34 34 1F 1D 39 0A 20 2B 2B 2B 2B 2B 2B 1E 0F 04 0F 37
0F 39 00 00 00 00 00 39 18 3C 3C 3F 3C 1F 36 3C 1F 18 1E 2B 2B 2B 2B 1E 1E 26 2A 15 00 0F 2A 1F 15 39 00 00 00 39 15 3C 3F 3F 3E 3F 3C 2C 34 2C 04 1E 2B 2B 2B
1E 2A 3F 3F 3F 3C 09 34 3F 3F 34 15 39 00 39 15 3C 3F 3E 3E 3E 3F 3F 3C 34 18 04 2B 2B 2B 20 26 3F 3F 3F 3F 3E 36 3E 3F 3F 3F 34 1D 39 39 15 3F 36 34 3F 3C 36
36 36 3E 25 03 2B 2B 2B 20 2A 3E 3E 3E 3C 2C 3E 34 3F 3F 3F 3F 15 39 39 15 34 3C 3F 3C 3E 3F 3C 3C 34 1F 03 2B 2B 2B 20 2A 3F 3E 3F 0B 09 25 00 18 3E 3F 2C 1D
39 39 1F 1F 3C 3C 3C 3E 3C 34 2A 18 2A 0A 1E 2B 2B 2B 12 34 3C 3F 34 0B 36 18 1F 3F 3F 15 39 00 00 39 2A 1F 34 34 36 36 18 04 04 2A 00 1E 2B 2B 2B 1E 0F 34 3F
3F 3F 36 3E 3F 3F 1F 39 00 00 00 00 39 15 0B 0B 0B 09 04 0F 04 0F 04 0F 12 20 2B 20 1E 26 2A 2A 2C 0F 1F 2C 1F 39 00 00 00 00 00 00 39 39 39 15 15 34 15 34 2C
18 34 15 12 1E 1E 12 12 1E 1E 1E 1E 1E 12 39 00 00 00 00 00 00 00 00 39 00 00 15 04 15 1F 18 15 04 15 39 0F 25 3E 2A 1E 1E 1E 12 0F 00 39 00 00 00 00 00 00 00
39 39 0F 15 0B 00 15 0F 15 0B 04 39 39 0B 2C 3F 2C 0A 0A 0A 2A 2A 04 39 00 00 00 00 00 00 00 00 39 09 39 39 39 39 09 39 39 39 00 00 39 0B 2C 1F 09 15 2A 15 15
39 00 00 00 00 00 00 00 00 00 00 39 00 00 00 00 39 00 00 00 00 00 00 39 0F 39 39 39 39 39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 39 00 00 00 00 00 00 00 00 00 00 00 00
```



This is the data from the file "Alien3.mem" - Sprite Size 31 x 27 pixels

```
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 03 39
00 39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 03 03 0B 39 14 0B 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39
39 39 39 39 39 39 03 15 03 00 05 14 03 39 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 05 05 05 03 03 05 10 05 05 25 03 00 03 14 03 39 00 00 00 00 00 00 00 00
00 00 00 00 39 00 05 10 21 14 03 05 21 21 21 27 10 05 03 03 14 03 39 00 00 00 00 00 00 00 00 00 00 39 03 05 10 21 13 05 10 21 24 24 24 21 27 27 14 14 14 03
39 00 00 00 00 00 00 00 00 00 00 39 09 03 05 21 21 05 05 21 24 24 24 24 24 24 13 25 27 14 03 39 00 00 00 00 00 00 00 00 00 39 03 03 05 21 21 13 03 13 24 24 24
24 24 21 21 10 27 27 27 10 1D 39 00 00 00 00 00 00 00 39 14 05 03 13 24 21 05 10 24 24 24 24 24 13 25 2C 2C 25 10 27 14 14 1D 39 00 00 00 00 00 00 39 14 14 05
21 24 10 05 21 24 24 24 24 10 2C 3E 3F 3F 3F 34 14 36 3C 18 0B 39 00 00 00 00 39 10 10 14 05 21 24 05 05 24 24 24 24 21 25 3E 3F 3E 3E 2C 2C 3C 3F 3F 36 0B 1D
39 00 00 00 39 05 27 05 13 24 24 05 13 24 24 24 24 13 25 3F 3F 36 3C 2C 09 34 3F 3F 1F 1F 14 39 00 00 39 14 10 21 03 13 21 21 05 10 24 24 24 24 10 2C 3F 3F 2C
0B 0B 09 25 3F 18 0B 25 14 39 00 00 39 14 10 27 14 10 27 27 1F 25 25 10 21 24 13 25 36 3E 3C 18 0B 18 34 3C 29 1F 25 14 39 00 00 39 14 27 14 14 25 36 36 36 3C
3E 27 21 24 21 14 36 36 3C 34 36 29 1F 36 36 34 15 39 00 00 00 39 14 14 25 36 3C 3F 3F 3E 3E 36 13 21 24 21 13 14 2C 2C 2C 25 14 10 10 25 15 0B 39 00 00 00 39
14 25 34 36 34 3E 3F 3E 36 14 21 24 24 24 21 13 10 14 14 10 21 21 21 10 03 39 00 00 00 39 0B 36 3C 34 36 2C 25 25 18 14 21 24 24 13 13 24 24 24 24 24 24 24 24
24 13 05 39 00 00 39 14 34 1F 0B 0B 0B 0B 14 27 10 05 13 24 21 13 10 21 24 24 24 24 24 24 21 21 05 39 00 00 00 39 03 1F 18 0B 0B 0B 09 10 21 21 05 05 21 21 21
10 21 24 24 24 24 24 21 10 05 18 39 00 00 00 39 03 14 14 00 00 03 03 03 10 1A 13 05 10 21 24 21 13 05 13 13 05 05 10 05 00 39 00 00 00 00 00 39 03 03 39 39 39
0B 03 05 21 21 05 05 13 21 24 1A 1A 1A 1A 13 27 14 18 39 00 00 00 00 00 00 00 39 39 00 00 00 39 39 14 10 13 13 05 05 13 1A 24 24 24 1A 13 05 0B 39 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 39 0B 05 10 14 0B 05 10 21 13 13 05 0B 39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 18 14 03 03 03 00 03 1D
39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 39 39 39 39 39 39 00 00 00 00 00 00 00 00 00 00 00
```



This is the code from the file “HiveSprites.v”

```
//----------------------------------------------
// HiveSprites.v module
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//----------------------------------------------

