FPGA and Cameras

ECE 1210: “Smartphone” course
ECE 2300: Digital Logic and Computer Organization
ECE 5760: Advanced Microcontroller Design
ECE 5470: Computer Vision
CS 4670 / 5670: Introduction to Computer Vision
CS 6670: Computer Vision

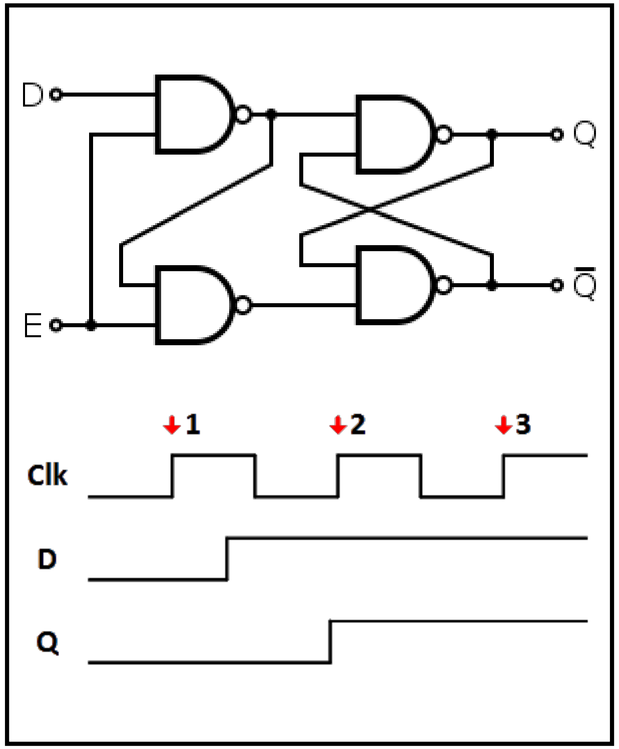
- Recap on FPGAs
- Lab 4
- Setting up the camera
- Reading from the camera
- Treasure detection

ECE 3400: Intelligent Physical Systems

FPGAs (*revisited*)

- *What does the name stand for?*
  - Field Programmable Gate Array
- *What does it contain?*
  - Configurable Logic Blocks
    - Flip-Flops
- *What is the difference between sequential logic and registered logic?*
  - Sequential logic operates on clock transitions

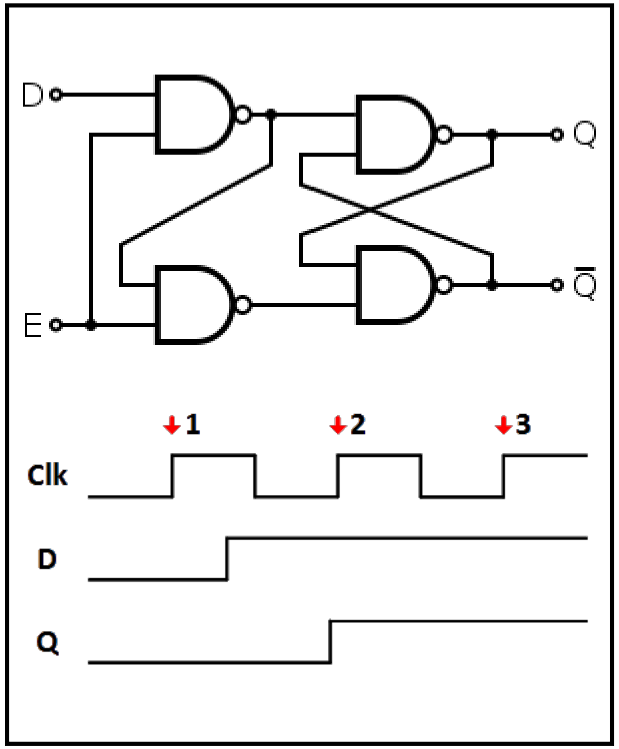
Flip Flop



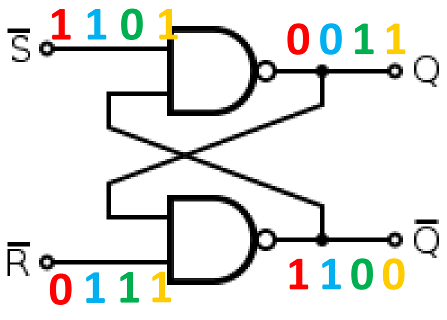
FPGAs (*revisited*)

- *What does the name stand for?*
  - Field Programmable Gate Array
- *What does it contain?*
  - Configurable Logic Blocks
    - Flip-Flops
- *Example of registered logic?*

Flip Flop



Latch



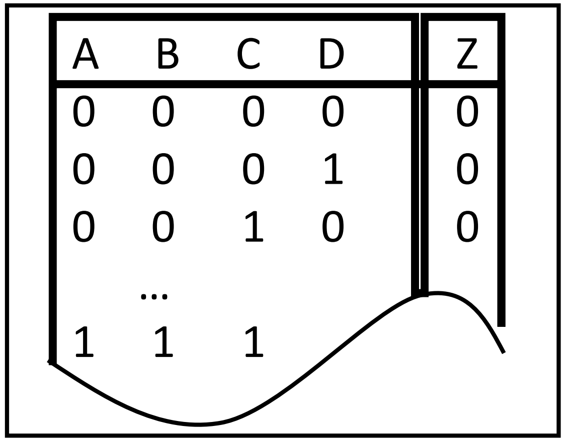
State	S	R	Q		Description
Set	1	0	0	1	Set $\overline{Q}$ » 1
	1	1	0	1	no change
Reset	0	1	1	0	Reset $\overline{Q}$ » 0
	1	1	1	0	no change
Invalid	0	0	1	1	Invalid Condition

Problem with an inferred latch

FPGAs (*revisited*)

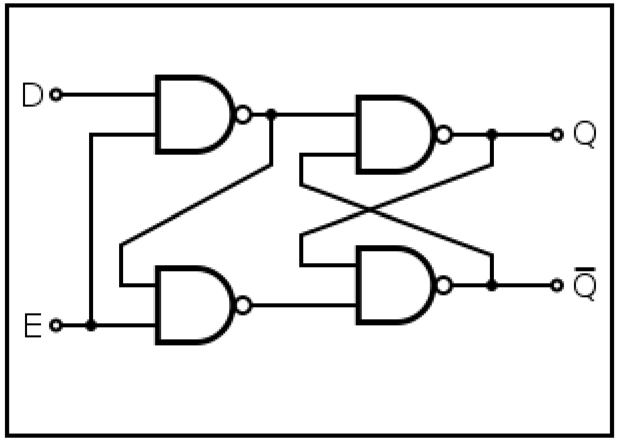
- ***What does the name stand for?***
  - Field Programmable Gate Array
- ***What does it contain?***
  - Configurable Logic Blocks
    - Flip-Flops
    - Lookup Tables (LUTs)
      - Multiplier units
  - Memory (M9K)
  - Programmable interconnects

Look Up Tables



A	B	C	D	Z
0	0	0	0	0
0	0	0	1	0
0	0	1	0	0
	…			
1	1	1		

Flip Flop



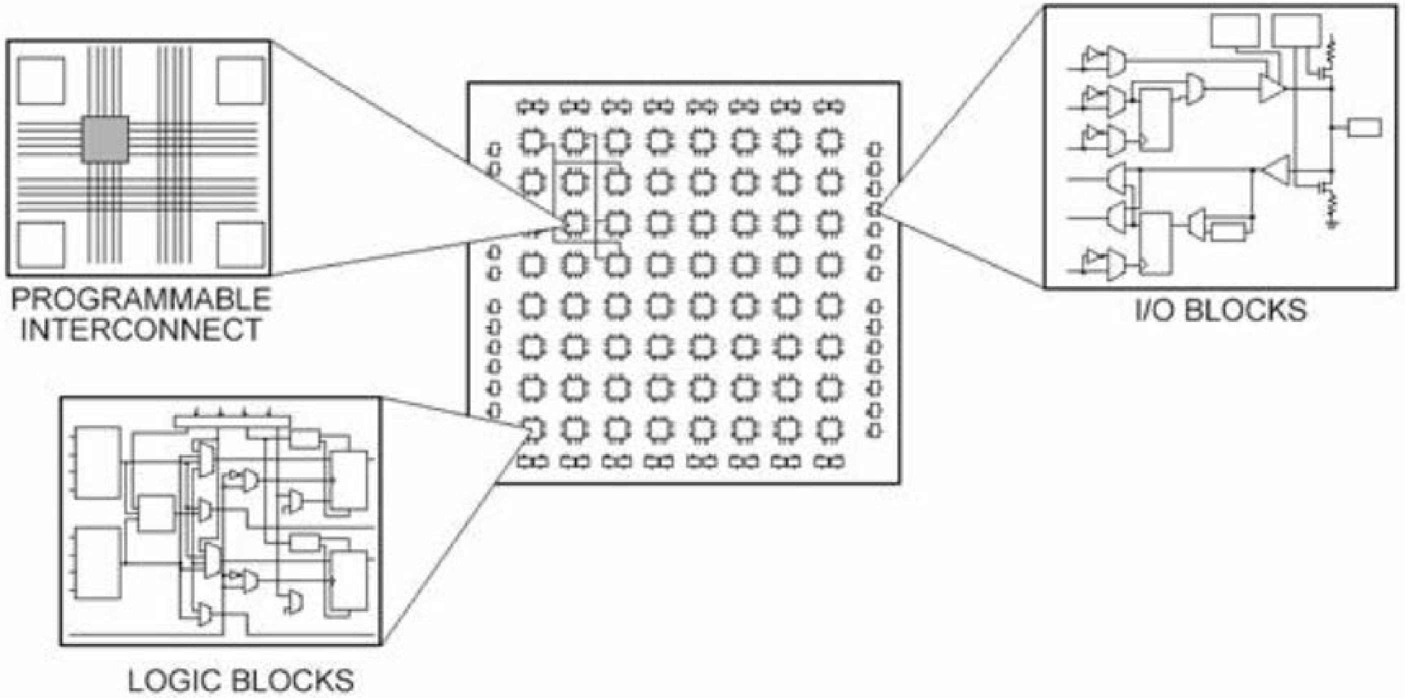
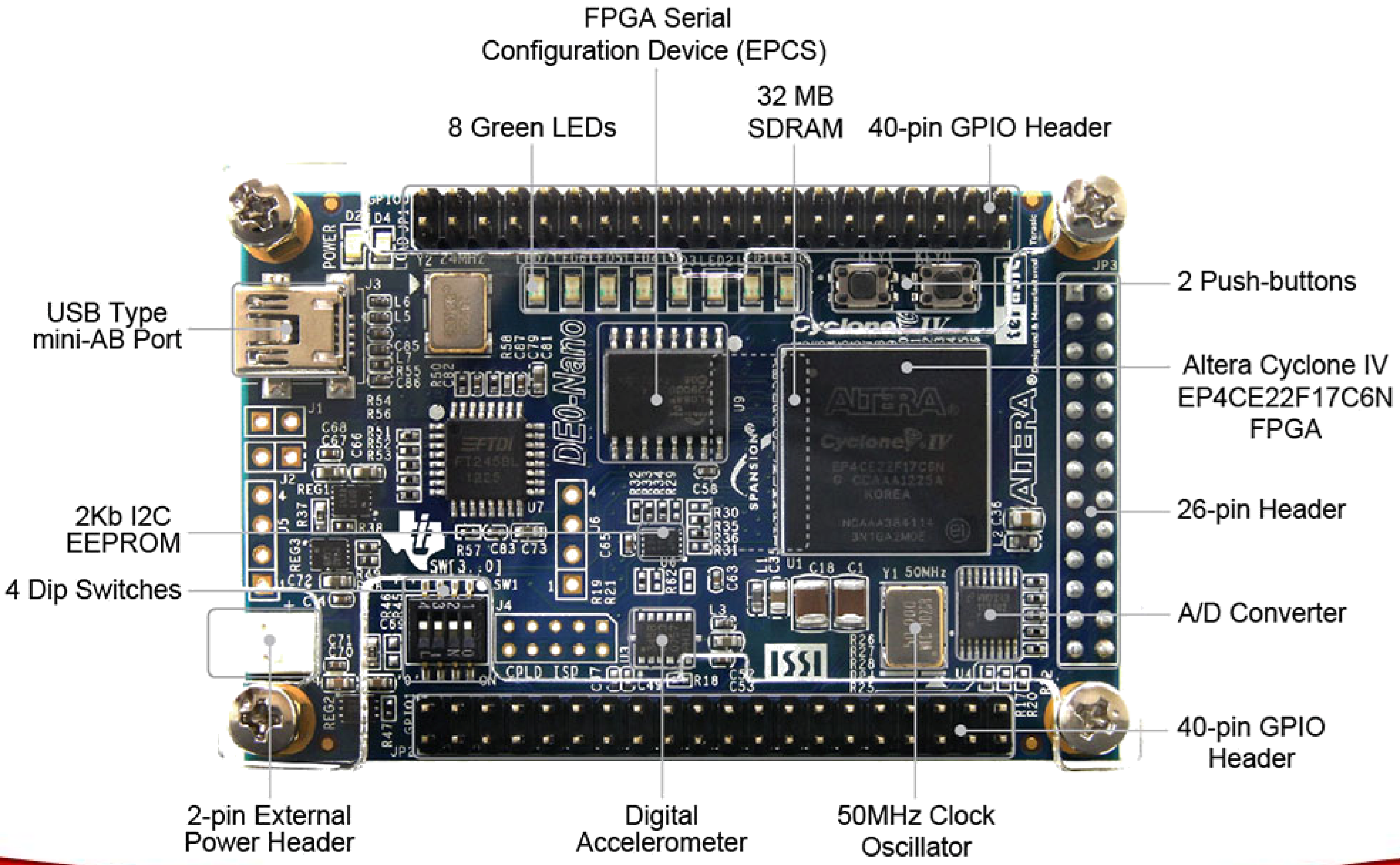


Figure 2. The Different Parts of an FPGA

FPGAs (*revisited*)

https://cei-lab.github.io/ece3400-2018/tutorials/
https://cei-lab.github.io/ece3400-2018/lectures/lectures.html

