BEE INVADERS

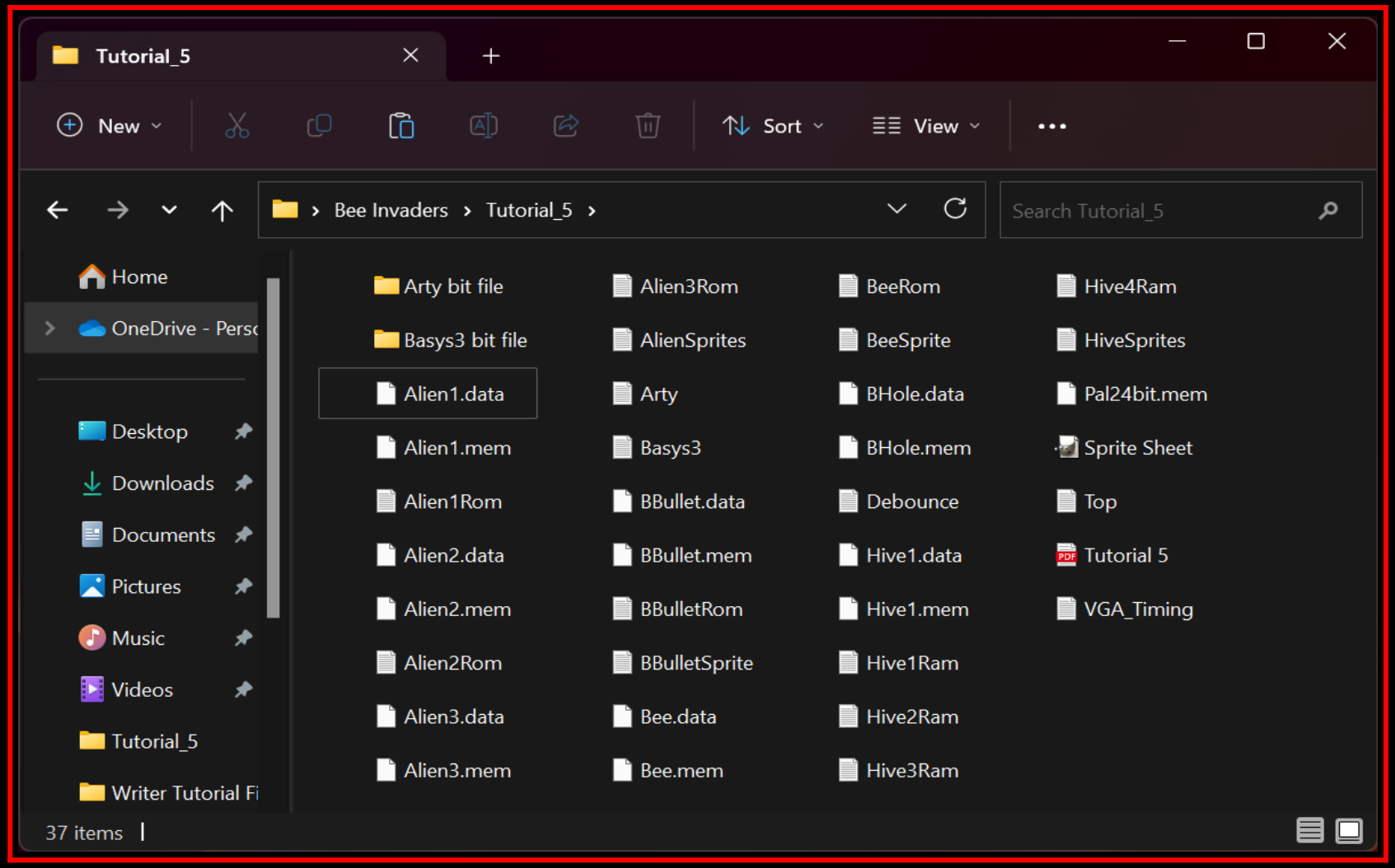
This Step By Step Tutorial Is For The
Digilent Basys3 FPGA Board Or The Digilent Arty A7-35 FPGA Board With A VGA Pmod Connected
But Can Be Adapted To Other FPGA Boards
A Modern Version Of The Popular Arcade Game
Space Invaders

Tutorial 5 - Firing Honey Bullets & Creating Holes In The Bee Hives

CONTENTS

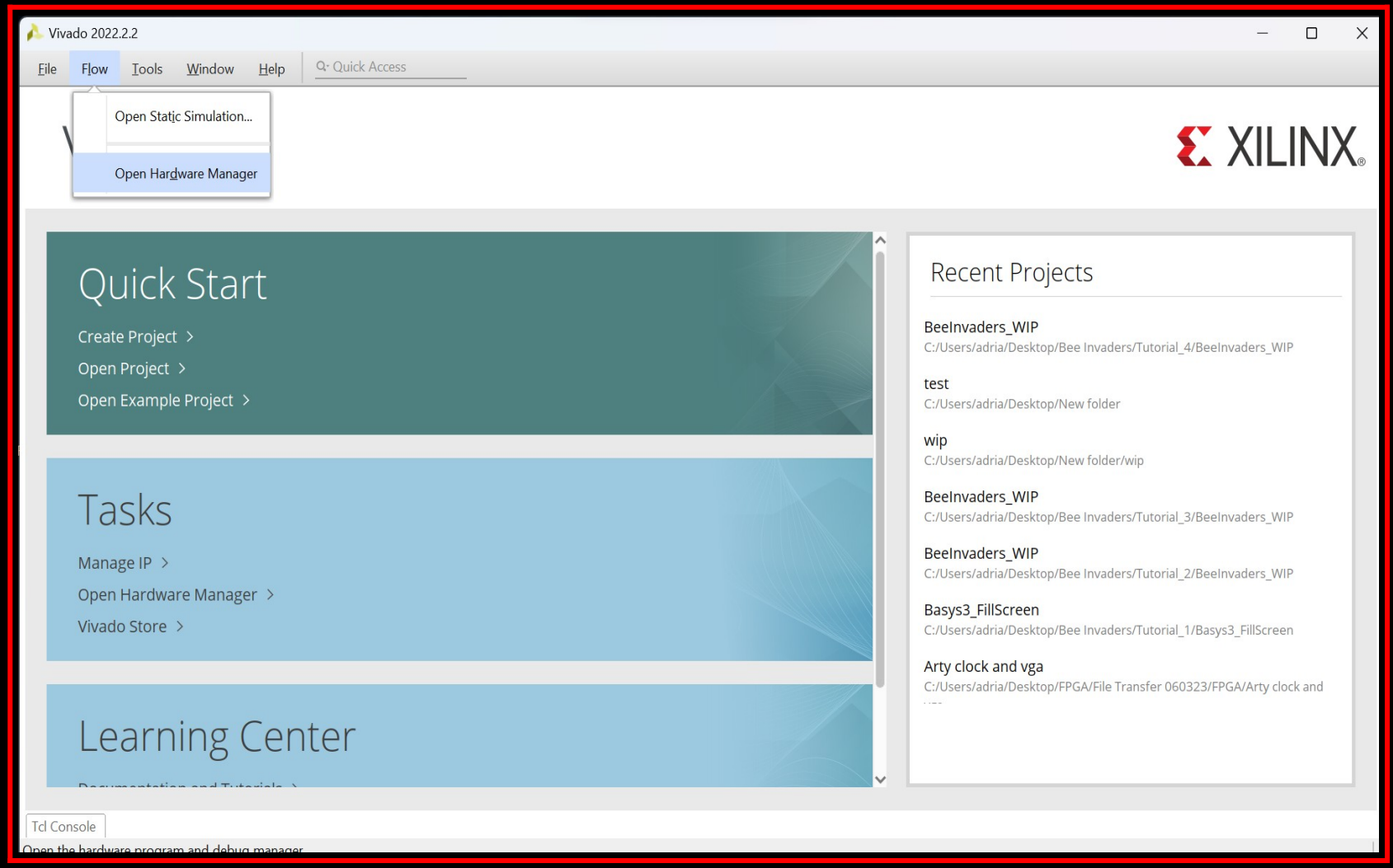
(A) EXTRACTING THE FILES AND RUNNING THE COMPILED BIT FILE

01 In the folder "Bee Invaders" create a folder called "Tutorial_5" and extract the files from the downloaded file "Tutorial_5 Files.zip" to this folder

