CSCE 313: Embedded Systems

Video Out and Image Transformation

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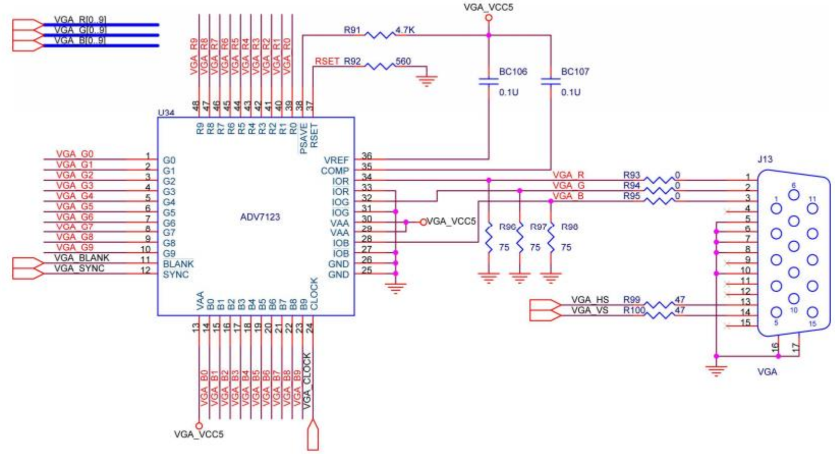
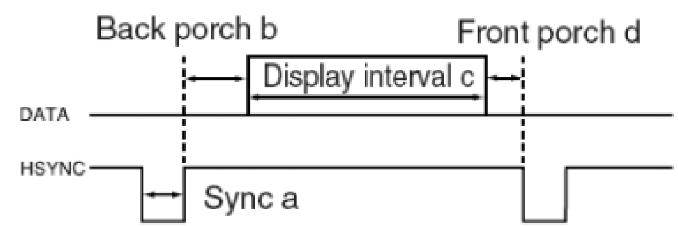
Video on DE2 Board

- VGA is a video standard from the late 1980's
  - Uses a 15-pin connector, but only 5 pins are needed at a minimum:
  - 3 analog pins: red, green, blue using amplitude modulation
  - 2 digital pins: horizontal sync, vertical sync

- DE2-115 has an off-chip video chip
  - Mostly just an digital-to-analog converter connected to VGA output
  - VGA contains analog reg, green, blue intensity and digital synthronization signals





VGA mode		Horizontal Timing Spec				
Configuration	Resolution(HxV)	a(us)	b(us)	c(us)	d(us)	Pixel clock(Mhz)
VGA(60Hz)	640x480	3.8	1.9	25.4	0.6	25 (640/c)

VGA mode		Vertical Timing Spec			
Configuration	Resolution (HxV)	a(lines)	b(lines)	c(lines)	d(lines)
VGA(60Hz)	640x480	2	33	480	10

Video on DE2 Board

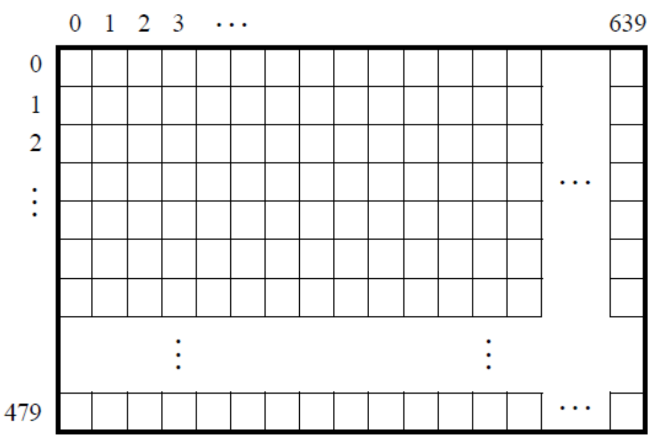
- VGA controller (in Platform Designer) sends 8-bit digital versions of R, G, and B to the onboard DAC; sends HS and VS directly