`timescale 1ns / 1ps

// Setup HiveSprites Module
module HiveSprites(
    input wire clk_pix,               // 25.2MHz pixel clock
    input wire [9:0] sx,              // current x position
    input wire [9:0] sy,              // current y position
    input wire de,                    // high during active pixel drawing
    output reg [1:0] Hive1SpriteOn, // 1=on, 0=off
    output reg [1:0] Hive2SpriteOn, // 1=on, 0=off
    output reg [1:0] Hive3SpriteOn, // 1=on, 0=off
    output reg [1:0] Hive4SpriteOn, // 1=on, 0=off
    output wire [7:0] H1dout,        // 8 bit pixel value from Hive1
    output wire [7:0] H2dout,        // 8 bit pixel value from Hive2
    output wire [7:0] H3dout,        // 8 bit pixel value from Hive3
    output wire [7:0] H4dout         // 8 bit pixel value from Hive4
    );

    // instantiate Hive1Ram
    reg [11:0] H1address;            // 2^12 or 4096, need 56 x 39 = 2184
    Hive1Ram Hive1VRam (
        .clk_pix(clk_pix),
        .H1address(H1address),
        .H1dout(H1dout),
        .write(0),
        .data(0)
    );

    // instantiate Hive2Ram
    reg [11:0] H2address;            // 2^12 or 4096, need 56 x 39 = 2184
    Hive2Ram Hive2VRam (
        .clk_pix(clk_pix),
        .H2address(H2address),
        .H2dout(H2dout),
        .write(0),
        .data(0)
    );

    // instantiate Hive3Ram
    reg [11:0] H3address;            // 2^12 or 4096, need 56 x 39 = 2184
    Hive3Ram Hive3VRam (
        .clk_pix(clk_pix),
        .H3address(H3address),
        .H3dout(H3dout),
        .write(0),
        .data(0)
    );

    // instantiate Hive4Ram
    reg [11:0] H4address;            // 2^12 or 4096, need 56 x 39 = 2184
    Hive4Ram Hive4VRam (
        .clk_pix(clk_pix),
        .H4address(H4address),
        .H4dout(H4dout),
        .write(0),
        .data(0)
    );

    // setup character positions and sizes
    reg [9:0] Hive1X = 83;          // Hive1 X start position
    reg [8:0] Hive1Y = 360;         // Hive1 Y start position
    reg [9:0] Hive2X = 222;         // Hive2 X start position
    reg [8:0] Hive2Y = 360;         // Hive2 Y start position
    reg [9:0] Hive3X = 361;         // Hive3 X start position
    reg [8:0] Hive3Y = 360;         // Hive3 Y start position
    reg [9:0] Hive4X = 500;         // Hive4 X start position
    reg [8:0] Hive4Y = 360;         // Hive4 Y start position
    localparam HiveWidth = 56;      // Hive width in pixels
    localparam HiveHeight = 39;     // Hive height in pixels

    always @ (posedge clk_pix)
    begin
        if (de)
            // check if sx,sy are within the confines of the Hive characters
            // hive1
            begin
                if (sx==Hive1X-2 && sy==Hive1Y)
                    begin
                        H1address <= 0;
                        Hive1SpriteOn <=1;
                    end
                if ((sx>Hive1X-2) && (sx<Hive1X+HiveWidth-1) && (sy>Hive1Y-1) && (sy<Hive1Y+HiveHeight))
                    begin
                        H1address <= H1address + 1;
                        Hive1SpriteOn <=1;
                    end
                else
                    Hive1SpriteOn <=0;

                // hive2
                if (sx==Hive2X-2 && sy==Hive2Y)
                    begin
                        H2address <= 0;
                        Hive2SpriteOn <=1;
                    end
                if ((sx>Hive2X-2) && (sx<Hive2X+HiveWidth-1) && (sy>Hive2Y-1) && (sy<Hive2Y+HiveHeight))
                    begin
                        H2address <= H2address + 1;
                        Hive2SpriteOn <=1;
                    end
                else
                    Hive2SpriteOn <=0;

                // hive3
                if (sx==Hive3X-2 && sy==Hive3Y)
                    begin
                        H3address <= 0;
                        Hive3SpriteOn <=1;
                    end
                if ((sx>Hive3X-2) && (sx<Hive3X+HiveWidth-1) && (sy>Hive3Y-1) && (sy<Hive3Y+HiveHeight))
                    begin
                        H3address <= H3address + 1;
                        Hive3SpriteOn <=1;
                    end
                else
                    Hive3SpriteOn <=0;

                // hive4
                if (sx==Hive4X-2 && sy==Hive4Y)
                    begin
                        H4address <= 0;
                        Hive4SpriteOn <=1;
                    end
                if ((sx>Hive4X-2) && (sx<Hive4X+HiveWidth-1) && (sy>Hive4Y-1) && (sy<Hive4Y+HiveHeight))
                    begin
                        H4address <= H4address + 1;
                        Hive4SpriteOn <=1;
                    end
                else
                    Hive4SpriteOn <=0;
            end
    end
endmodule
```

This is the code from the file “Hive1Ram.v”

```
//-----------------------------------------------
// Hive1Ram.v Module - Single Port RAM
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//-----------------------------------------------
`timescale 1ns / 1ps

// Setup Hive1Ram Module
module Hive1Ram(
    input wire clk_pix,
    input wire [11:0] H1address,    // (11:0) or 2^12 or 4096, need 56 x 39 = 2184
    output reg [7:0] H1dout,        // (7:0) 8 bit pixel value from Hive1
    input wire write,               // 1=write, 0=read data
    input wire [7:0] data           // (7:0) 8 bit pixel value to Hive1
    );

    (*ROM_STYLE="block"*) reg [7:0] H1memory_array [0:2183]; // 8 bit values for 2184 pixels of Hive1 (56 x 39)

    initial begin
            $readmemh("Hive1.mem", H1memory_array);
    end

    always @ (posedge clk_pix)
         if(write)
            H1memory_array[H1address] <= data;
        else
            H1dout <= H1memory_array[H1address];
endmodule
```

This is the code from the file “Hive2Ram.v”

```
//----------------------------------------------
// Hive2Ram.v Module - Single Port RAM
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//----------------------------------------------
`timescale 1ns / 1ps