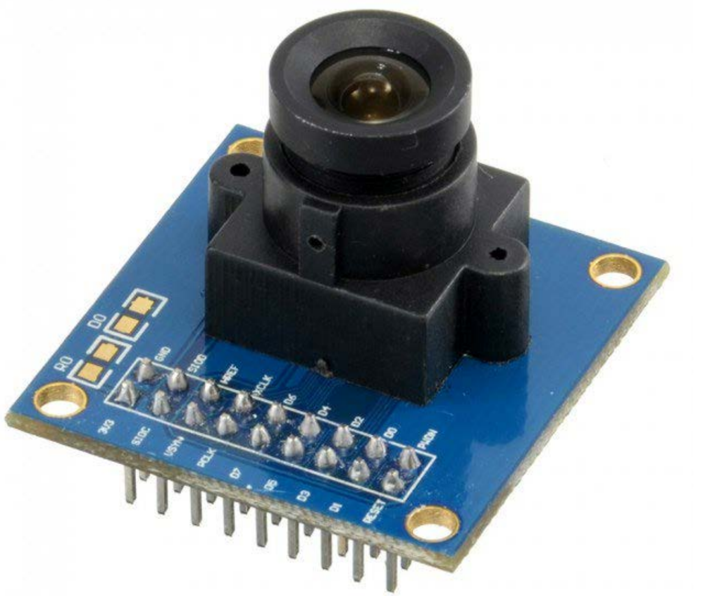
- ***Remember!***
  - ¡3V supply!
  - Parallel processing
- ***Tips:***
  - Check that you got the pin out right!
  - Use the green LEDs for debugging!
  - *Always downshift to 3V*



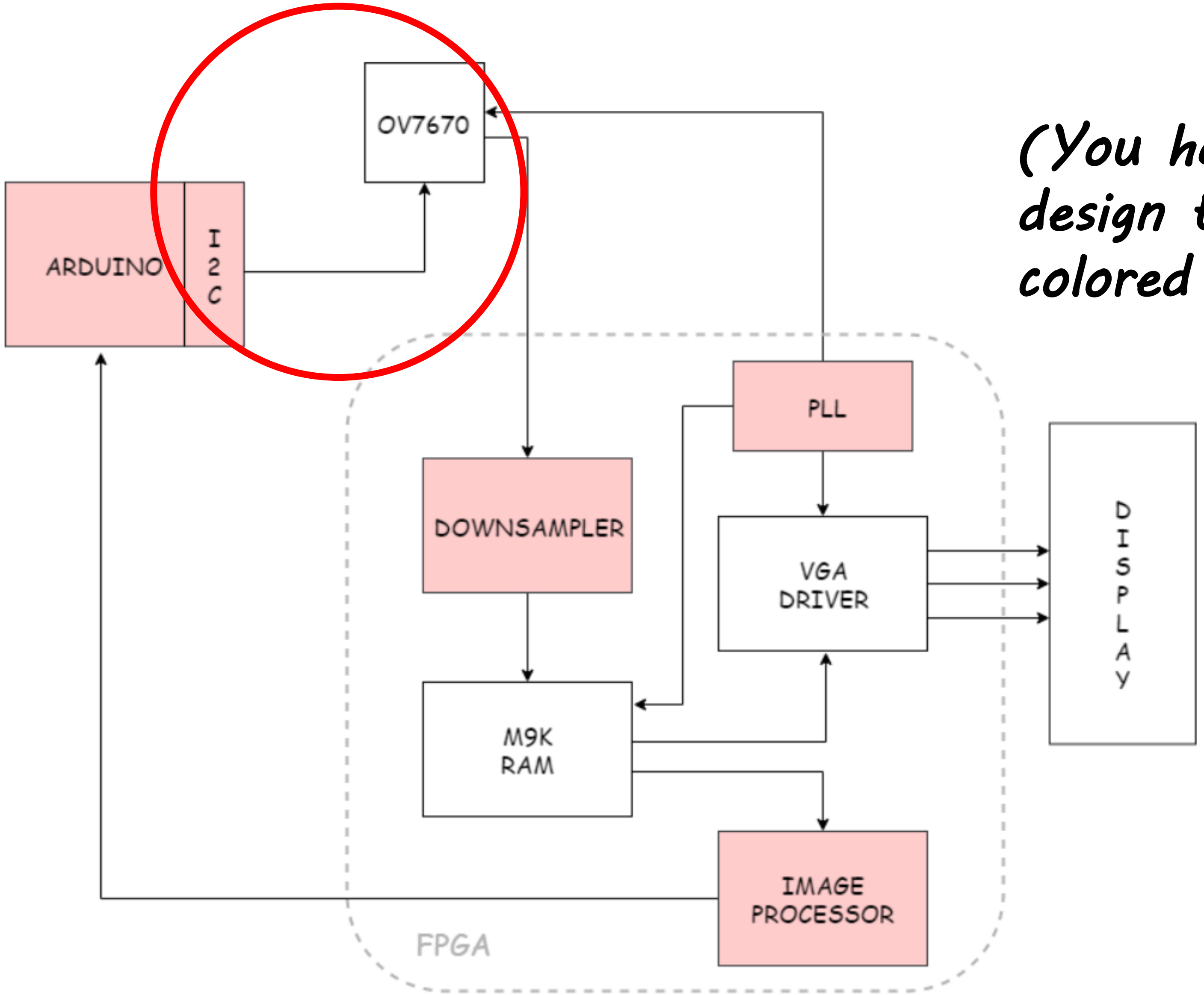
Lab 4: Camera / FPGA

OV7670

3V supply!



- Sensor size: 2.36 x 1.76mm
- Max resolution: 640x480 pixels



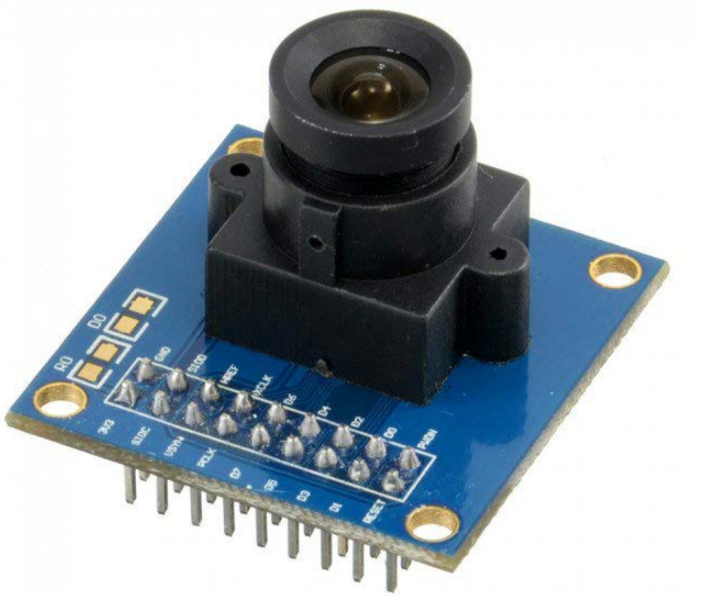
(You have to design the boxes colored in red)

Setting up the camera

http://www.arducam.com/camera-modules/0-3mp-ov7670/

OV7670

3V supply!



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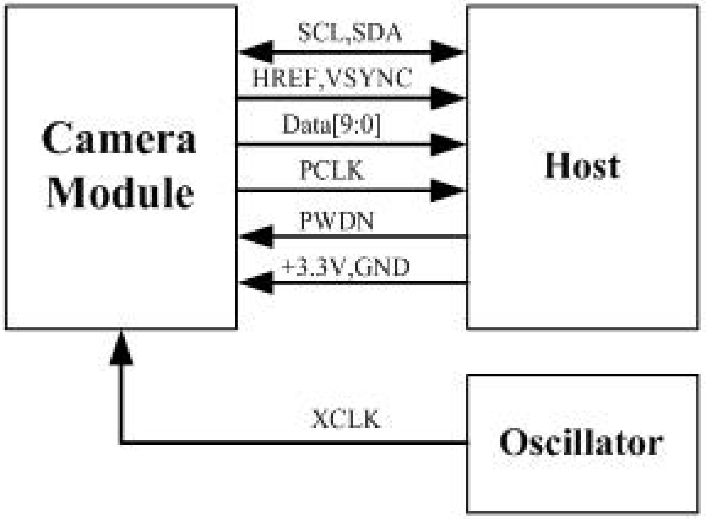
- Camera Communication
  - I2C (Arduino or FPGA)…
  - Serial Camera Control Bus (SCCB) Interface
- What needs to be setup?
  - Exposure control
  - Gamma
  - White balance
  - Color saturation
  - Hue control
- Frame rate
  - Depends on image resolution, color resolution, and clock rate
- Fixed focal length
  - F1.8 / 6mm lens



Lab 4: Camera / FPGA

OV7670

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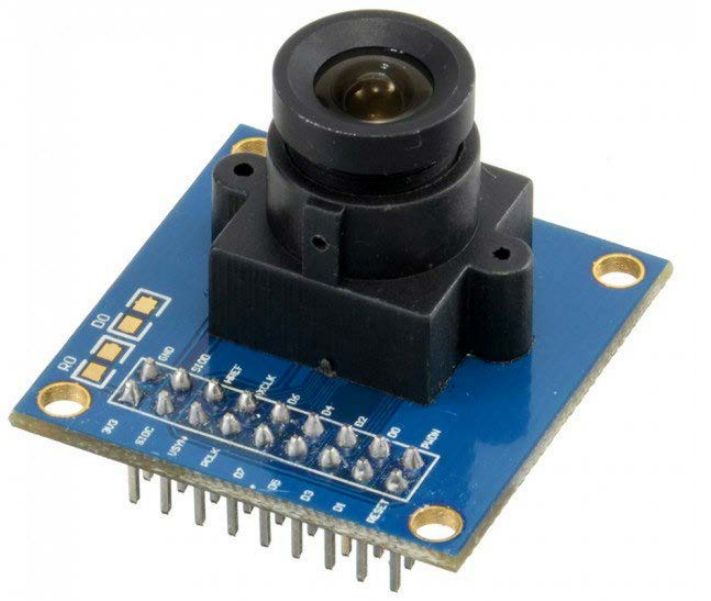