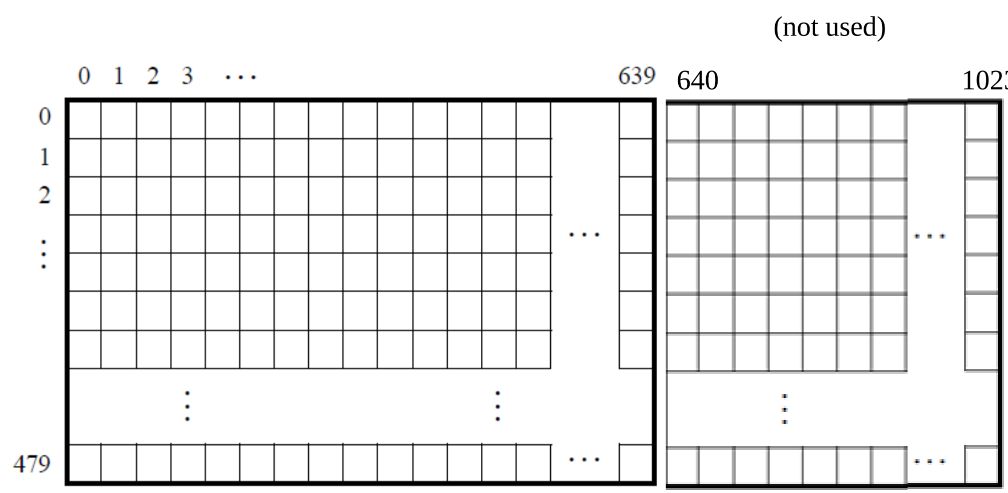
8 bits	8 bits	8 bits
RED INTENSITY	GREEN INTENSITY	BLUE INTENSITY

- Images are transmitted to the DAC as "row-major" (line-by-line) array of pixels
  - Each pixel has three components: red, green, blue
  - All 0's is black, all 1's is white
- "frame buffer" in memory holds a picture to display that the CPU can manipulate
  - Use the on-board SRAM as our frame buffer ("pixel memory")
  - 320 x 240 x 24 bits = 225 KB
- The Altera University Program contains cores to perform color-space and resolution re-sampling (scaling/conversion) in hardware

Video on DE2 Board

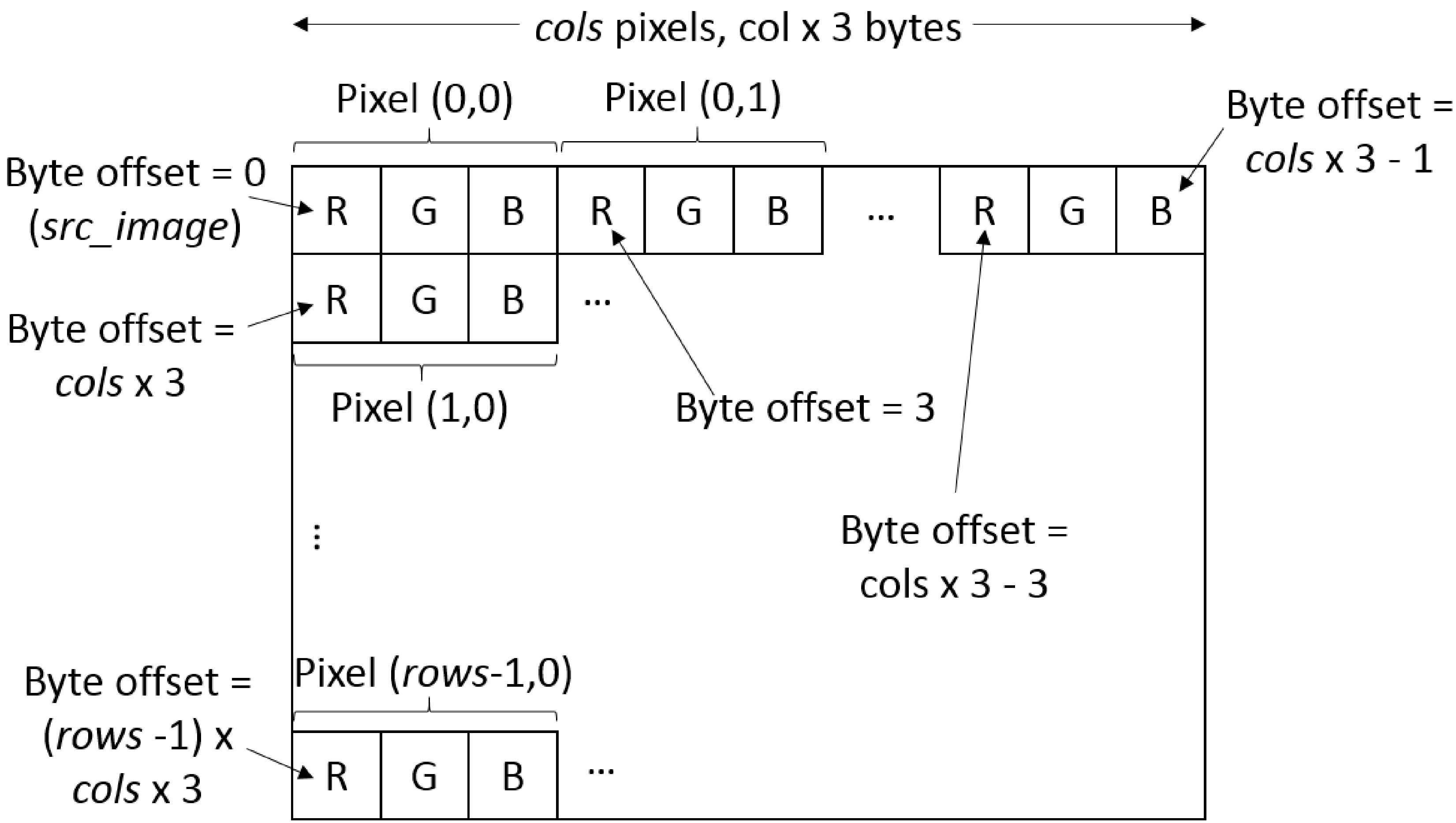
- Frame layout:
  - Consecutive addressing, each row stored consecutively
  - X-Y addressing, pad each row to make it a power of 2