// Setup Hive2Ram Module
module Hive2Ram(
    input wire clk_pix,
    input wire [11:0] H2address,    // (11:0) or 2^12 or 4096, need 56 x 39 = 2184
    output reg [7:0] H2dout,        // (7:0) 8 bit pixel value from Hive1
    input wire write,               // 1=write, 0=read data
    input wire [7:0] data           // (7:0) 8 bit pixel value to Hive1
    );

    (*ROM_STYLE="block"*) reg [7:0] H2memory_array [0:2183]; // 8 bit values for 2184 pixels of Hive1 (56 x 39)

    initial begin
            $readmemh("Hive1.mem", H2memory_array);
    end

    always @ (posedge clk_pix)
         if(write)
            H2memory_array[H2address] <= data;
        else
            H2dout <= H2memory_array[H2address];
endmodule
```

This is the code from the file “Hive3Ram.v”

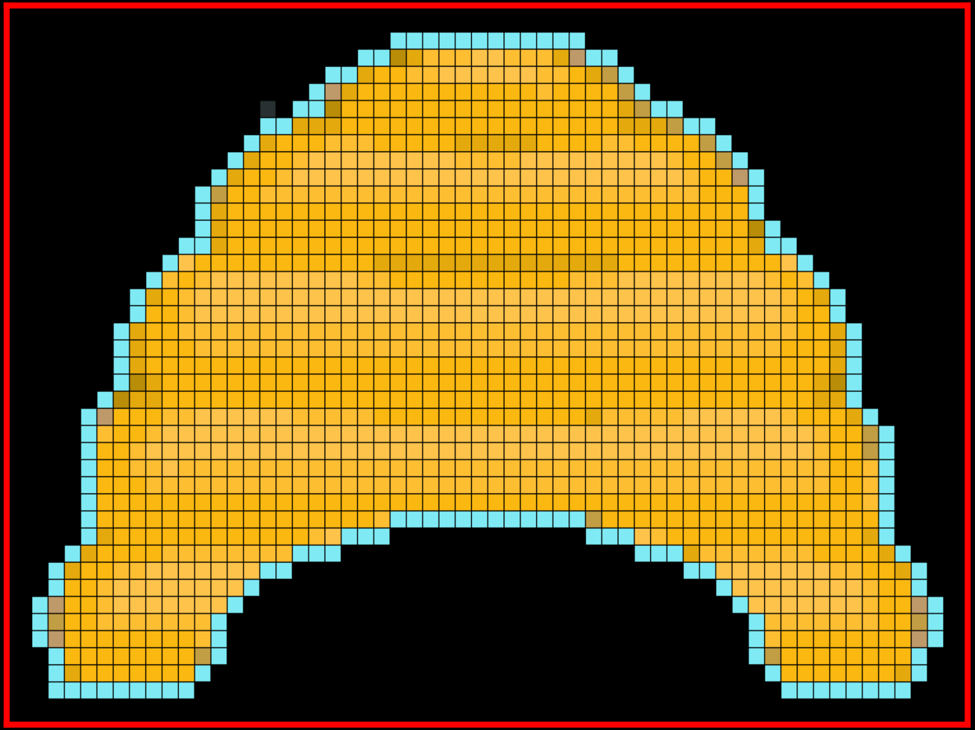
```
//----------------------------------------------
// Hive3Ram.v Module - Single Port RAM
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//----------------------------------------------
`timescale 1ns / 1ps

// Setup Hive3Ram Module
module Hive3Ram(
    input wire clk_pix,
    input wire [11:0] H3address,    // (11:0) or 2^12 or 4096, need 56 x 39 = 2184
    output reg [7:0] H3dout,        // (7:0) 8 bit pixel value from Hive1
    input wire write,               // 1=write, 0=read data
    input wire [7:0] data           // (7:0) 8 bit pixel value to Hive1
    );

    (*ROM_STYLE="block"*) reg [7:0] H3memory_array [0:2183]; // 8 bit values for 2184 pixels of Hive1 (56 x 39)

    initial begin
            $readmemh("Hive1.mem", H3memory_array);
    end
    always @ (posedge clk_pix)
         if(write)
            H3memory_array[H3address] <= data;
        else
            H3dout <= H3memory_array[H3address];
endmodule
```

This is the code from the file “Hive4Ram.v”

```
//------------------------------------------------
// Hive4Ram.v Module - Single Port RAM
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//------------------------------------------------
`timescale 1ns / 1ps

// Setup Hive4Ram Module
module Hive4Ram(
    input wire clk_pix,
    input wire [11:0] H4address,   // (11:0) or 2^12 or 4096, need 56 x 39 = 2184
    output reg [7:0] H4dout,    // (7:0) 8 bit pixel value from Hive1
    input wire write,         // 1=write, 0=read data
    input wire [7:0] data     // (7:0) 8 bit pixel value to Hive1
    );

    (*ROM_STYLE="block"*) reg [7:0] H4memory_array [0:2183]; // 8 bit values for 2184 pixels of Hive1 (56 x 39)

    initial begin
            $readmemh("Hive1.mem", H4memory_array);
    end

    always @ (posedge clk_pix)
         if(write)
            H4memory_array[H4address] <= data;
        else
            H4dout <= H4memory_array[H4address];
endmodule
```

This is the data from the file "Hive1.mem" - Sprite Size 56 x 39 pixels