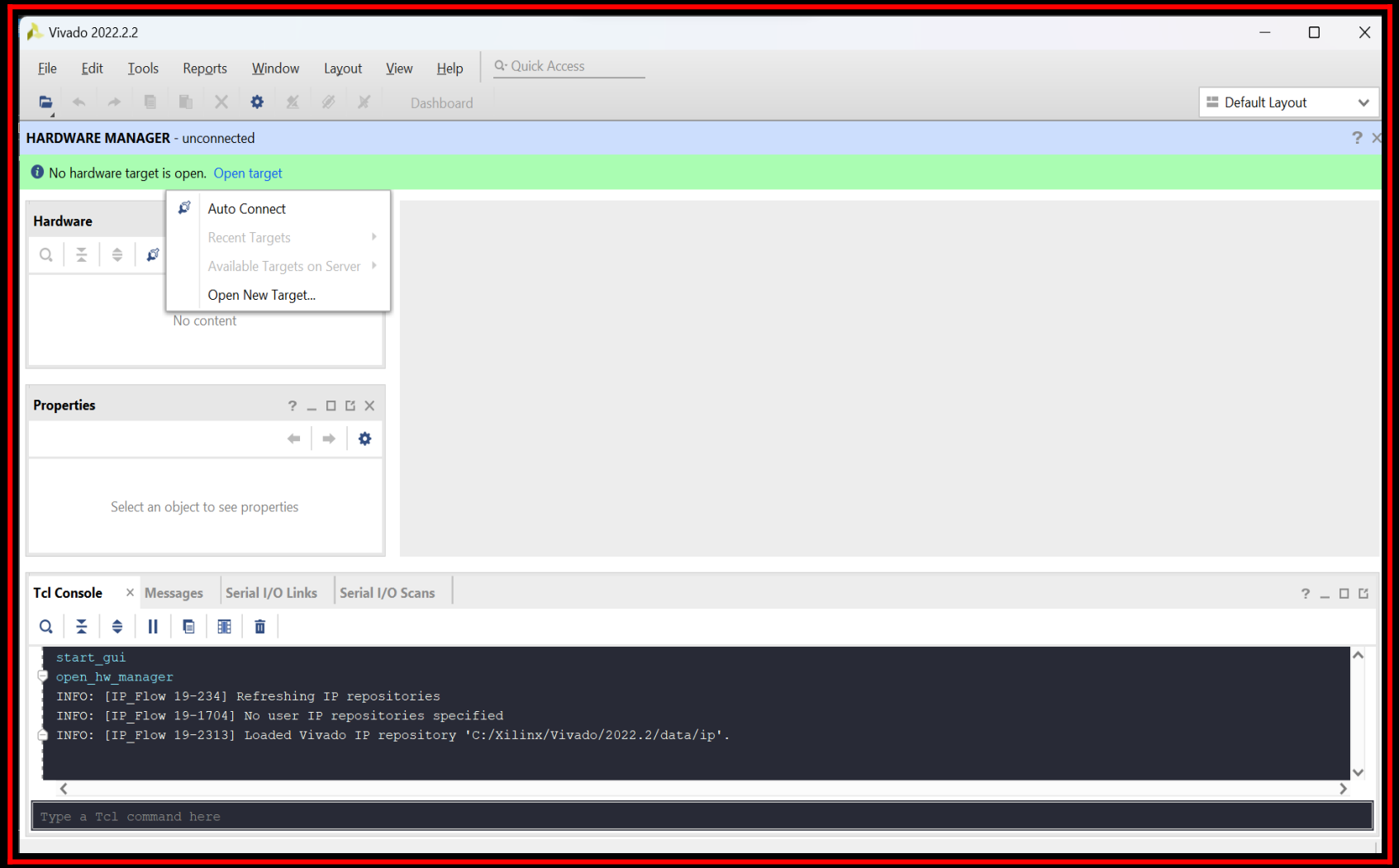


02

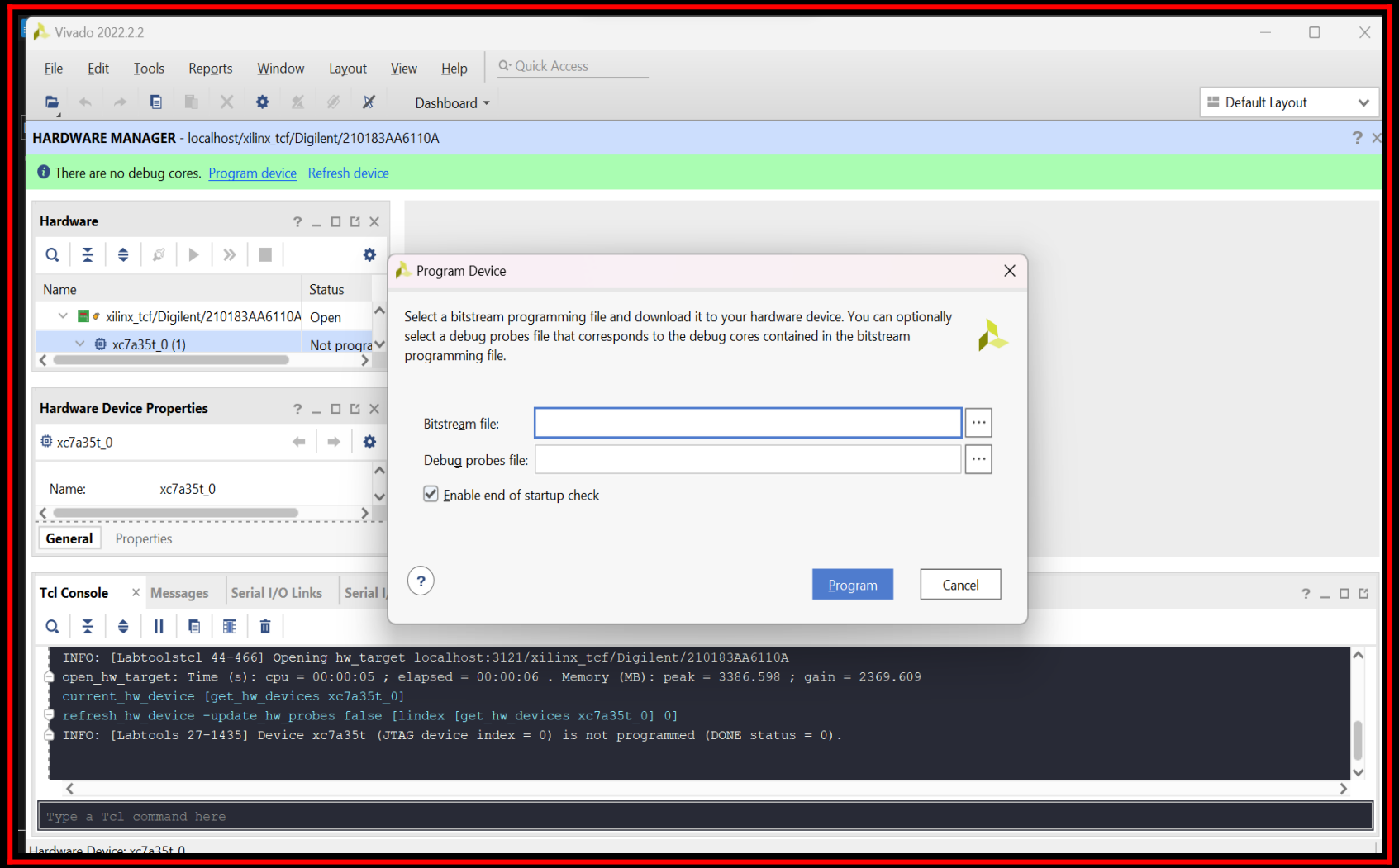
If you would like to run the compiled tutorial, you will find a bit file in the folders "Basys3 bit file" and "Arty bit file" for the Basys3 FPGA board and the Arty A7-35 FPGA board. To do this, run Vivado and select "Flow" and "Open Hardware Manager"



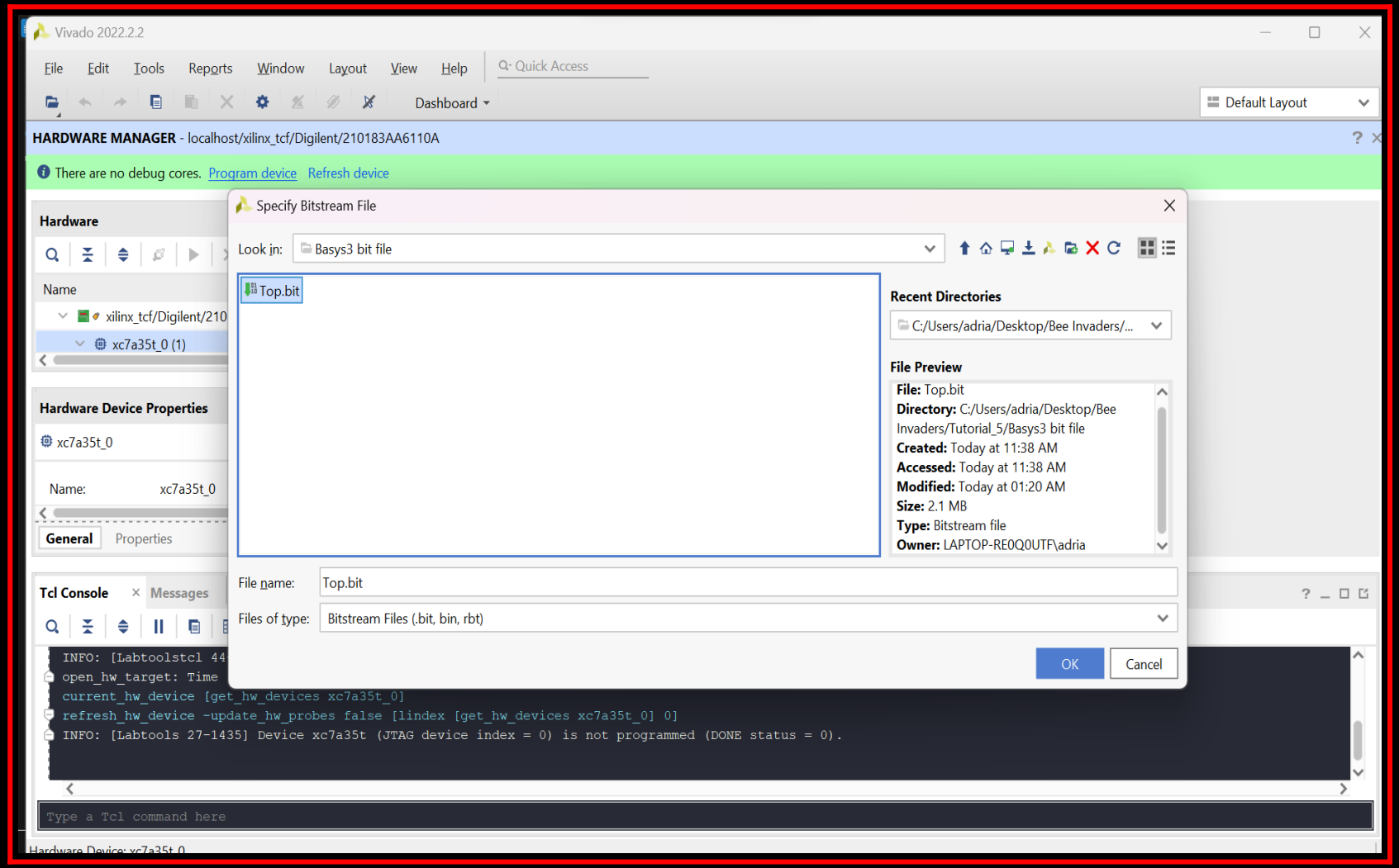
03 Connect the FPGA board to your computer / VGA screen and switch the board on (Basys3). Select "Open Target" and "Auto Connect"



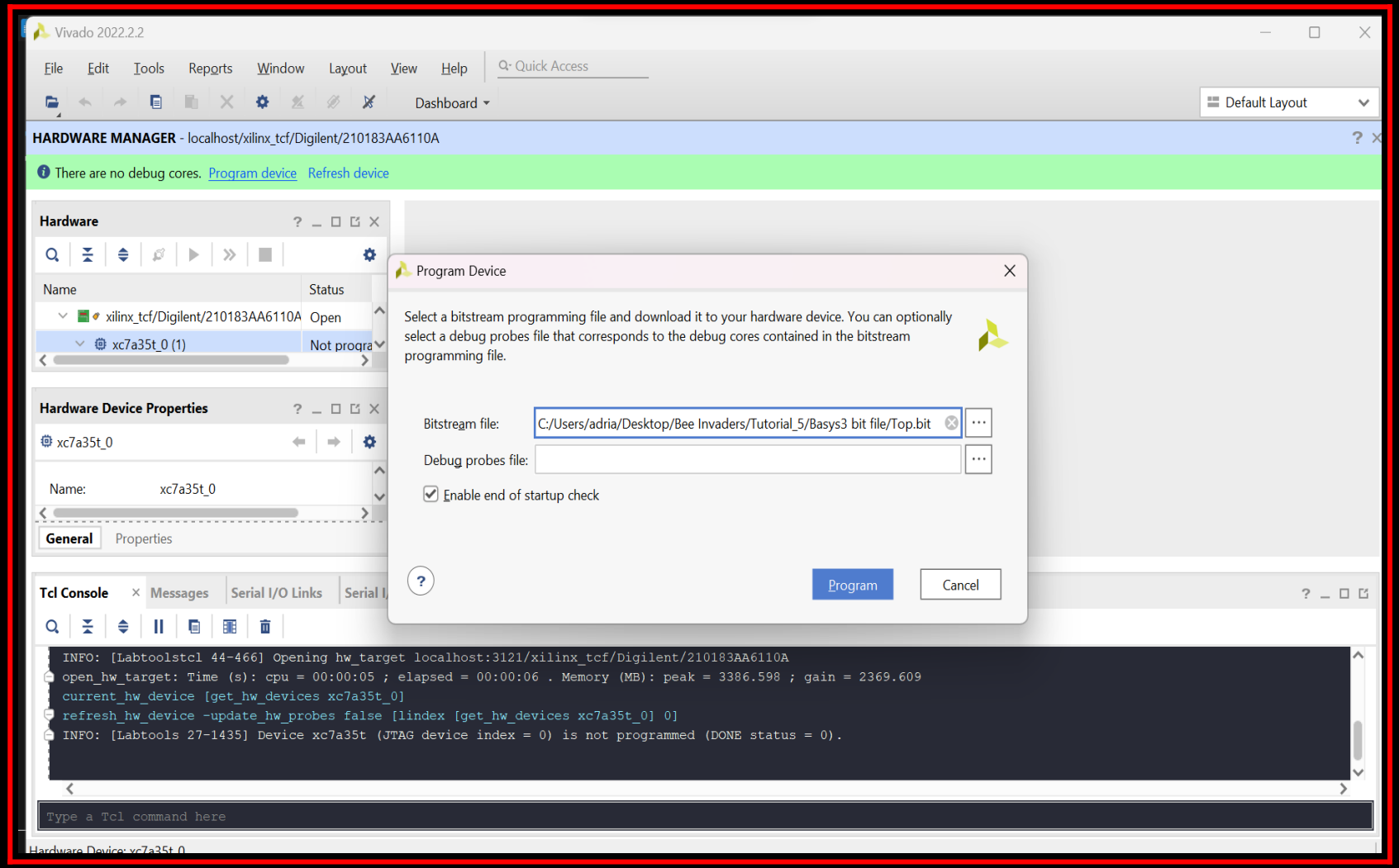
04 When Vivado has connected to the FPGA board select "Program device" and click on the 3 dots next to the "Bitstream file:" box



05 Navigate to the "Bee Invaders/Tutorial_5/Basys3 bit file" or the "Arty bit file" folder if you are using the Arty A7-35 board. Select the "Top.bit" file and select "OK"



