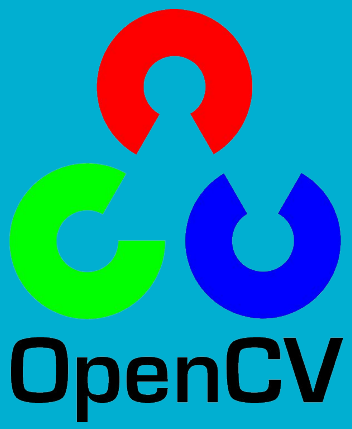
OpenCV for FTC

101 - Setup

FTC 7393
Johan Vandegriff
Nikita Wootten
gearbox4h.org



Who is this class for?

What you should know to fully learn this material:

- Java programming
- Android Studio Basics (enough to make/modify an app and upload it to a phone)

This class is mostly targeted at veteran team members, but if you are a rookie, you can still learn it, especially once your season has started and you are more familiar with programming your robot. You will also do fine in this class if you have made apps with Android Studio before.

Outline

Classes **101** and 102

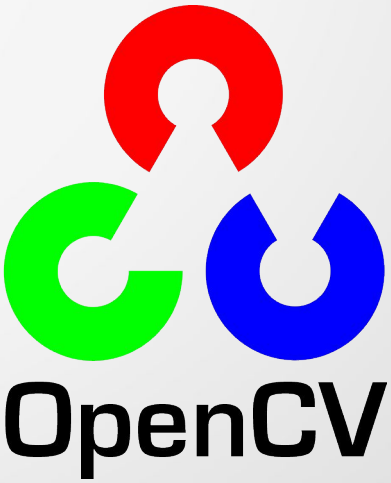
I. **101**
   A. **Set up Beta FTC App**
   B. **Add OpenCV**
   C. **Write Simple Program**

II. 102
   A. Improve Framework
   B. Write Beacon Detection Code

OpenCV for FTC 101 - Setup

What is OpenCV?
(opencv.org) OpenCV (Open Source Computer Vision Library) is an open source computer vision and machine learning software library.

What will we use it for?
Today: Detecting the beacon color
Later: Anything!



OpenCV for FTC 101 Overview

I. Download needed files
II. Set up the FTC beta app
III. Import OpenCV into the app
    A. Modify the build.gradle files
    B. Add OpenCV as a dependency
    C. Copy the OpenCV jniLibs into the app
IV. Add camera capability
    A. Add the camera permission
    B. Add the camera frame and button to the layout
    C. Show the camera frame on the screen

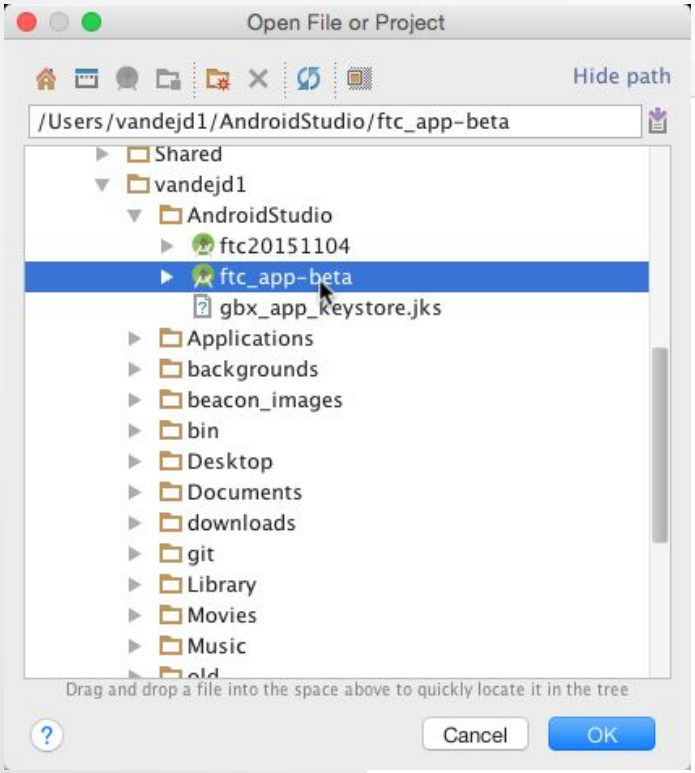
What You Need

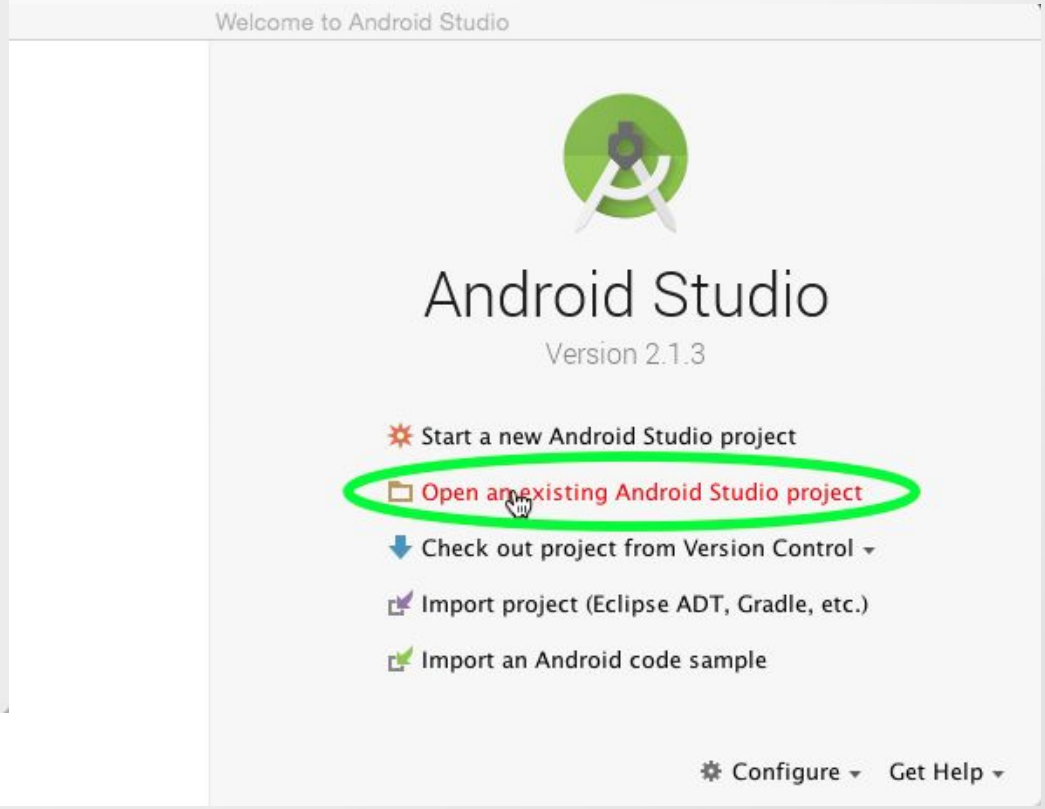
A copy of the beta version of the ftc_app, as released on 2016-08-09
The OpenCV library, version 3.1 for Android
A copy of the tutorial code for the class
(Optional) Pictures of the beacon for easy testing

Visit gearbox4h.org/opencv for download links

Set up the app

Extract the beta app from the zip file.
Start Android Studio and select "Open Existing Project"
Select the ftc_app-beta folder and Click “OK”.