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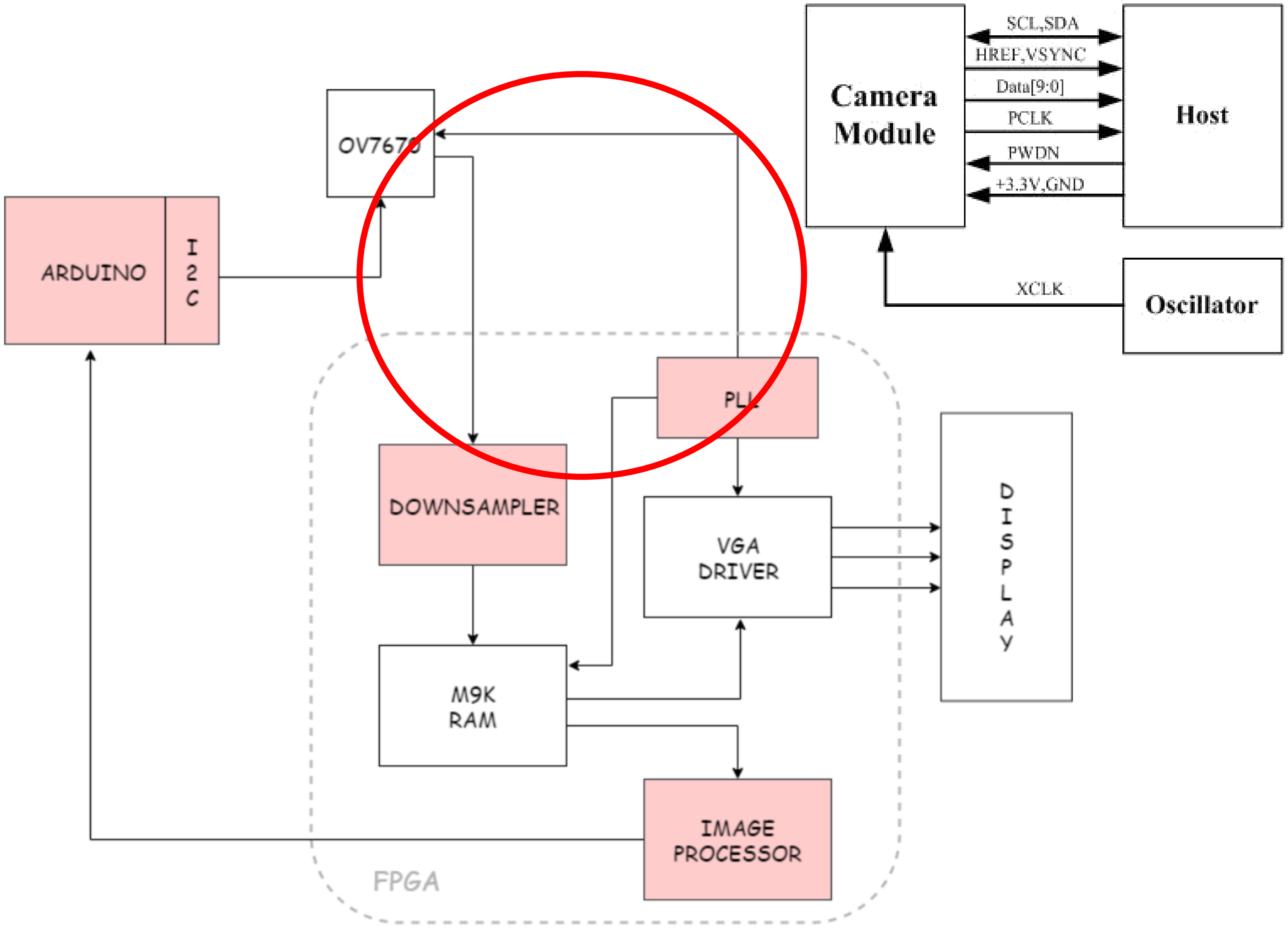
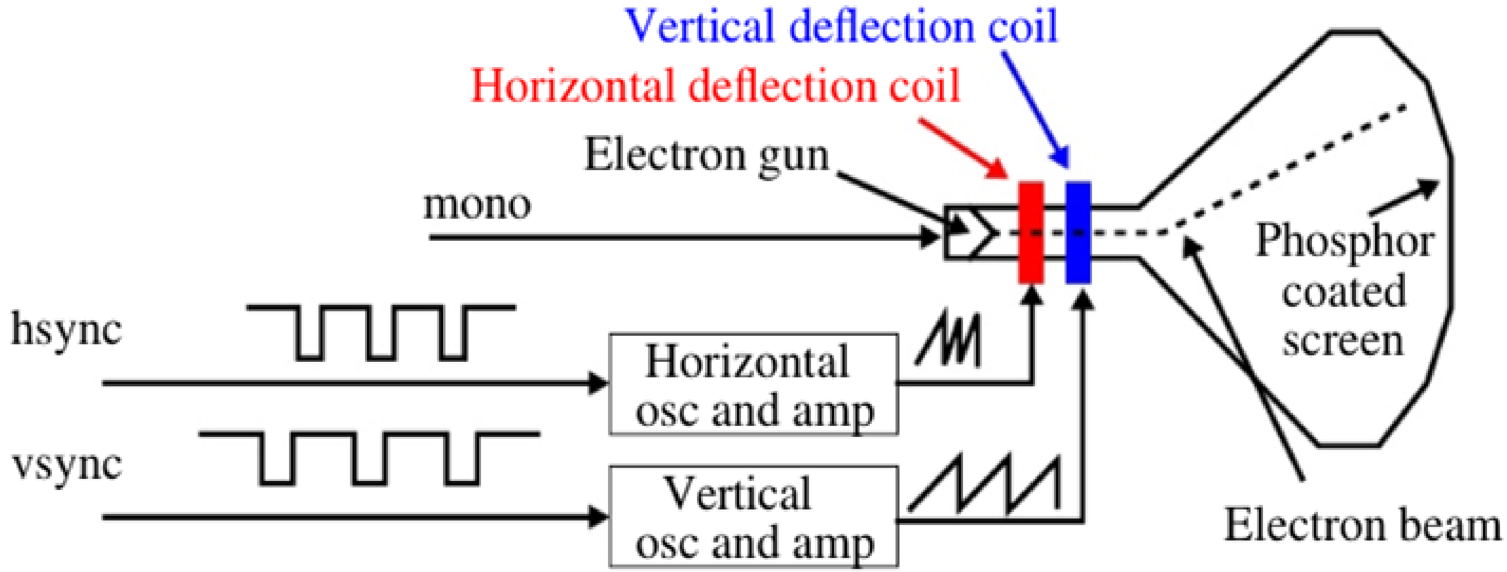
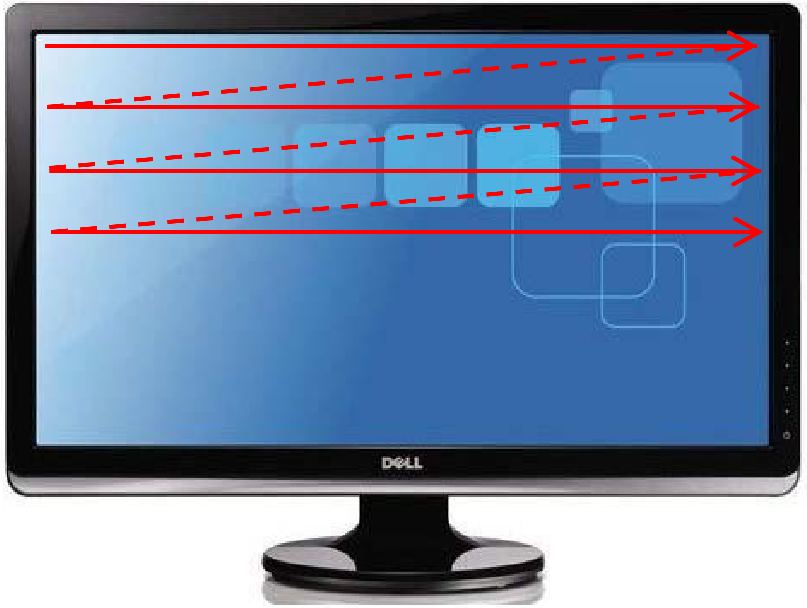
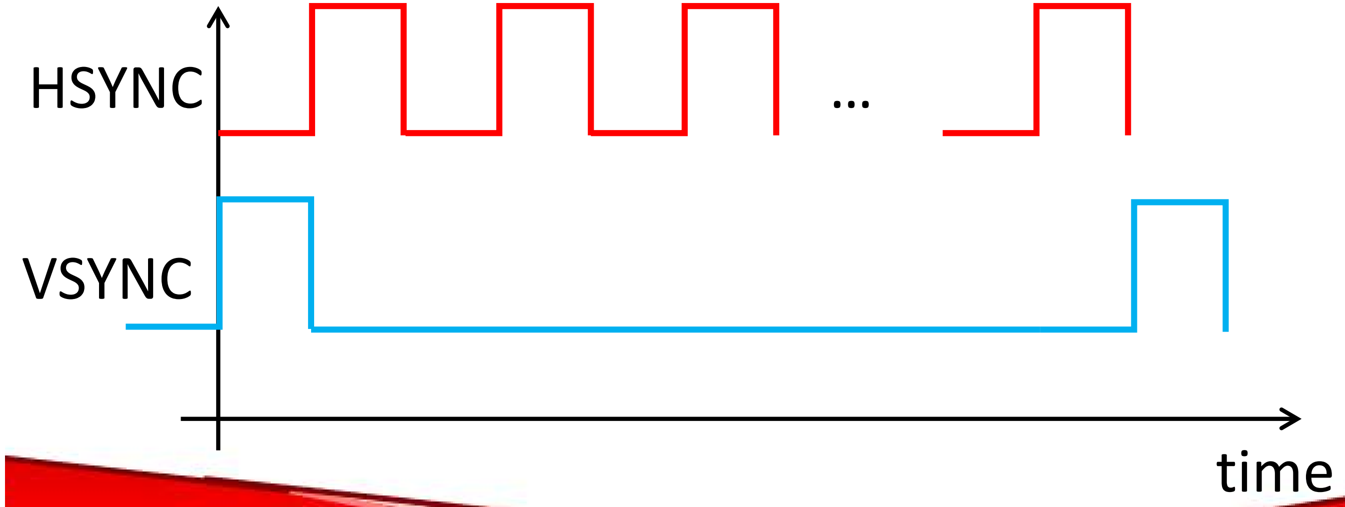


Monitors


Vertical deflection coil
Horizontal deflection coil
Electron gun
mono
hsync
vsync
Horizontal osc and amp
Vertical osc and amp
Phosphor coated screen
Electron beam

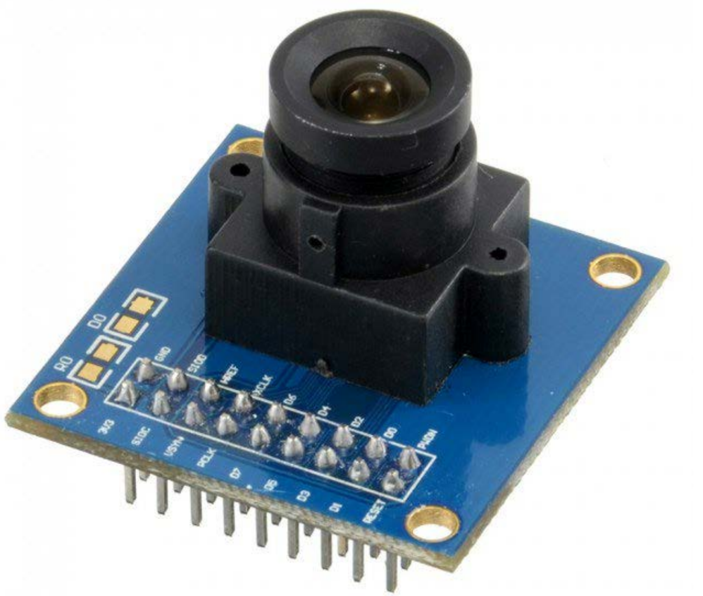

DELL


HSYNC
...
VSYNC
time

Lab 4: Camera / FPGA

OV7670

3V supply!



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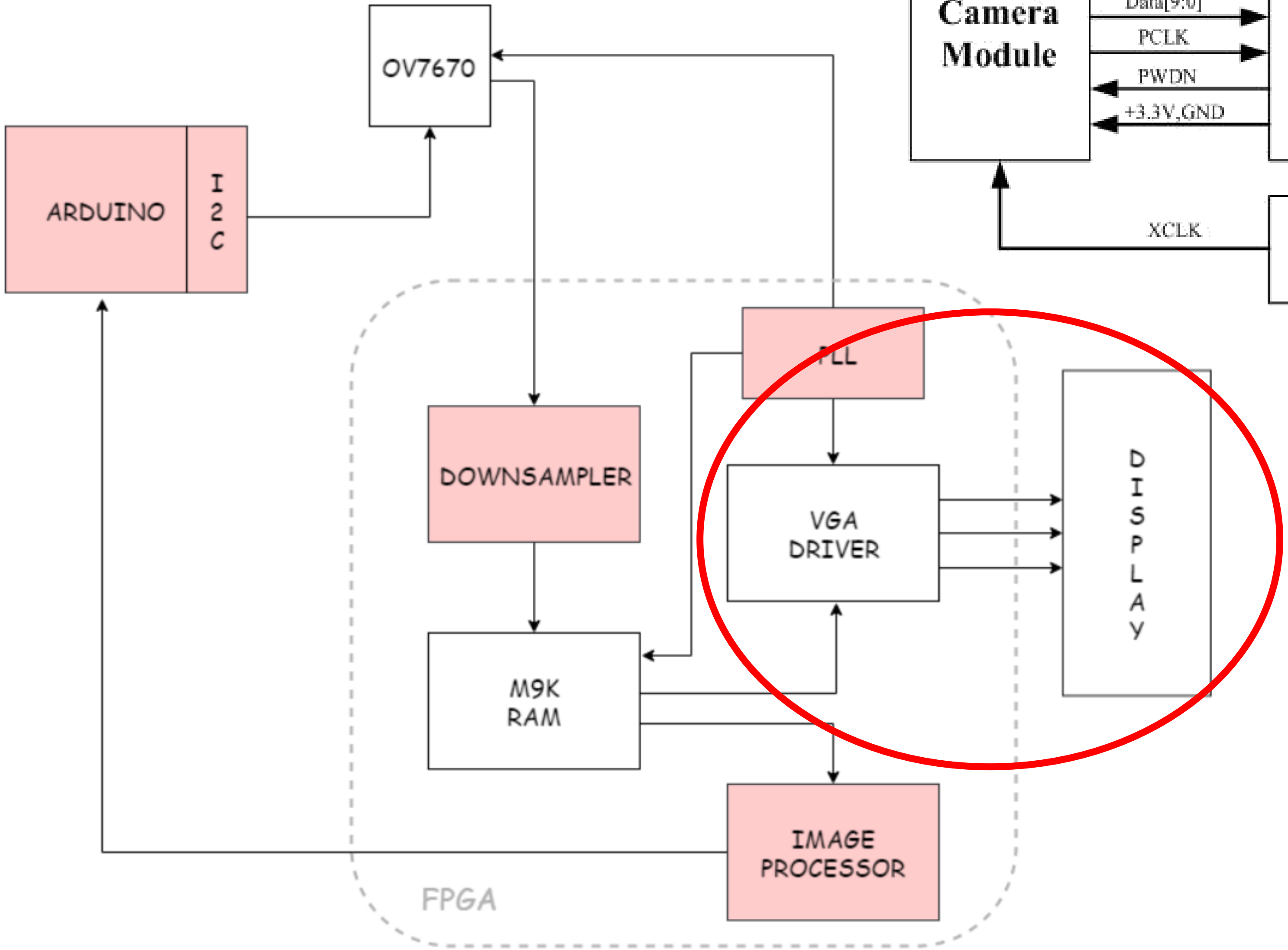