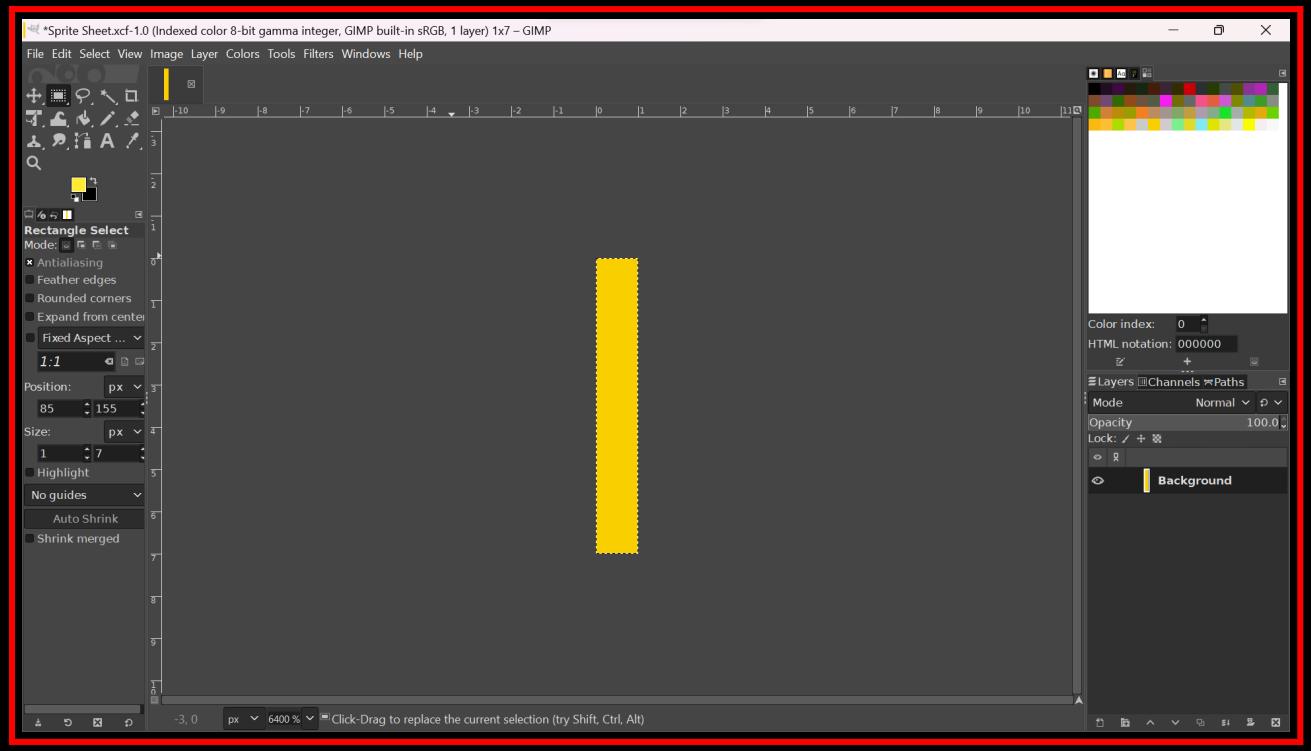
06 Then click on the "Program" button and you should see the game running on the FPGA board / VGA screen



(B) USING GIMP TO GENERATE THE GRAPHICS FOR THE BEE BULLET

01 The files for the Bee Bullet are in the files which were extracted in section (A). The "Hive1.mem" file has changed slightly due to the Bullet Hole routine. Jump to section (C) if you do not wish to see how the files were made in Gimp

Open "Sprite Sheet.xcf" in the "Tutorial_5" 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 Bee Bullet character and using the "rectangle select tool" select around the Bullet (this should be a rectangle 1 x 7 pixels) and crop it



02 The image needs to be saved as a Raw Data File, do this using File → Export As → Raw image data. Call the file "BBullet.data"

Using HxD Hex Editor (or similar) load the file "BBullet.data", select all the data and copy it

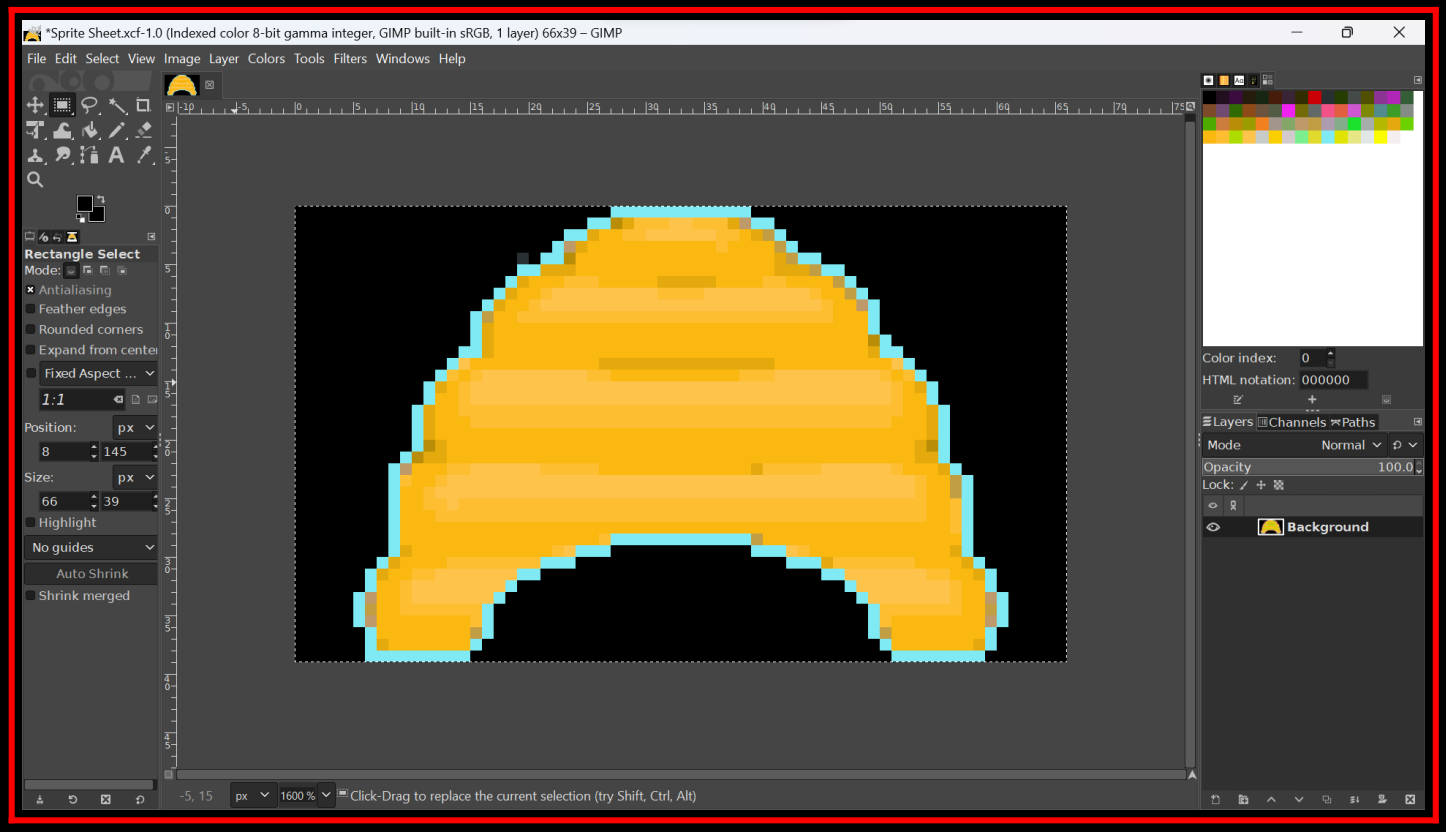
Then paste the data into a Notepad file and save it as "BBullet.mem" in the folder "Tutorial_5"

Using HxD Hex Editor (or similar) load the file "BBullet.pal", select all the data and copy it

Then paste the data into a Notepad file and save it as "Pal24bit.mem" in the folder "Tutorial_5"

03

Zoom in on the Hive character (inside the white border) and using the "rectangle select tool" select around the Hive (this should be a rectangle 66 x 39 pixels) and crop it



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" in the folder "Tutorial_5"

(C) CREATING THE PROJECT IN VIVADO

01 Follow the instructions in "Tutorial 1" to create a new project in the "Tutorial_5" folder in Vivado but call it "BeeInvaders_WIP"

Add these design sources from the "Tutorial 5" 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	BBulletSprite.v
Alien1Rom.v	Debounce.v	BBulletRom.v
Alien2Rom.v	HiveSprites.v	BBullet.mem
Alien3Rom.v	Hive1Ram.v	BHole.mem

Add a constraints file from the "Tutorial 5" 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:

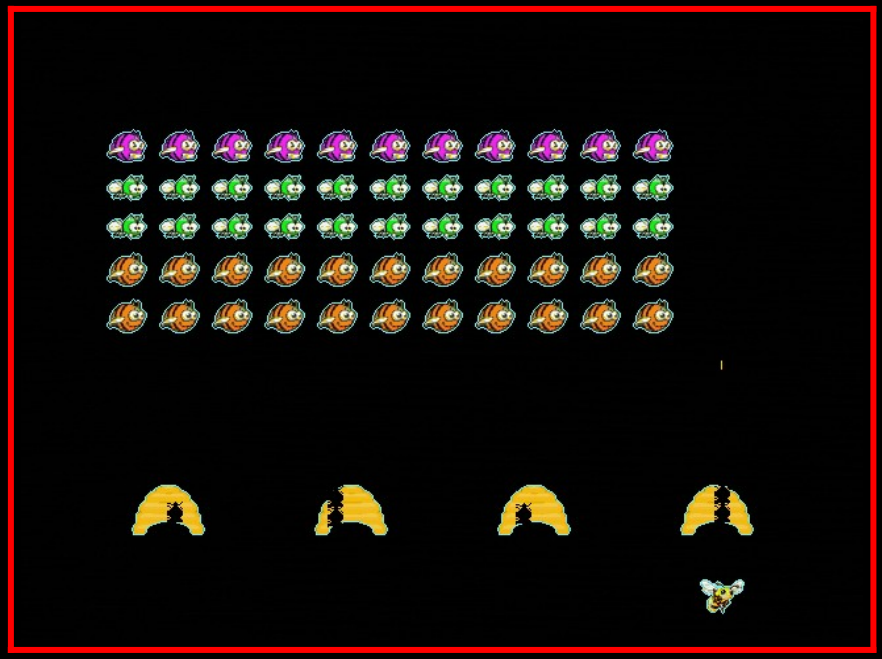
```
.reset(!btn_rst_n),      // reset button is active low
```

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"

With your FPGA board connected, 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 a Bee Bullet when you press the fire button and holes in the Hives when you shoot at them



(D) THE CODE FOR THIS TUTORIAL

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

```
//------------------------------------------
// Top.v module
// Digilent Basys 3
// Bee Invaders Tutorial_5
// 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
    input wire btnF                         // Fire 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
wire [9:0] BeeX;
BeeSprite BeeDisplay (
    .clk_pix(clk_pix),
    .sx(sx),
    .sy(sy),
    .de(de),
    .btnR(btnR),
    .btnL(btnL),
    .BeeX(BeeX),
    .BeeSpriteOn(BeeSpriteOn),
    .dataout(dout)
);

// Instantiate BBulletSprite
wire [1:0] BBulletSpriteOn;             // 1=on, 0=off
wire [7:0] BBdout;                      // pixel value from BBullet.mem
wire [9:0] yBBullet;                    // y coordinate for Bee Bullet
wire [9:0] xBBullet;                    // y coordinate for Bee Bullet
reg [1:0] BBulletHive1 = 0;             // 1 = bullet hit hive, 0 = no hit
reg [1:0] BBulletHive2 = 0;             // 1 = bullet hit hive, 0 = no hit
reg [1:0] BBulletHive3 = 0;             // 1 = bullet hit hive, 0 = no hit
reg [1:0] BBulletHive4 = 0;             // 1 = bullet hit hive, 0 = no hit
wire [1:0] BBulletstate;
BBulletSprite BBulletDisplay (
    .clk_pix(clk_pix),
    .sx(sx),
    .sy(sy),
    .de(de),
    .btnF(btnF),
    .BeeX(BeeX),
    .BBhithive1(BBhithive1),
    .BBhithive2(BBhithive2),
    .BBhithive3(BBhithive3),
    .BBhithive4(BBhithive4),
    .BBulletSpriteOn(BBulletSpriteOn),
    .BBdout(BBdout),
    .yBBullet(yBBullet),
    .xBBullet(xBBullet),
    .BBulletstate(BBulletstate)
);

// 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
wire [1:0] BBhithive1;                 // Bee Bullet Hit Hive1 (0 = Yes, 1 = No)
wire [1:0] BBhithive2;                 // Bee Bullet Hit Hive2 (0 = Yes, 1 = No)
wire [1:0] BBhithive3;                 // Bee Bullet Hit Hive3 (0 = Yes, 1 = No)
wire [1:0] BBhithive4;                 // Bee Bullet Hit Hive4 (0 = Yes, 1 = No)

HiveSprites HDisplay (
    .clk_pix(clk_pix),
    .sx(sx),
    .sy(sy),
    .de(de),
    .xBBullet(xBBullet),
    .yBBullet(yBBullet),
    .BBhithive1(BBhithive1),
    .BBhithive2(BBhithive2),
    .BBhithive3(BBhithive3),
    .BBhithive4(BBhithive4),
    .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 (BBulletSpriteOn==1)
                begin
                    vga_r <= (palette[(BBdout*3)])>>4;      // RED bits(7:4) from colour palette
                    vga_g <= (palette[(BBdout*3)+1])>>4;    // GREEN bits(7:4) from colour palette
```

```
                vga_b <= (palette[(BBdout*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_5
// 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_5
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//----------------------------------------------
`timescale 1ns / 1ps

// Setup BeeSprite module
module BeeSprite(
    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
    input wire btnR,                    // right button
    input wire btnL,                    // left button
    output reg [9:0] BeeX,              // Bee X position
    output reg [1:0] BeeSpriteOn,       // 1=on, 0=off
    output wire [7:0] dataout           // pixel value from Bee.mem
    );

    // instantiate BeeRom
    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 [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
        if(de)
            begin
                if((sx==BeeX-2) && (sy==BeeY))
                    begin
                        address <= 0;
```