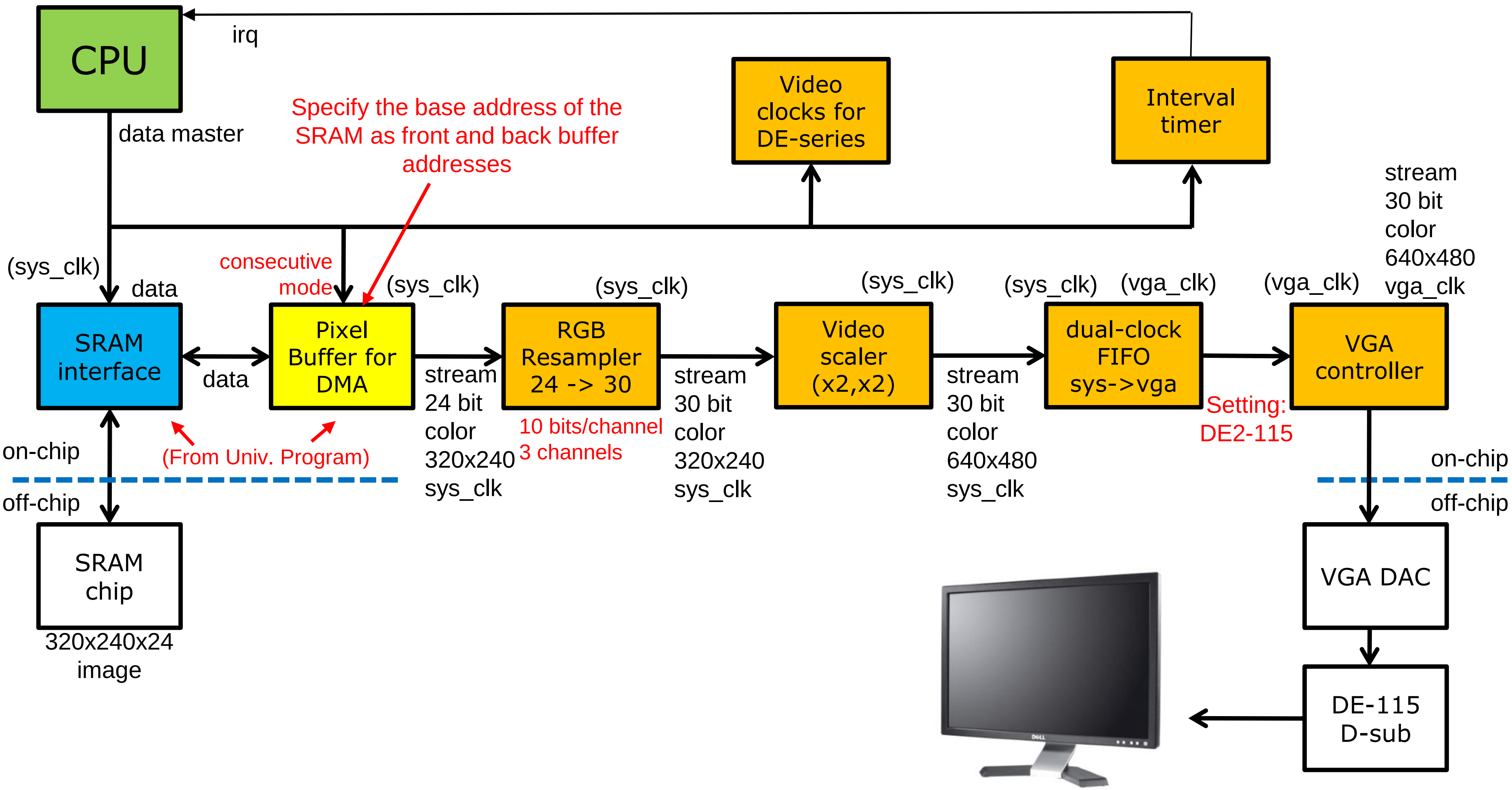
- pixel x,y has offset (y*row_siz + x) in pixels from base address
- pixel x,y has offset (y<<10 | x) in pixels from base address
- wastes 184 KB