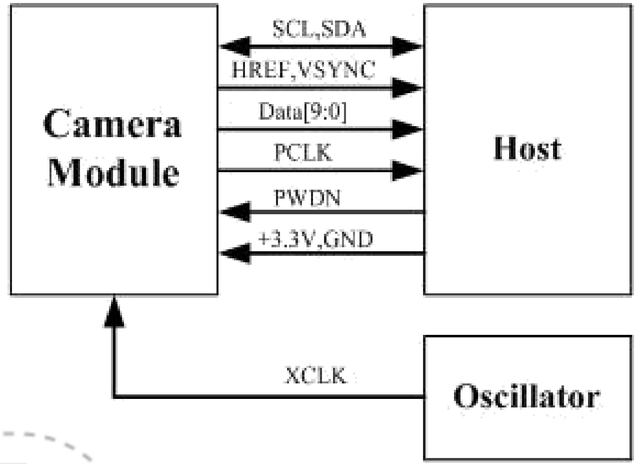

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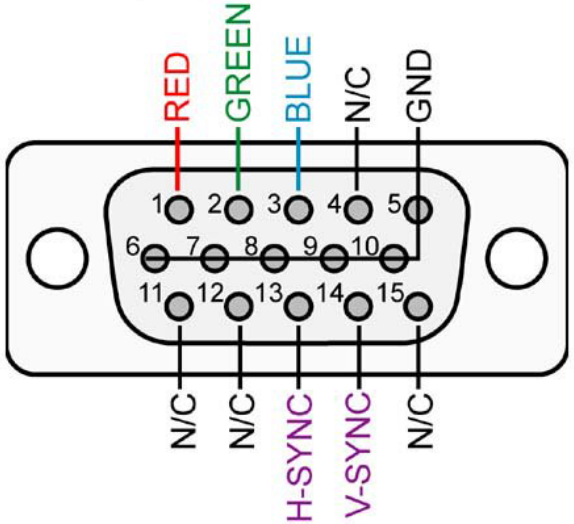
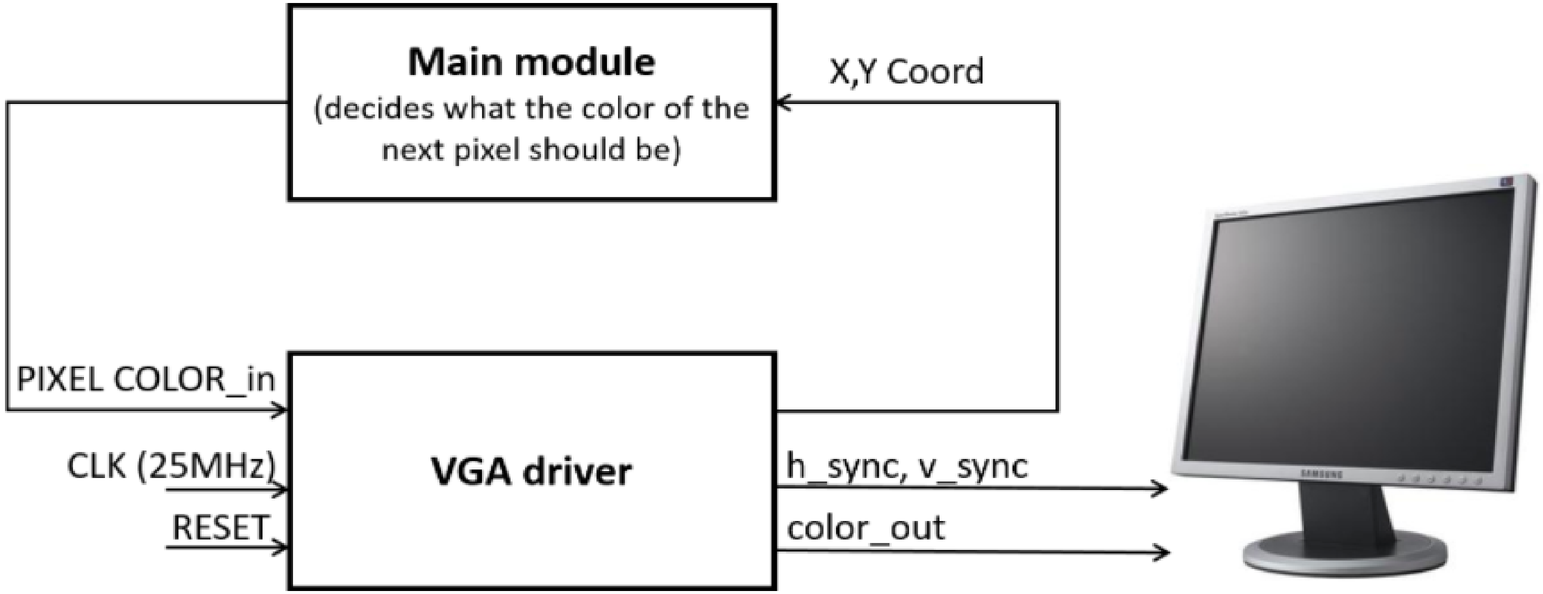
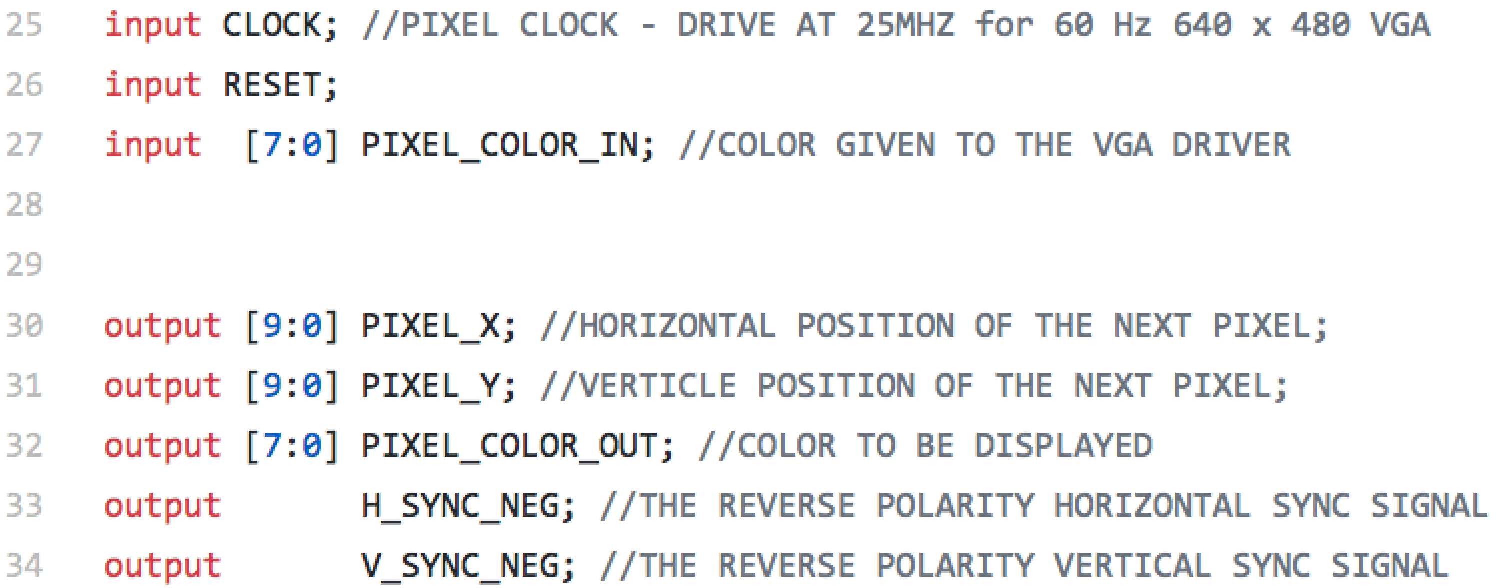




- Resistive 8-bit DAC
- FPGA Digital to Analog [0-1]V



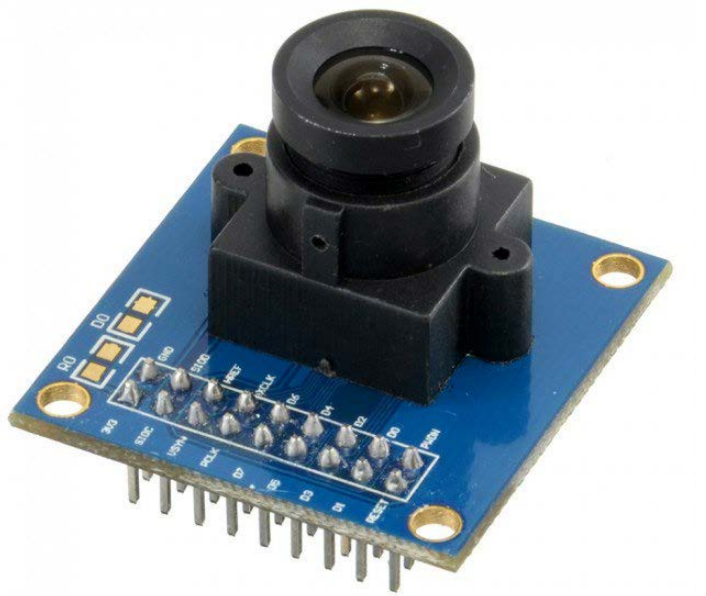
```
input CLOCK; //PIXEL CLOCK - DRIVE AT 25MHZ for 60 Hz 640 x 480 VGA
input RESET;
input  [7:0] PIXEL_COLOR_IN; //COLOR GIVEN TO THE VGA DRIVER


output [9:0] PIXEL_X; //HORIZONTAL POSITION OF THE NEXT PIXEL;
output [9:0] PIXEL_Y; //VERTICLE POSITION OF THE NEXT PIXEL;
output [7:0] PIXEL_COLOR_OUT; //COLOR TO BE DISPLAYED
output       H_SYNC_NEG; //THE REVERSE POLARITY HORIZONTAL SYNC SIGNAL
output       V_SYNC_NEG; //THE REVERSE POLARITY VERTICAL SYNC SIGNAL
```

Lab 4: Camera / FPGA

http://www.arducam.com/camera-modules/0-3mp-ov7670/

OV7670

3V supply!



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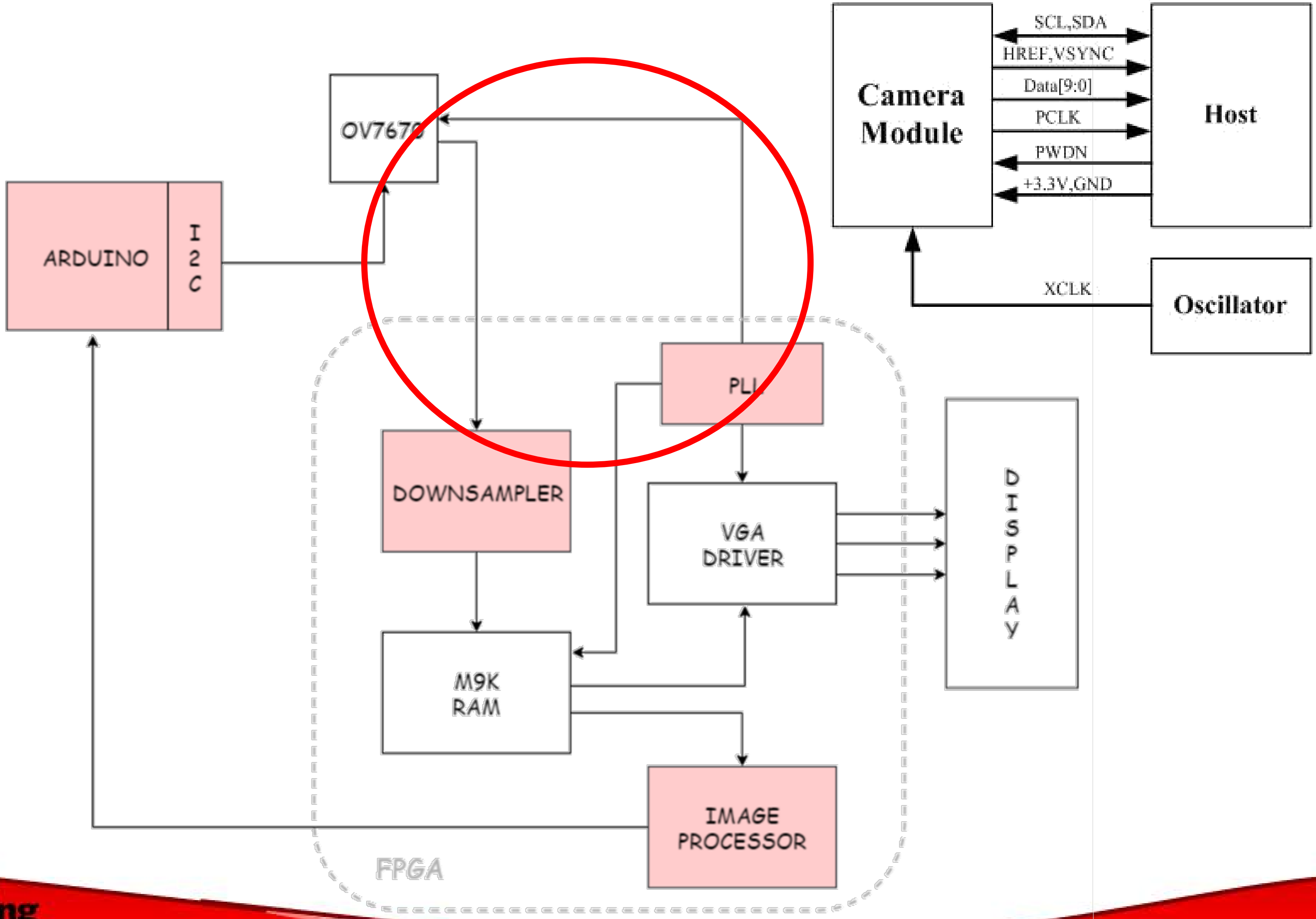

Lab 4: Camera / FPGA

http://web.mit.edu/6.111/www/f2016/tools/OV7670_2006.pdf

OV7670

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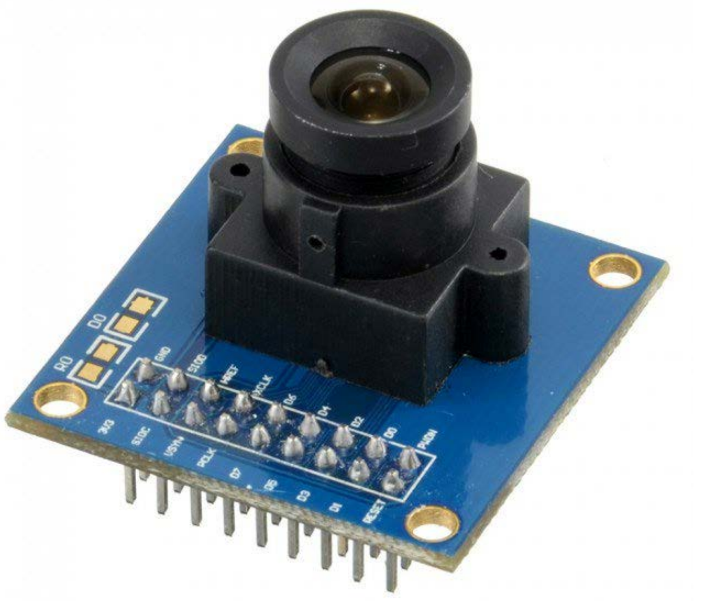
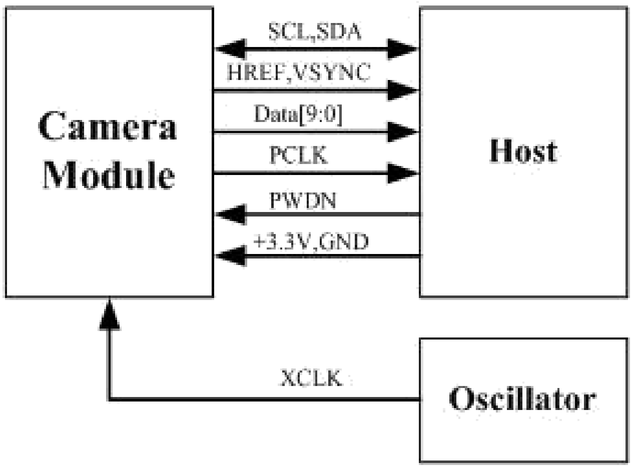
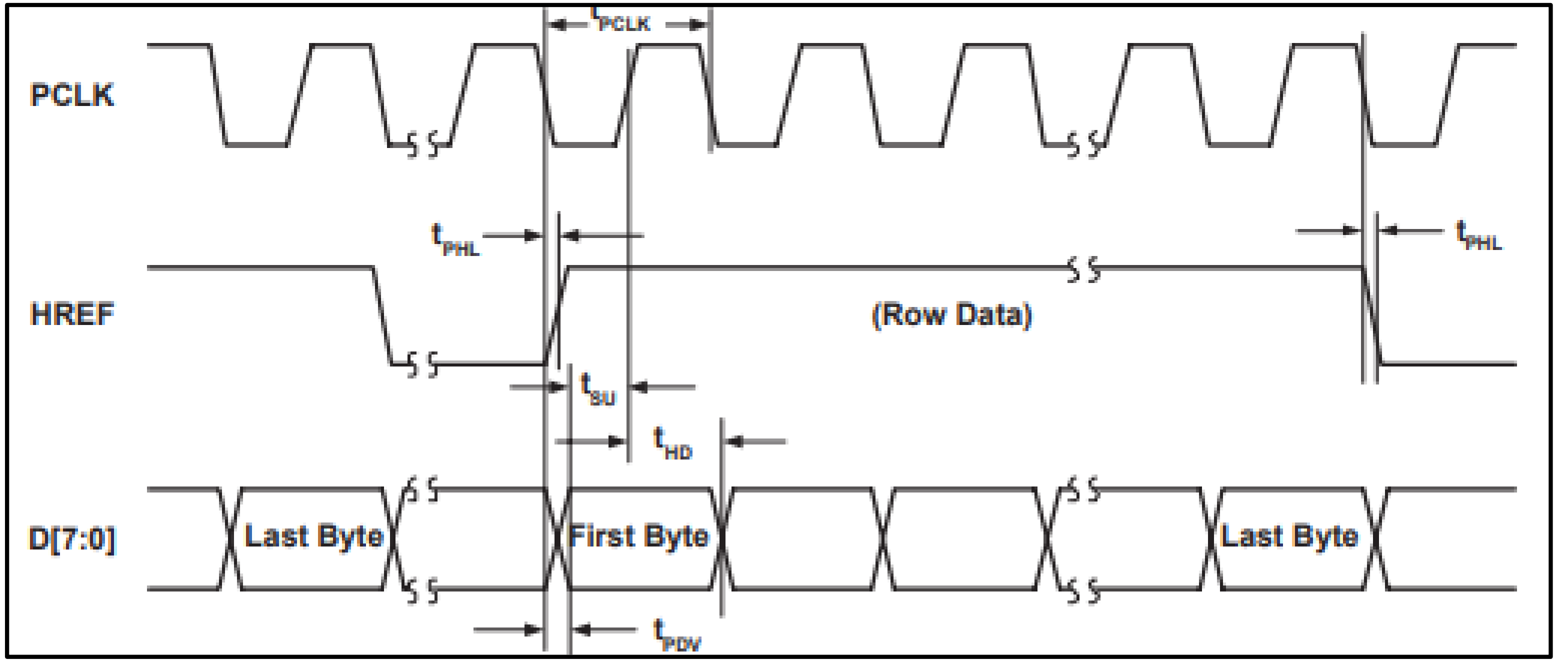