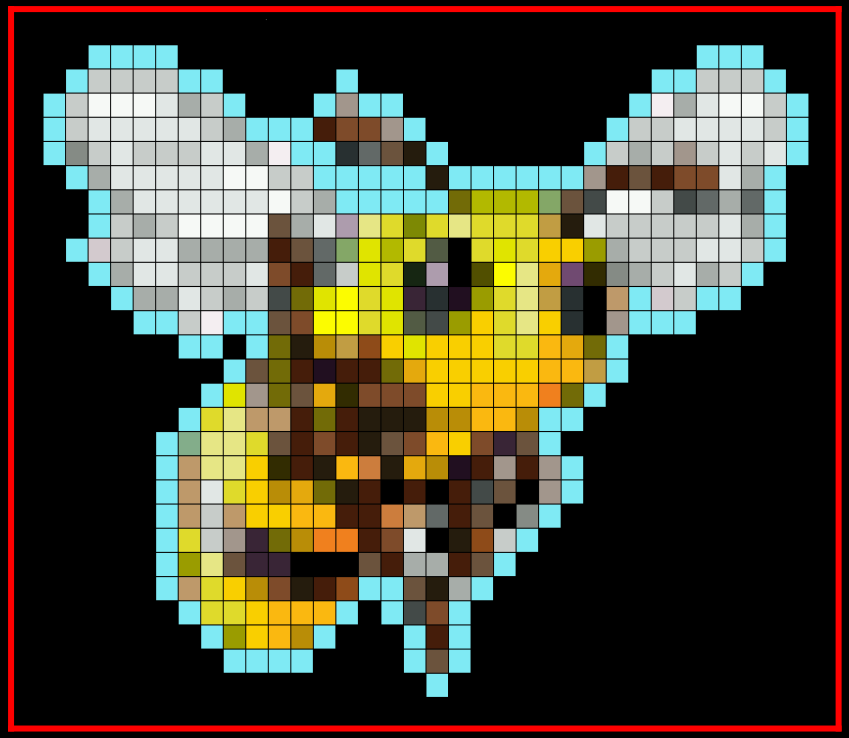
```
                        BeeSpriteOn <=1;
                    end
                if((sx>BeeX-2) && (sx<BeeX+BeeWidth-1) && (sy>BeeY-1) && (sy<BeeY+BeeHeight))
                    begin
                        address <= address +1;
                        BeeSpriteOn <=1;
                    end
                else
                        BeeSpriteOn <=0;
            end

        // if left or right button pressed, move the Bee
        if (BeeX == 0)
            BeeX <= 320;                                    // initailise Bee x position
        if ((sx==64) && (sy==480))                          // check for buttons once every frame
            begin
                if ((sig_right == 1) && (BeeX<640-BeeWidth))    // Check for right button
                    BeeX<=BeeX+1;                           // move right
                if ((sig_left == 1) && (BeeX>2))                // Check for left button
                    BeeX<=BeeX-1;                           // move left
            end
    end
endmodule
```

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

```
//----------------------------------------------
// BeeRom.v Module
// Single Port ROM
// Digilent Basys 3
// Bee Invaders Tutorial_5
// 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,         // pixel clock
    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 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 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 39 03 39 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 00 39 35 34 3C 3C 2C 2C 2C 2C 05 14 18 26 3A 2D 38 15 00 38 3A 38 36 36 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 35 34 39 39
00 00 00 00 00 00 00 00 39 39 34 3E 39 39 14 10 3D 3D 38 3A 15 0B 23 36 38 3B 36 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 38
3A 36 36 36 38 38 30 2E 17 39 00 00 00 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 36 36 36 36 36 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 36 36 30 30 30 24 17 39 00 00 00 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 00 00 00 39 2A 3B 3B 38 14 05 10 05 03 14 10 30 36 10 06 14 39 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
39 27 3B 3B 36 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 00 00 00 00 00 39 27 3C 38 36 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 00 00 00 39 27 34 27 36 36 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 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 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 00 00 00 39 27 38 36 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 00 00 39 38 38 36 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 00 00 00 00 00 00 39 23 36 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 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 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_5
// 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 "BBulletSprite.v"

```
//----------------------------------------------
// BBulletSprite.v Module
// Digilent Basys 3
// Bee Invaders Tutorial_5
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//----------------------------------------------
`timescale 1ns / 1ps

// Setup BBulletSprite module
module BBulletSprite(
    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,                      // 1 = visible pixels, 0 = blanking period
    input wire btnF,                    // fire button
    input wire [9:0] BeeX,              // bee bullet x position
    input wire [1:0] BBhithive1,        // 1 = bullet hit hive, 0 = no hit
    input wire [1:0] BBhithive2,        // 1 = bullet hit hive, 0 = no hit
    input wire [1:0] BBhithive3,        // 1 = bullet hit hive, 0 = no hit
    input wire [1:0] BBhithive4,        // 1 = bullet hit hive, 0 = no hit
    output reg [1:0] BBulletSpriteOn,   // 1=on, 0=off
    output wire [7:0] BBdout,           // pixel value from BBullet.mem
    output reg [9:0] yBBullet,          // y coordinate for Bee Bullet
    output reg [9:0] xBBullet,          // bee bullet x position
    output reg [1:0] BBulletstate       // 1 = moving, 2 = stopped
    );

    // instantiate BBulletRom
    reg [3:0] BBaddress;                // 2^4 or 15, need 1 x 7 = 7
    BBulletRom BBulletVRom (
        .BBaddress(BBaddress),
        .clk_pix(clk_pix),
        .BBdout(BBdout)
    );

    // Instantiate Debounce
    Debounce deb_fire (
        .clk_pix(clk_pix),
        .btn(btnF),
        .out(sig_fire)
    );

    // setup character size
    localparam BBWidth = 1;             // Bee Bullet width in pixels
    localparam BBHeight = 7;            // Bee Bullet height in pixels

    always @ (posedge clk_pix)
    begin
        // if sx,sy are within the confines of the Bee Bullet character, switch the Bee Bullet On
        if((de) && (BBulletstate == 1))
            begin
                if((sx==xBBullet-2) && (sy==yBBullet))
                    begin
                        BBaddress <= 0;
                        BBulletSpriteOn <=1;
                    end
                if((sx>xBBullet-2) && (sx<xBBullet+BBWidth-1) && (sy>yBBullet-1) && (sy<yBBullet+BBHeight))
                    begin
```

```
                    BBaddress <= BBaddress +1;
                    BBulletSpriteOn <=1;
                end
            else
                BBulletSpriteOn <=0;
        end
    else
    // if fire button pressed, move the Bee Bullet up the screen
    if ((sx==640) && (sy==480))                         // check for movement once every frame
    begin
        if (BBulletstate == 0)
            begin
                BBulletstate <= 2;                      // initialise BBulletstate = stopped
            end
        if ((sig_fire == 1) && (xBBullet == 0))         // Check for fire button and bullet stopped
            begin
                xBBullet <= BeeX + 16;
                yBBullet<=425;
                BBulletstate<=1;                        // 1 = bullet moving, 2 = bullet stopped
            end
        if ((BBulletstate == 1))
            begin
                yBBullet<=yBBullet-1;                   // move bullet up the screen
                if ((BBhithive1 == 1) || (BBhithive2 == 1) || (BBhithive3 == 1) || (BBhithive4 == 1)) // Check if Bee Bullet has hit hive1-4
                    begin
                        BBulletstate<=2;                // stop the bullet
                        yBBullet<=425;                  // bullet y start position
                        xBBullet<=0;
                    end
                if (yBBullet<10)                        // Check if Bee Bullet at top of screen
                    begin
                        BBulletstate<=2;                // stop the bullet
                        yBBullet<=425;                  // bullet y start position
                        xBBullet<=0;
                    end
            end
    end
  end
endmodule
```

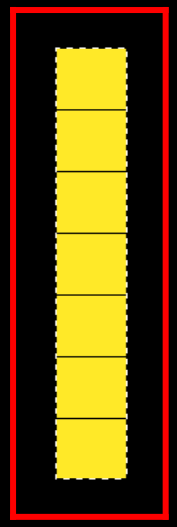
This is the code from the file “BBulletRom.v”

```
//----------------------------------------------
// BBulletRom.v Module
// Single Port ROM
// Digilent Basys 3
// Bee Invaders Tutorial_5
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//----------------------------------------------
`timescale 1ns / 1ps

// Setup BBulletRom module
module BBulletRom(
    input wire [3:0] BBaddress, // 2^4 or 15, need 1 x 7 = 7
    input wire clk_pix,
    output reg [7:0] BBdout     // (7:0) 8 bit pixel value from BBullet.mem
    );

    (*ROM_STYLE="block"*) reg [7:0] BBmemory_array [0:6]; // 8 bit values for 7 pixels of BBullet (1 x 7)
```

```
    initial
    begin
        $readmemh("BBullet.mem", BBmemory_array);
    end

    always @ (posedge clk_pix)
            BBdout <= BBmemory_array[BBaddress];
endmodule
```

This is the data from the file "Bbullet.mem" - Sprite Size 1 x 7 pixels

```
35 35 35 35 35 35 35
```



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

```
//----------------------------------------------
// AlienSprites.v module
// Digilent Basys 3
// Bee Invaders Tutorial_5
// 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_5
// 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_5
// 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"

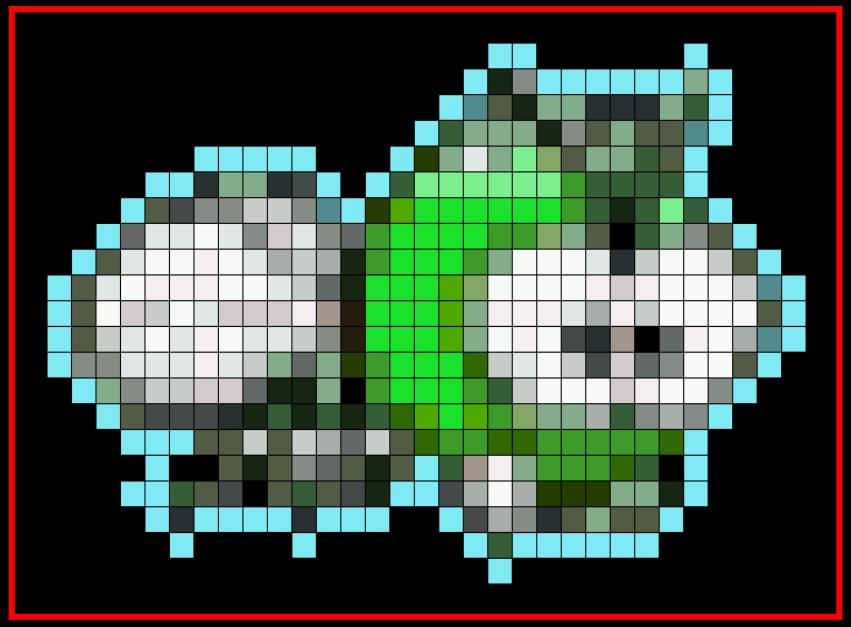
```
//-----------------------------------------------
// Alien3Rom.v Module
// Single Port ROM
// Digilent Basys 3
// Bee Invaders Tutorial_5
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//-----------------------------------------------
`timescale 1ns / 1ps

// 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 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 39 01 39
00 39 39 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 01 01 01 39 01 09 39 00 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 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 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 00 39 02 11 01 0E 16 0D 02 0D 16 16 16 16 0E 11 35 3E 3E 35 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 35 3F 3C 29 06 39 00 00 00 00 39 02 0D 02 02 16 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 35 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 35 35 35 35 11 16 16 0E 29 35 35 2C 35 3E 3E 2C 35 2C 3E 11 39 00 00 00 39 11 11 11 35 3E 3E 3F 3F 3F
3E 0D 16 16 16 0D 29 35 34 35 35 25 06 11 35 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 35 29 1F 11 1B 16 16 16 16 16 0E 0E 0D 0D 0E 16 16 16 0E 02 39 00 00 39 11 35 35 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 35 35 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 35 2C 35 3E 3E 3E 3E 35 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 35 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 35 35 29 29 29 11 06 39 00 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 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
```