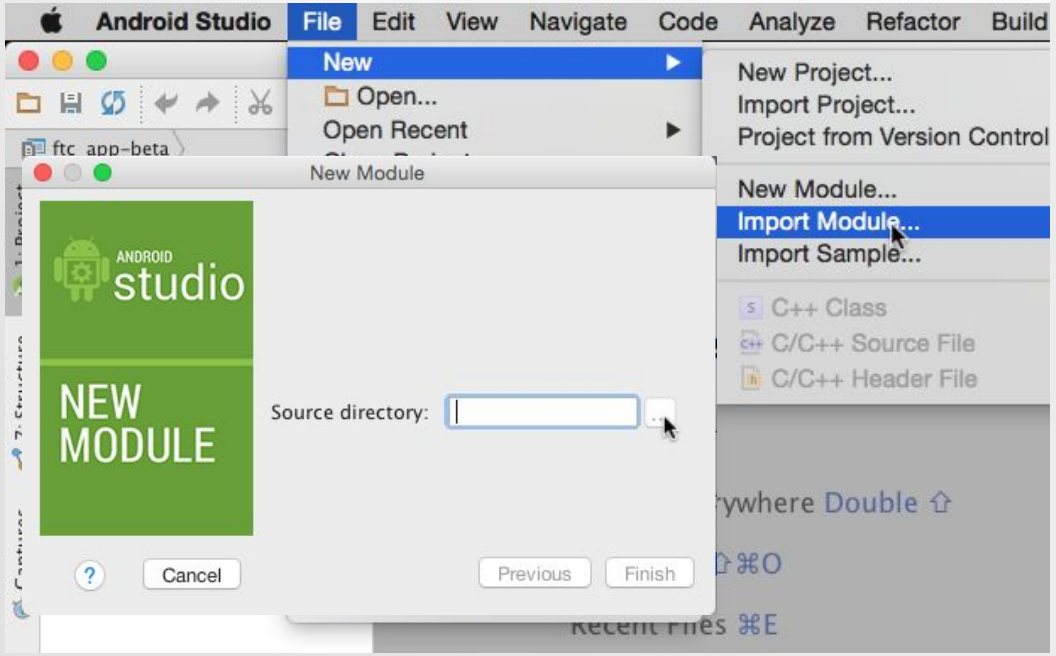


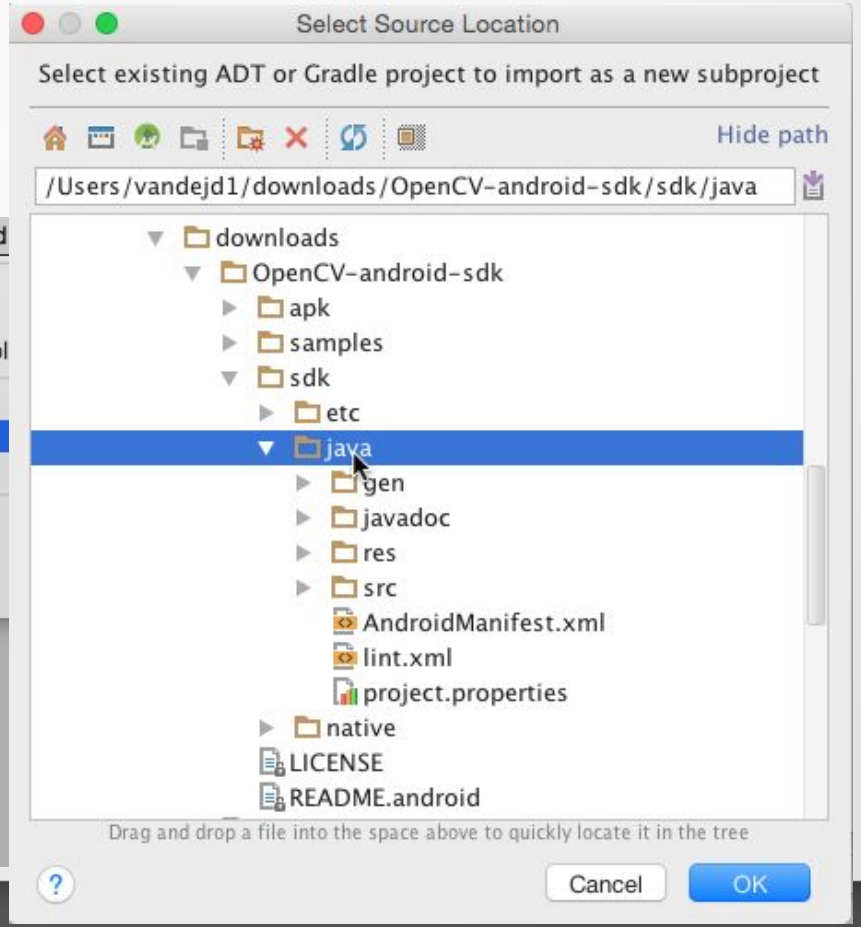


Wait for Gradle to build (someday)....

Import OpenCV into the app

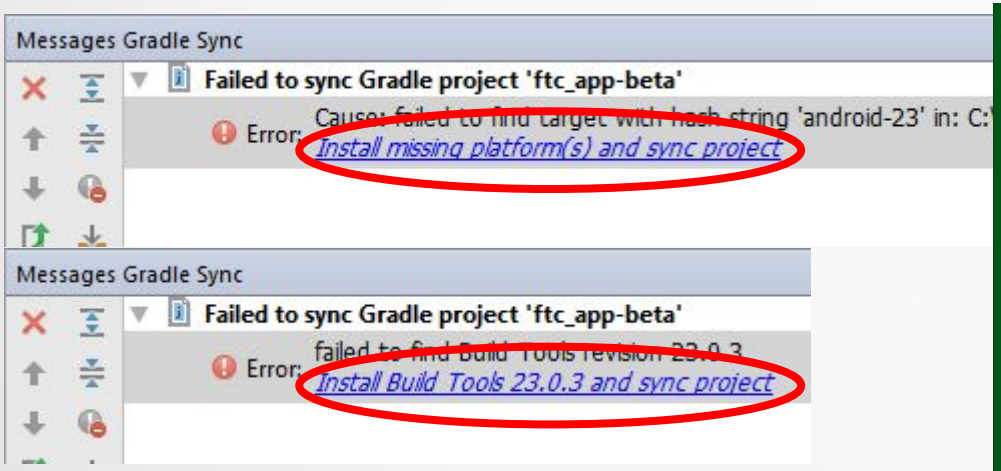
Extract OpenCV from the zip file.
In Android studio, choose File->New->Import Module.
Navigate to the place where you extracted OpenCV, and choose the folder sdk/java. Click OK, then Next, then Finish to choose the folder.
In the next step, we will fix the errors that pop up.

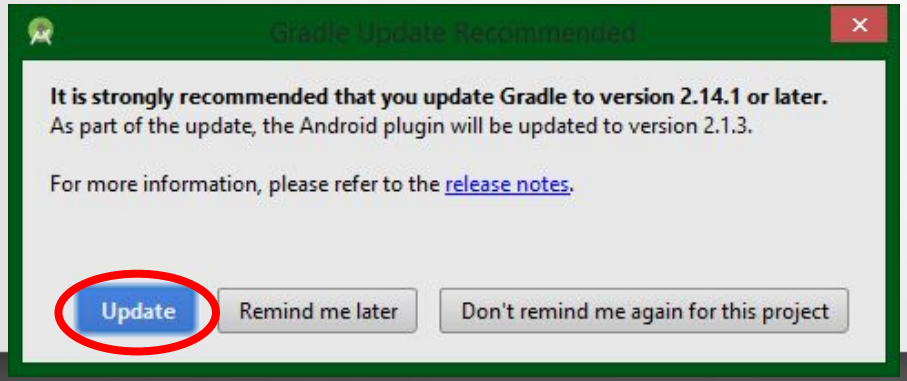


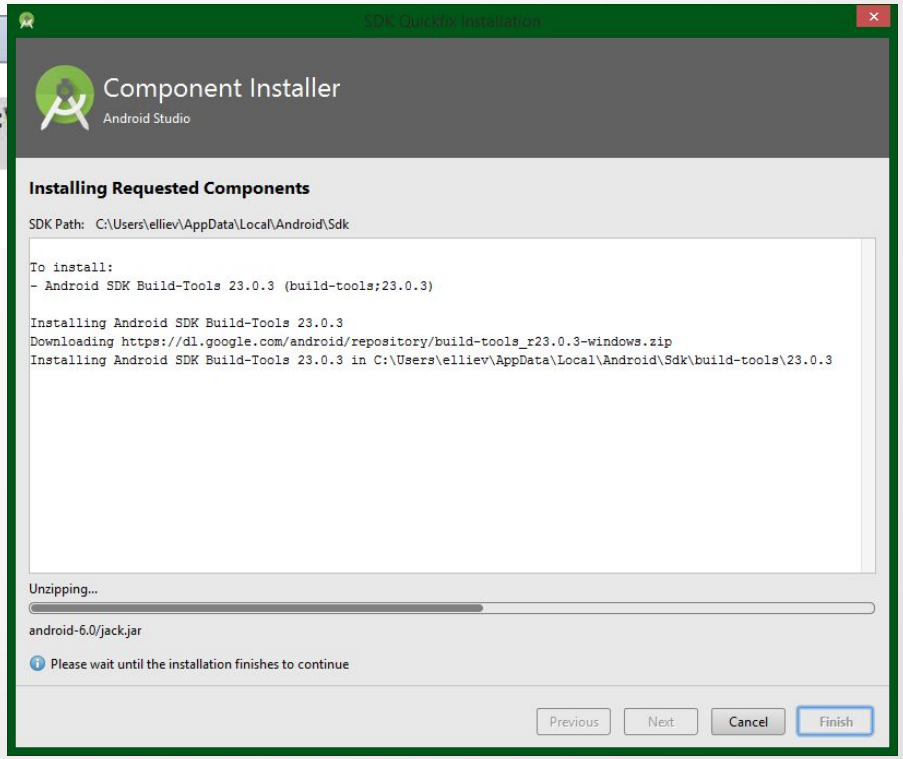


Resolve Missing Build Tools

If you encounter any of the following errors, Click on the blue link to install the missing components for Android Studio. If you have already set up Android Studio, you will not get these errors.
Ignore all the “cannot find symbol variable XYZ” errors for now.