- 8 pins for data transfer
- 3-4 pins for clock signals
- *Remember to do level shifting!*

- Sample D0-7 on PCLK rising edge
- Sample D0-7 when HREF is high
- HREF ↑edge is the start of a line (↓edge is the end)
- VSYNC ↓edge is frame start (VSYNC ↑edge is the end)





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OV7670

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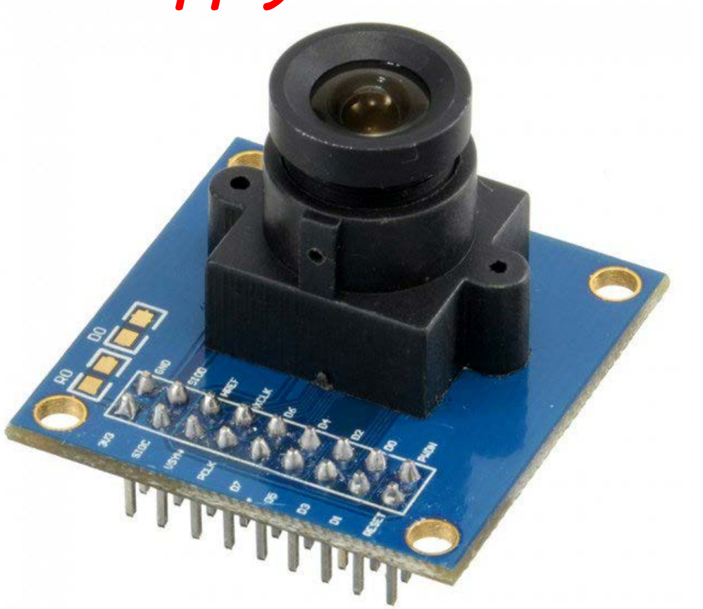

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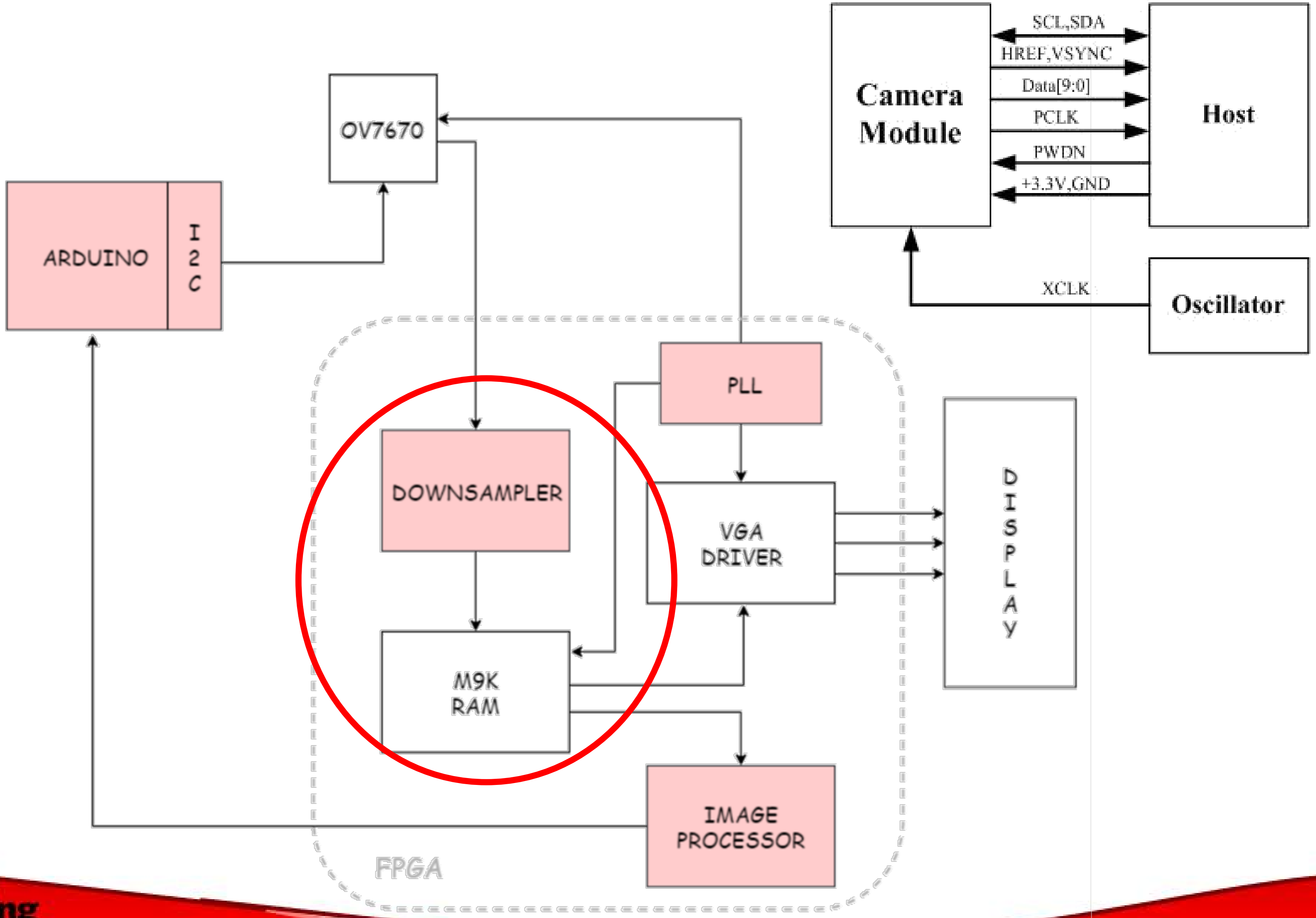
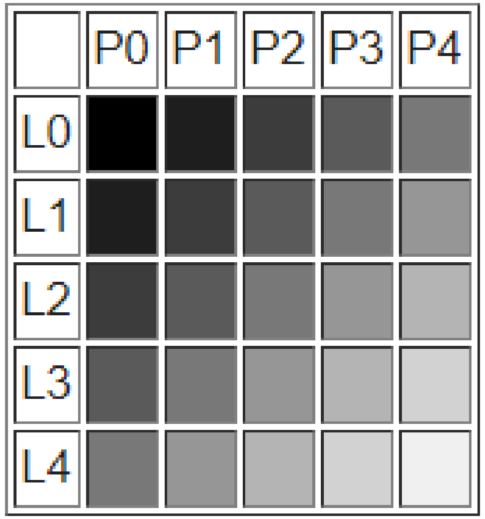
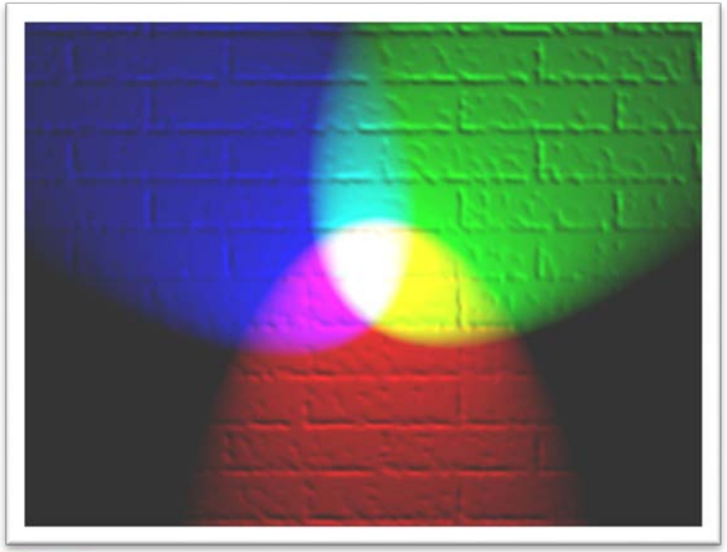


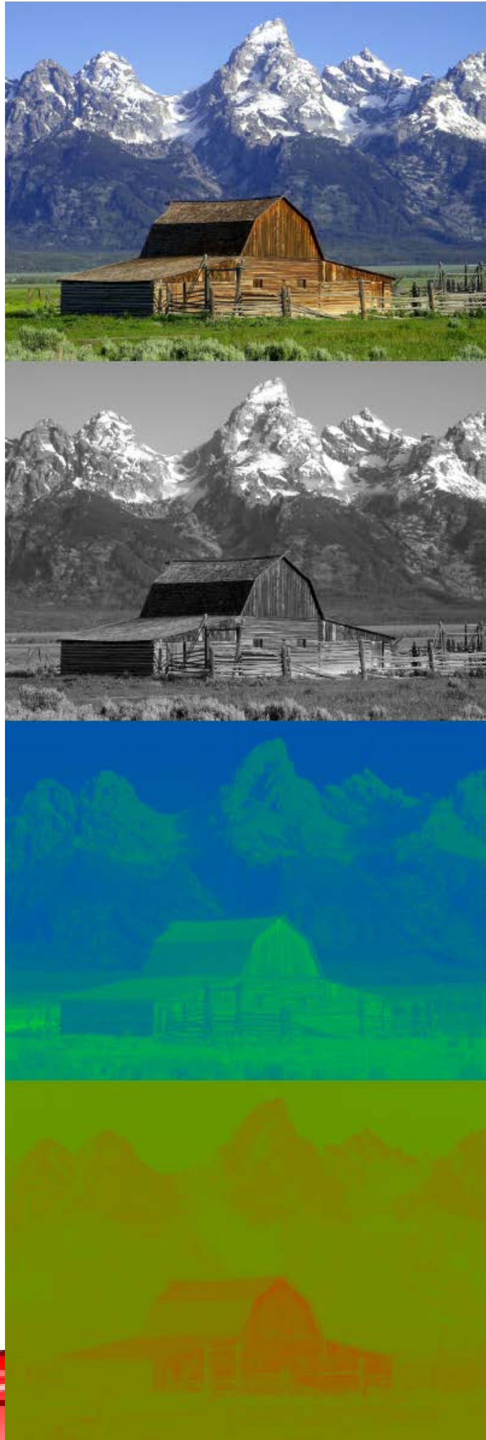
Image and Color Formats

- Image structure
- Monochrome
  - 8 bits/pixel
- RGB
  - RGB888: 24 bits/pixel
  - RGB565: 16 bits/pixel
- YCbCr/YUB
  - Luminance
  - Chroma blue/red



A 5x5 image





Source: http://embeddedprogrammer.blogspot.com/2012/07/hacking-ov7670-camera-module-sccb-cheat.html

Lab 4: Camera / FPGA

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OV7670

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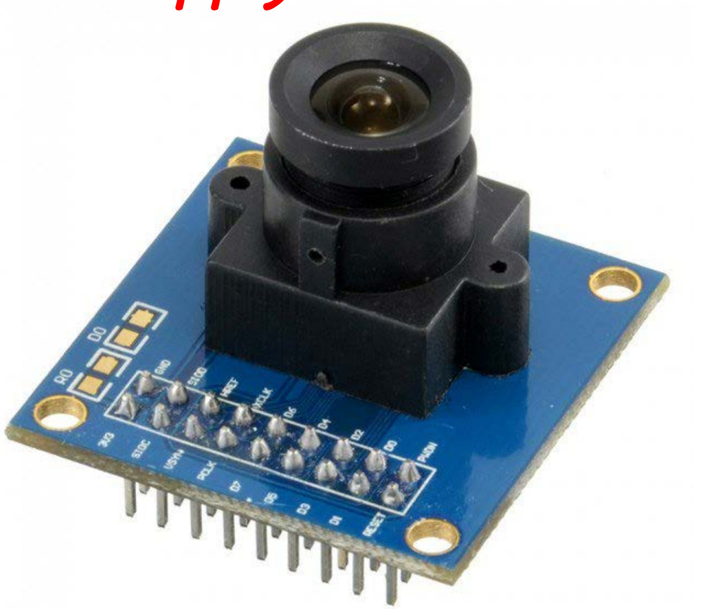

- Sensor size: 2.36 x 1.76mm
- Max resolution: 640x480 pixels

- Full resolution (640x480 pixels)
- Full color resolution (3 bytes/pixel)
- Clock signal (10-48 MHz)

- *What is the maximum frame rate at full resolution?*
  - 1/48MHz*3*640*480 = 19.5 fps
  - (+ delays you introduce on the FPGA)
  - *How fast does your robot need to see?*
- *How much memory would this consume?*
  - 640*480*3 bytes = 921.6 kB
  - Embedded memory on the FPGA is 74.25 kB
  - You'll have to lower both resolution and color resolution!