```
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 39 39 39 39 39 39 39 39 39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 22 2E 31 31 31 33 33 31 31 31 2E 27 39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 2E 30 30 31 31 33 33 33 33 33 33 31 31 30 2E 28 39 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 27 2E 30 30 30 30 30 30 30 30 30 30 30 31 30 30 30 30 28 39 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 09 00 39 39 22 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 2E 28 39 39 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 2E 2E 2E 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 2E 2E
2E 28 39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 2E 30 30 30 31 31 31 30 30 30 30 30 2E 2E 2E 2E 2E 30 30 30 30
31 31 30 30 30 30 28 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 2E 30 30 31 33 33 33 33 33 33 33 33 33 31 31 31 31 33 33
33 33 33 33 33 33 33 31 30 30 28 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 2E 30 30 31 33 33 33 33 33 33 33 33 33 33 33 33 33
33 33 33 33 33 33 33 33 33 33 33 31 30 30 27 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 28 30 30 31 31 31 31 31 31 31 31 31 31 31 31
31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 30 30 30 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 2E 30 30 30 30 30 30 30 30 30 30 30 30
30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 2E 30 30 30 30 30 30 30 30 30 30
30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 22 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 2E 30 30 30 30 30
30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 2E 39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 33 30 30 30 30
30 30 30 30 30 30 30 2E 2E 2E 2E 2E 2E 2E 2E 2E 2E 2E 2E 2E 2E 2E 30 30 30 30 30 30 30 30 30 30 33 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 31 30 31
33 33 33 33 33 33 33 33 33 31 31 30 30 30 30 30 30 30 30 30 30 30 31 31 31 33 33 33 33 33 33 33 33 33 31 30 31 39 00 00 00 00 00 00 00 00 00 00 00 00 00 39 2E
30 31 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 31 30 2E 39 00 00 00 00 00 00 00 00 00 00 00
00 39 30 30 31 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 31 30 30 39 00 00 00 00 00 00 00 00
00 00 00 39 2E 30 30 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 30 30 2E 39 00 00 00 00
00 00 00 00 00 00 39 2E 30 30 30 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 30 30 30 2E 39 00
00 00 00 00 00 00 00 00 00 39 2E 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30
2E 39 00 00 00 00 00 00 00 00 00 00 39 22 2E 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30
30 30 2E 22 39 00 00 00 00 00 00 00 00 00 39 22 2E 2E 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30
30 30 30 30 30 2E 2E 39 00 00 00 00 00 00 00 00 39 27 30 30 30 31 31 33 33 33 33 33 33 31 31 31 31 31 30 30 30 30 30 30 30 30 30 30 30 30 30 2E 31 31 31 31 31
33 33 33 33 33 33 31 30 30 30 2E 39 00 00 00 00 00 00 00 39 31 30 30 31 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33
33 33 33 33 33 33 33 33 33 33 33 31 30 30 28 39 00 00 00 00 00 00 39 30 30 31 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33 33
33 33 33 33 33 33 33 33 33 33 33 33 33 33 31 30 30 28 39 00 00 00 00 00 00 39 30 30 31 31 33 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31
31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 30 30 31 39 00 00 00 00 00 00 39 30 30 30 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31
31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 31 30 30 31 39 00 00 00 00 00 00 39 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30
30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 31 39 00 00 00 00 00 00 39 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 31
39 39 39 39 39 39 39 39 39 39 39 39 28 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 30 39 00 00 00 00 00 00 39 2E 30 30 30 30 30 30 30 30 30 30 30 30 31 33
39 39 39 00 00 00 00 00 00 00 00 00 00 00 00 39 39 39 33 31 30 30 30 30 30 30 30 30 30 30 30 30 2E 39 00 00 00 00 00 39 2E 30 30 30 30 31 31 31 31 31 31 31 31
39 39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 39 2E 31 31 31 31 31 31 31 30 30 30 30 2E 39 00 00 00 39 2E 30 30 31 31 33 33 33 33 33 33
33 39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 39 33 33 33 33 33 33 33 31 31 30 30 2E 39 00 00 39 30 30 31 33 33 33 33 33
33 33 33 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 33 33 33 33 33 33 33 33 31 30 30 39 00 39 27 30 30 31 33 33
33 33 33 33 33 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 33 33 33 33 33 33 33 31 30 30 27 39 39 28 30 30
31 31 31 31 31 31 31 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 31 31 31 31 31 31 31 30 30 28 39 39
27 30 30 30 30 30 30 30 30 31 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 31 30 30 30 30 30 30 30 30 30
27 39 00 39 30 30 30 30 30 30 30 30 28 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 28 30 30 30 30 30 30
30 30 30 39 00 00 39 2E 30 30 30 30 30 30 30 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 39 30 30
30 30 30 30 30 2E 39 00 00 39 39 39 39 39 39 39 39 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 39 39 39 39 39 39 39 39 00 00
```



This is the data from the file "Pal24bit.mem"

```
00 00 00 21 0F 20 3C 0B 40 25 1C 0D 16 26 12 45 1D 0A 39 25 36 32 2C 01 CA 00 06 28 30 31 26 3D 01 43 4A 48 51 4F 00 8C 34 93 B1 26 B7 34 5F 36 7E 4B 2A 70 4A
71 31 69 04 8E 4B 19 6B 53 3D 52 5B 44 F1 21 F0 72 6B 07 62 69 67 F2 52 87 E1 5E 3F CD 58 D1 7D 89 04 51 8B 8E 3C 9B 29 85 8B 85 4E A9 01 CC 7D 3D B9 8D 07 9A
9C 00 F0 80 1E A2 96 8C 84 A7 67 BE 99 6A C1 9D 43 AD 9C AD 83 AD 8A 1A E2 2A A7 AD A9 B2 B9 00 E4 A9 0D 6C D1 00 FA B8 10 FD BE 32 AF DC 00 FD C3 4B C7 CC C9
F9 CF 00 D3 CA CE 7B EF 8D DF DA 2B 7F EA F4 E0 E4 00 E6 E6 85 E1 E7 E5 FC FC 00 F4 EE F1 F6 F9 F6
```

This is the code from the file "Basys3.xdc"

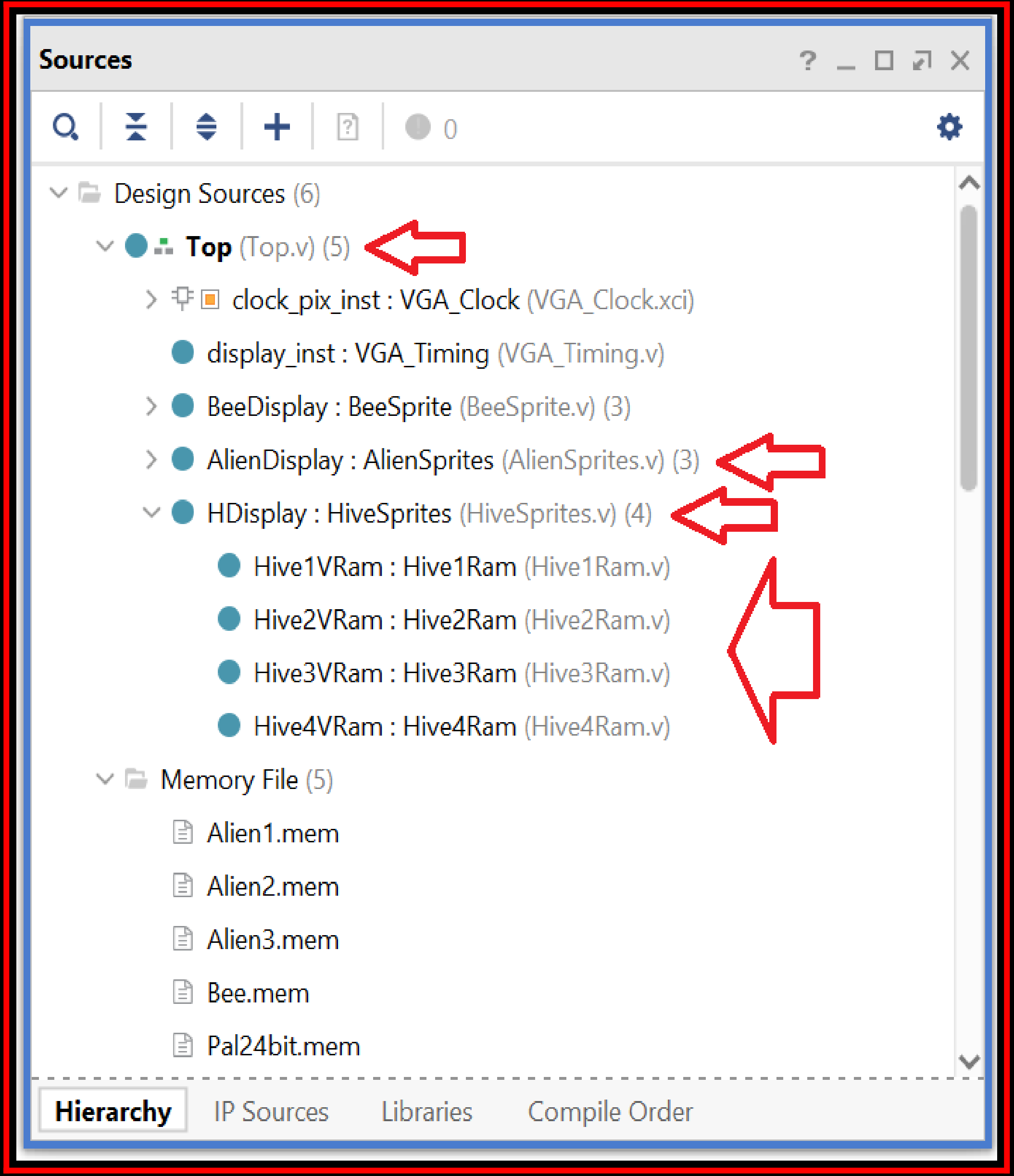
```
##-----------------------------------
## Constraints Module
## Digilent Basys 3
## BeeInvaders : Onboard clock 100MHz
## VGA Resolution: 640x480 @ 60Hz
## Pixel Clock 25.2MHz
##-----------------------------------