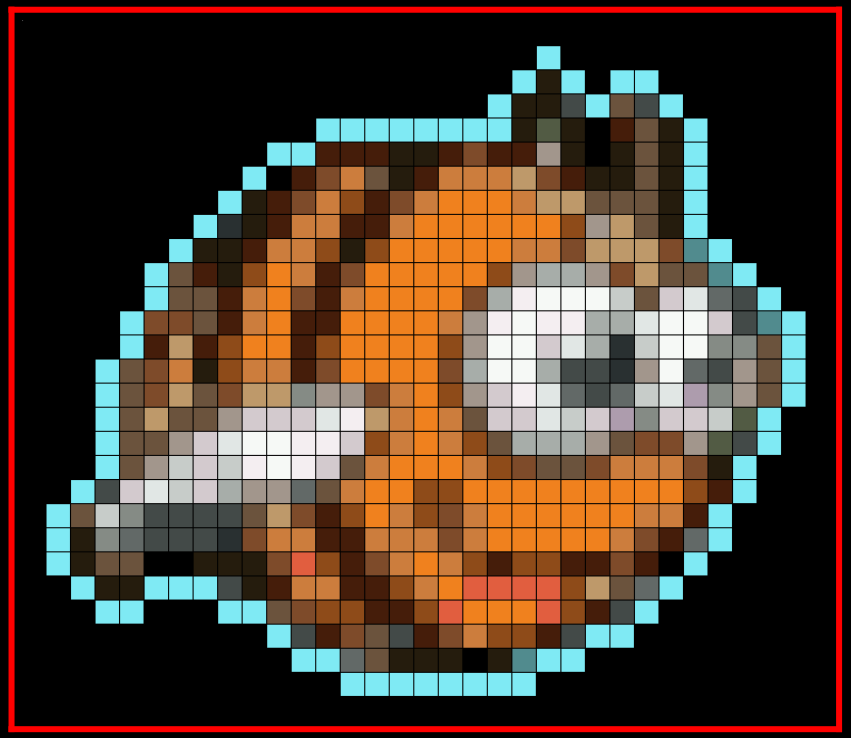
This is the data from the file "Alien2.mem" - Sprite Size 31 x 21 pixels

```
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 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 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 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 00 39 0F 2A 2A 2A 04 1F 15 2A 15 15 1D 39 00 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 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 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 35 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 35 3E 3F 3F 3F 34 1D 39 39 15 3F 35 34 3F 3C 35
35 35 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 35 18 1F 3F 3F 15 39 00 00 39 2A 1F 34 34 35 35 18 04 04 2A 00 1E 2B 2B 2B 1E 0F 34 3F
3F 3F 35 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 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 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 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 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 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 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 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 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 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 00 39 14 05 03 13 24 21 05 10 24 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 3F 3F 3F 3F 34 14 35 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 35 0B 1D
39 00 00 00 39 05 27 05 13 24 24 05 13 24 24 24 24 13 25 3F 3F 35 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 35 3E 3C 18 0B 18 34 3C 29 1F 25 14 39 00 00 39 14 27 14 14 25 35 35 35 3C
3E 27 21 24 21 14 35 35 3C 34 35 29 1F 35 35 34 15 39 00 00 00 39 14 14 25 35 3C 3F 3F 3E 3E 35 13 21 24 21 13 14 2C 2C 2C 25 14 10 10 25 15 0B 39 00 00 00 39
14 25 34 35 34 3E 3F 3E 35 14 21 24 24 24 21 13 10 14 14 10 21 21 21 10 03 39 00 00 00 39 0B 35 3C 34 35 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 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 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 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 00 39 39 39 39 39 39 39 00 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_5
// 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
    input wire [9:0] xBBullet,      // x coordinate for Bee Bullet
    input wire [9:0] yBBullet,      // y coordinate for Bee Bullet
    output reg [1:0] BBhithive1,    // set to 1 when Bee Bullet hit hive1
    output reg [1:0] BBhithive2,    // set to 1 when Bee Bullet hit hive2
    output reg [1:0] BBhithive3,    // set to 1 when Bee Bullet hit hive3
    output reg [1:0] BBhithive4,    // set to 1 when Bee Bullet hit hive4
    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 [1:0] write1;               // write1 = 0 (read data), write1 = 1 (write data)
    reg [7:0] data1;                // Data to write if write1 = 1 (write data)
    reg [11:0] H1address;           // Address to read/write data from/to Hive1 (2^12 or 4095, need 66 x 39 = 2574)

    Hive1Ram Hive1VRam (
        .clk_pix(clk_pix),
        .H1address(H1address),
        .write1(write1),
        .data1(data1),
        .H1dout(H1dout)
    );

    // instantiate Hive2Ram
    reg [1:0] write2;               // write2 = 0 (read data), write2 = 1 (write data)
    reg [7:0] data2;                // Data to write if write2 = 1 (write data)
    reg [11:0] H2address;           // Address to read/write data from/to Hive2 (2^12 or 4095, need 66 x 39 = 2574)

    Hive2Ram Hive2VRam (
        .clk_pix(clk_pix),
        .H2address(H2address),
        .write2(write2),
        .data2(data2),
        .H2dout(H2dout)
    );

    // instantiate Hive3Ram
    reg [1:0] write3;               // write3 = 0 (read data), write3 = 1 (write data)
```

```
reg [7:0] data3;               // Data to write if write3 = 1 (write data)
reg [11:0] H3address;          // Address to read/write data from/to Hive3 (2^12 or 4095, need 66 x 39 = 2574)

Hive3Ram Hive3VRam (
    .clk_pix(clk_pix),
    .H3address(H3address),
    .write3(write3),
    .data3(data3),
    .H3dout(H3dout)
);

// instantiate Hive4Ram
reg [1:0] write4;              // write4 = 0 (read data), write4 = 1 (write data)
reg [7:0] data4;               // Data to write if write4 = 1 (write data)
reg [11:0] H4address;          // Address to read/write data from/to Hive4 (2^12 or 4095, need 66 x 39 = 2574)

Hive4Ram Hive4VRam (
    .clk_pix(clk_pix),
    .H4address(H4address),
    .write4(write4),
    .data4(data4),
    .H4dout(H4dout)
);

// Load BHole.mem
reg [7:0] BHoleaddress;                // 2^8 or 255, need 11 x 16 = 176
reg [7:0] BHoledata [0:175];           // 8 bit values from BHole.mem
initial begin
    $readmemh("BHole.mem", BHoledata);  // load 176 hex values into BHole.mem
end

// setup Hive character positions and sizes
localparam Hive1X = 78;            // Hive1 X start position
localparam Hive1Y = 360;           // Hive1 Y start position
localparam Hive2X = 217;           // Hive2 X start position
localparam Hive2Y = 360;           // Hive2 Y start position
localparam Hive3X = 356;           // Hive3 X start position
localparam Hive3Y = 360;           // Hive3 Y start position
localparam Hive4X = 495;           // Hive4 X start position
localparam Hive4Y = 360;           // Hive4 Y start position
localparam HiveWidth = 66;         // Hive width in pixels
localparam HiveHeight = 39;        // Hive height in pixels

reg [9:0] BHit1x;                  // Saves the x position of where the bee bullet hit hive1
reg [9:0] BHit1y;                  // Saves the y position of where the bee bullet hit hive1
reg [9:0] BHit2x;                  // Saves the x position of where the bee bullet hit hive2
reg [9:0] BHit2y;                  // Saves the y position of where the bee bullet hit hive2
reg [9:0] BHit3x;                  // Saves the x position of where the bee bullet hit hive3
reg [9:0] BHit3y;                  // Saves the y position of where the bee bullet hit hive3
reg [9:0] BHit4x;                  // Saves the x position of where the bee bullet hit hive4
reg [9:0] BHit4y;                  // Saves the y position of where the bee bullet hit hive4
reg [3:0] hzcounter1 = 0;          // Hole 11 pixels wide - Hive1
reg [4:0] vtcounter1 = 0;          // Hole 16 pixels high - Hive1
reg [3:0] hzcounter2 = 0;          // Hole 11 pixels wide - Hive2
reg [4:0] vtcounter2 = 0;          // Hole 16 pixels high - Hive2
reg [3:0] hzcounter3 = 0;          // Hole 11 pixels wide - Hive2
reg [4:0] vtcounter3 = 0;          // Hole 16 pixels high - Hive2
reg [3:0] hzcounter4 = 0;          // Hole 11 pixels wide - Hive2
reg [4:0] vtcounter4 = 0;          // Hole 16 pixels high - Hive2

always @ (posedge clk_pix)
begin
```

```
if (de)
    begin
        // check if sx,sy are within the confines of the Hive character - hive1
        if ((sx==Hive1X-2) && (sy==Hive1Y))
            begin
                write1<=0;
                H1address <= 0;
                Hive1SpriteOn <=1;
            end
        if ((sx>Hive1X-2) && (sx<Hive1X+HiveWidth-1) && (sy>Hive1Y-1) && (sy<Hive1Y+HiveHeight))
            begin
                write1<=0;
                H1address <= H1address + 1;
                Hive1SpriteOn <= 1;
                // Check if Bee Bullet Has Hit Hive 1
                if ((sx == xBBullet) && (sy == yBBullet) && (sx>Hive1X-1) && (BBhithive1 == 0) && (H1dout > 0))
                    begin
                        BBhithive1 <= 1;
                        BHit1x <= xBBullet - 5;
                        BHit1y <= yBBullet - 15;
                    end
            end
        else
            Hive1SpriteOn <= 0;

        // check if sx,sy are within the confines of the Hive character - hive2
        if ((sx==Hive2X-2) && (sy==Hive2Y))
            begin
                write2<=0;
                H2address <= 0;
                Hive2SpriteOn <=1;
            end
        if ((sx>Hive2X-2) && (sx<Hive2X+HiveWidth-1) && (sy>Hive2Y-1) && (sy<Hive2Y+HiveHeight))
            begin
                write2<=0;
                H2address <= H2address + 1;
                Hive2SpriteOn <= 1;
                // Check if Bee Bullet Has Hit Hive 2
                if ((sx == xBBullet) && (sy == yBBullet) && (sx>Hive2X-1) && (BBhithive2 == 0) && (H2dout > 0))
                    begin
                        BBhithive2 <= 1;
                        BHit2x <= xBBullet - 5;
                        BHit2y <= yBBullet - 15;
                    end
            end
        else
            Hive2SpriteOn <= 0;

         // check if sx,sy are within the confines of the Hive character - hive3
        if ((sx==Hive3X-2) && (sy==Hive3Y))
            begin
                write3<=0;
                H3address <= 0;
                Hive3SpriteOn <=1;
            end
        if ((sx>Hive3X-2) && (sx<Hive3X+HiveWidth-1) && (sy>Hive3Y-1) && (sy<Hive3Y+HiveHeight))
            begin
                write3<=0;
                H3address <= H3address + 1;
                Hive3SpriteOn <= 1;
                // Check if Bee Bullet Has Hit Hive 3
                if ((sx == xBBullet) && (sy == yBBullet) && (sx>Hive3X-1) && (BBhithive3 == 0) && (H3dout > 0))
```

```
                begin
                    BBhithive3 <= 1;
                    BHit3x <= xBBullet - 5;
                    BHit3y <= yBBullet - 15;
                end
            end
        else
            Hive3SpriteOn <= 0;

         // check if sx,sy are within the confines of the Hive character - hive4
        if ((sx==Hive4X-2) && (sy==Hive4Y))
            begin
                write4<=0;
                H4address <= 0;
                Hive4SpriteOn <=1;
            end
        if ((sx>Hive4X-2) && (sx<Hive4X+HiveWidth-1) && (sy>Hive4Y-1) && (sy<Hive4Y+HiveHeight))
            begin
                write4<=0;
                H4address <= H4address + 1;
                Hive4SpriteOn <= 1;
                // Check if Bee Bullet Has Hit Hive 4
                if ((sx == xBBullet) && (sy == yBBullet) && (sx>Hive4X-1) && (BBhithive4 == 0) && (H4dout > 0))
                    begin
                        BBhithive4 <= 1;
                        BHit4x <= xBBullet - 5;
                        BHit4y <= yBBullet - 15;
                    end
            end
        else
            Hive4SpriteOn <= 0;
    end
else

// insert bullet hole - Hive1
if ((sx>640) && (sy>480) && (BBhithive1 == 1))
    begin
        if ((hzcounter1 == 0) && (vtcounter1 == 0))
            begin
                H1address <= (BHit1x - Hive1X) + ((BHit1y - Hive1Y) * HiveWidth);
                BHoleaddress <= 0;
                hzcounter1 <= hzcounter1 + 1;
            end
        else
        if (hzcounter1 < 12)
            begin
                if (BHoledata[BHoleaddress] > 0)
                    write1<=0;
                else
                    begin
                        write1<=1;
                        data1 <= BHoledata[BHoleaddress];
                    end

                BHoleaddress <= BHoleaddress + 1;
                H1address <= H1address + 1;
                hzcounter1 <= hzcounter1 + 1;
            end
        else
        if ((hzcounter1 == 12) && (vtcounter1 < 16))
            begin
                if (BHoledata[BHoleaddress] > 0)
```

```
                    write1<=0;
                else
                    begin
                        write1<=1;
                        data1 <= BHoledata[BHoleaddress];
                    end

                H1address <= H1address + HiveWidth - 11;
                vtcounter1 <= vtcounter1 + 1;
                hzcounter1 <= 1;
            end

        if (vtcounter1 > 15)
            begin
                BBhithive1 <= 0;
                write1 <= 0;
                hzcounter1 <= 0;
                vtcounter1 <= 0;
            end
    end

// insert bullet hole - Hive2
if ((sx>640) && (sy>480) && (BBhithive2 == 1))
    begin
        if ((hzcounter2 == 0) && (vtcounter2 == 0))
            begin
                H2address <= (BHit2x - Hive2X) + ((BHit2y - Hive2Y) * HiveWidth);
                BHoleaddress <= 0;
                hzcounter2 <= hzcounter2 + 1;
            end
        else
        if (hzcounter2 < 12)
            begin
                if (BHoledata[BHoleaddress] > 0)
                    write2<=0;
                else
                    begin
                        write2<=1;
                        data2 <= BHoledata[BHoleaddress];
                    end

                BHoleaddress <= BHoleaddress + 1;
                H2address <= H2address + 1;
                hzcounter2 <= hzcounter2 + 1;
            end
        else
        if ((hzcounter2 == 12) && (vtcounter2 < 16))
            begin
                if (BHoledata[BHoleaddress] > 0)
                    write2<=0;
                else
                    begin
                        write2<=1;
                        data2 <= BHoledata[BHoleaddress];
                    end

                H2address <= H2address + HiveWidth - 11;
                vtcounter2 <= vtcounter2 + 1;
                hzcounter2 <= 1;
            end

        if (vtcounter2 > 15)
```

```
            begin
                BBhithive2 <= 0;
                write2 <= 0;
                hzcounter2 <= 0;
                vtcounter2 <= 0;
            end
    end
// insert bullet hole - Hive3
if ((sx>640) && (sy>480) && (BBhithive3 == 1))
    begin
        if ((hzcounter3 == 0) && (vtcounter3 == 0))
            begin
                H3address <= (BHit3x - Hive3X) + ((BHit3y - Hive3Y) * HiveWidth);
                BHoleaddress <= 0;
                hzcounter3 <= hzcounter3 + 1;
            end
        else
        if (hzcounter3 < 12)
            begin
                if (BHoledata[BHoleaddress] > 0)
                    write3<=0;
                else
                    begin
                        write3<=1;
                        data3 <= BHoledata[BHoleaddress];
                    end

                BHoleaddress <= BHoleaddress + 1;
                H3address <= H3address + 1;
                hzcounter3 <= hzcounter3 + 1;
            end
        else
        if ((hzcounter3 == 12) && (vtcounter3 < 16))
            begin
                if (BHoledata[BHoleaddress] > 0)
                    write3<=0;
                else
                    begin
                        write3<=1;
                        data3 <= BHoledata[BHoleaddress];
                    end

                H3address <= H3address + HiveWidth - 11;
                vtcounter3 <= vtcounter3 + 1;
                hzcounter3 <= 1;
            end

        if (vtcounter3 > 15)
            begin
                BBhithive3 <= 0;
                write3 <= 0;
                hzcounter3 <= 0;
                vtcounter3 <= 0;
            end
    end
// insert bullet hole - Hive4
if ((sx>640) && (sy>480) && (BBhithive4 == 1))
    begin
        if ((hzcounter4 == 0) && (vtcounter4 == 0))
            begin
                H4address <= (BHit4x - Hive4X) + ((BHit4y - Hive4Y) * HiveWidth);
                BHoleaddress <= 0;
```

```
                    hzcounter4 <= hzcounter4 + 1;
                end
            else
            if (hzcounter4 < 12)
                begin
                    if (BHoledata[BHoleaddress] > 0)
                        write4<=0;
                    else
                        begin
                            write4<=1;
                            data4 <= BHoledata[BHoleaddress];
                        end

                    BHoleaddress <= BHoleaddress + 1;
                    H4address <= H4address + 1;
                    hzcounter4 <= hzcounter4 + 1;
                end
            else
            if ((hzcounter4 == 12) && (vtcounter4 < 16))
                begin
                    if (BHoledata[BHoleaddress] > 0)
                        write4<=0;
                    else
                        begin
                            write4<=1;
                            data4 <= BHoledata[BHoleaddress];
                        end

                    H4address <= H4address + HiveWidth - 11;
                    vtcounter4 <= vtcounter4 + 1;
                    hzcounter4 <= 1;
                end

            if (vtcounter4 > 15)
                begin
                    BBhithive4 <= 0;
                    write4 <= 0;
                    hzcounter4 <= 0;
                    vtcounter4 <= 0;
                end
        end
end
endmodule
```