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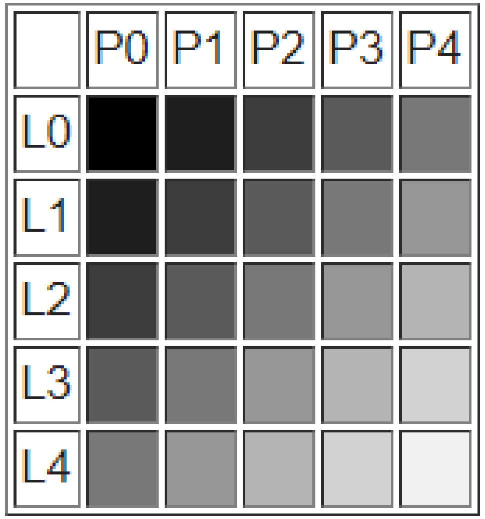

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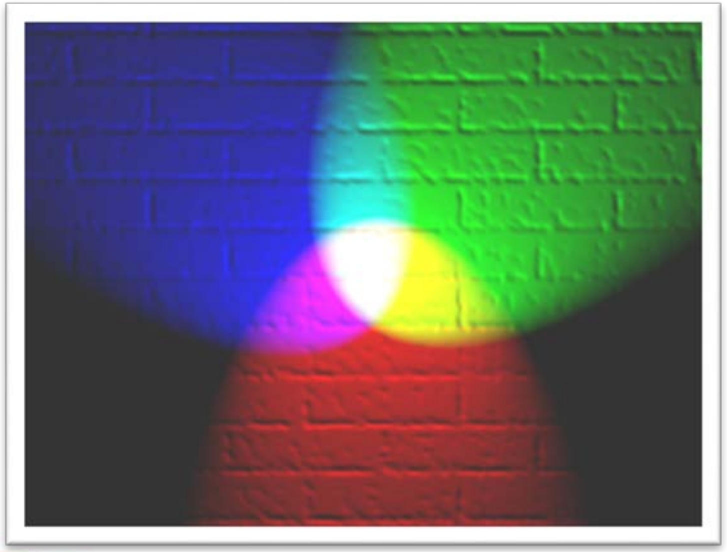

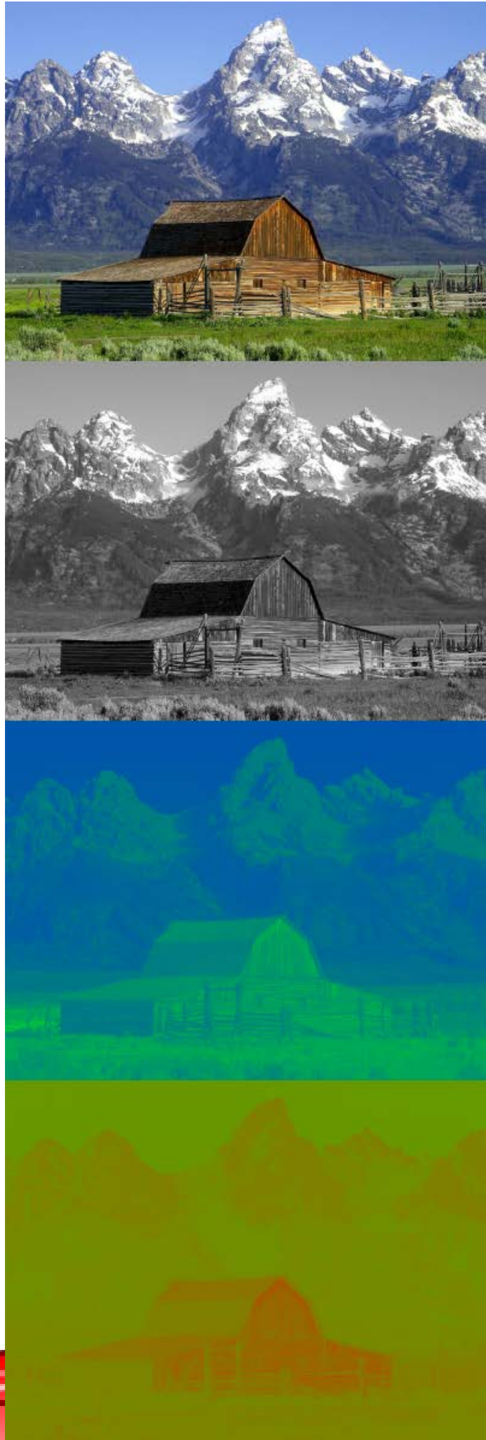

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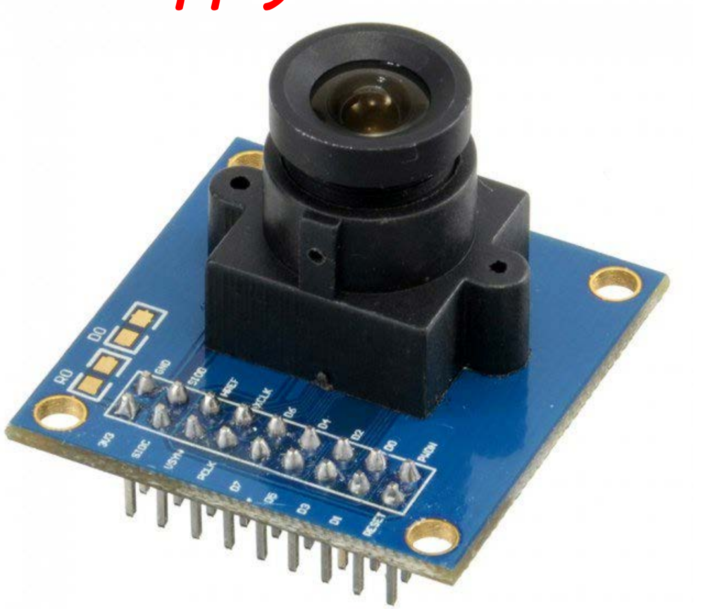
Lab 4: Camera / FPGA

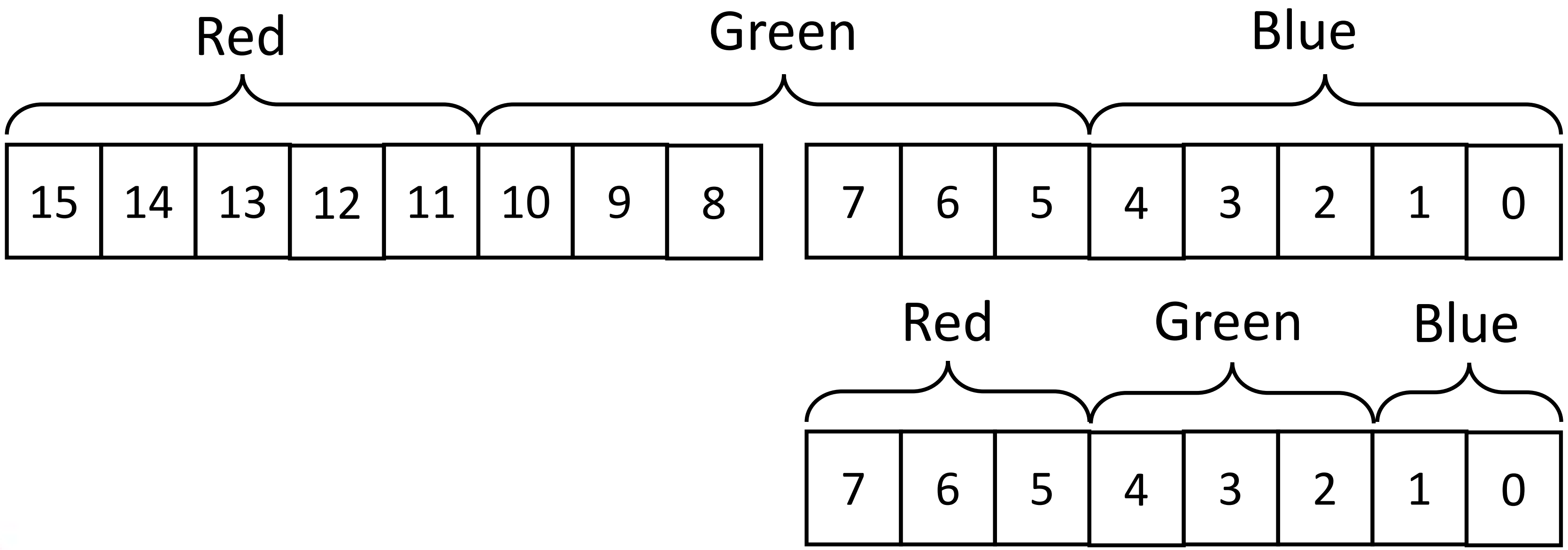
OV7670

3V supply!



- Sensor size: 2.36 x 1.76mm
- Max resolution: 640x480 pixels

- Full resolution (640x480 pixels)
- Full color resolution (3 bytes/pixel)
- *What is the maximum frame rate at full resolution?*
- *How much memory would this consume?*
- *How to downsample RGB565 to RGB332?*



Red Green Blue

15 14 13 12 11 10 9 8 | 7 6 5 4 3 2 1 0

Red Green Blue

7 6 5 4 3 2 1 0

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OV7670

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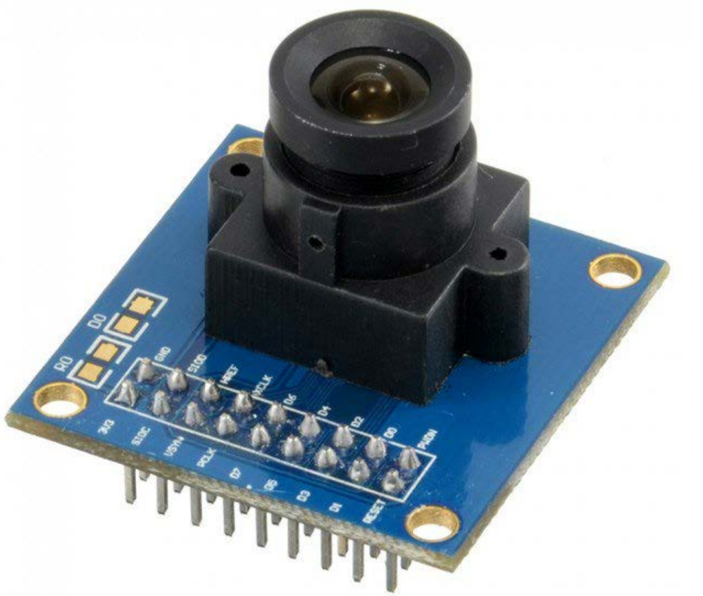

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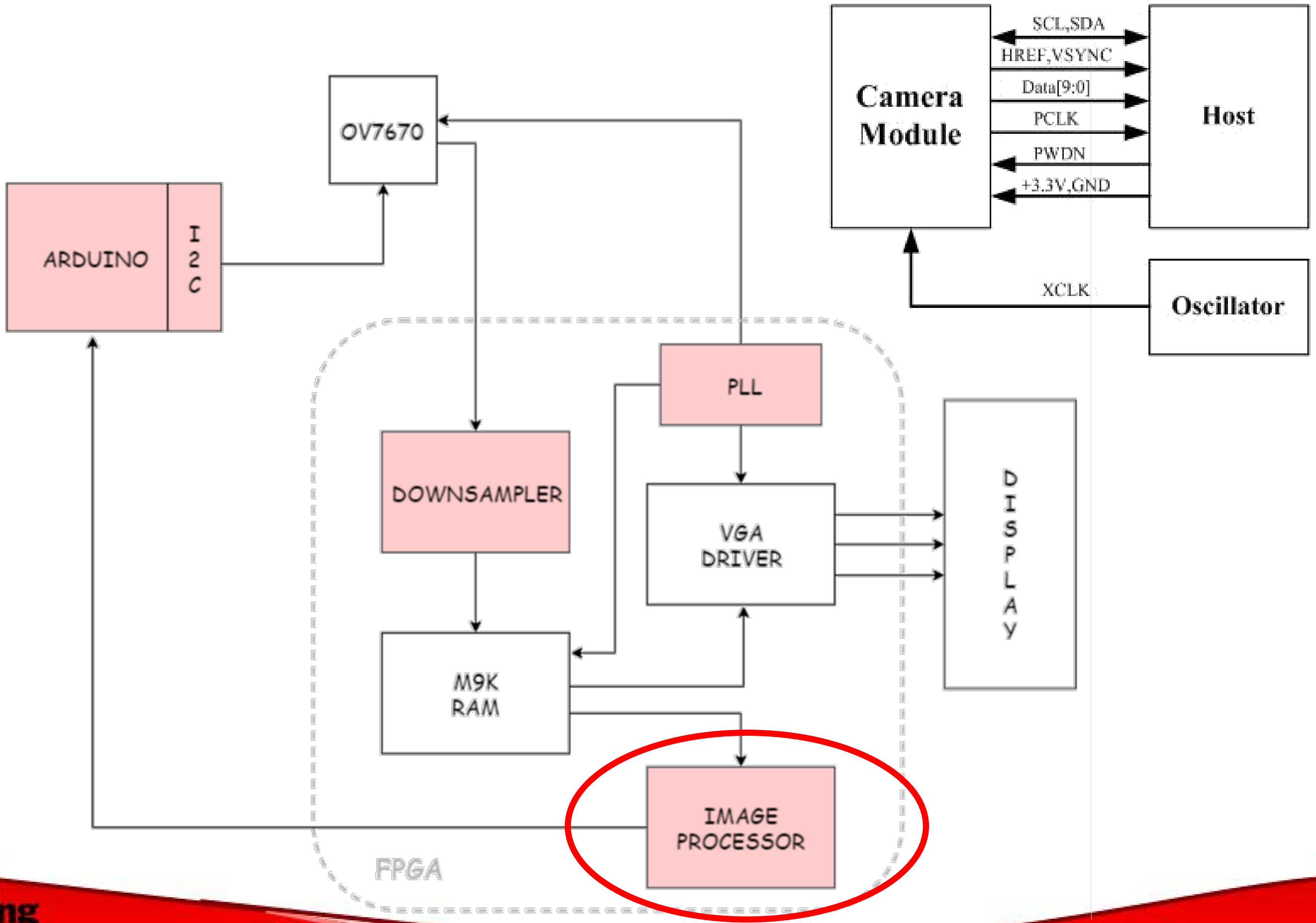
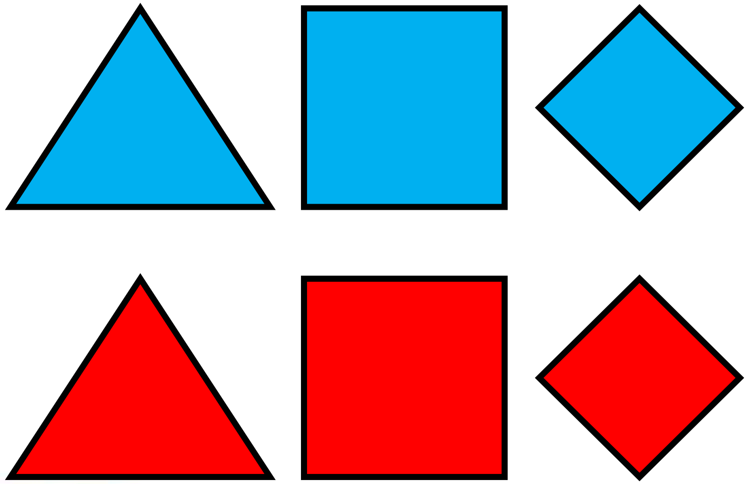
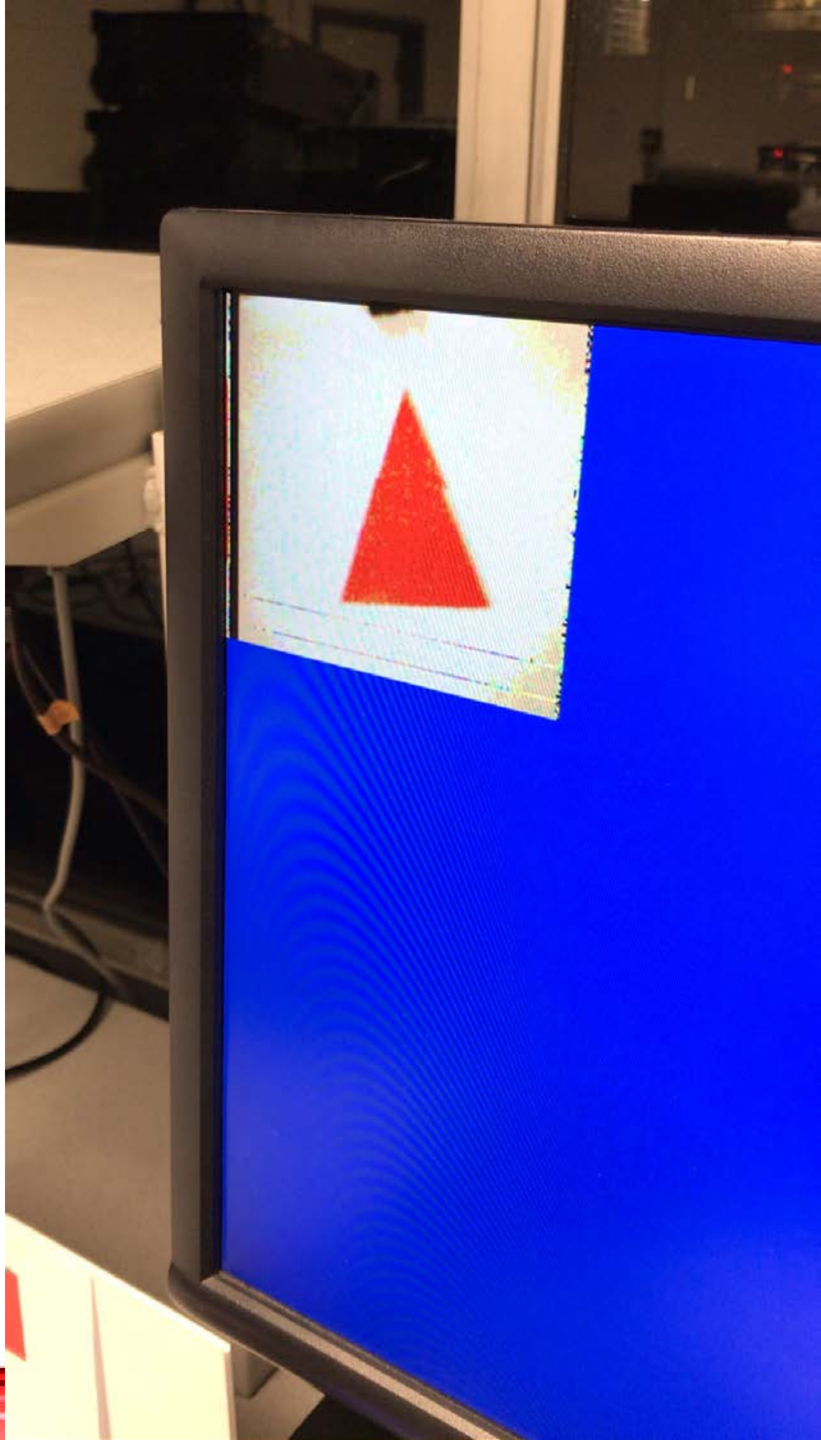


