Image Manipulation: Filters and Convolutions
Per-Pixel Manipulation

- Individual pixels do not influence neighboring pixels
- Possible modifications include shifts in:
  - Color
  - Brightness
  - Opacity
Grayscale

- RGB channels of pixel have the same value
- Content of image expressed through color value rather than hue or saturation
- How might we find a single value that captures the information of three color channels?
High Contrast

- Increase or decrease value of RGB channels based on pixel brightness
- Changes in value across image further emphasized
- How might we make some pixels darker and some pixels brighter?
HSV/HSB

- Hue-Saturation-Value commonly used in digital color pickers
- Hue: pure color
- Saturation: amount of color
- Value (Brightness): darkness or lightness of color
Setting Color Mode

- `colorMode(model, range1, range2, range3)`
- **Examples:**
  - `colorMode(RGB, 255, 255, 255);`
  - `colorMode(HSB, 360, 100, 100);`
  - `colorMode(RGB, 1.0, 1.0, 1.0);`
  - `colorMode(HSB, 100);`
RGB Methods

- Extract red, green, and blue channels from a pixel:
  - red(color c)
  - green(color c)
  - blue(color c)
HSB Methods

- Extract hue, saturation and brightness from a pixel:
  - hue(color c)
  - saturation(color c)
  - brightness(color c)
Consider...

colorMode(RGB, 255, 255, 255);
fill(50, 100, 100);
rect(0, 0, 50, 50);  //Rect1

colorMode(HSB, 360, 100, 100);
fill(50, 100, 100);
rect(50, 50, 50, 50);  //Rect2
Image Kernels

❖ Also called convolution matrix or mask
❖ Matrix used to convolve kernel values with image values
  ❖ Square and small (3x3, 5x5 etc)
  ❖ The larger the matrix, the more local information is lost
❖ Allows for “area” effects such as blur, sharpening and edge-detection
Matrix convolution

1. Multiplication of corresponding cells
2. Summation of these values

\[
\begin{array}{ccc}
39 & 33 & 35 & 36 & 31 \\
35 & 34 & 36 & 33 & 34 \\
34 & 33 & 36 & 34 & 32 \\
32 & 36 & 35 & 36 & 35 \\
33 & 31 & 34 & 31 & 32
\end{array}
\texttimes
\begin{array}{ccc}
\phantom{1} & 2 & 1 \\
\phantom{2} & 4 & 2 \\
\phantom{1} & 2 & 1
\end{array} = \begin{pmatrix}
1 \cdot 34 & 2 \cdot 36 & 1 \cdot 33 \\
2 \cdot 33 & 4 \cdot 36 & 2 \cdot 34 \\
1 \cdot 36 & 2 \cdot 35 & 1 \cdot 36
\end{pmatrix} = \{139 + 278 + 142\} = 559
Kernel Application

- Each pixel has the convolution matrix applied to it
- Value is stored at corresponding location
Quiz Question!

What do image kernels allow for?

A. Matrix multiplication

B. Color change effects like gray-scale and high-contrast

C. Area effects like blur, sharpen and edge-detection
Quiz Answer

- C: Area effects like blur, sharpen and edge-detection
Hands-on: Understanding Convolutions

Today’s activities:

1. Complete your `tint` method if it’s not finished
2. Experiment with `colorMode`, switching between RGB and HSB
3. Use RGB and HSB methods
4. Construct this kernel in Processing:

```
0   -1   0
-1   5   -1
0   -1   0
```
Applying Convolutions

Original Image

Sharpened Image
Kernel Traversal

- How can we traverse both the image pixels and the cells of the kernel?
Accessing pixel neighborhoods

- Consider the call:

  ```java
  int index = (x + i - 1) + img.width*(y + j - 1);
  ```

- Provides an offset to the target pixel

- Based on i and j values, offset reaches certain number of neighboring pixels in the x and y directions
Sharpen Example Code

```c
float[][[] matrix = {{0, -1, 0}, {-1, 5, -1}, {0, -1, 0}};

/* Access individual pixel location (x, y) and initialize rgb floats to store new color channel values */
for (int i = 0; i < 3; i++) {
    for (int j = 0; j < 3; j++) {
        int index = (x + i - 1) + img.width*(y + j - 1);
        red += red(img.pixels[index]) * matrix[i][j];
        ... //Perform convolution on green and blue color channels
    }
}

red = constrain(abs(red), 0, 255);
... //Clamp green and blue values
```
Revisiting the Convolution Matrix

- Each pixel has the convolution matrix applied to it
- Value is stored at corresponding location

What happens if we store values in existing image?
Intermediate Buffer

- Array of pixels that matches the size of the image
- Provides “safe” location for storing image data
- Allows program to preserve original image data if necessary
- Buffering is also a common trick to increase speed of rendering (aka double buffering)
Creating a Buffer

- Can create a duplicate image:
  ```java
  loadImage(image_file);
  ```
- Can create a blank image:
  ```java
  createImage(width, height, ARGB);
  ```
- Can copy pixel values from one buffer to another
  ```java
  copy(img, x, y, width, height, x, y, width, height);
  ```
Copying an Image

❖ Shallow copy:

```java
PImage img1;
PImage img2 = img1;
```

❖ Deep copy*:

```java
img2.copy(img1, 0, 0, img1.width, img1.height, 0, 0, img2.width, img2.height);
```

* Note that `img2` must be initialized (either loaded from image or created as a blank image) before a deep copy will work!
Box Blur

- Pixel value is based on average of its neighborhood:

\[
\frac{1}{9} \times \begin{bmatrix}
1 & 1 & 1 \\
1 & 1 & 1 \\
1 & 1 & 1
\end{bmatrix}
\]
or

\[
\begin{bmatrix}
0.11 & 0.11 & 0.11 \\
0.11 & 0.11 & 0.11 \\
0.11 & 0.11 & 0.11
\end{bmatrix}
\]
Gaussian Blur

- Use of Gaussian function for convolution:
  \[ G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \]

- Low-pass filter that reduces high frequency features including noise

- Weighted average better preserves features

1D Gaussian distribution
Edge Detection

- Determines sharp discontinuities in value (i.e. edges)
- Provides information about scene:
  - Depth
  - Illumination
  - Material
- Important filter for computer vision/feature extraction
Sobel Operator

- Two 3x3 kernels that approximate horizontal and vertical derivatives (i.e. changes in light intensity)

\[
G_x = \begin{bmatrix}
-1 & 0 & +1 \\
-2 & 0 & +2 \\
-1 & 0 & +1 \\
\end{bmatrix} \ast A \quad \text{and} \quad G_y = \begin{bmatrix}
-1 & -2 & -1 \\
+1 & +2 & +1 \\
0 & 0 & 0 \\
\end{bmatrix} \ast A
\]

- Horizontal and vertical convolutions performed independently

- Gradient magnitude calculated from results
Edge Cases

- What happens when we try to convolve the edge pixels of our image?
- How can we handle this “missing” data?
  - Leave edges untouched
  - Fill in missing pixels with 0 or 255
  - Wrap missing pixels
  - Mirror missing pixels
- How do these choices affect the image appearance?
Hands-on: Using Convolutions

Today’s activities:

1. Create a 3x3 2D array in Processing to hold the “sharpen” image kernel
2. Create an image buffer to store the convolved image data
3. Apply the sharpen kernel to your image and store the convolutions into your secondary image buffer (which displays to the screen)