# MIT EECS 6.815/6.865: Assignment 1:
# Basic Image Processing

Due Wednesday September 23 at 9pm

## 1 Summary

- Image Class
- Brightness and Contrast
- More Image Class Methods
- Colorspaces
- Spanish Castle Illusion
- White Balance

## 2 The Image Class

The Image class specification is given in `Image.h`. Images are three dimensional arrays (width $\times$ height $\times$ color channel) that store pixels as a vector of floats called `image_data`. In memory, the pixels in the image are stored sequentially in row-major order in three adjacent color planes. That is, the distance or *stride* between adjacent values in the same row in `image_data` is equal to 1. The stride between adjacent values in the same column is equal to the width of the image and the stride between the different color channels at the same pixel is width$\times$height. You can use the method `int stride(int dimension)` to compute these values.

`image_data` is a C++ vector, which is essentially an array which manages its own memory. You can access elements of it using brackets. For instance, `image_data[0]` returns the front element in the vector. More information about vectors can be found at http://www.cplusplus.com/reference/vector/vector/.

For images that correspond to pictures, the floating points in `image_data` will be between 0 and 1. There is nothing guaranteeing that the values of `image_data` stay in this range and there may be times when you want to use the Image class to store intermediate data that doesn't correspond to pictures, in which case the range is not meaningful. When the image is written to a file, it will assume the data lies in this range and will clip values outside of the range to one of the endpoints.

You can use the Image `write` method to write images to `.png` files. For example:

```
my_im.write("./my_image.png");
```

Then, you can view them in your favorite image viewer. This may be useful for debugging. Alternatively, if you don't feel like providing a filename, you can use `my_im.debug_write()` to write an image to an automatically named file. This might make debugging easier

## 2.1 Pixel Accessors and Setters

You are going to implement the accessor and setter operators for pixel values in the image. We adopt the convention that the elements are accessed via the () operator. This is contrary to C++ convention, but will allow us to match the syntax of Halide (`http://halide-lang.org/`), which we will use at the end of the semester to write fast image processing code. That is, the pixel at location $(x, y)$ in the third color channel of `my_im` is accessed via

```
my_im(x,y,2);
```

The third color channel is accessed via the number 2, not 3. That is because we want to use 0-indexing, in which the first element in a given index is specified by 0.

Implement three accessors with 0-indexing and bounds checking to make sure the input is valid. If the input is not valid, throw an exception using the command `throw OutOfBoundsException();`.

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In `Image.cpp` implement:

1.a `number_of_elements()` : returns the number of elements in the image. An RGB (3 color channels) image of $100 \times 100$ pixels has 30000 elements.

1.b `my_im(x)` : returns the value of `image_data` at location $x$ as long as $x$ is less than (<) the total number of pixels and at least (>=) 0. You need to implement the functions
`const float & operator()(int x) const`
`float & operator()(int x)`
with identical code. Use `number_of_elements()` for bounds checking.

1.c `my_im(x,y,z)` : returns the value at location $(x, y)$ in the $z$-th color channel. You need to implement the functions
`const float & operator()(int x, int y, int z) const`
`float & operator()(int x, int y, int z)`
with identical code. Use `width()`, `height()` and `channels()` for bounds checking.

1.d `my_im(x,y)` : returns the value at location $(x, y)$ in the 0-th color channel. You need to implement the functions
`const float & operator()(int x, int y) const`
`float & operator()(int x, int y)` with identical code.

## 3 Brightness and Contrast

Now for the fun part. Once we have these accessors, we can perform simple operations like increasing the brightness or contrast of an image.

2.a Implement the function `brightness` in `a1.cpp`, which multiplies the pixels in an image by the value `factor`. Make sure to create a new image and return that rather than modifying the input image. This is good practice in case you want to use the input again.

2.b Implement the function `contrast`, which increases the contrast of an image around a specified `midpoint` by the value `factor`. That is, you should apply the following function to every pixel's value

$$I_{out} = \texttt{factor} \times (I_{in} - \texttt{midpoint}) + \texttt{midpoint}.$$

**Extra:** Try handling the values going out of the range 0 and 1 in a sensible way.

You can test your functions on the included `Input/Boston_low_contrast.png`. This input image has very low contrast. You can use your `contrast` function to increase it.

## 4 More Image Class Methods

We have added operators for the `Image` class that allow you to add, subtract, multiply and divide images element-wise in the same way as built-in types like `float`. That is, you can now do things like

```
Image im1(640,480,3), im2(640,480,3);
float a = 2.0, b = -1.0, c = 0.0;
Image out1 = im1 + im2;
Image out2 = im1 - b;
Image out3 = a * im2;
Image out3 = im1/c; // This will throw a DivideByZeroException();
```

You can inspect the code in `Image.cpp`. When an operator is used with two images, they must be of the same size or a `MismatchedDimensionsException()` will be thrown.

We also added an `InvalidArgument` exception that you can throw using `throw InvalidArgument();` if you want to handle arguments that you think are not valid. Since this isn't a software engineering class, we won't test you on whether you handled invalid input correctly. If you do chose to use this exception, make sure the input is actually invalid.

## 5 Colorspaces

In this section, you will implement several functions related to changing an image from RGB colorspace to other colorspaces.

3 Implement the function `color2gray` in `a1.cpp`, which performs a weighted average across color channels of an input image `im` and outputs a grayscale image. The weights are in the length 3 vector `weights`. The returned image should be a two dimensional image with one color channel (instead of three color channels).