Final Competition and Treasures

- **Round:** [0-20] points
- **Coverage:** [0-15] points
- **Treasures:**
  - Correctly located: 1 point
  - Correctly located, and correct color: 1 point
  - Correctly located, and correct shape: 1 point
  - Faulty location: -1 point

- 4.5% of the population is color blind
- New treasure set consist of:
  - Red/Blue treasures
  - Triangles, Squares, Diamonds





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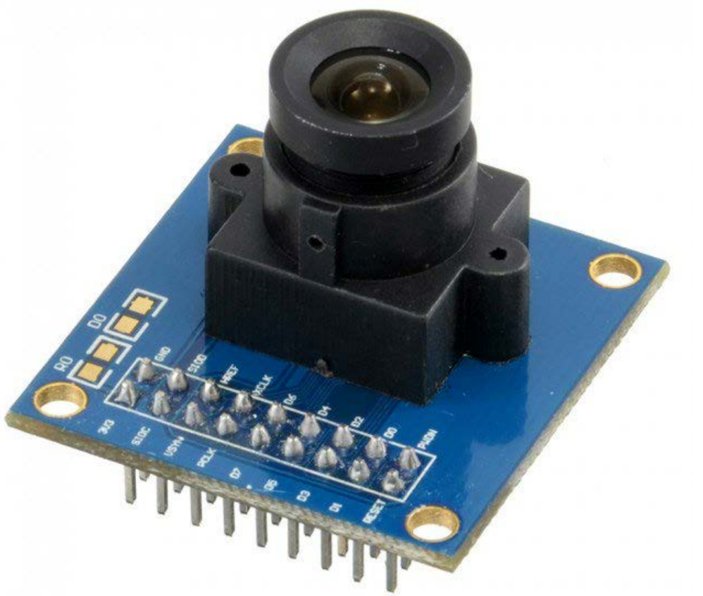

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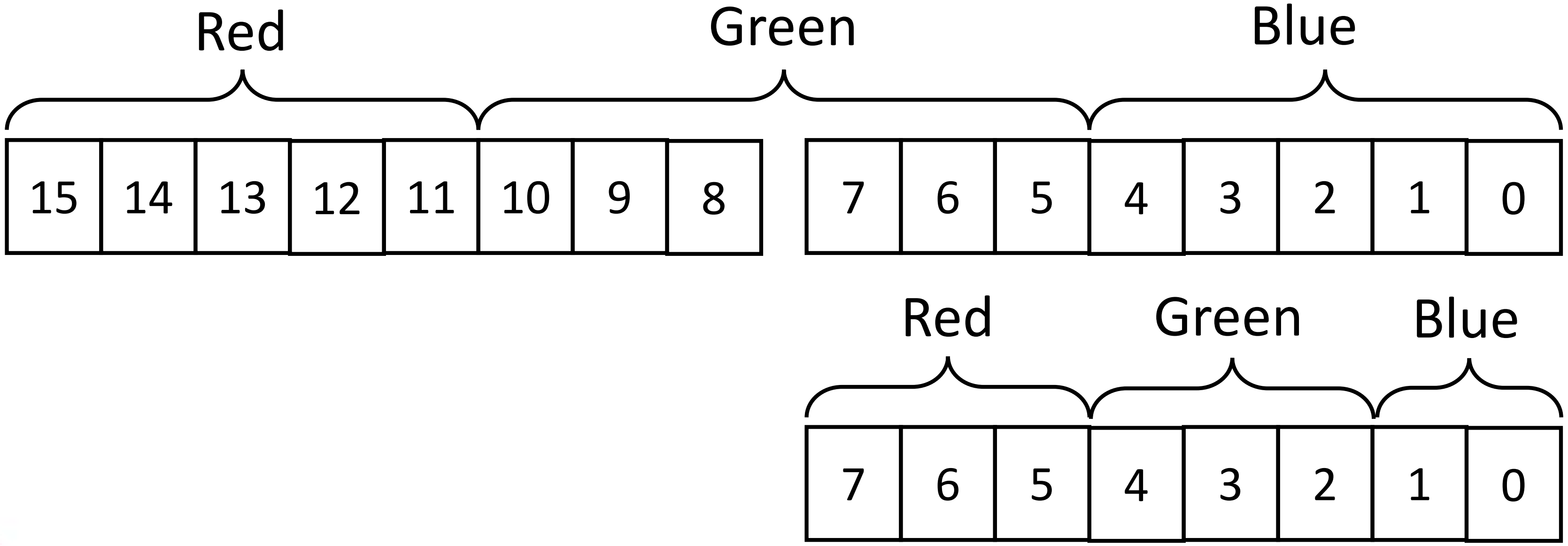

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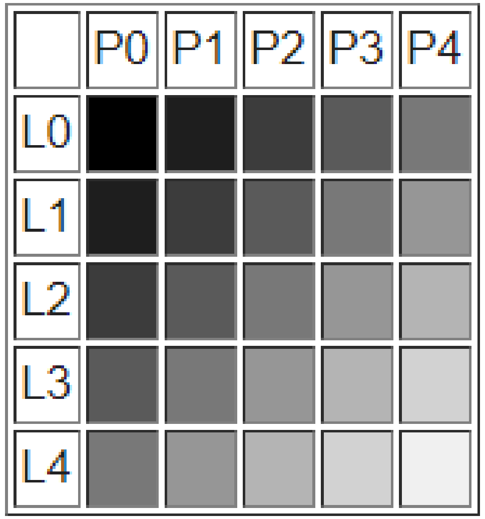

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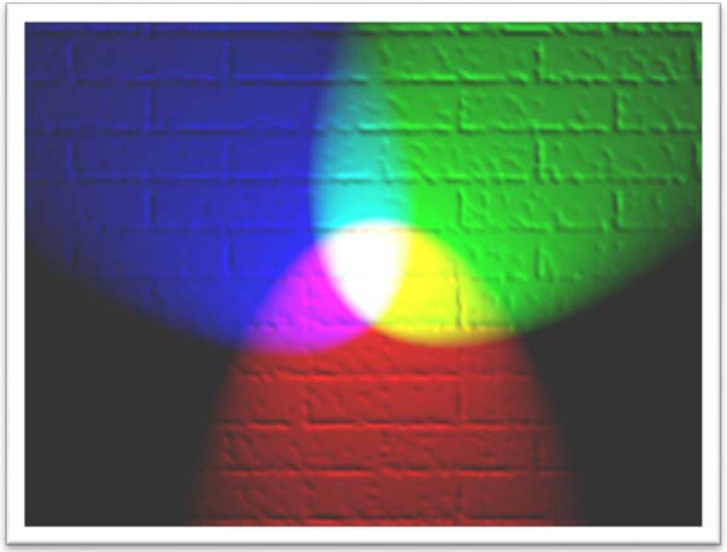

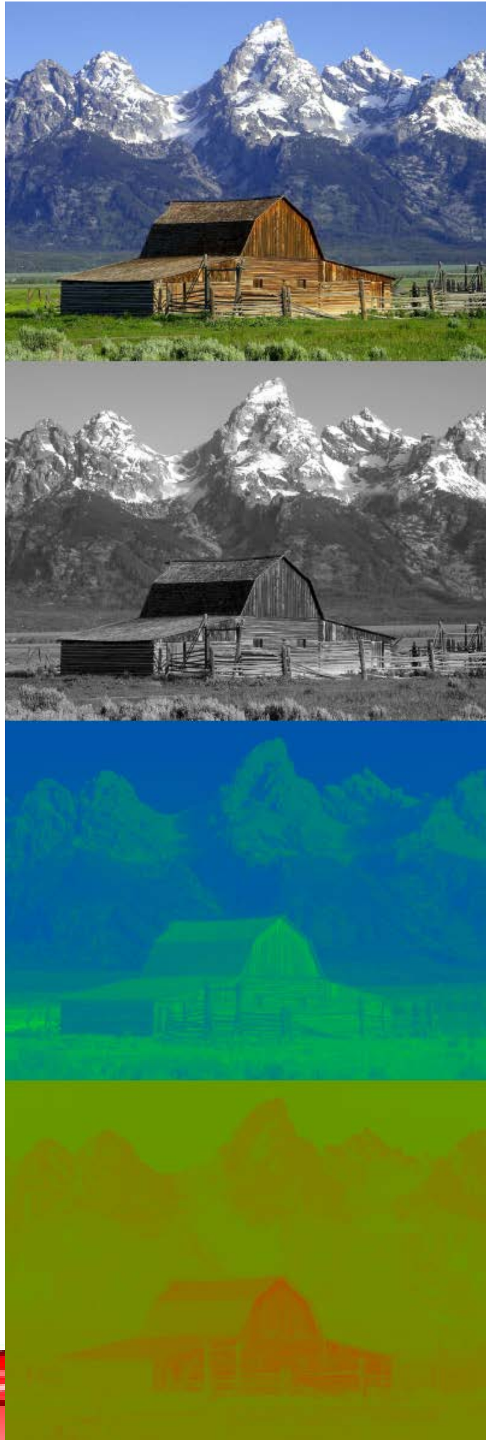

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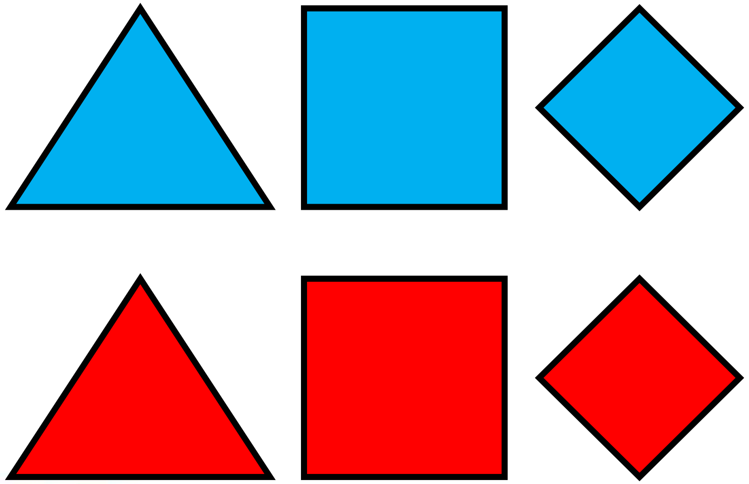