Image Representation



address = row x cols x 3 + col x 3 + channel

System Design for Video (DE2/DE2-115)



Parameters

Pixel Buffer DMA Controller

System: nios_system **Path:** video_pixel_buffer_dma_0

Pixel Buffer DMA Controller
altera_up_avalon_video_pixel_buffer_dma

Addressing Parameters

Addressing Mode:	Consecutive
Default Buffer Start Address:	0x00000000
Default Back Buffer Start Address:	0x00000000

Frame Resolution

Width (# of pixels):	320
Height (# of lines):	240

Pixel Format

Color Space:	24-bit RGB

RGB Resampler

Parameters

System: nios_system **Path:** video_rgb_resampler_0

RGB Resampler
altera_up_avalon_video_rgb_resampler

Parameters

Incoming Format:	24-bit RGB
Outgoing Format:	30-bit RGB
Alpha Value for Output:	1023

Scaler

System: nios_system **Path:** video_scaler_0

Scaler
altera_up_avalon_video_scaler

Scaling Parameters

Width Scaling Factor:	2
Height Scaling Factor:	2

☐ Output Scaling as Channel

Incoming Frame Resolution

Width (# of pixels):	320
Height (# of lines):	240

Pixel Format

Data Bits per Symbol:	10
Symbols per Beat:	3

Dual clock buffer

System: nios_system **Path:** video_dual_clock_buffer_0

Dual-Clock FIFO
altera_up_avalon_video_dual_clock_buffer

Pixel Format

Color Bits:	10
Color Planes:	3

VGA Controller

System: nios_system **Path:** video_vga_controller_0

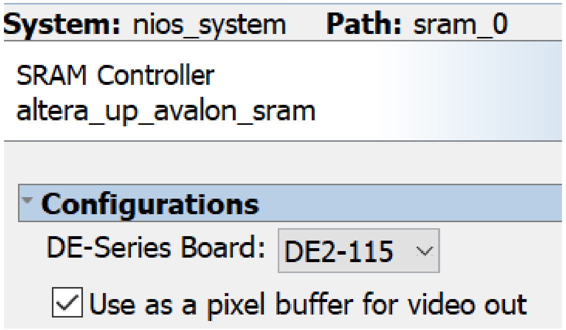
VGA Controller
altera_up_avalon_video_vga_controller

Device and Mode

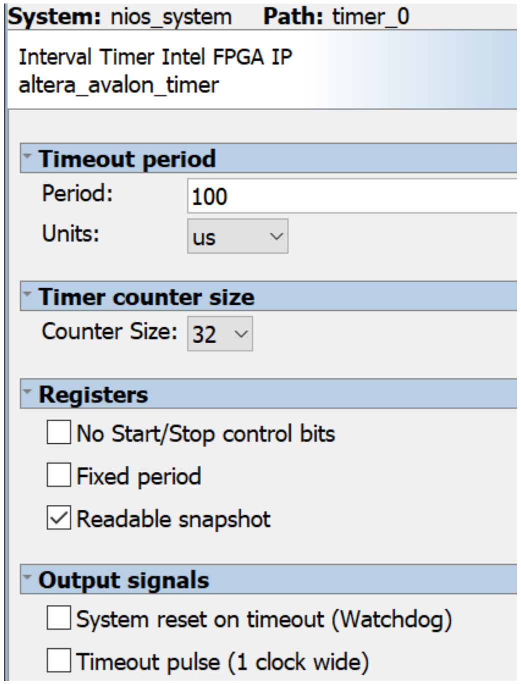
DE-Series Board:	DE2-115
Video Out Device:	VGA Connector
VGA Resolution:	VGA 640x480