### 5.1 Luminance-Chrominance

When we convert a color image to grayscale using the `color2gray` function, we get the *luminance* of the image, but lose the color information or *chrominance* $(kr, kg, kb)$. You can compute this chrominance by dividing the input image by the luminance. Once the luminance and color information have been separated, you can modify them separately to produce interesting effects.

4.a Implement the function `lumiChromi` in `a1.cpp`. This function should return a vector of two images, a luminance image and a chrominance image. The luminance image should be the first element in the vector and it can be computed using `color2gray` with the default weights.

4.b Implement the function `brightnessContrastLumi` in `a1.cpp`, in which brightness and contrast of only the luminance of the image should be modified. Decompose the image into luminance and chrominance and then modify the luminance. Recombine the modified luminance with the chrominance by multiplying to produce the output image.

### 5.2 YUV

Another representation of an image that separates overall brightness and color is the YUV colorspace. An RGB image can be converted to and from a YUV image using the matrix multiplications

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix},$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.14 \\ 1 & -0.395 & -0.581 \\ 1 & 2.032 & 0 \end{bmatrix} \begin{bmatrix} Y \\ U \\ V \end{bmatrix}.$$

5.a Implement the functions `rgb2yuv` and `yuv2rgb`, which convert images from one colorspace to the other.

5.b Implement the function `saturate(const Image & im, float factor)`, which multiplies the U and V channels of an image by a multiplicative `factor`. The input and returned image should be in RGB colorspace.

In YUV space, the elements of the image won't necessarily be in the range 0 to 1. If you try to write the image, the image write function will assume the input is an RGB image and it will round values outside of the range to the endpoints. Keep this in mind when testing and debugging your functions. Up to rounding errors, the functions `rgb2yuv` and `yuv2rgb` will be inverses of each other.

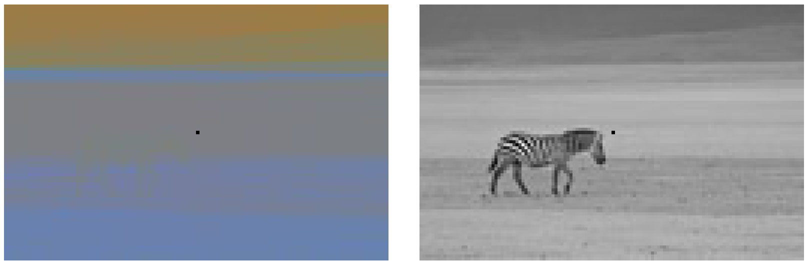
### 5.3 Discussion

The chrominance-luminance and the YUV conversions perform similar operations: they decouple an image's intensity from its color. There are, however, important differences. YUV is obtained by a purely linear transformation, whereas our chrominance-luminance decomposition requires a division. Furthermore, the latter is overcomplete (we now need 4 numbers), while YUV only requires 3. YUV does a better job of organizing color along opponents and the notion of a negative is more perceptually meaningful. On the other hand, the separation between intensity and color is not as good as with the ratio computation used for luminance-chrominance. As a result, modifying Y without updating U and V changes not only the luminance but also the apparent saturation of the color. In contrast, because the luminance-chrominance decomposition relies on ratios, it preserves colors better when luminance is modified. This is because the human visual system tends be sensitive to ratios of color channels, and it discounts constant multiplicative factors. The color elicited by $r$, $g$, $b$, is the same as the color impression due to $kr$, $kg$, $kb$, only the brightness/luminance is changed. This makes sense because we want objects to appear to have the same color regardless of the amount of light that falls upon them.

## 6 Spanish Castle Illusion

You can use the colorspace functions you implemented to implement the Spanish castle illusion, which you can read more about at http://www.johnsadowski.com/big_spanish_castle.php.

Given an input image, you should create two images. The first image has a constant luminance (Y) and its chrominance are the opposite of the input's chrominance (-U and -V). The second image is a black-and-white version of the original, i.e. both U and V should be uniformly zero. In the first image, set the luminance to be 0.5. To help people focus on the same location, add a black dot in the middle of both images. If image has dimensions $w \times h$, make sure that the black dot is at the 0-indexed location $\texttt{floor}(w/2), \texttt{floor}(h/2)$.



6 Implement the function `spanish`, which takes an input image and returns a pair of images that can be used within the Spanish castle illusion. Make sure the gray scale image is the second element in the returned `vector`.

You can try out your function on the included `castle_small.png` and `zebra.png` or your own images.

## 7 White Balance

You will implement a function to white balance an image using the gray world assumption, in which the mean color of a scene is assumed to be gray. Specifically, you want to white balance an input image by multiplying each channel of the image by a factor, so that the mean value of each of the three channels of the output image is the same.

7 Implement the function `grayworld` in `a1.cpp`, which automatically white balances the input image by using the gray world assumption. Make the average gray value of the output image equal to the average value of the green channel of the input image.

You can try out your function on the include `flower.png` image.

### 6.865 Only

8 For what kind of images do you think white balancing with the gray world assumption will not produce a good result? (Answer in the submission form).

## 8 Submission

Turn in your files to the online submission system (link is on Stellar) and make sure all your files are in the `asst` directory under the root of the zip file. If your code compiles on the submission system, it is organized correctly. The submission system will run code in your main function, but we will not use this code for grading.

In the submission system, there will be a form in which you should answer the following questions:

- How long did the assignment take? (in minutes)
- Potential issues with your solution and explanation of partial completion (for partial credit)
- Any extra credit you may have implemented
- Collaboration acknowledgment (you must write your own code)
- What was most unclear/difficult?
- What was most exciting?