This is the code from the file "Hive1Ram.v"

```
//-----------------------------------------------
// Hive1Ram.v Module - Single Port RAM
// Digilent Basys 3
// Bee Invaders Tutorial_5
// 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,        // Address to read/write data from/to Hive1 (2^12 or 4095, need 66 x 39 = 2574)
    input wire [1:0] write1,            // 1 = write, 0 = read data
```

```
    input wire [7:0] data1,             // 8 bit pixel value to Hive1
    output reg [7:0] H1dout             // 8 bit pixel value from Hive1
    );

    (*RAM_STYLE="block"*) reg [7:0] H1memory_array [0:2573]; // 8 bit values for 2574 pixels of Hive1 (66 x 39)
    initial $readmemh("Hive1.mem", H1memory_array);

    always @ (posedge clk_pix)
        if (write1==1)
            H1memory_array[H1address] <= data1;
        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_5
// 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,        // Address to read/write data from/to Hive2 (2^12 or 4095, need 66 x 39 = 2574)
    input wire [1:0] write2,            // 1 = write, 0 = read data
    input wire [7:0] data2,             // 8 bit pixel value to Hive2
    output reg [7:0] H2dout             // 8 bit pixel value from Hive2
    );

    (*RAM_STYLE="block"*) reg [7:0] H2memory_array [0:2573]; // 8 bit values for 2574 pixels of Hive2 (66 x 39)
    initial $readmemh("Hive1.mem", H2memory_array);

    always @ (posedge clk_pix)
        if (write2==1)
            H2memory_array[H2address] <= data2;
        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_5
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//----------------------------------------------
`timescale 1ns / 1ps

// Setup Hive3Ram Module
module Hive3Ram(
    input wire clk_pix,
```

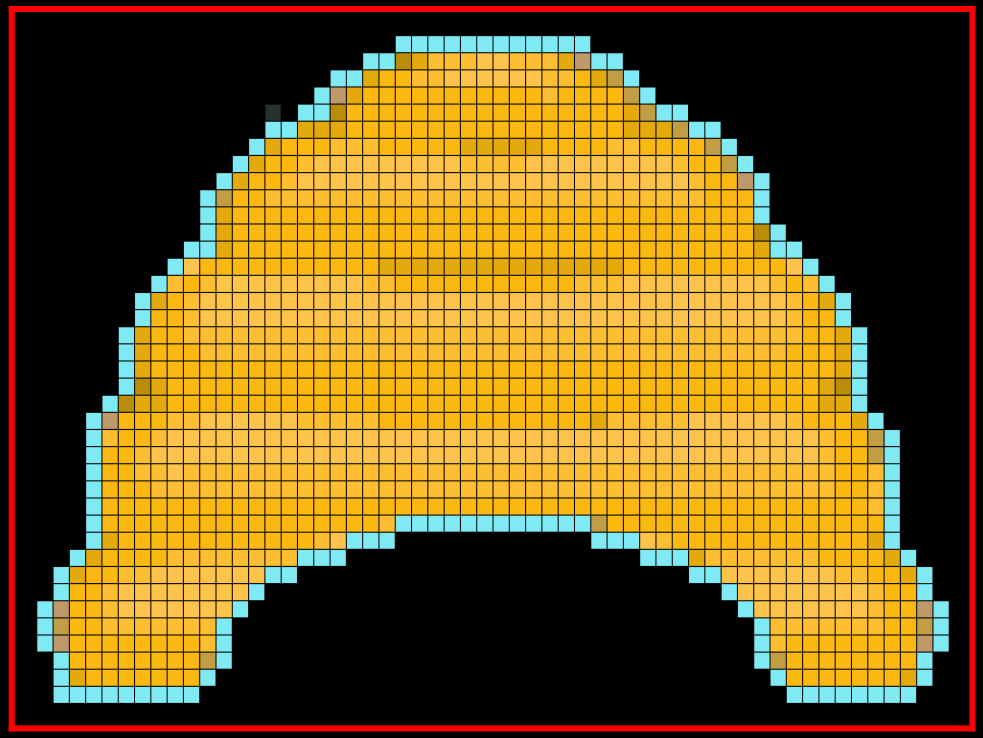
```
    input wire [11:0] H3address,        // Address to read/write data from/to Hive3 (2^12 or 4095, need 66 x 39 = 2574)
    input wire [1:0] write3,            // 1 = write, 0 = read data
    input wire [7:0] data3,             // 8 bit pixel value to Hive3
    output reg [7:0] H3dout             // 8 bit pixel value from Hive3
    );

    (*RAM_STYLE="block"*) reg [7:0] H3memory_array [0:2573]; // 8 bit values for 2574 pixels of Hive3 (66 x 39)
    initial $readmemh("Hive1.mem", H3memory_array);

    always @ (posedge clk_pix)
        if (write3==1)
            H3memory_array[H3address] <= data3;
        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_5
// 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,        // Address to read/write data from/to Hive4 (2^12 or 4095, need 66 x 39 = 2574)
    input wire [1:0] write4,            // 1 = write, 0 = read data
    input wire [7:0] data4,             // 8 bit pixel value to Hive4
    output reg [7:0] H4dout             // 8 bit pixel value from Hive4
    );

    (*RAM_STYLE="block"*) reg [7:0] H4memory_array [0:2573]; // 8 bit values for 2574 pixels of Hive4 (66 x 39)
    initial $readmemh("Hive1.mem", H4memory_array);

    always @ (posedge clk_pix)
        if (write4==1)
            H4memory_array[H4address] <= data4;
        else
            H4dout <= H4memory_array[H4address];
endmodule
```

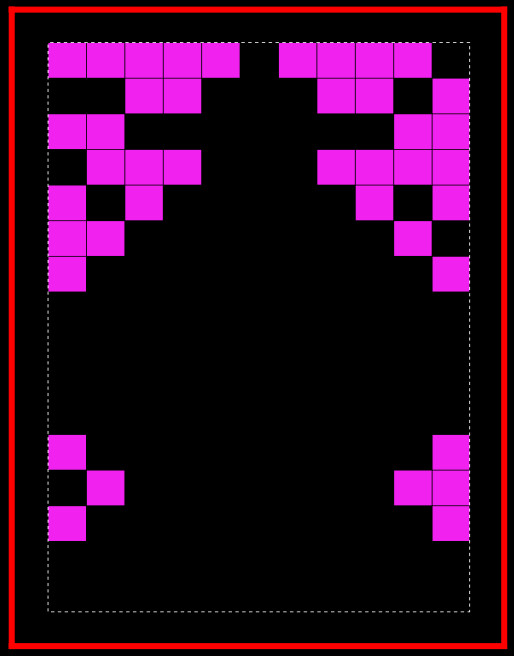
This is the data from the file "Hive1.mem" - Sprite Size 66 x 39 pixels