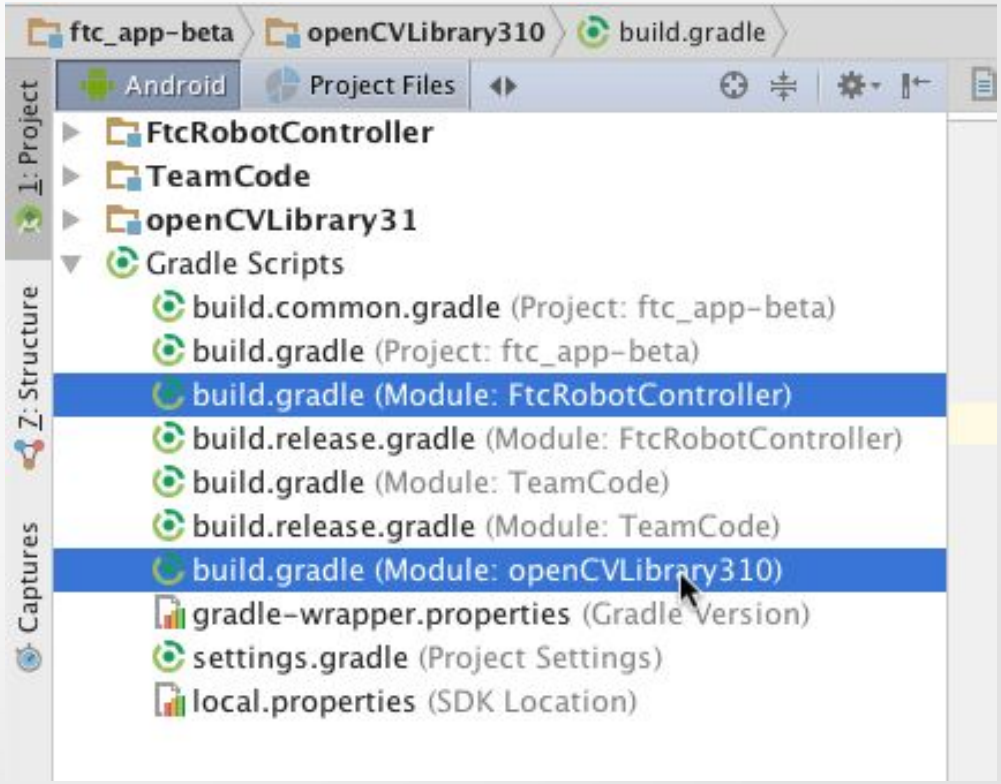




Modify build.gradle Files

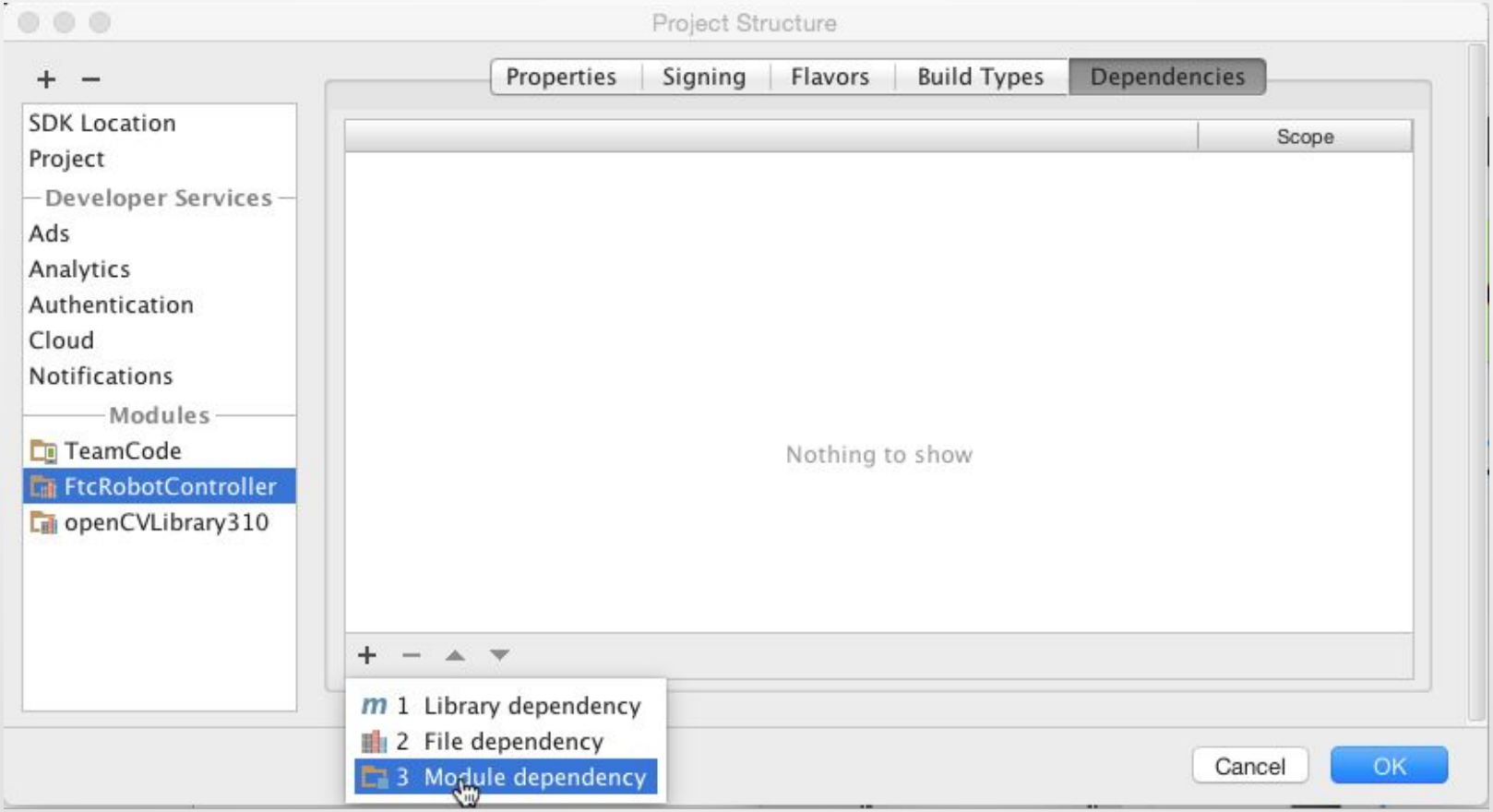
Modify the build.gradle files for FtcRobotController and openCVLibrary310.
For FtcRobotController, change targetSdkVersion to 23.
For openCVLibrary310, change these 4 fields to have the same values that they have in the FtcRobotController build.gradle file:

compileSdkVersion
buildToolsVersion
minSdkVersion
targetSdkVersion



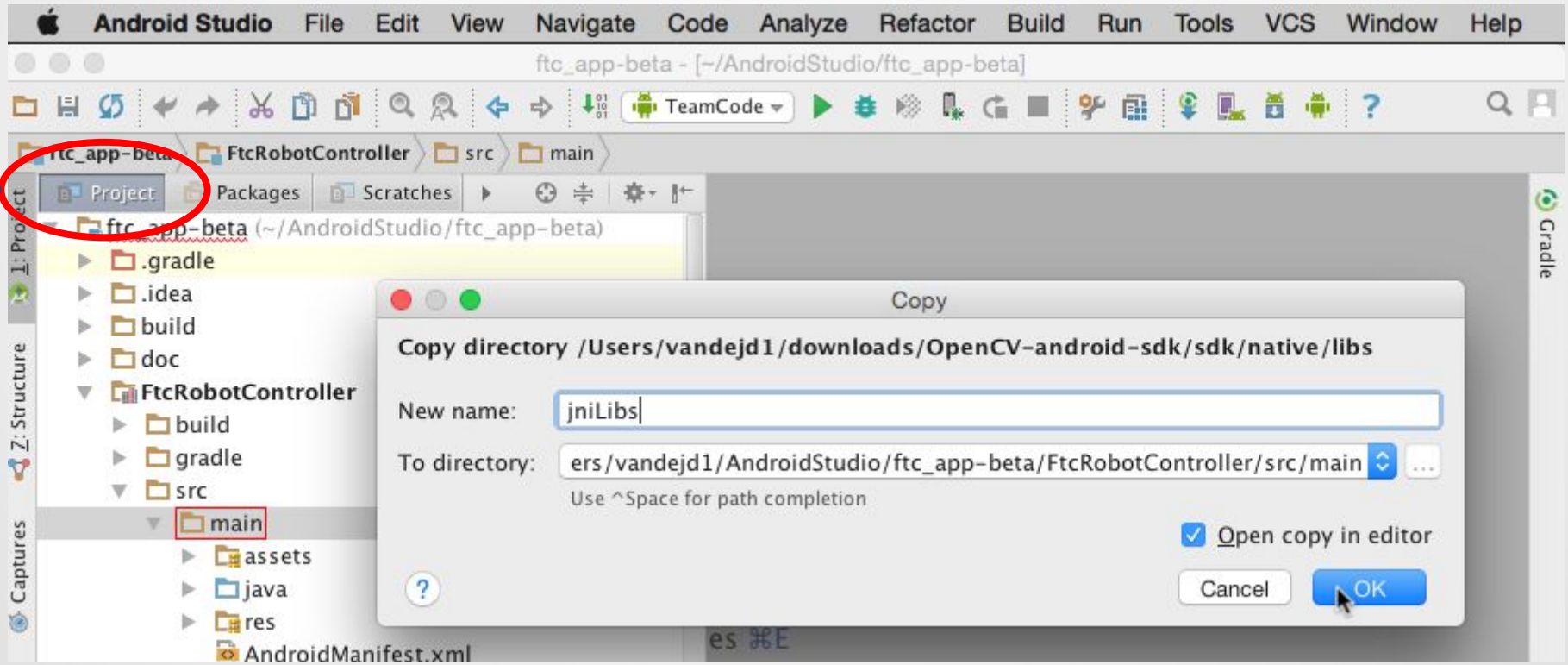
Add OpenCV as a Dependency

Right click on FtcRobotController in the left navigation pane, then click Open Module Settings. Select the Dependencies tab. Click the "+" icon at the bottom (on the top-right for Windows) left, and on the pop-up menu, choose Module Dependency. Select module openCVLibrary310, and click OK, then OK again.