## Clock signal
set_property PACKAGE_PIN W5 [get_ports clk_100m]
   set_property IOSTANDARD LVCMOS33 [get_ports clk_100m]
   create_clock -add -name sys_clk_pin -period 10.00 -waveform {0 5} [get_ports clk_100m]


## Buttons
set_property PACKAGE_PIN U18 [get_ports btn_rst_n]
```

```
   set_property IOSTANDARD LVCMOS33 [get_ports btn_rst_n]
set_property PACKAGE_PIN W19 [get_ports btnL]
   set_property IOSTANDARD LVCMOS33 [get_ports btnL]
set_property PACKAGE_PIN T17 [get_ports btnR]
   set_property IOSTANDARD LVCMOS33 [get_ports btnR]

## VGA Connector
set_property -dict {PACKAGE_PIN G19 IOSTANDARD LVCMOS33} [get_ports {vga_r[0]}]
set_property -dict {PACKAGE_PIN H19 IOSTANDARD LVCMOS33} [get_ports {vga_r[1]}]
set_property -dict {PACKAGE_PIN J19 IOSTANDARD LVCMOS33} [get_ports {vga_r[2]}]
set_property -dict {PACKAGE_PIN N19 IOSTANDARD LVCMOS33} [get_ports {vga_r[3]}]
set_property -dict {PACKAGE_PIN N18 IOSTANDARD LVCMOS33} [get_ports {vga_b[0]}]
set_property -dict {PACKAGE_PIN L18 IOSTANDARD LVCMOS33} [get_ports {vga_b[1]}]
set_property -dict {PACKAGE_PIN K18 IOSTANDARD LVCMOS33} [get_ports {vga_b[2]}]
set_property -dict {PACKAGE_PIN J18 IOSTANDARD LVCMOS33} [get_ports {vga_b[3]}]
set_property -dict {PACKAGE_PIN J17 IOSTANDARD LVCMOS33} [get_ports {vga_g[0]}]
set_property -dict {PACKAGE_PIN H17 IOSTANDARD LVCMOS33} [get_ports {vga_g[1]}]
set_property -dict {PACKAGE_PIN G17 IOSTANDARD LVCMOS33} [get_ports {vga_g[2]}]
set_property -dict {PACKAGE_PIN D17 IOSTANDARD LVCMOS33} [get_ports {vga_g[3]}]
set_property -dict {PACKAGE_PIN P19 IOSTANDARD LVCMOS33} [get_ports {vga_hsync}]
set_property -dict {PACKAGE_PIN R19 IOSTANDARD LVCMOS33} [get_ports {vga_vsync}]

## Configuration options, can be used for all designs
set_property CONFIG_VOLTAGE 3.3 [current_design]
set_property CFGBVS VCCO [current_design]
```

This is the code from the file “Arty.xdc”

```
##---------------------------------------------
## Constraints File
## Digilent Arty A7-35
## Bee Invaders Tutorial_1
## Onboard clock 100MHz
## VGA Resolution: 640x480 @ 60Hz
## Pixel Clock 25.2MHz
##---------------------------------------------

## FPGA Configuration I/O Options
set_property CONFIG_VOLTAGE 3.3 [current_design]
set_property CFGBVS VCCO [current_design]

## Board Clock: 100 MHz
set_property -dict {PACKAGE_PIN E3 IOSTANDARD LVCMOS33} [get_ports {clk_100m}]
create_clock -name clk_100m -period 10.00 [get_ports {clk_100m}]

## Buttons
set_property -dict {PACKAGE_PIN C2 IOSTANDARD LVCMOS33} [get_ports {btn_rst_n}]
set_property -dict {PACKAGE_PIN D9 IOSTANDARD LVCMOS33} [get_ports {btnL}]
set_property -dict {PACKAGE_PIN B8 IOSTANDARD LVCMOS33} [get_ports {btnR}]