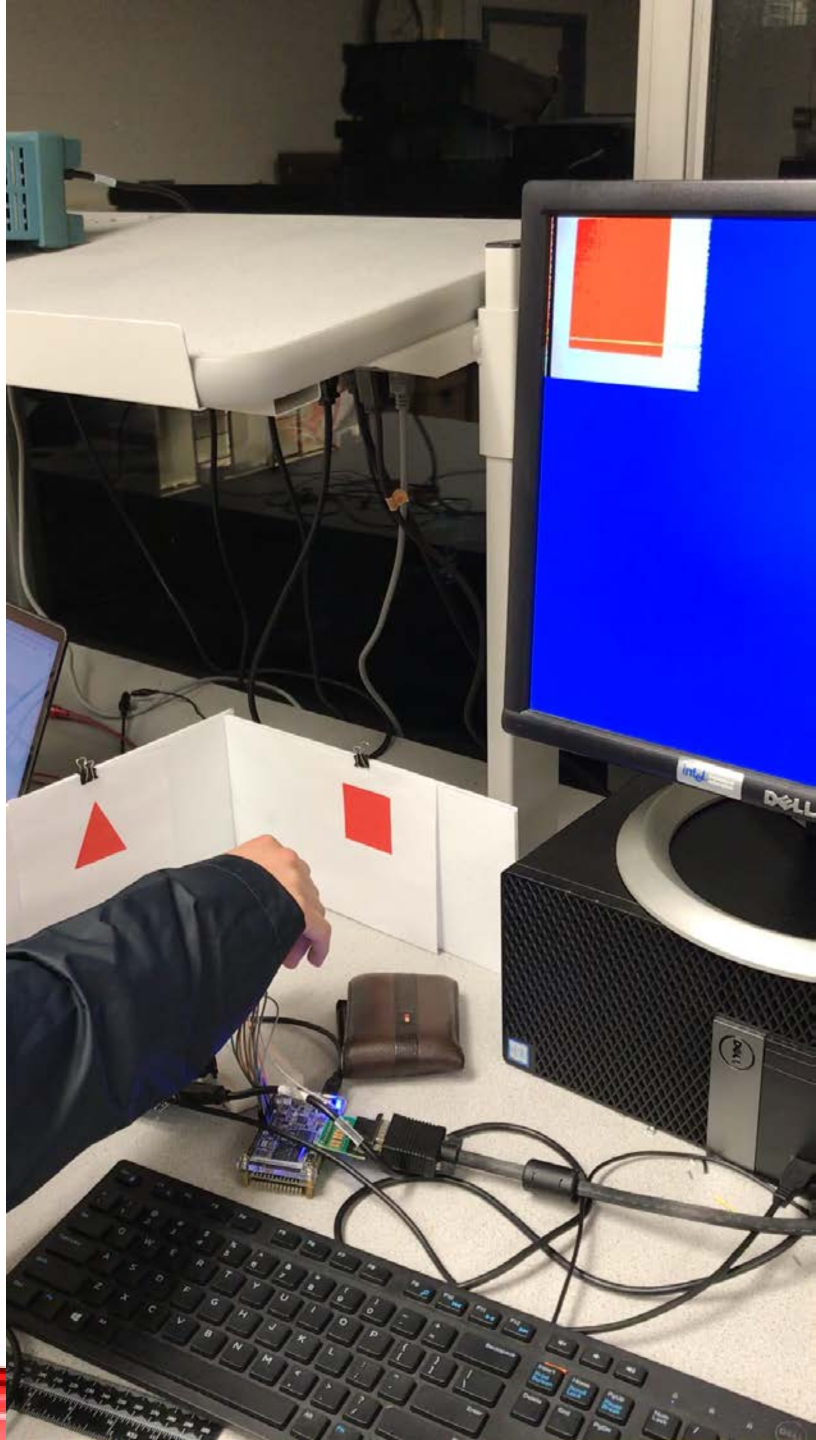
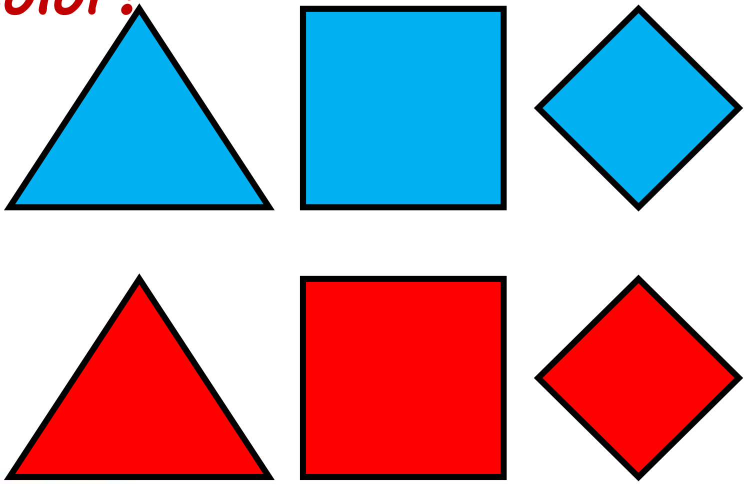
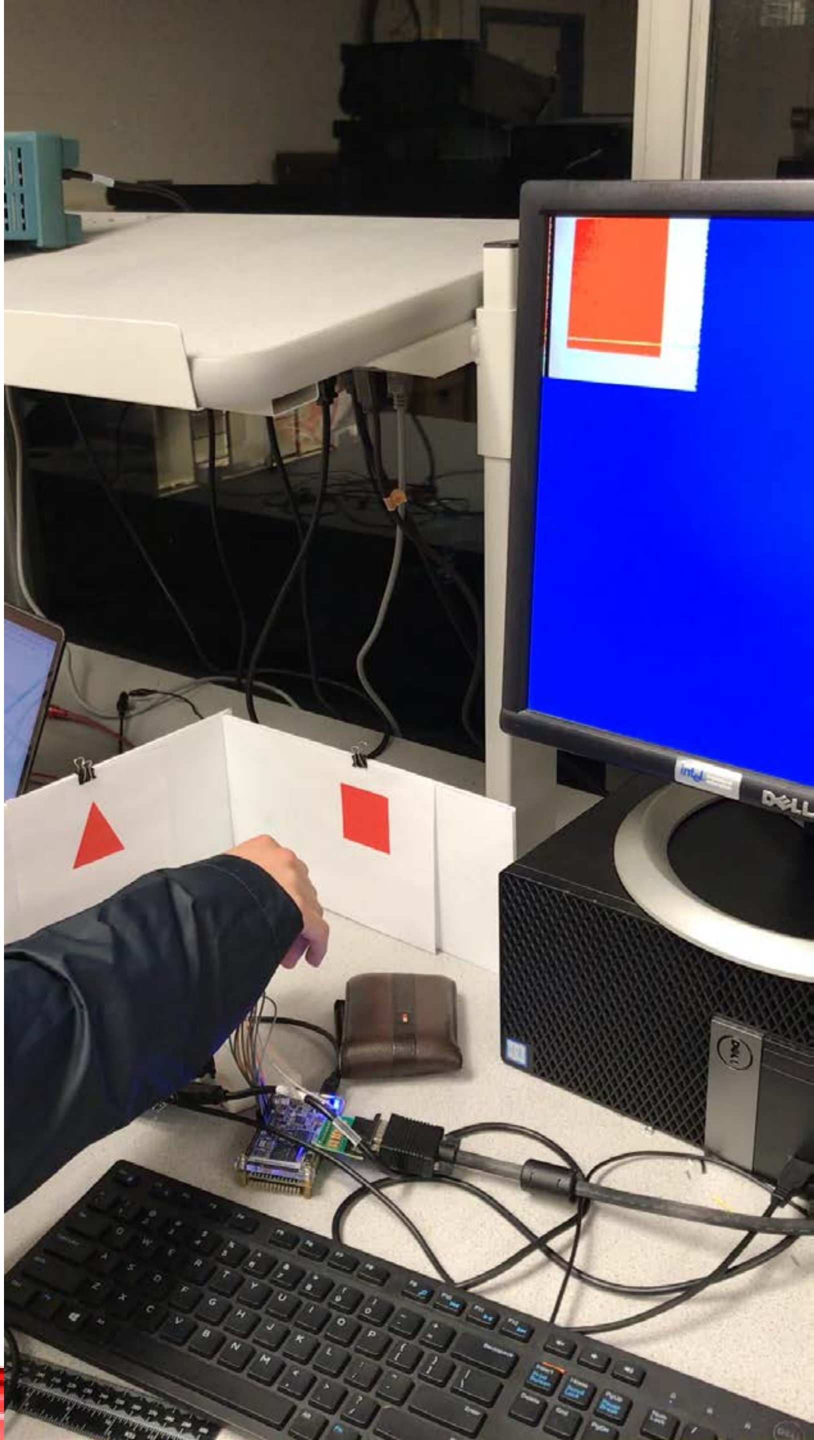


Image Processing

- Your job is to figure out whether…
  - …there is a treasure? what color? what shape?
- *Do you have to check the camera all the time?*
  - Just at junctions
  - Only next to walls
- Template matching, edge detection, filters, ML, etc…
- *Do you have to check all pixels?*
  - Just a few lines
- *How would you detect the color?*
  - Thresholding
  - Relative thresholding
  - +averaging…



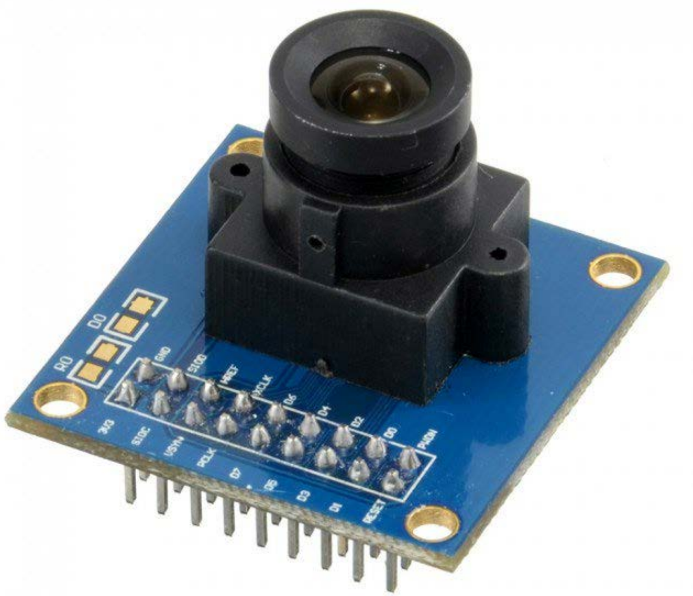


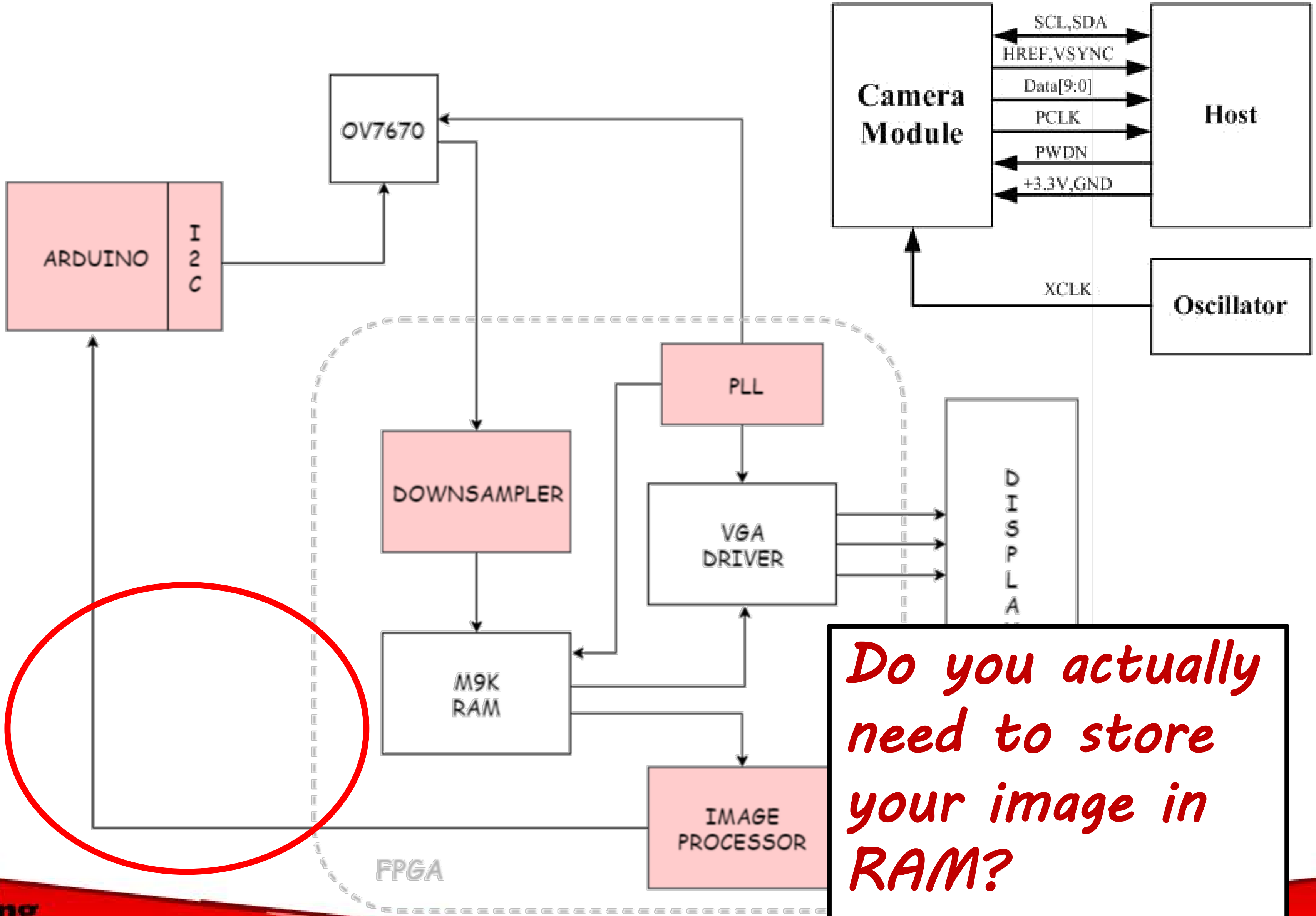
Lab 4: Camera / FPGA

http://www.arducam.com/camera-modules/0-3mp-ov7670/

OV7670

3V supply!





SPI or parallel communication

Do you actually need to store your image in RAM?

Next week:

- Fall break!

Go make Robots!