Copy OpenCV jniLibs into the app

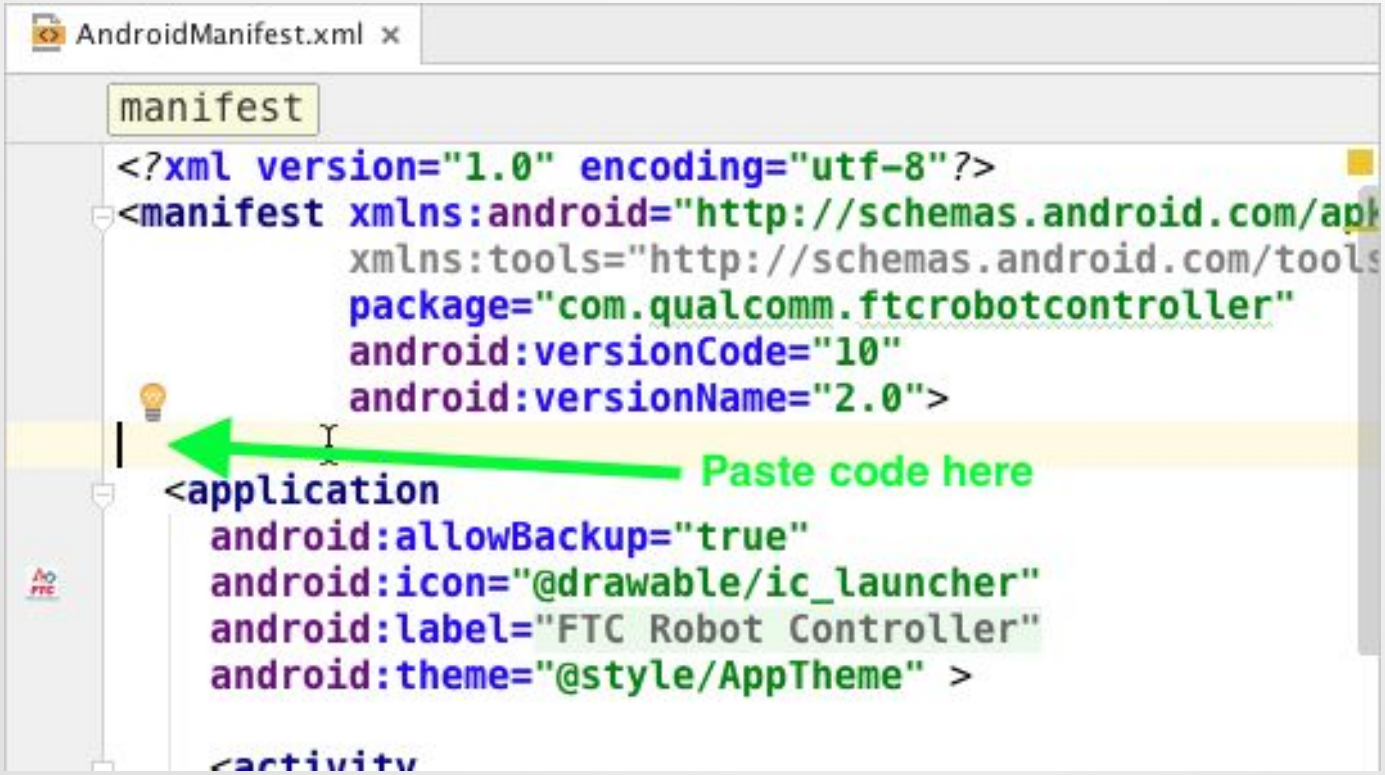
Switch Android Studio to the Project view. From the downloaded OpenCV folder, copy the sdk/native/libs to Android Studio under FtcRobotController/src/main. When asked what to name it, enter jniLibs.



Checkpoint: At this point, the app should build with no errors.

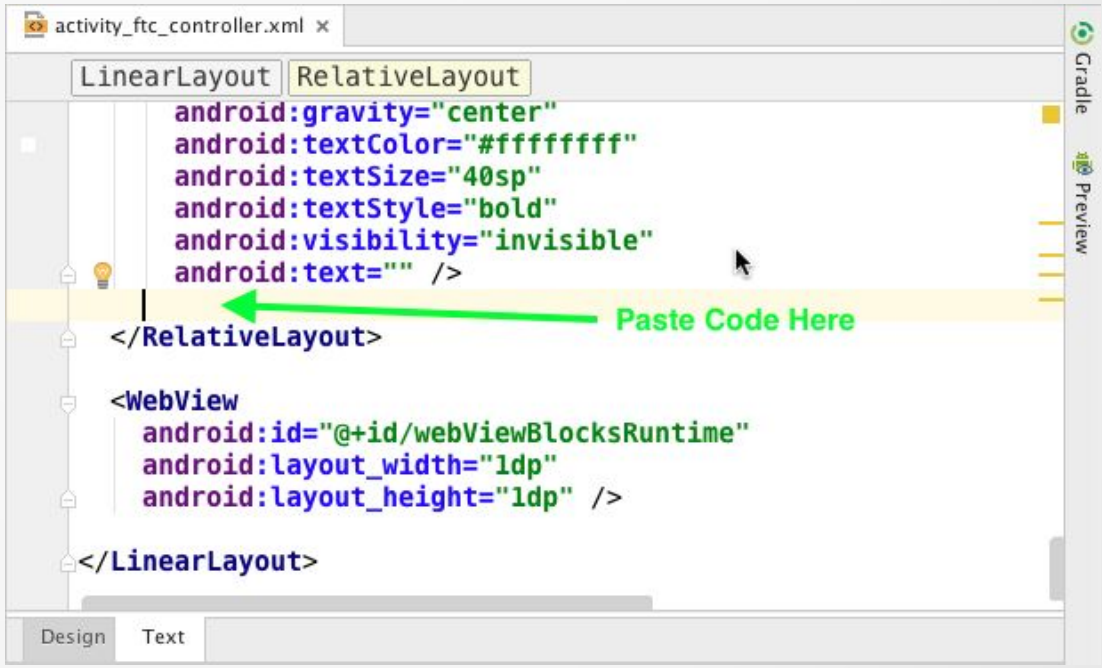
Adding Camera Permission

Switch the left navigation pane back to the Android View.
Open FtcRobotController/manfests/AndroidManifest.xml
Right before the XML tag for "<application …", insert the text from 101/CameraPermission.txt from the tutorial files.



Adding Camera Frame & Button

Open FtcRobotController/res/layout/activity_ftc_controller.xml and click the tab that says “Text” at the bottom-left of the editor. Before the last </RelativeLayout> XML tag, paste the code from 101/CameraLayout.txt from the tutorial folder.



Click on the red text here: **opencv:show_fps="true"** and type alt-enter, which automatically adds this line to the beginning of the file: **xmlns:opencv="http://schemas.android.com/apk/res-auto"**

You are getting close! The next step involves the code that takes a picture and shows it on the screen.

Modify FtcRobotControllerActivity

This step requires modifying the FtcRobotController/java/org.firstinspires.ftc.robotcontroller.internal/FtcRobotControllerActivity.java class. In the tutorial folder 101, look at the modified version of FtcRobotControllerActivity.java for code inside these markers:

//////////// START VISION PROCESSING CODE ////////////

//////////// END VISION PROCESSING CODE ////////////

Copy the code into FtcRobotControllerActivity.java in the same places it appears in the reference. **If you have not modified the file before, you might be able to copy and paste the entire file (but be careful).**

Ignore all the errors for now. They will be fixed in later steps.

Show the Frame on the Screen

Make a new package in FtcRobotController/java called ftc.vision. This is where we will put all our vision code
Make a new Class in that package:

```
public class FrameGrabber implements
CameraBridgeViewBase.CvCameraViewListener2 {
}
```

Click on the error and type Alt-Enter
Select “Implement Methods” and click “OK”
This will create 3 methods automatically to override the ones on the CvCameraViewListener2 interface.

Show the Frame on the Screen

Make a Constructor for the Class:

```
public FrameGrabber(CameraBridgeViewBase c) {
  c.setVisibility(SurfaceView.VISIBLE);
  c.setCvCameraViewListener(this);
}
```

Then change the line in the onCameraFrame method:

```
  return null;
```

to return the frame:

```
  return inputFrame.rgba();
```

Checkpoint: Try running the app.

It should display the camera on the screen!

Troubleshooting

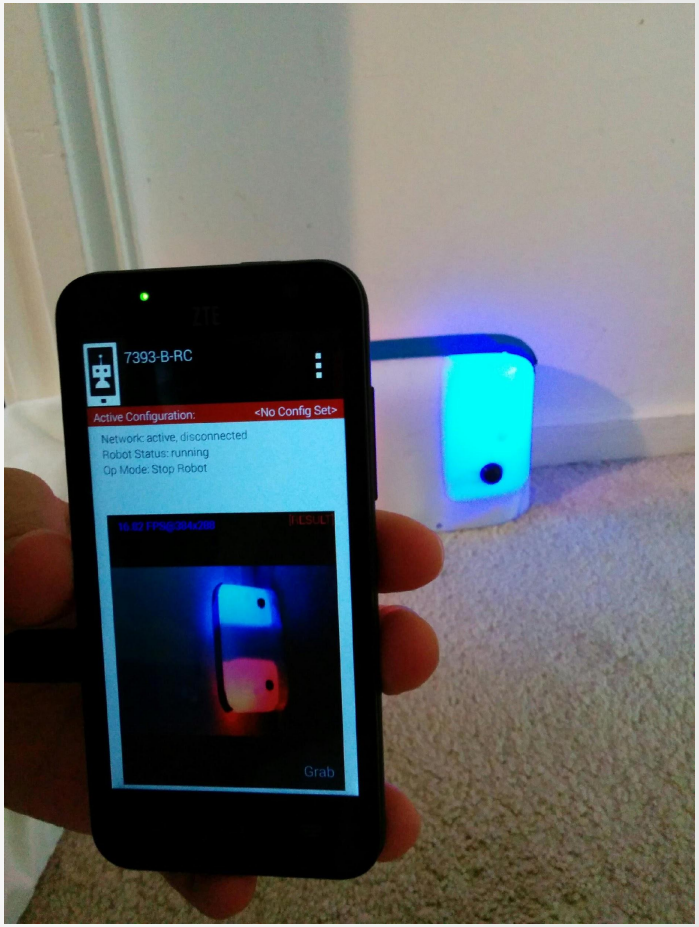
The app fails to build!
Most likely an issue with the build.gradle files. Go back to the "Modify build.gradle Files" step. Otherwise, make sure your changes to FtcRobotControllerActivity.java did not overwrite any updates to the beta app.

The app runs, but the camera is not displayed.
Did you insert the CameraLayout.txt code in th right place in activity_ftc_controller.xml? Go back to the "Adding Camera Frame & Button" step. If that doesn't work, double-check that you got the permissions correct in the "Adding Camera Permission" step.

Results

The image is sideways!
For some reason, OpenCV provides the frames rotated to the left 90 degrees. There are operations you can use to rotate it if you want. We will use them in the 102 class.