## VGA Pmod on Header JB/JC
set_property -dict {PACKAGE_PIN U14 IOSTANDARD LVCMOS33} [get_ports {vga_hsync}]
set_property -dict {PACKAGE_PIN V14 IOSTANDARD LVCMOS33} [get_ports {vga_vsync}]
set_property -dict {PACKAGE_PIN E15 IOSTANDARD LVCMOS33} [get_ports {vga_r[0]}]
set_property -dict {PACKAGE_PIN E16 IOSTANDARD LVCMOS33} [get_ports {vga_r[1]}]
set_property -dict {PACKAGE_PIN D15 IOSTANDARD LVCMOS33} [get_ports {vga_r[2]}]
set_property -dict {PACKAGE_PIN C15 IOSTANDARD LVCMOS33} [get_ports {vga_r[3]}]
set_property -dict {PACKAGE_PIN U12 IOSTANDARD LVCMOS33} [get_ports {vga_g[0]}]
set_property -dict {PACKAGE_PIN V12 IOSTANDARD LVCMOS33} [get_ports {vga_g[1]}]
set_property -dict {PACKAGE_PIN V10 IOSTANDARD LVCMOS33} [get_ports {vga_g[2]}]
set_property -dict {PACKAGE_PIN V11 IOSTANDARD LVCMOS33} [get_ports {vga_g[3]}]
set_property -dict {PACKAGE_PIN J17 IOSTANDARD LVCMOS33} [get_ports {vga_b[0]}]
set_property -dict {PACKAGE_PIN J18 IOSTANDARD LVCMOS33} [get_ports {vga_b[1]}]
set_property -dict {PACKAGE_PIN K15 IOSTANDARD LVCMOS33} [get_ports {vga_b[2]}]
set_property -dict {PACKAGE_PIN J15 IOSTANDARD LVCMOS33} [get_ports {vga_b[3]}]
```

(D) EXPLANATION OF THE VERILOG CODE USED



```
Design Sources (6)
  Top (Top.v) (5)
    clock_pix_inst : VGA_Clock (VGA_Clock.xci)
    display_inst : VGA_Timing (VGA_Timing.v)
    BeeDisplay : BeeSprite (BeeSprite.v) (3)
    AlienDisplay : AlienSprites (AlienSprites.v) (3)
    HDisplay : HiveSprites (HiveSprites.v) (4)
      Hive1VRam : Hive1Ram (Hive1Ram.v)
      Hive2VRam : Hive2Ram (Hive2Ram.v)
      Hive3VRam : Hive3Ram (Hive3Ram.v)
      Hive4VRam : Hive4Ram (Hive4Ram.v)
  Memory File (5)
    Alien1.mem
    Alien2.mem
    Alien3.mem
    Bee.mem
    Pal24bit.mem
```

01 Top.v module additional code

```
// instantiate HiveSprites
wire [1:0] Hive1SpriteOn;           // 1=on, 0=off
wire [1:0] Hive2SpriteOn;           // 1=on, 0=off
wire [1:0] Hive3SpriteOn;           // 1=on, 0=off
wire [1:0] Hive4SpriteOn;           // 1=on, 0=off
wire [7:0] H1dataout;               // pixel value from Hive1
wire [7:0] H2dataout;               // pixel value from Hive2
wire [7:0] H3dataout;               // pixel value from Hive3
wire [7:0] H4dataout;               // pixel value from Hive4
```

We add to the Top module the SpriteOn and dataout wires for the 4 hives

```
HiveSprites HDisplay (
        .clk_pix(clk_pix),
        .sx(sx),
        .sy(sy),
        .de(de),
        .Hive1SpriteOn(Hive1SpriteOn),
        .Hive2SpriteOn(Hive2SpriteOn),
        .Hive3SpriteOn(Hive3SpriteOn),
        .Hive4SpriteOn(Hive4SpriteOn),
        .H1dout(H1dataout),
        .H2dout(H2dataout),
        .H3dout(H3dataout),
        .H4dout(H4dataout)
 );
```

This instantiates the HiveSprites module

```
// VGA Output
assign vga_hsync = hsync;
..
..
if (Hive1SpriteOn==1)
            begin
               vga_r <= (palette[(H1dataout*3)])>>4;          // RED bits(7:4) from colour palette
               vga_g <= (palette[(H1dataout*3)+1])>>4;        // GREEN bits(7:4) from colour palette
               vga_b <= (palette[(H1dataout*3)+2])>>4;        // BLUE bits(7:4) from colour palette
            end
         else
         if (Hive2SpriteOn==1)
            begin
               vga_r <= (palette[(H2dataout*3)])>>4;          // RED bits(7:4) from colour palette
               vga_g <= (palette[(H2dataout*3)+1])>>4;        // GREEN bits(7:4) from colour palette
               vga_b <= (palette[(H2dataout*3)+2])>>4;        // BLUE bits(7:4) from colour palette
            end
         else
         if (Hive3SpriteOn==1)
            begin
               vga_r <= (palette[(H3dataout*3)])>>4;          // RED bits(7:4) from colour palette
               vga_g <= (palette[(H3dataout*3)+1])>>4;        // GREEN bits(7:4) from colour palette
               vga_b <= (palette[(H3dataout*3)+2])>>4;        // BLUE bits(7:4) from colour palette
            end
         else
         if (Hive4SpriteOn==1)
            begin
               vga_r <= (palette[(H4dataout*3)])>>4;          // RED bits(7:4) from colour palette
               vga_g <= (palette[(H4dataout*3)+1])>>4;        // GREEN bits(7:4) from colour palette
               vga_b <= (palette[(H4dataout*3)+2])>>4;        // BLUE bits(7:4) from colour palette
            end
```

We have added Hive1, Hive2, Hive3 and Hive4 to the VGA Output routine. If any of the Hives are On (equal to “1”) then the Hive data is sent to the VGA Output

02 AlienSprites.v module additional code

```
reg [1:0] Adir = 2;             // direction of aliens: 2=right, 1=left
reg [2:0] delaliens = 0;        // counter to slow alien movement
reg [2:0] delloop = 5;          // counter end value for delaliens
```

This adds Adir which determines the direction of the aliens, delaliens which is a counter to slow down the speed of the aliens and delloop to set the length of the delaliens counter