Parameters

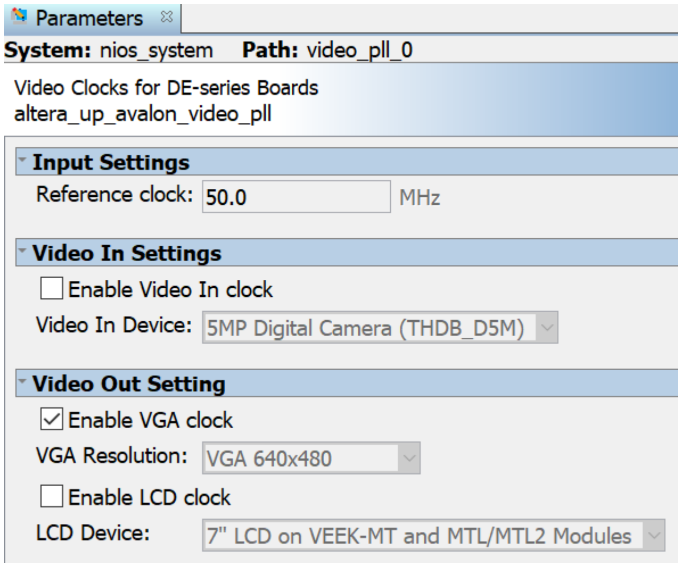
SRAM Controller



Interval Timer



Video Clocks



Verilog Modifications

```
module lights (input CLOCK_50,
          …
          output VGA_CLK,
          output VGA_HS,
          output VGA_VS,
          output VGA_BLANK_N,
          output VGA_SYNC_N,
          output [7:0] VGA_R,
          output [7:0] VGA_G,
          output [7:0] VGA_B,
          inout [15:0] SRAM_DQ,
          output [19:0] SRAM_ADDR,
          output SRAM_LB_N,
          output SRAM_UB_N,
          output SRAM_CE_N,
          output SRAM_OE_N,
          output SRAM_WE_N);
```

Verilog Modifications

```
nios_system u0 (
        .clk_clk        (CLOCK_50),      //      clk.clk
        …
        .vga_CLK        (VGA_CLK),       //      vga.CLK
        .vga_HS         (VGA_HS),        //         .HS
        .vga_VS         (VGA_VS),        //         .VS
        .vga_BLANK      (VGA_BLANK_N),   //         .BLANK
        .vga_SYNC       (VGA_SYNC_N),    //         .SYNC
        .vga_R          (VGA_R),         //         .R
        .vga_G          (VGA_G),         //         .G
        .vga_B          (VGA_B),         //         .B
        .sram_DQ        (SRAM_DQ),       //     sram.DQ
        .sram_ADDR      (SRAM_ADDR),     //         .ADDR
        .sram_LB_N      (SRAM_LB_N),     //         .LB_N
        .sram_UB_N      (SRAM_UB_N),     //         .UB_N
        .sram_CE_N      (SRAM_CE_N),     //         .CE_N
        .sram_OE_N      (SRAM_OE_N),     //         .OE_N
        .sram_WE_N      (SRAM_WE_N)      //         .WE_N
);
```