The Grab button does nothing!
It will be used in the next tutorial (OpenCV 102)



This Concludes Lesson 101

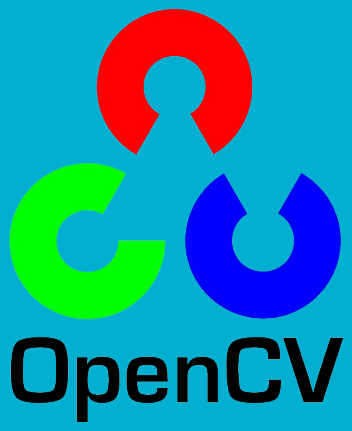
At this point you have OpenCV set up. You have two options from here:

- Write your own code inside the FrameGrabber class.
- Continue the slides to class 102 to detect the beacon.

OpenCV for FTC

102 - Beacon Detection

FTC 7393
Johan Vandegriff
Nikita Wootten
gearbox4h.org



Outline

Classes 101 and **102**

I. 101
   A. Set up Beta FTC App
   B. Add OpenCV
   C. Write Simple Program

II. 102
   A. Improve Framework
   B. Write Beacon Detection Code

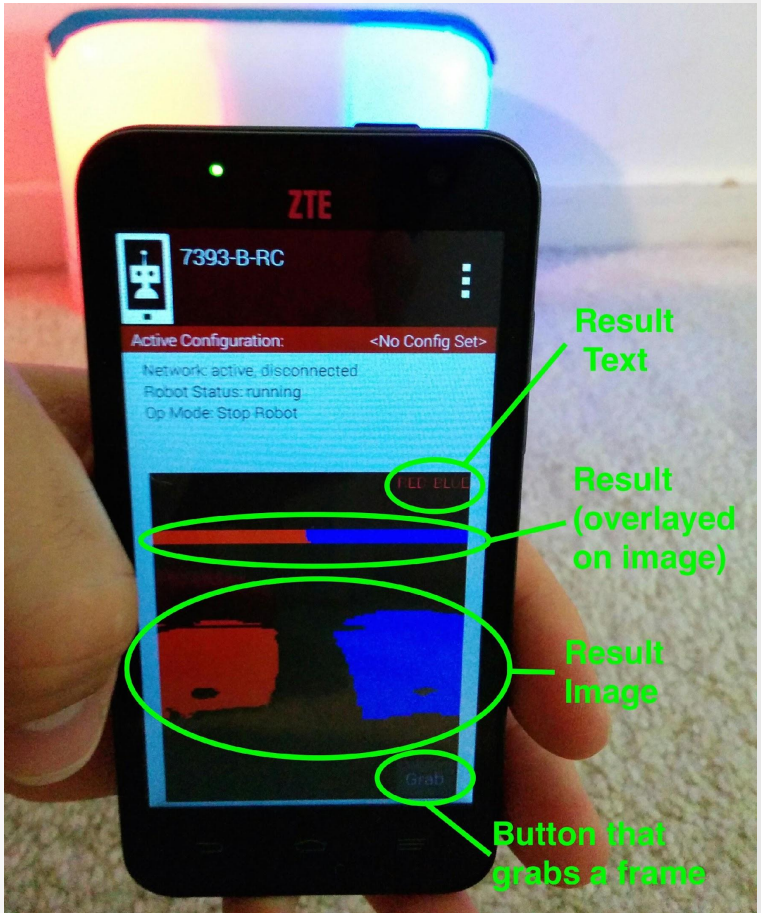
OpenCV for FTC 102 - Beacon Detection

Goal:

- Grab a frame when the Grab button is pressed
- Process the image to identify the beacon colors

Steps:

- Improve FrameGrabber to grab one a frame when it is requested
- Update FtcRobotControllerActivity
- Make a container class for the beacon color on each side
- Make the image processor for the beacon



Improve FrameGrabber

The current FrameGrabber is very simple. All it does when it receives a frame is immediately return it.

Copy the new files from 102/FrameGrabber.java, 102/ImageProcessor.java, 102/ImageProcessorResult.java, and 102/ImageUtil.java into the ftc.vision package select "Overwrite".

This version of FrameGrabber waits for a frame request, processes it, and returns a result. The way it processes frames is through an interface called ImageProcessor:

```
public interface ImageProcessor<ResultType> {
      ImageProcessorResult<ResultType> process(long startTime,
                                               Mat rgbaFrame,
                                               boolean saveImages);
}
```

This interface says that anything that wants to process an image must accept certain arguments and return an ImageProcessorResult as a result.

Update FtcRobotControllerActivity

Open 102/FtcRobotControllerActivity.java
Find all the following tags:

////////////// START VISION PROCESSING CODE //////////////
////////////// END VISION PROCESSING CODE //////////////

And copy the code between them into the android app's FtcRobotControllerActivity.java
This updates the way that the activity uses the FrameGrabber and other Classes. **As before, you can also just copy in the new file in its entirety (this will overwrite any other changes you made in that file).**

Beacon Color Result Container Class

Create a new class in ftc.vision called BeaconColorResult. Add an inner enum called BeaconColor with items RED, GREEN, BLUE, and UNKNOWN.

```
public class BeaconColorResult {


 public enum BeaconColor {
   RED,
   GREEN,
   BLUE,
   UNKNOWN;
 }

}
```

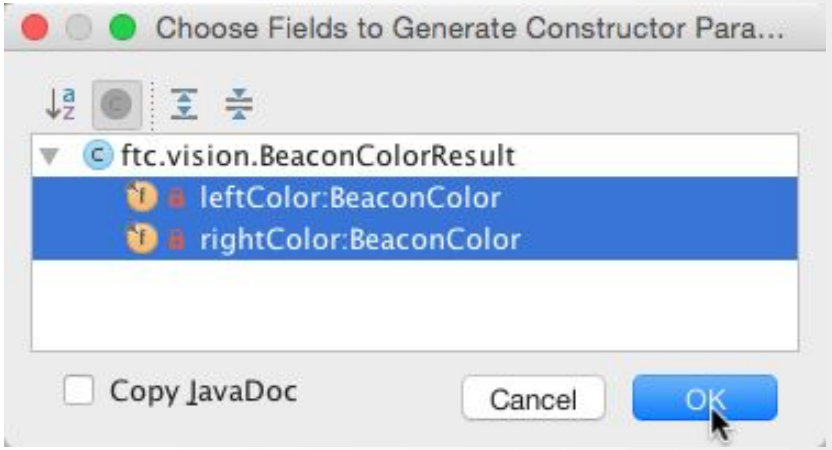
Beacon Result Container Class

Add a parameter to the enum called color:

```
public class BeaconColorResult {

 public enum BeaconColor {
   RED     (ImageUtil.RED),
   GREEN   (ImageUtil.GREEN),
   BLUE    (ImageUtil.BLUE),
   UNKNOWN (ImageUtil.BLACK);

   public final Scalar color;

   BeaconColor(Scalar color) {
     this.color = color;
   }
 }

}
```

Beacon Result Container Class

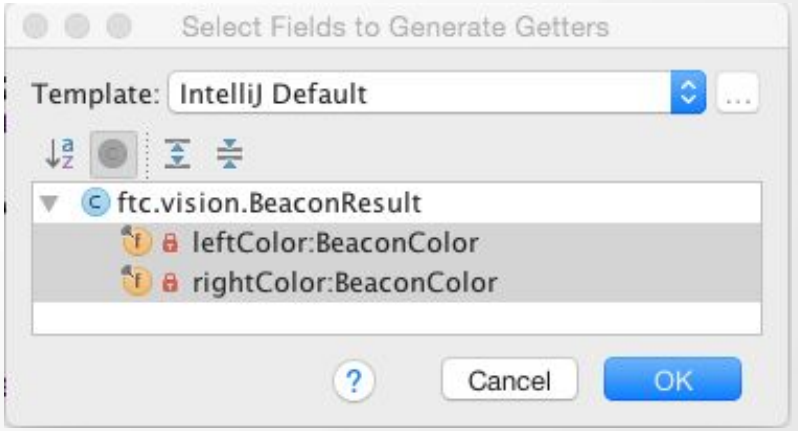
Now add two BeaconColor variables to BeaconColorResult:
private final BeaconColor **leftColor**, **rightColor**;
It will be underlined in red. Click on it and type Alt-Enter. Select "Add constructor parameters", select both variables, and hit Enter.



Now we need to make getters.
Type Ctrl-Enter (Alt-Insert on windows) and select "Getter". Select both variables and hit enter.

The last step is to make a toString() method which is used to display or log the result:

```
@Override
public String toString(){
 return leftColor + ", " + rightColor;
}
```



Beacon Image Processor Overview

1. Save the raw image
2. Convert to HSV
3. Set HSV color thresholds
4. Set up the loop variables
5. The loop
    a. Apply the HSV thresholds
    b. Apply the column sum
    c. Left-right sub-loop
        i. Calculate the mass for one side
        ii. Find the max mass for that side
6. Generate the output image
7. Retrieve the beacon color from the max mass index
8. Draw result rectangles
9. Save output image
10. Return the result

Beacon Image Processor

This is the final class! It is also the hardest since all the processing for the beacon takes place in this class.
Copy 102/BeaconProcessor.java to ftc.vision
The following slides will go over each section of code.