```
else
  // slow down the alien movement / move aliens left or right
  if (sx==640 && sy==480)
     begin
        delaliens<=delaliens+1;
        if (delaliens>delloop)
           begin
              delaliens<=0;
              if (Adir==2)
                 begin
                    A1X<=A1X+1;
                    A2X<=A2X+1;
                    A3X<=A3X+1;
                    if (A1X+A1Width+((AcolCount-1)*40)>636)
                       Adir<=1;
                 end
```

The line if (sx==640 && sy==480) makes sure that this routine is executed once every frame

If delaliens is equal to 6 then delaliens is set to 0 and

If alien direction equals right, the start x co-ordinate of each line of alien sprites is incremented by 1
If the right most alien reaches the edge of the screen, the direction of the aliens is changed

```
            else
            if (Adir==1)
               begin
                  A1X<=A1X-1;
                  A2X<=A2X-1;
                  A3X<=A3X-1;
                  if (A1X<4)
                     Adir<=2;
               end
         end
      end
```

If alien direction equals left, the start x co-ordinate of each line of alien sprites is decremented by 1

If the left most alien reaches the edge of the screen, the direction of the aliens is changed

03 HiveSprites.v module

```
//--------------------------------------------
// HiveSprites.v module
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//--------------------------------------------
`timescale 1ns / 1ps


// Setup HiveSprites Module
module HiveSprites(
    input wire clk_pix,                 // 25.2MHz pixel clock
    input wire [9:0] sx,                // current x position
    input wire [9:0] sy,                // current y position
    input wire de,                      // high during active pixel drawing
    output reg [1:0] Hive1SpriteOn,     // 1=on, 0=off
    output reg [1:0] Hive2SpriteOn,     // 1=on, 0=off
    output reg [1:0] Hive3SpriteOn,     // 1=on, 0=off
    output reg [1:0] Hive4SpriteOn,     // 1=on, 0=off
    output wire [7:0] H1dout,           // 8 bit pixel value from Hive1
    output wire [7:0] H2dout,           // 8 bit pixel value from Hive2
    output wire [7:0] H3dout,           // 8 bit pixel value from Hive3
    output wire [7:0] H4dout            // 8 bit pixel value from Hive4
    );
```

This sets up the HiveSprites module: Registers for the 4 HiveSpriteOn and Wires for the 4 pixel values from each Hive

```
// instantiate Hive1Ram
   reg [11:0] H1address;          // 2^12 or 4096, need 56 x 39 = 2184
   Hive1Ram Hive1VRam (
      .clk_pix(clk_pix),
      .H1address(H1address),
      .H1dout(H1dout),
      .write(0),
      .data(0)
   );

   // instantiate Hive2Ram
   reg [11:0] H2address;          // 2^12 or 4096, need 56 x 39 = 2184
   Hive2Ram Hive2VRam (
      .clk_pix(clk_pix),
      .H2address(H2address),
      .H2dout(H2dout),
      .write(0),
      .data(0)
   );

   // instantiate Hive3Ram
   reg [11:0] H3address;          // 2^12 or 4096, need 56 x 39 = 2184
   Hive3Ram Hive3VRam (
      .clk_pix(clk_pix),
      .H3address(H3address),
      .H3dout(H3dout),
      .write(0),
      .data(0)
   );

   // instantiate Hive4Ram
   reg [11:0] H4address;          // 2^12 or 4096, need 56 x 39 = 2184
   Hive4Ram Hive4VRam (
      .clk_pix(clk_pix),
      .H4address(H4address),
      .H4dout(H4dout),
      .write(0),
      .data(0)
   );
```

The above code instantiates each of the 4 hives

```
// setup character positions and sizes
reg [9:0] Hive1X = 83;              // Hive1 X start position
reg [8:0] Hive1Y = 360;             // Hive1 Y start position
reg [9:0] Hive2X = 222;             // Hive2 X start position
reg [8:0] Hive2Y = 360;             // Hive2 Y start position
reg [9:0] Hive3X = 361;             // Hive3 X start position
reg [8:0] Hive3Y = 360;             // Hive3 Y start position
reg [9:0] Hive4X = 500;             // Hive4 X start position
reg [8:0] Hive4Y = 360;             // Hive4 Y start position
localparam HiveWidth = 56;          // Hive width in pixels
localparam HiveHeight = 39;         // Hive height in pixels
```

This defines the x, y positions for the 4 hives and the width, height of the hive

```
always @ (posedge clk_pix)
    begin
        if (de)
            // check if sx,sy are within the confines of the Hive characters
            // hive1
            begin
                if (sx==Hive1X-2 && sy==Hive1Y)
                    begin
                        H1address <= 0;
                        Hive1SpriteOn <=1;
                    end
                if ((sx>Hive1X-2) && (sx<Hive1X+HiveWidth-1) && (sy>Hive1Y-1) && (sy<Hive1Y+HiveHeight))
                    begin
                        H1address <= H1address + 1;
                        Hive1SpriteOn <=1;
                    end
                else
                    Hive1SpriteOn <=0;
```

This checks if sx, sy are within Hive1 screen area. If so, switch Hive1 on and count through Hive1 data

```
// hive2
if (sx==Hive2X-2 && sy==Hive2Y)
   begin
      H2address <= 0;
      Hive2SpriteOn <=1;
   end
if ((sx>Hive2X-2) && (sx<Hive2X+HiveWidth-1) && (sy>Hive2Y-1) && (sy<Hive2Y+HiveHeight))
   begin
      H2address <= H2address + 1;
      Hive2SpriteOn <=1;
   end
else
   Hive2SpriteOn <=0;

// hive3
if (sx==Hive3X-2 && sy==Hive3Y)
   begin
      H3address <= 0;
      Hive3SpriteOn <=1;
   end
if ((sx>Hive3X-2) && (sx<Hive3X+HiveWidth-1) && (sy>Hive3Y-1) && (sy<Hive3Y+HiveHeight))
   begin
      H3address <= H3address + 1;
      Hive3SpriteOn <=1;
   end
else
   Hive3SpriteOn <=0;

// hive4
if (sx==Hive4X-2 && sy==Hive4Y)
   begin
      H4address <= 0;
      Hive4SpriteOn <=1;
   end
```

```
                if ((sx>Hive4X-2) && (sx<Hive4X+HiveWidth-1) && (sy>Hive4Y-1) && (sy<Hive4Y+HiveHeight))
                    begin
                        H4address <= H4address + 1;
                        Hive4SpriteOn <=1;
                    end
                else
                    Hive4SpriteOn <=0;
            end
        end
    endmodule
```

Switch Hive2, Hive3 and Hive4 on and count through Hive1, Hive2, Hive3 and Hive4 data

04 Hive1Ram.v module