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



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

```
16 16 16 16 16 00 16 16 16 16 00 00 00 16 16 00 00 00 16 16 00 16 16 16 00 00 00 00 00 00 16 16 00 16 16 16 00 00 00 16 16 16 16 16 00 16 00 00 00 00 00 16
00 16 16 16 00 00 00 00 00 00 00 16 00 16 00 00 00 00 00 00 00 00 00 00 16 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 00 00 16 00 00 00 00 00 00 00 00 00 00 16 00 16 00 00 00 00 00 00 00 00 16 16 16 00 00 00 00 00 00 00 00 00 00 16 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 00 00 00 00 00 00 00 00 00 00 00 00 00 00 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 Tutorial_5
## 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]
set_property PACKAGE_PIN T18 [get_ports btnF]
   set_property IOSTANDARD LVCMOS33 [get_ports btnF]

## 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_5
## 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 C9 IOSTANDARD LVCMOS33} [get_ports {btnF}]
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]}]
```

(E) EXPLANATION OF THE VERILOG CODE USED

01 Top.v module additional code

```
// Instantiate BeeSprite
wire [9:0] BeeX;
BeeSprite BeeDisplay (
   .clk_pix(clk_pix),
   ..
   ..
   .BeeX(BeeX),
```

BeeX value has been passed from BeeSprite.v to the new routine BBulletSprite.v

```
// Instantiate BBulletSprite
   wire [1:0] BBulletSpriteOn;          // 1=on, 0=off
   wire [7:0] BBdout;                   // pixel value from BBullet.mem
   wire [9:0] yBBullet;                 // y coordinate for Bee Bullet
   wire [9:0] xBBullet;                 // x coordinate for Bee Bullet
   reg [1:0] BBulletHive1 = 0;          // 1 = bullet hit hive1, 0 = no hit
   reg [1:0] BBulletHive2 = 0;          // 1 = bullet hit hive2, 0 = no hit
   reg [1:0] BBulletHive3 = 0;          // 1 = bullet hit hive3, 0 = no hit
   reg [1:0] BBulletHive4 = 0;          // 1 = bullet hit hive4, 0 = no hit
   wire [1:0] Bbulletstate;             // 1 = moving, 2 = stopped
   BBulletSprite BBulletDisplay (
      .clk_pix(clk_pix),
      .sx(sx),
      .sy(sy),
      .de(de),
      .btnF(btnF),
      .BeeX(BeeX),
      .BBhithive1(BBhithive1),
      .BBhithive2(BBhithive2),
      .BBhithive3(BBhithive3),
      .BBhithive4(BBhithive4),
      .BbulletSpriteOn(BBulletSpriteOn),
```

```
        .BBdout(BBdout),
        .yBBullet(yBBullet),
        .xBBullet(xBBullet),
        .BBulletstate(BBulletstate)
    );
```

This instantiates a new module called BBulletSprite

```
// instantiate HiveSprites
wire [1:0] BBhithive1;          // Bee Bullet Hit Hive1 (0 = Yes, 1 = No)
wire [1:0] BBhithive2;          // Bee Bullet Hit Hive2 (0 = Yes, 1 = No)
wire [1:0] BBhithive3;          // Bee Bullet Hit Hive3 (0 = Yes, 1 = No)
wire [1:0] BBhithive4;          // Bee Bullet Hit Hive4 (0 = Yes, 1 = No)

HiveSprites HDisplay (
   .BBhithive1(BBhithive1),
   .BBhithive2(BBhithive2),
   .BBhithive3(BBhithive3),
   .BBhithive4(BBhithive4),
```

BBhithive1 – 4 have been passed from HiveSprites to BBulletSprite

```
// VGA Output
..
..
        if (BBulletSpriteOn==1)
           begin
              vga_r <= (palette[(BBdout*3)])>>4;        // RED bits(7:4) from colour palette
              vga_g <= (palette[(BBdout*3)+1])>>4;      // GREEN bits(7:4) from colour palette
              vga_b <= (palette[(BBdout*3)+2])>>4;      // BLUE bits(7:4) from colour palette
           end
```

BBdout has been added to the VGA Output routine, to display the Bee Bullet

02 BeeSprite.v module additional code

```
module BeeSprite(
    output reg [9:0] BeeX,          // Bee X position
```

BeeX value has been passed from this module to BBulletSprite.v, used when setting the bullet x position when the fire button is pressed

03 BBulletSprite.v module added

```
//----------------------------------------------
// BBulletSprite.v Module
// Digilent Basys 3
// Bee Invaders Tutorial_5
// Onboard clock 100MHz
// VGA Resolution: 640x480 @ 60Hz
// Pixel Clock 25.2MHz
//----------------------------------------------
`timescale 1ns / 1ps

// Setup BBulletSprite module
module BBulletSprite(
    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,                          // 1 = visible pixels, 0 = blanking period
    input wire btnF,                        // fire button
    input wire [9:0] BeeX,                  // bee bullet x position
    input wire [1:0] BBhithive1,            // 1 = bullet hit hive, 0 = no hit
    input wire [1:0] BBhithive2,            // 1 = bullet hit hive, 0 = no hit
    input wire [1:0] BBhithive3,            // 1 = bullet hit hive, 0 = no hit
    input wire [1:0] BBhithive4,            // 1 = bullet hit hive, 0 = no hit
    output reg [1:0] BBulletSpriteOn,       // 1=on, 0=off
    output wire [7:0] BBdout,               // pixel value from BBullet.mem
    output reg [9:0] yBBullet,              // y coordinate for Bee Bullet
    output reg [9:0] xBBullet,              // bee bullet x position
    output reg [1:0] BBulletstate           // 1 = moving, 2 = stopped
    );
```

This sets up the variables used in this module. The fire button has been introduced, BBhithive1 – 4 will be set to 1 if the Bee Bullet has hit one of the 4 hives. BBulletstate tracks the Bee Bullet state (1 = moving and 2 = stopped)

```
 // instantiate BBulletRom
reg [3:0] BBaddress;                    // 2^4 or 15, need 1 x 7 = 7
BBulletRom BBulletVRom (
    .BBaddress(BBaddress),
    .clk_pix(clk_pix),
    .BBdout(BBdout)
);

// Instantiate Debounce
Debounce deb_fire (
    .clk_pix(clk_pix),
    .btn(btnF),
    .out(sig_fire)
);

// setup character size
localparam BBWidth = 1;                 // Bee Bullet width in pixels
localparam BBHeight = 7;                // Bee Bullet height in pixels
```

Instantiating BBulletRom.v loads the 7 pixels used to create the Bee Bullet into Bbdout

The Debounce.v routine is instantiated for the Fire routine

BBWidth and BBHeight sets the width and height of the Bee Bullet

```
always @ (posedge clk_pix)
   begin
      // if sx,sy are within the confines of the Bee Bullet character, switch the Bee Bullet On
      if((de) && (BBulletstate == 1))
         begin
            if((sx==xBBullet-2) && (sy==yBBullet))
               begin
                  BBaddress <= 0;
                  BBulletSpriteOn <=1;
               end
            if((sx>xBBullet-2) && (sx<xBBullet+BBWidth-1) && (sy>yBBullet-1) && (sy<yBBullet+BBHeight))
               begin
                  BBaddress <= BBaddress +1;
                  BBulletSpriteOn <=1;
               end
            else
               BBulletSpriteOn <=0;
         end
```

This code is executed if de is set to 1 (when sx, sy are in the active pixel area) and if BBulletstate is set to 1 (the Bee Bullet is moving)

If sx, sy match the xBBullet, yBBullet position, set the Bee Bullet BBaddress to 0 (this will load the first pixel value into BBdout from Bbullet.mem) and switch the BbulletSpriteOn to 1

Increment BBaddress until sx, sy are passed the confines of BBulletSprite

```
else
      // if fire button pressed, move the Bee Bullet up the screen
      if ((sx==640) && (sy==480))                              // check for movement once every frame
      begin
         if (BBulletstate == 0)
            begin
               BBulletstate <= 2;                              // initialise BBulletstate = stopped
            end
         if ((sig_fire == 1) && (xBBullet == 0))                 // Check for fire button and bullet stopped
            begin
               xBBullet <= BeeX + 16;
               yBBullet<=425;
               BBulletstate<=1;                                // 1 = bullet moving, 2 = bullet stopped
            end
         if ((BBulletstate == 1))
            begin
               yBBullet<=yBBullet-1;                           // move bullet up the screen
               if ((BBhithive1 == 1) || (BBhithive2 == 1) || (BBhithive3 == 1) || (BBhithive4 == 1)) // Check if Bee Bullet has hit hive1-4
                  begin
                     BBulletstate<=2;                          // stop the bullet
                     yBBullet<=425;                            // bullet y start position
                     xBBullet<=0;
                  end
               if (yBBullet<10)                                // Check if Bee Bullet at top of screen
                  begin
                     BBulletstate<=2;                          // stop the bullet
                     yBBullet<=425;                            // bullet y start position
                     xBBullet<=0;
                  end
            end
      end
   end
endmodule
```

If de is not set to 1, check every frame for Fire button pressed / move the Bee Bullet up the screen

Initialise BBulletstate to 2 (bullet stopped)

If the Fire button has been pressed (sig_fire = 1) and xBBullet = 0 (set to 0 when Bee Bullet has stopped), set xBullet and yBullet equal to the Bee position and set BBulletstate to 1 (Bee Bullet is now moving)

If the Bee Bullet is set to moving, decrement it's y position by 1

If BBHithive1 – 4 is set to 1 (the Bee Bullet has hit a hive – see the HiveSprites.v module), stop the Bee Bullet and reset it's x, y position

If yBullet is less than 10 (top of the screen), stop the Bee Bullet and reset it's x, y position

04 HiveSprites.v module

```
module HiveSprites(
    input wire [9:0] xBBullet,          // x coordinate for Bee Bullet
    input wire [9:0] yBBullet,          // y coordinate for Bee Bullet
    output reg [1:0] BBhithive1,        // set to 1 when Bee Bullet hit hive1
    output reg [1:0] BBhithive2,        // set to 1 when Bee Bullet hit hive2
    output reg [1:0] BBhithive3,        // set to 1 when Bee Bullet hit hive3
    output reg [1:0] BBhithive4,        // set to 1 when Bee Bullet hit hive4
```

xBullet, yBullet values are passed to this module from the BBulletSprite.v

The 4 BBhithive1 – 4 (set to 1 if Bee Bullet has hit hive1 – 4) values are passed out to BbulletSprite.v to check if any are set to 1

```
// instantiate Hive1Ram
reg [1:0] write1;                   // write1 = 0 (read data), write1 = 1 (write data)
reg [7:0] data1;                    // Data to write if write1 = 1 (write data)
reg [11:0] H1address;               // Address to read/write data from/to Hive1 (2^12 or 4095, need 66 x 39 = 2574)

Hive1Ram Hive1VRam (
    .clk_pix(clk_pix),
    .H1address(H1address),
    .write1(write1),
    .data1(data1),
    .H1dout(H1dout)
);
```

write1 - 4 and data1 - 4 registers have been added

If write1 - 4 is set to 0 data is read from Hive1 - 4Ram.v using H1 - 4address and H1 - 4dout
If it is set to 1 data is written to Hive1 - 4Ram.v using H1 - 4address and data1 - 4

```
// Load BHole.mem
reg [7:0] BHoleaddress;                    // 2^8 or 255, need 11 x 16 = 176
reg [7:0] BHoledata [0:175];               // 8 bit values from BHole.mem
initial begin
   $readmemh("BHole.mem", BHoledata);      // load 176 hex values into BHole.mem
end
```

This section of code loads the 176 x 8 bit pixel values from Bullet Hole (BHole.mem) into BHoledata

```
reg [9:0] BHit1x;                  // Saves the x position of where the bee bullet hit hive1
reg [9:0] BHit1y;                  // Saves the y position of where the bee bullet hit hive1
reg [9:0] BHit2x;                  // Saves the x position of where the bee bullet hit hive2
reg [9:0] BHit2y;                  // Saves the y position of where the bee bullet hit hive2
reg [9:0] BHit3x;                  // Saves the x position of where the bee bullet hit hive3
reg [9:0] BHit3y;                  // Saves the y position of where the bee bullet hit hive3
reg [9:0] BHit4x;                  // Saves the x position of where the bee bullet hit hive4
reg [9:0] BHit4y;                  // Saves the y position of where the bee bullet hit hive4
reg [3:0] hzcounter1 = 0;          // Hole 11 pixels wide - Hive1
reg [4:0] vtcounter1 = 0;          // Hole 16 pixels high - Hive1
reg [3:0] hzcounter2 = 0;          // Hole 11 pixels wide - Hive2
reg [4:0] vtcounter2 = 0;          // Hole 16 pixels high - Hive2
reg [3:0] hzcounter3 = 0;          // Hole 11 pixels wide - Hive2
reg [4:0] vtcounter3 = 0;          // Hole 16 pixels high - Hive2
reg [3:0] hzcounter4 = 0;          // Hole 11 pixels wide - Hive2
reg [4:0] vtcounter4 = 0;          // Hole 16 pixels high - Hive2
```