Alternatively, you can type the code yourself by copying 102/BeaconProcessorStart.java to ftc.vision and renaming it to BeaconProcessor.java
You will be writing the code that actually processes the frame in this class at the line:

```
//<Type the processing code here>
```

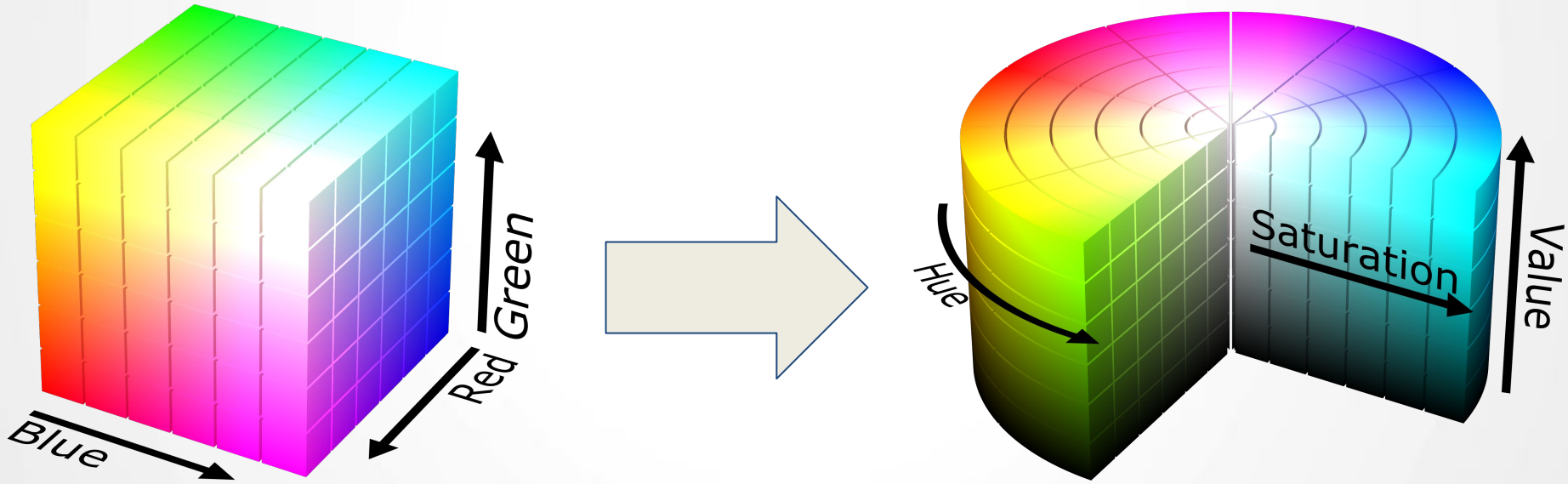
Step 1: Save the Raw Image

```
//save the image in the Pictures directory
if (saveImages) {
  ImageUtil.saveImage(TAG, rgbaFrame,
Imgproc.COLOR_RGBA2BGR, "0_camera", startTime);
}
```

This calls the saveImage method from the ImageUtil Class that you copied in earlier. It will save the image in the /root/sdcard/Pictures directory on the phone. If you want to view or delete these images, you should install a file manager app on the robot phone. Alternatively, you can use your computer to view the files on your phone (for Macs, you could use Android File Transfer).

Step 2: Convert to HSV (Hue, Saturation, Value)

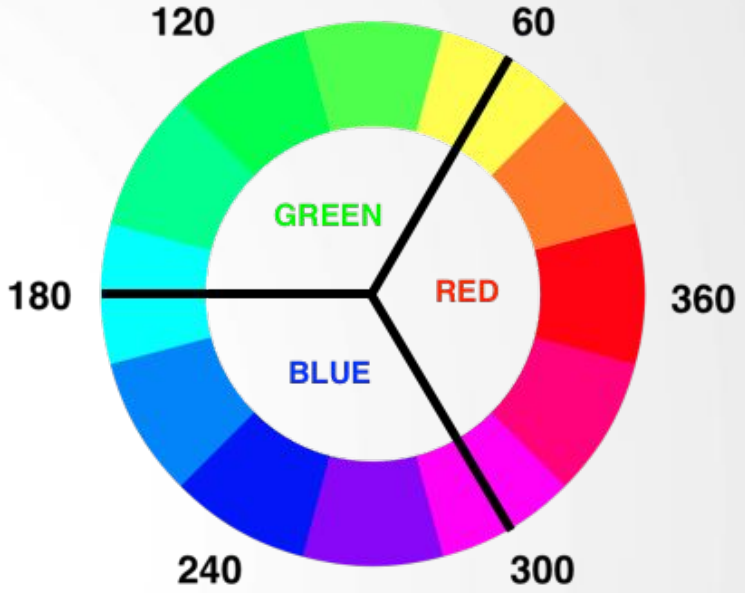
```
//convert image to hsv
Mat hsv = new Mat();
Imgproc.cvtColor(rgbaFrame, hsv, Imgproc.COLOR_RGB2HSV);
// rgbaFrame is untouched
```

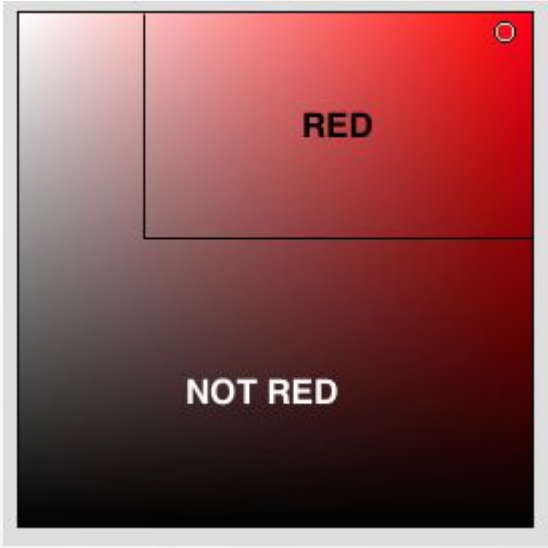


This code converts from the RGB cube-based colorspace to the HSV cylinder-based colorspace. HSV is better for our application because the hue is separated from the other parameters.

Step 3: Set HSV thresholds

```
//the h range is 0 to 179
//the s range is 0 to 255
//the v range is 0 to 255

//the values are stored as a list of min HSV
//and a list of max HSV
List<Scalar> hsvMin = new ArrayList<>();
List<Scalar> hsvMax = new ArrayList<>();

//hsvMin.add(new Scalar(  H,   S,   V  ));
hsvMin.add(new Scalar(300/2,  50, 150)); //red min
hsvMax.add(new Scalar( 60/2, 255, 255)); //red max

hsvMin.add(new Scalar( 60/2,  50, 150)); //green min
hsvMax.add(new Scalar(180/2, 255, 255)); //green max

hsvMin.add(new Scalar(180/2,  50, 150)); //blue min
hsvMax.add(new Scalar(300/2, 255, 255)); //blue max
```





Step 4: Set up Loop Variables

```
// make a list of channels that are blank (used for combining binary images)
List<Mat> rgbaChannels = new ArrayList<>();

double [] maxMass = { Double.MIN_VALUE, Double.MIN_VALUE }; //max mass for left and right
int[] maxMassIndex = { 3, 3}; // index of the max mass

// We are about to loop over the filters and compute the "color mass" for each color on each side of the image.

// These variables are used inside the loop:
Mat maskedImage;
Mat colSum = new Mat();
double mass;
int[] data = new int[3]; //used to read the colSum
```

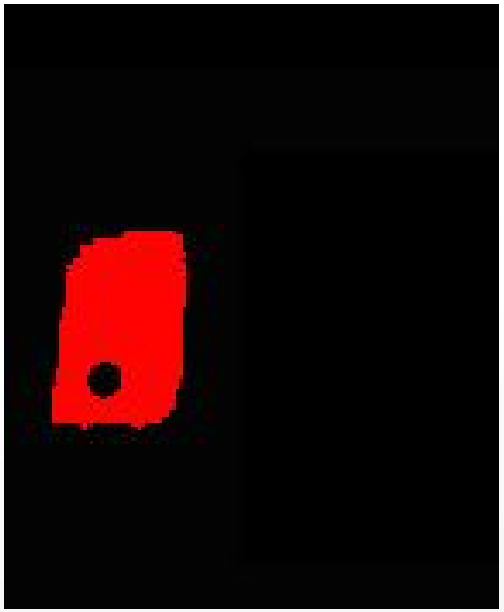
Step 5: The RGB Loop

```
//loop through the rgb channels
for(int i=0; i<3; i++) {
  //<insert loop code here from Steps 5a to 5c>
}
```

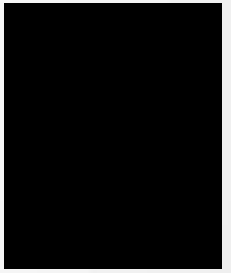
This is the main part of the BeaconProcessor. It loops through red, green, and blue to find those colors in the input image.