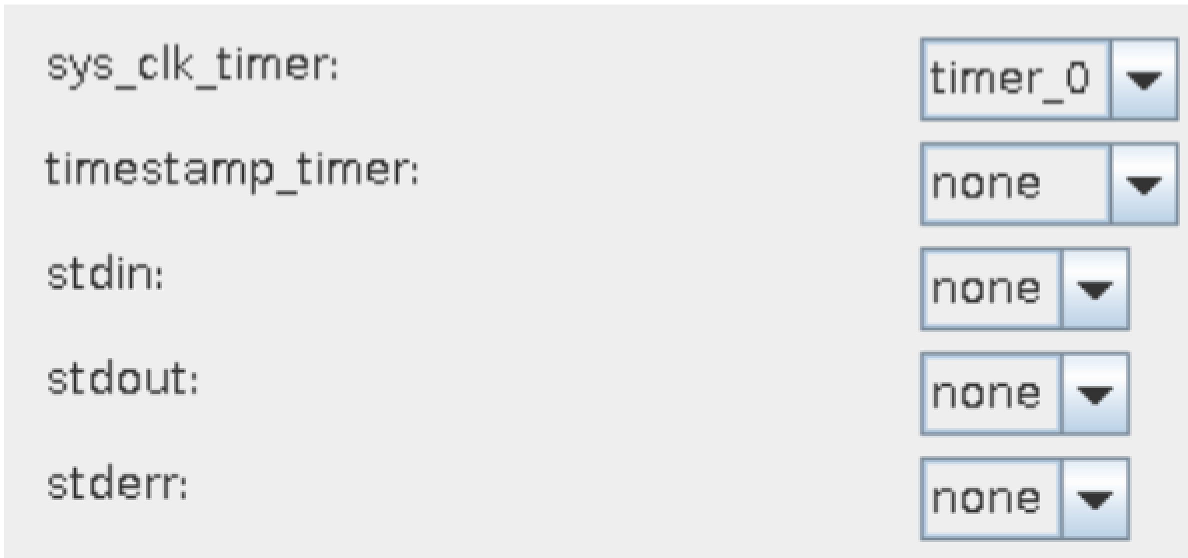
Copying Image to RO File System

- To load an image into the DE2, I wrote a Matlab script that can:
  - read image file
  - add a border around the image if aspect ratio <> 4/3
  - save into a C source code file (global constant array **myimage**)

- To use it:
  - download it from Dropbox
  - open MATLAB (command: “octave”)
  - change current folder to where you downloaded it
  - type: convert_image_to_c_file(‘<filename>');
    - You may use my image, lumcat.jpg or use your own
  - this will generate myfile.c and myfile.h
  - Add to makefile:
    - From app directory (e.g. lights/software/lights):
      - nios2-app-update-makefile --add-src-files myfile.c --app-dir .

BSP Settings Modification

- nios2-bsp-editor:




```
#include <sys/alt_alarm.h>
…
alt_u32 alt_nticks();  // returns number of timer ticks (us)
void alt_ticks_per_second();  // returns the number of ticks per second (should be 10000)
```

Pointers

- In Java, all object “handles” are pointers (references)
- In C/C++, object handles can be either actual or pointers:
  - int a; (integer)
  - int *b; (pointer to an integer)
  - b = &a (address of a)
  - *b = 2; (assign contents of b)
- Arrays are pointers:
  - int a[100];
  - a[0] = 2; ⇔ *(a) = 2;
  - a[5] = 5; ⇔ *(a+5) = 5;
- 2-dimensional arrays can be “superimposed” over one dimensional:
  - a[i * (2nd dimension size) + j]
- 3-dimensional arrays can be “superimposed” over one dimensional:
  - a[i * (2nd dimension size) * (3nd dimension size) + j * (3nd dimension size) + k]

Typecasting

- In lab 2, you will need to make use of floats and convert to integers

- Examples:

```
float a;
alt_u16 b;

a = sin(2.5);
b = (alt_u16)roundf(a);
```

Accessing the Source Image

- We're using consecutive mode for the pixel memory, so pixels are stored consecutively

row 0, 320 pixels	row 1, 320 pixels	row 2, 320 pixels	...	row 239, 320 pixels

low addresses high addresses

- Each pixel is 3-byte value

RED	GREEN	BLUE
23 16	15 8	7 0

- To access pixel at row=100, col=200:
  - my_image[100*320*3+200*3+0] (red)
  - my_image[100*320*3+200*3+1] (green)
  - my_image[100*320*3+200*3+2] (blue)

New Header Files

- Add:

```
#include <stdio.h>
#include <stdlib.h>
#include <altera_up_avalon_video_pixel_buffer_dma.h>
#include <math.h>  // for trigonometry functions
#include <sys/alt_alarm.h>
#include "myfile.h"
```

The Pixel Buffer

- To use:
  - Declare global variable:

```
alt_up_pixel_buffer_dma_dev *my_pixel_buffer;
```

  - Assign it:

```
my_pixel_buffer=
alt_up_pixel_buffer_dma_open_dev("/dev/video_pixel_buffer_dma_0");
```

  - To clear screen:

```
alt_up_pixel_buffer_dma_clear_screen(my_pixel_buffer,0);
```

  - To draw pixel:

```
alt_up_pixel_buffer_dma_draw(my_pixel_buffer,
                 (my_image[(i*320*3+j*3+2)]) +
                 (my_image[(i*320*3+j*3+1)]<<8) +
                 (my_image[(i*320*3+j*3+0)]<<16),j,i);
```

Image Transformation Matrices

- Simple image transformation matrix can be used to…
  - rotate, scale, shear, reflect, and orthogonal projection
- For Lab 2, we want to perform rotation and scaling
- The matrices we use are 2x2 and used to determine how to move each pixel from the original image to the new image in order to perform the transformation
- Consider:
  - source pixels (row,col) of original image
  - destination pixels (row’,col’) of transformed image