BHit1 – 4x and BHit1 – 4y saves the x, y position of where the Bee Bullet hits Hive1 – 4

hzcounter1 – 4 and vtcounter1 – 4 are counters used to write the Bullet Hole pixel values to Hive1 – 4Ram.v

```
// Check if Bee Bullet Has Hit Hive 1
if ((sx == xBBullet) && (sy == yBBullet) && (sx>Hive1X-1) && (BBhithive1 == 0) && (H1dout > 0))
    begin
        BBhithive1 <= 1;
        BHit1x <= xBBullet - 5;
        BHit1y <= yBBullet - 15;
    end
```

If sx, sy matches xBBullet, yBBullet position and sx is greater than H1ve1 – 4X position and BBhithive1 – 4 equals 0 (Hive1 – 4 has not been hit by a Bee Bullet) and H1 - 4dout is greater than 0 (i.e. H1 – 4dout is not 0, the background colour)

Set BBhithive1 – 4 to 1 (Bee Bullet has hit Hive1 – 4)

Save xBullet, yBullet values in BHit1 – 4x, BHit1 - 4y

```
// insert bullet hole - Hive1
if ((sx>640) && (sy>480) && (BBhithive1 == 1))
   begin
      if ((hzcounter1 == 0) && (vtcounter1 == 0))
         begin
            H1address <= (BHit1x - Hive1X) + ((BHit1y - Hive1Y) * HiveWidth);
            BHoleaddress <= 0;
            hzcounter1 <= hzcounter1 + 1;
         end
      else
      if (hzcounter1 < 12)
         begin
            if (BHoledata[BHoleaddress] > 0)
               write1<=0;
            else
```

```
            begin
               write1<=1;
               data1 <= BHoledata[BHoleaddress];
            end

         BHoleaddress <= BHoleaddress + 1;
         H1address <= H1address + 1;
         hzcounter1 <= hzcounter1 + 1;
      end
   else
   if ((hzcounter1 == 12) && (vtcounter1 < 16))
      begin
         if (BHoledata[BHoleaddress] > 0)
            write1<=0;
         else
            begin
               write1<=1;
               data1 <= BHoledata[BHoleaddress];
            end

         H1address <= H1address + HiveWidth - 11;
         vtcounter1 <= vtcounter1 + 1;
         hzcounter1 <= 1;
      end

   if (vtcounter1 > 15)
      begin
         BBhithive1 <= 0;
         write1 <= 0;
         hzcounter1 <= 0;
         vtcounter1 <= 0;
      end
end
```

This section inserts a Bullet Hole in Hive1 – 4 if the Bee Bullet has hit a hive

If sx, sy are outside the active pixel area and BBhithive1 – 4 is equal to 1 (Bee Bullet has hit a hive)

If hzcounter1 – 4, vtcounter1 – 4 are equal 0
H1 - 4address equals a pointer into H1 - 4memory_array
Set BHoleaddress to 0 (the start address into the BHole.mem file)
Increment hzcounter1 - 4 by 1

Else loop until hzcounter1 – 4 equals 12
If the pixel value from BHoledata[BHoleaddress] is greater than 0 (i.e. not a background colour)
Set write1 – 4 equal to 0 (read only)
Else write1 – 4 equal to 1 (write data) and data1 – 4 equal to Bholedata[BHoleaddress]

Increment BHoleaddress by 1 (pointer into BHoledata)
Increment H1 - 4address by 1 (pointer into Hive1 – 4Ram)
Increment hzcounter1 – 4 until it equals 12

Else if hzcounter1 - 4 equals 12 and vtcounter1 – 4 is less than 16
If BHoledata[BHoleaddress] is greater than 0 (not the background)
write1 – 4 equal to 0 (read only)
Else write1 - 4 equal to 1 (write) and data1 – 4 equal to BHoledata[BHoleaddress]

Move H1 - 4address down one line
Increment vtcounter1 - 4 by 1
Set hzcounter1 – 4 to 1
If vtcounter1 – 4 is equal to 16
Set BBhithive1 – 4 equal to 0

Set write1 – 4 equal to 0 (read only)
Set hzcounter1 – 4 equal to 0
Set vtcounter1 – 4 equal to 0

Please Note, this code is duplicated 3 more times to include Hives 2, 3 and 4

05 Hive1 - 4Ram.v modules

```
//----------------------------------------------
// Hive1Ram.v Module - Single Port RAM
// Digilent Basys 3
// Bee Invaders Tutorial_5
// 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,          // Address to read/write data from/to Hive1 (2^12 or 4095, need 66 x 39 = 2574)
    input wire [1:0] write1,              // 1 = write, 0 = read data
    input wire [7:0] data1,               // 8 bit pixel value to Hive1
    output reg [7:0] H1dout               // 8 bit pixel value from Hive1
    );

    (*RAM_STYLE="block"*) reg [7:0] H1memory_array [0:2573]; // 8 bit values for 2574 pixels of Hive1 (66 x 39)
    initial $readmemh("Hive1.mem", H1memory_array);

    always @ (posedge clk_pix)
        if (write1==1)
            H1memory_array[H1address] <= data1;
        else
            H1dout <= H1memory_array[H1address];
endmodule
```

These modules have been changed to RAM_STYLE in order that data can be read or write

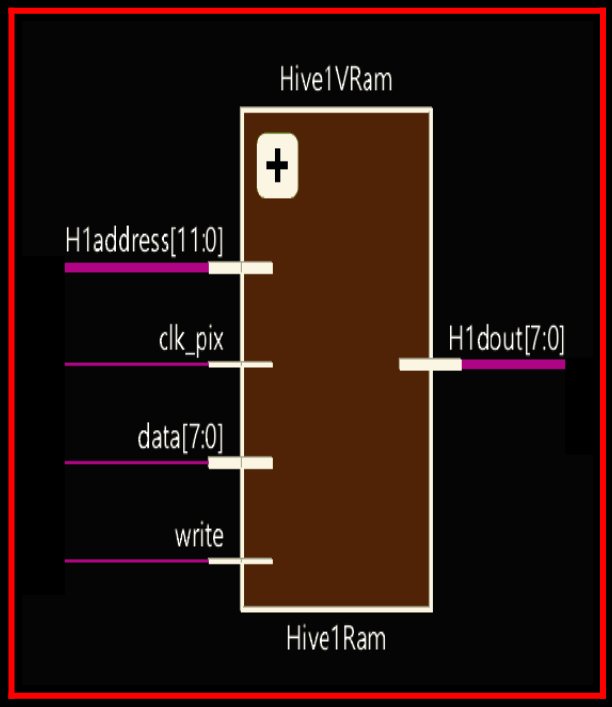
This diagram shows a "Single Port Ram" for Hive1Ram.v

When the input write is set to 0 (read only memory) it has

Input H1address which is used as a pointer into the H1memory_array which holds the data from Hive1.mem

Input The pixel clock clk_pix

Output H1dout which contains the pixel value from Hive1.mem



When the input write is set to 1 (write, random access memory) it has

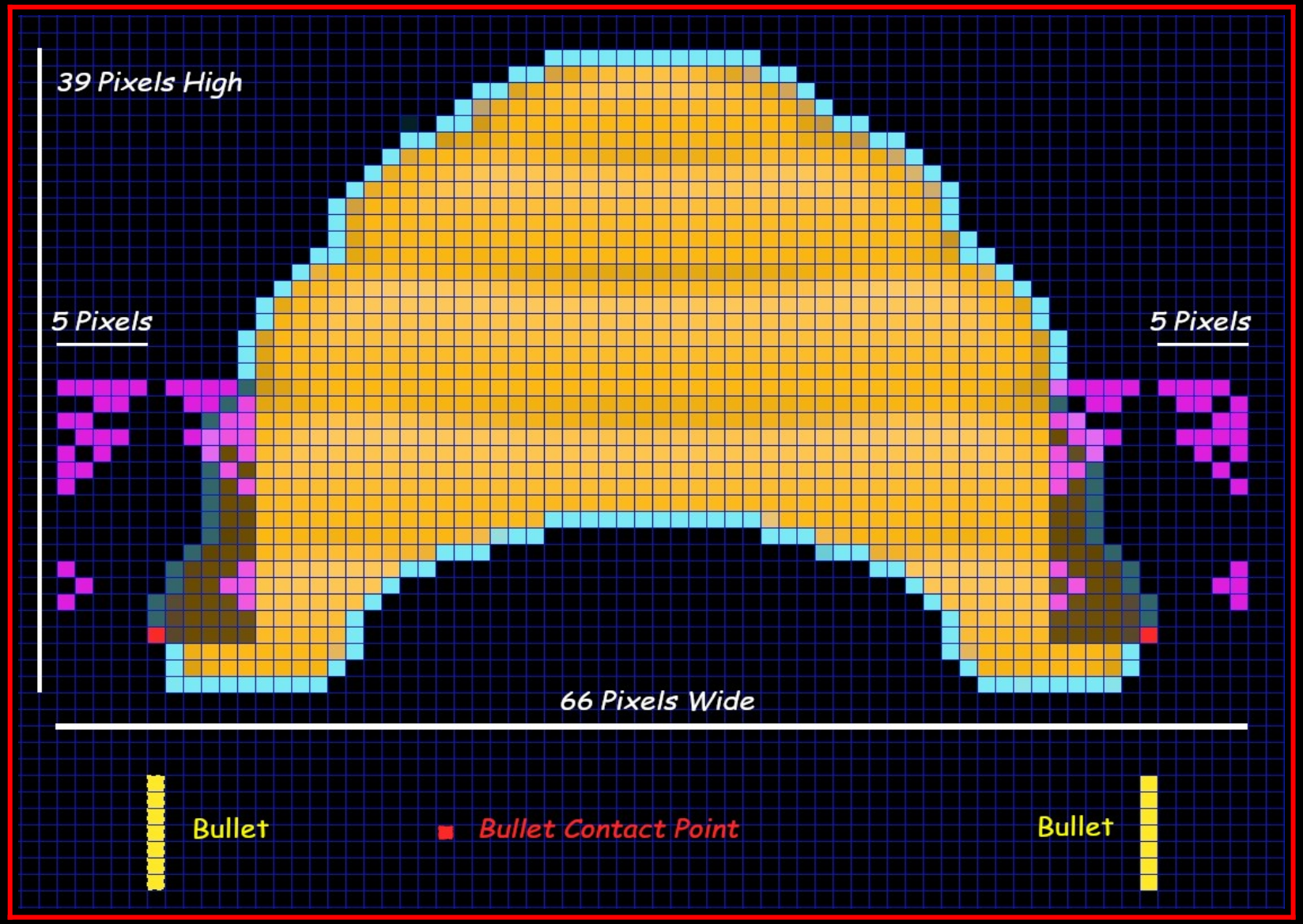
Input H1address which is used as a pointer into the H1memory_array which holds the data from Hive1.mem

Input The pixel clock clk_pix

Input Data which holds the pixel data from BHole.mem to write to the address pointed to by H1address in H1memory_array

06 Hive1.mem

This has changed slightly, the width of the Hive sprite has had 5 pixel columns added to the left side and 5 pixel columns added to the right hand side. This has been done to allow the Bullet Hole sprite to be written to the Hive sprite



07 Basys.xdc module

```
## Buttons
set_property PACKAGE_PIN T18 [get_ports btnF]
    set_property IOSTANDARD LVCMOS33 [get_ports btnF]
```

The Fire button (btnF) has been added to this module

08 Arty.xdc module

```
## Buttons
set_property -dict {PACKAGE_PIN C9 IOSTANDARD LVCMOS33} [get_ports {btnF}]
```

The Fire button (btnF) has been added to this module

(F) SPRITE SIZES

	Bee	34 x 27 Pixels (WxH)	918 Total Pixels
	Bee Bullet	1 x 7 Pixels (WxH)	7 Total Pixels
	Bee Hive	66 x 39 Pixels (WxH)	2574 Total Pixels
	Bullet Hole	11 x 16 Pixels (WxH)	176 Total Pixels
	Alien1	31 x 26 Pixels (WxH)	806 Total Pixels
	Alien2	31 x 21 Pixels (WxH)	651 Total Pixels
	Alien3	31 x 27 Pixels (WxH)	837 Total Pixels