Step 5a: Mask the image with HSV Thresholds

```
//apply HSV thresholds
ImageUtil.hsvInRange(hsv, hsvMin.get(i), hsvMax.get(i), maskedImage);

//copy the binary image to a channel of rgbaChannels
rgbaChannels.add(maskedImage.clone());
```



R

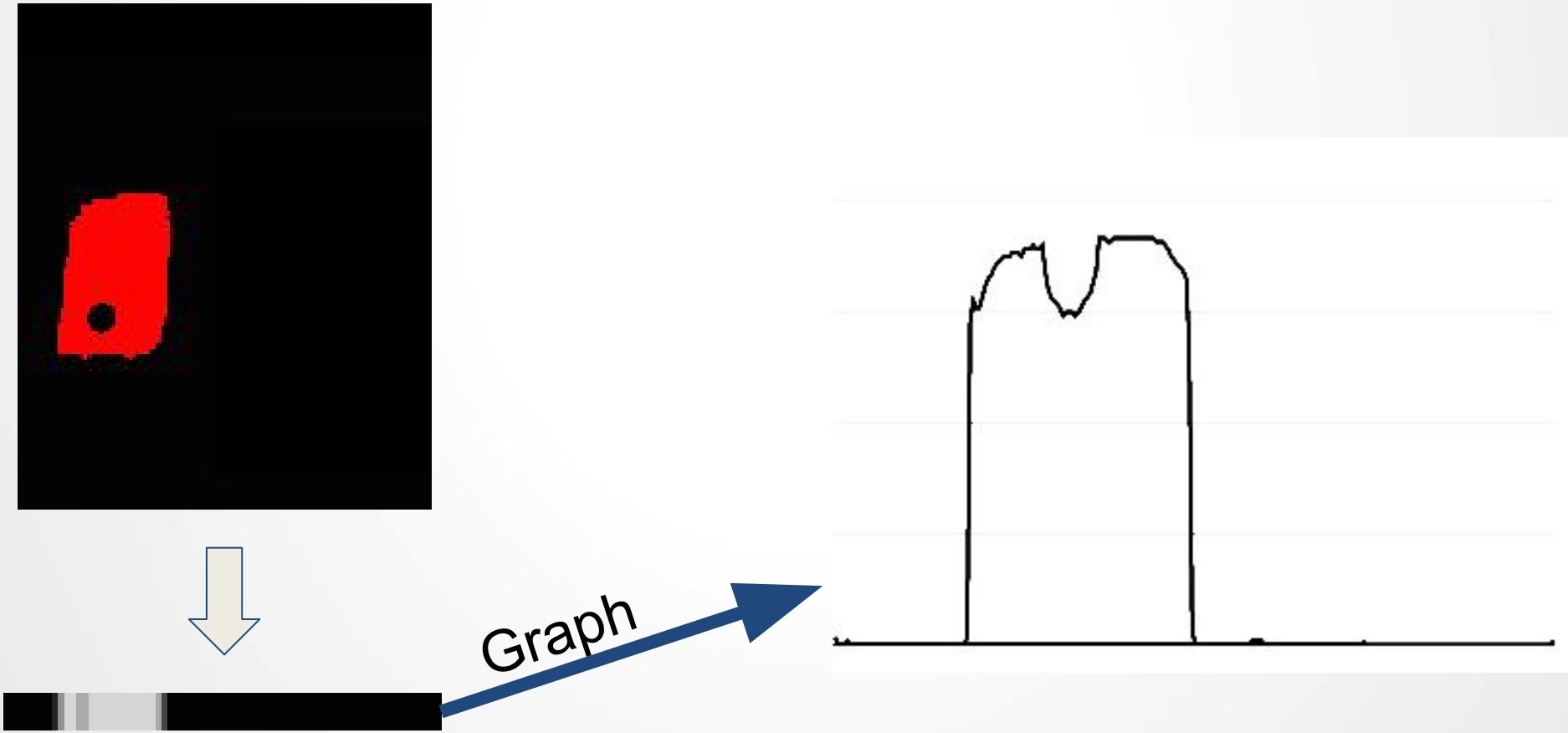


G

B

Step 5b: Column Sum

```
//apply a column sum to the (unscaled) binary image
Core.reduce(maskedImage, colSum, 0, Core.REDUCE_SUM, 4);
```



Step 5c: The left-right Sub-loop

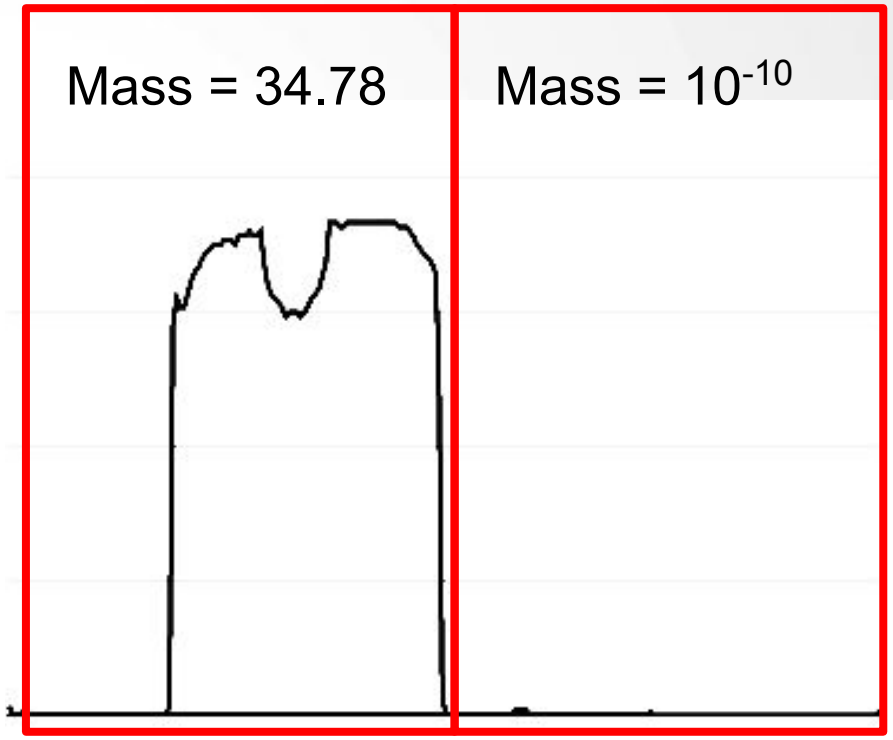
```
//loop through left and right to calculate mass
int start = 0;
int end = hsv.width()/2;
for(int j=0; j<2; j++){
 //<insert sub-loop code here from Steps 5c(i) to 5c(ii)>
 start = end;
 end = hsv.width();
}
```

On iteration 1:
start = 0
end = width/2
So it will loop through the left half of the column sum

On iteration 2:
start = width/2
end = width
So it will loop through the right half of the column sum

Step 5c(i): Calculate the mass

```
//calculate the mass
mass = 0;
for(int x=start; x<end; x++){
 colSum.get(0, x, data);
 mass += data[0];
}

//scale the mass by the image size
mass /= hsv.size().area();
```



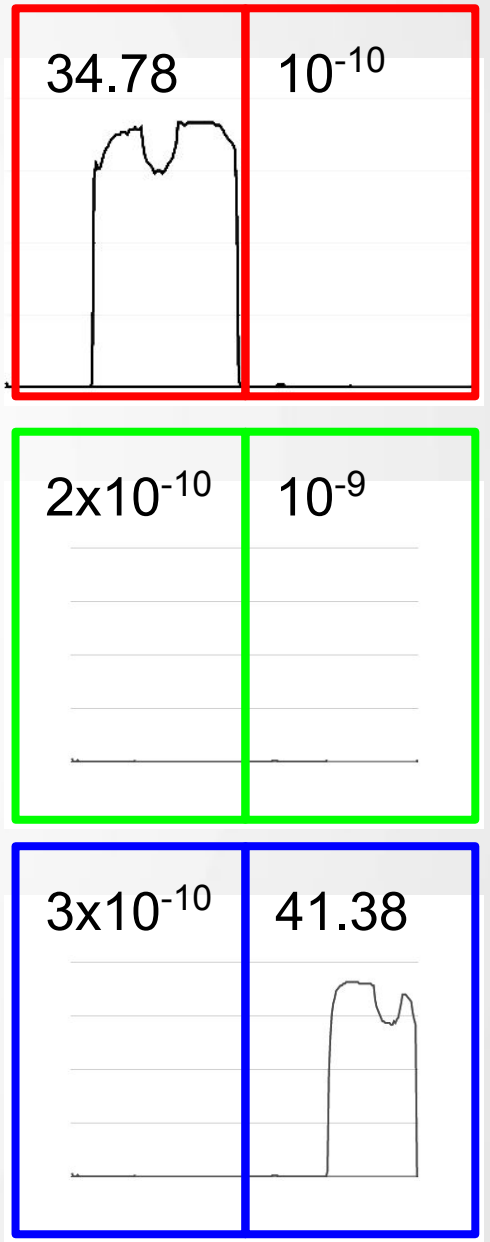
Step 5c(ii): Find Max Mass

This code compares the masses as they are found:

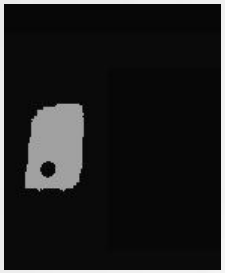
```
//if the mass found is greater than the max for this side
if(mass >= MIN_MASS && mass > max[j]){
 //this mass is the new max for this side
 max[j] = mass;
 //and this index is the new maxIndex for this side
 maxIndex[j] = i;
}
```

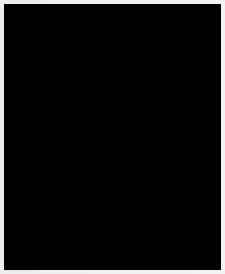
Make a constant field in BeaconProcessor:

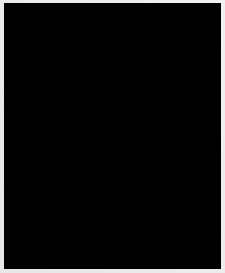
```
private static final double MIN_MASS = 6;
```



Step 6: Generate the output image







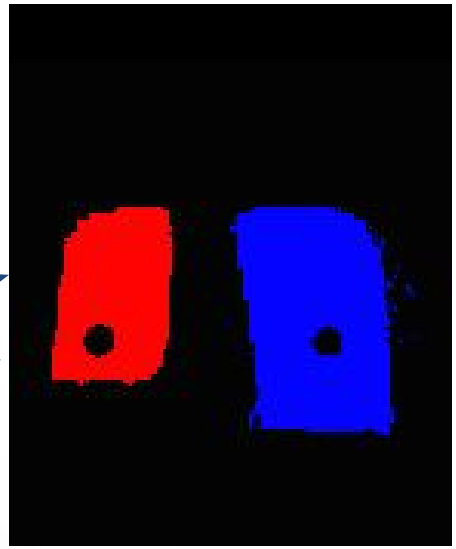
R

G

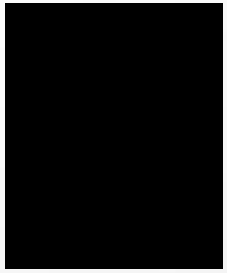
B

A

```
//add empty alpha channel
rgbaChannels.add(Mat.zeros(hsv.size(), CvType.CV_8UC1));
//merge the 3 binary images and 1 alpha channel into one image
Core.merge(rgbaChannels, rgbaFrame);
```