Image Transformation Matrices

- Clockwise rotation:

$$\begin{bmatrix} row' \\ col' \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} row \\ col \end{bmatrix}$$

$$row' = row \cdot \cos\theta + col \cdot \sin\theta$$

$$col' = -row \cdot \sin\theta + col \cdot \cos\theta$$

- Counterclockwise rotation:

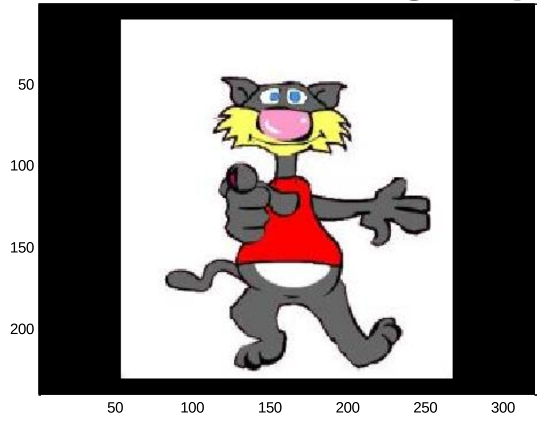
$$\begin{bmatrix} row' \\ col' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} row \\ col \end{bmatrix}$$

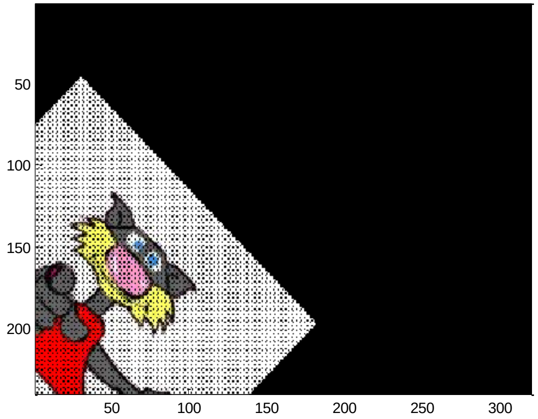
$$row' = row \cdot \cos\theta - col \cdot \sin\theta$$

$$col' = row \cdot \sin\theta + col \cdot \cos\theta$$

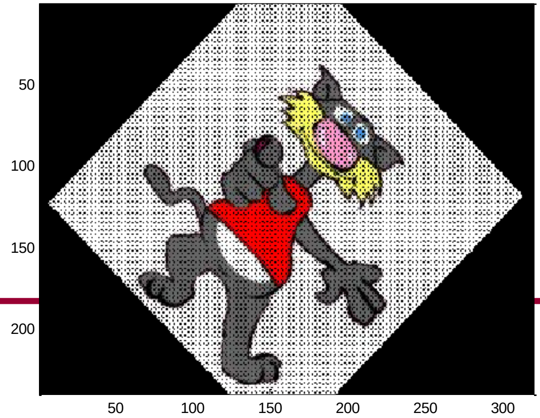
Issues to Resolve

- Using these algorithms directly, the rotation and scaling occur about the origin (0,0)





- We want it to occur about the center of the image



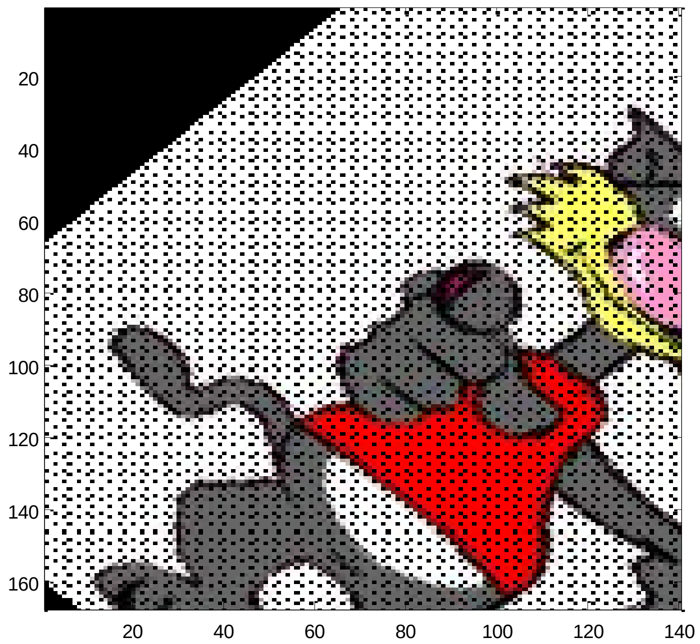
Issues to Resolve

- To fix this:
  - subtract 320/2 from the column
  - subtract 240/2 from the row