```
//----------------------------------------------
// Hive1Ram.v Module - Single Port RAM
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//----------------------------------------------
`timescale 1ns / 1ps

// Setup Hive1Ram Module
module Hive1Ram(
    input wire clk_pix,
    input wire [11:0] H1address,        // (11:0) or 2^12 or 4096, need 56 x 39 = 2184
    output reg [7:0] H1dout,            // (7:0) 8 bit pixel value from Hive1
    input wire write,                   // 1=write, 0=read data
    input wire [7:0] data               // (7:0) 8 bit pixel value to Hive1
    );

    (*ROM_STYLE="block"*) reg [7:0] H1memory_array [0:2183]; // 8 bit values for 2184 pixels of Hive1 (56 x 39)

    initial begin
            $readmemh("Hive1.mem", H1memory_array);
    end

    always @ (posedge clk_pix)
         if(write)
            H1memory_array[H1address] <= data;
        else
            H1dout <= H1memory_array[H1address];
endmodule
```

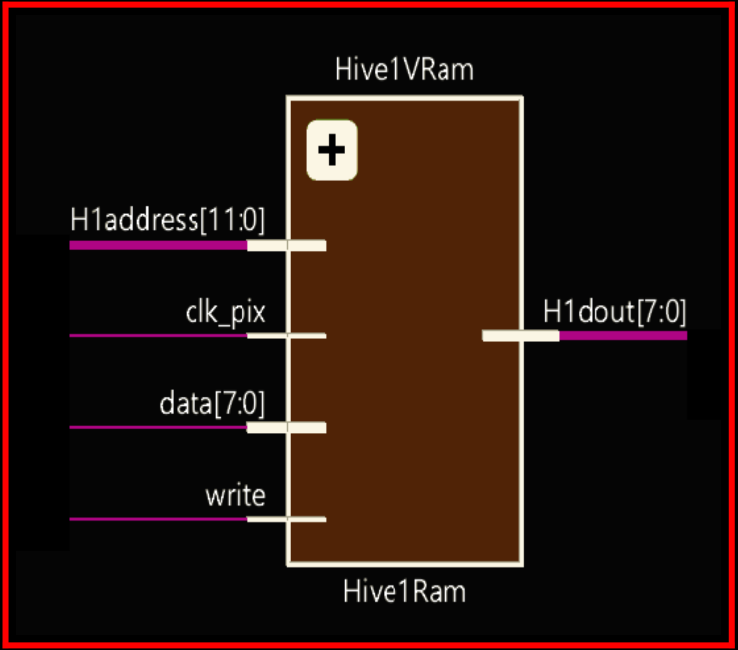
The “Hive1Ram.v” module used to read the Hive character data from the “Hive1.mem” file is a:

Single Port RAM

The below diagram shows a “Single Port Ram” with 4 inputs (a 12 bit address input, a clock input, an 8 bit data input and a write enable input) and 1 output (an 8 bit data output)

The Hive will be created as RAM in order that it can be reloaded with the original data when required or to allow the Hives data to be modified

HiveSprites passes the value “0” to write in the Hive1Ram, therefore the Ram will act as a Rom (read only) on this occassion



05 Hive2Ram.v module

```
//--------------------------------------------
// Hive2Ram.v Module - Single Port RAM
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//--------------------------------------------
`timescale 1ns / 1ps

// Setup Hive2Ram Module
module Hive2Ram(
    input wire clk_pix,
    input wire [11:0] H2address,       // (11:0) or 2^12 or 4096, need 56 x 39 = 2184
    output reg [7:0] H2dout,           // (7:0) 8 bit pixel value from Hive1
    input wire write,                  // 1=write, 0=read data
    input wire [7:0] data              // (7:0) 8 bit pixel value to Hive1
    );

    (*ROM_STYLE="block"*) reg [7:0] H2memory_array [0:2183]; // 8 bit values for 2184 pixels of Hive1 (56 x 39)

    initial begin
            $readmemh("Hive1.mem", H2memory_array);
    end

    always @ (posedge clk_pix)
         if(write)
            H2memory_array[H2address] <= data;
        else
            H2dout <= H2memory_array[H2address];
endmodule
```

This is the same as the Hive1Ram module

06 Hive3Ram.v module

```
//---------------------------------------------
// Hive3Ram.v Module - Single Port RAM
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//---------------------------------------------
`timescale 1ns / 1ps

// Setup Hive3Ram Module
module Hive3Ram(
    input wire clk_pix,
    input wire [11:0] H3address,        // (11:0) or 2^12 or 4096, need 56 x 39 = 2184
    output reg [7:0] H3dout,            // (7:0) 8 bit pixel value from Hive1
    input wire write,                   // 1=write, 0=read data
    input wire [7:0] data               // (7:0) 8 bit pixel value to Hive1
    );

    (*ROM_STYLE="block"*) reg [7:0] H3memory_array [0:2183]; // 8 bit values for 2184 pixels of Hive1 (56 x 39)

    initial begin
            $readmemh("Hive1.mem", H3memory_array);
    end

    always @ (posedge clk_pix)
         if(write)
            H3memory_array[H3address] <= data;
        else
            H3dout <= H3memory_array[H3address];
endmodule
```

This is the same as the Hive1Ram module

07 Hive4Ram.v module

```
//---------------------------------------------
// Hive4Ram.v Module - Single Port RAM
// Digilent Basys 3
// Bee Invaders Tutorial_4
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//---------------------------------------------
`timescale 1ns / 1ps

// Setup Hive4Ram Module
module Hive4Ram(
    input wire clk_pix,
    input wire [11:0] H4address,      // (11:0) or 2^12 or 4096, need 56 x 39 = 2184
    output reg [7:0] H4dout,          // (7:0) 8 bit pixel value from Hive1
    input wire write,                 // 1=write, 0=read data
    input wire [7:0] data             // (7:0) 8 bit pixel value to Hive1
    );

    (*ROM_STYLE="block"*) reg [7:0] H4memory_array [0:2183]; // 8 bit values for 2184 pixels of Hive1 (56 x 39)

    initial begin
            $readmemh("Hive1.mem", H4memory_array);
    end

    always @ (posedge clk_pix)
         if(write)
            H4memory_array[H4address] <= data;
        else
            H4dout <= H4memory_array[H4address];
endmodule
```

This is the same as the Hive1Ram module

I have also tidied the Basys3.xdc constraints file up slightly