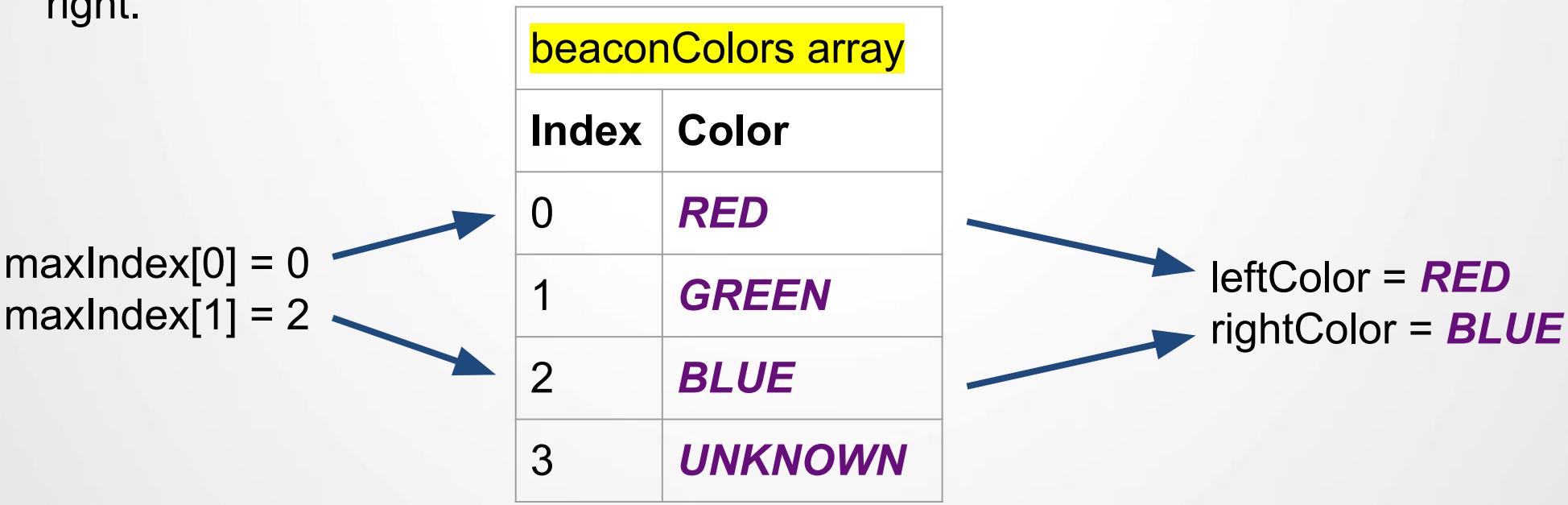
Create



Step 7: Retrieve the BeaconColor

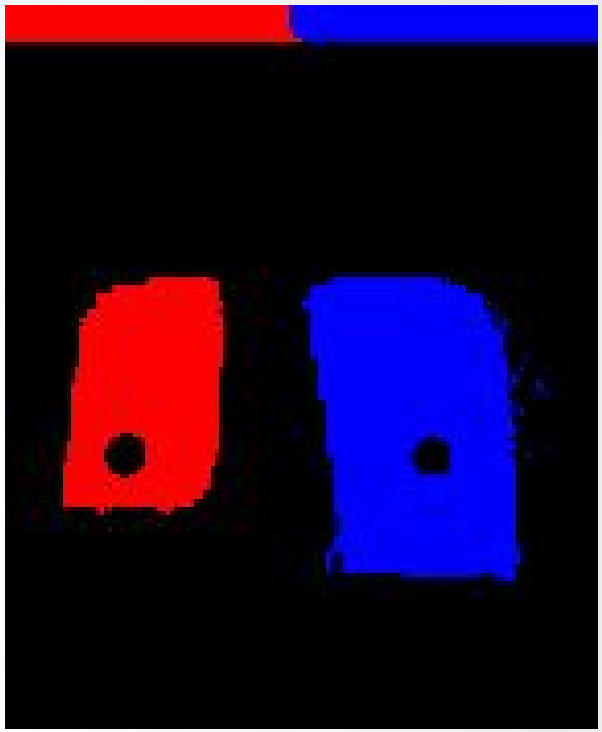
```
//use the maxIndex array to get the left and right colors
BeaconColorResult.BeaconColor[] beaconColors =
BeaconColorResult.BeaconColor.values();
BeaconColorResult.BeaconColor left = beaconColors[maxIndex[0]];
BeaconColorResult.BeaconColor right = beaconColors[maxIndex[1]];
```

This code retrieves all the possible values from the BeaconColor enum into an array. Then it selects the items from that array using the maxIndex for left and right.



Step 8: Draw Result Rectangles

```
//draw the color result bars
int barHeight = hsv.height()/30;

Imgproc.rectangle(rgbaFrame,
      new Point(0, 0),
      new Point(hsv.width()/2, barHeight),
      left.color, barHeight);

Imgproc.rectangle(rgbaFrame,
      new Point(hsv.width()/2, 0),
      new Point(hsv.width(), barHeight),
      right.color, barHeight);
```



Step 9: Save Output Image

```
if (saveImages) {
 ImageUtil.saveImage(TAG, rgbaFrame,
Imgproc.COLOR_RGBA2BGR, "1_binary", startTime);
}
```

Saving the output image for later analysis is really useful if something goes wrong!

Step 10: Return the Result

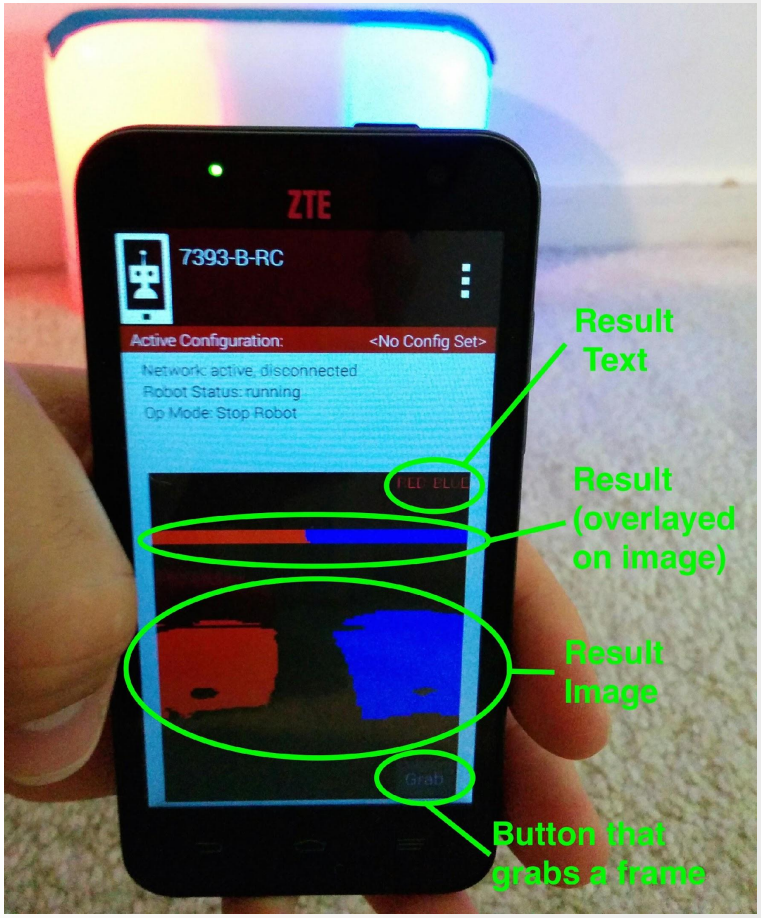
```
//construct and return the result
return new ImageProcessorResult<>(startTime, rgbaFrame,
        new BeaconColorResult(left, right)
);
```

This is the last step! From here your OpMode can easily make a decision on where to go!

Results

These are some other things you can try on your own:

1. Tune HSV thresholds
2. Find beacon position in image
3. Continuous frame grabbing mode
4. Distinguish between UNKNOWN and OFF



OpMode Code - paste into your LinearOpMode
(this only works after the other steps in the tutorial are done)

```
FrameGrabber frameGrabber = FtcRobotControllerActivity.frameGrabber; //Get the
frameGrabber

frameGrabber.grabSingleFrame(); //Tell it to grab a frame
while (!frameGrabber.isResultReady()) { //Wait for the result
 Thread.sleep(5); //sleep for 5 milliseconds
}

//Get the result
ImageProcessorResult imageProcessorResult = frameGrabber.getResult();
BeaconColorResult result = (BeaconColorResult) imageProcessorResult.getResult();

BeaconColorResult.BeaconColor leftColor = result.getLeftColor();
BeaconColorResult.BeaconColor rightColor = result.getRightColor();

telemetry.addData("Result", result); //Display it on telemetry
telemetry.update();
//wait before quitting (quitting clears telemetry)
Thread.sleep(1000);
```

And Furthermore, I would Like to Conclude …

Another team that did this:
https://github.com/lasarobotics/FTCVision

Visit us at gearbox4h.org

- This tutorial is posted there
- We also have a github repository
- There is a super cool video (that I may or may not have edited)

Download this tutorial! (for reference ‘n stuff) at
gearbox4h.org/opencv