…before you multiply against the transformation matrix, then add these values back after your multiply

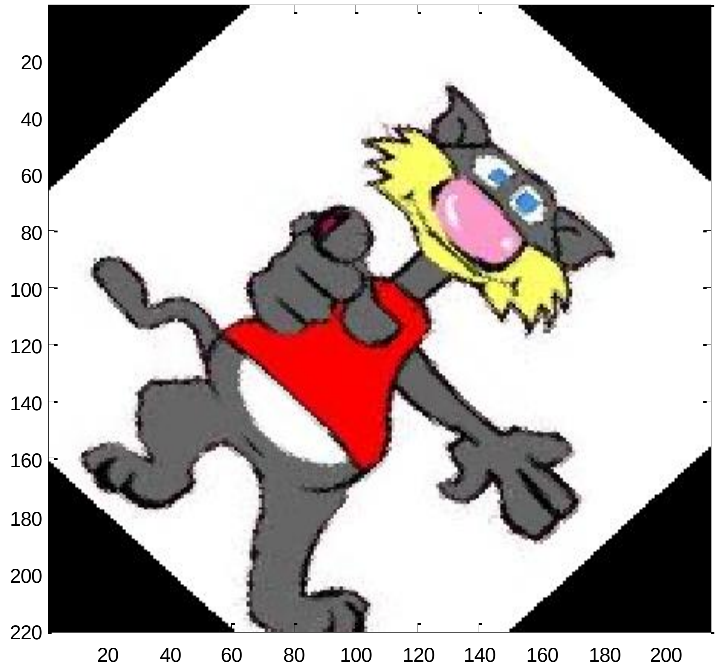
Issues to Resolve

- Second problem: pixels aliasing to same location, causing unfilled pixels in destination image



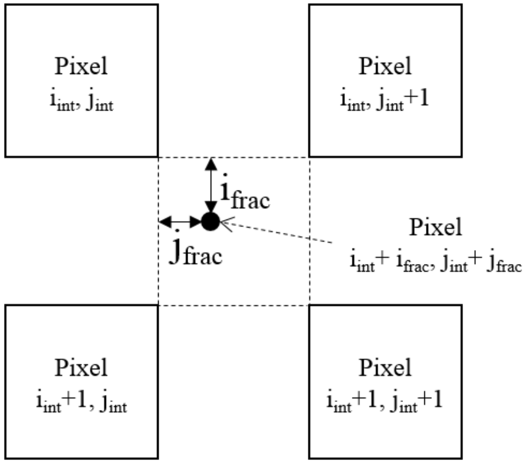
Issues to Resolve

- To solve this, iterate over all destination image pixels and calculate reverse transform
  - Counterclockwise rotation



Issues to Resolve

- Assume destination pixel (10,20) maps to source pixel (87.4,98.6)
- Must interpolate the value of this "virtual" source pixel



$$weight(i_{int}, j_{int}) = (1 - i_{frac}) \cdot (1 - j_{frac})$$

$$weight(i_{int}, j_{int} + 1) = (1 - i_{frac}) \cdot j_{frac}$$

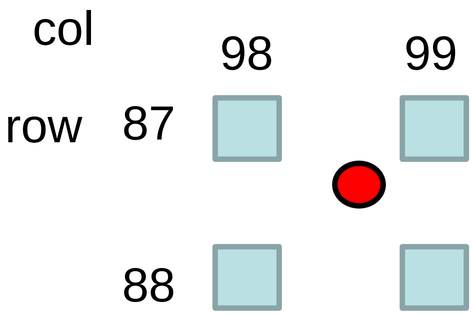
$$weight(i_{int} + 1, j_{int}) = i_{frac} \cdot (1 - j_{frac})$$

$$weight(i_{int} + 1, j_{int} + 1) = i_{frac} \cdot j_{frac}$$

Bilinear Interpolation

- Example:
  - Output pixel: (10,20)
  - Transformed pixel: (87.4,98.6)

- Set destination pixels (10,20) as a mixture of pixels:
  - (87,98), (88,98), (87,99), (88,99)



  - dest[10,20] = (1-.4)(1-.6)src[87,98] + (.4)(1-.6)src[88,98] + (1-.4)(.6)src[87,99] + (.4)(.6)src[88,98]
  - Must separate color channels in code

Issues to Resolve

- Make sure you…
  - use rounding and type casting for the transformation matrix (float and alt_u16)
  - disregard output coordinates that fall outside the frame
  - always transform against the original image
  - initialize the output image to black before transforming