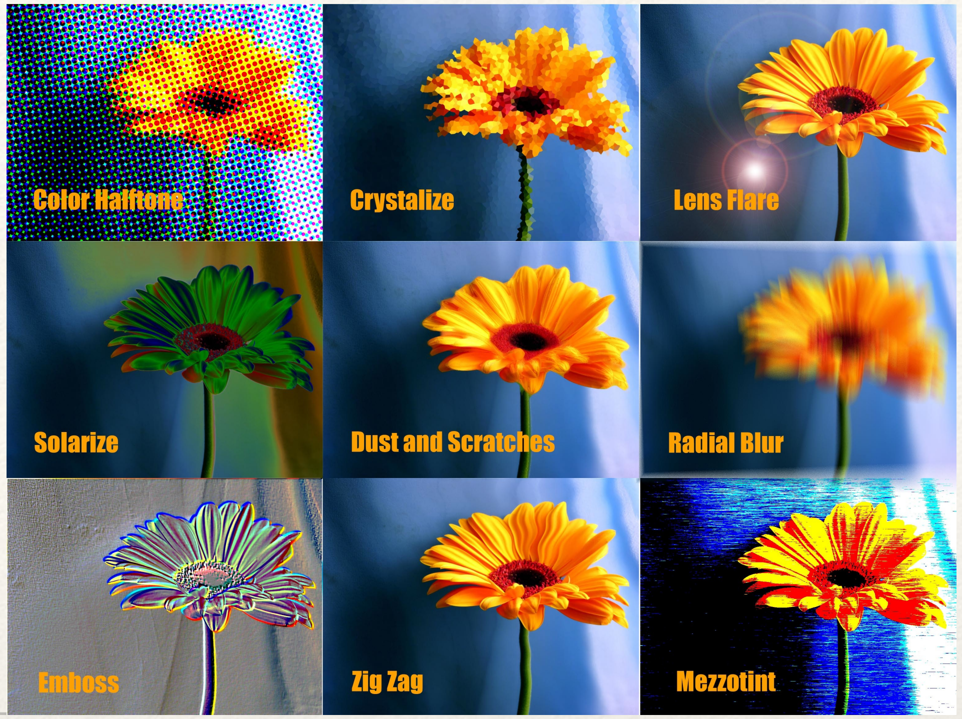

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Image Manipulation: Filters and Convolutions

Elements of Graphics
CS324e

Per-Pixel Manipulation

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

Grayscale

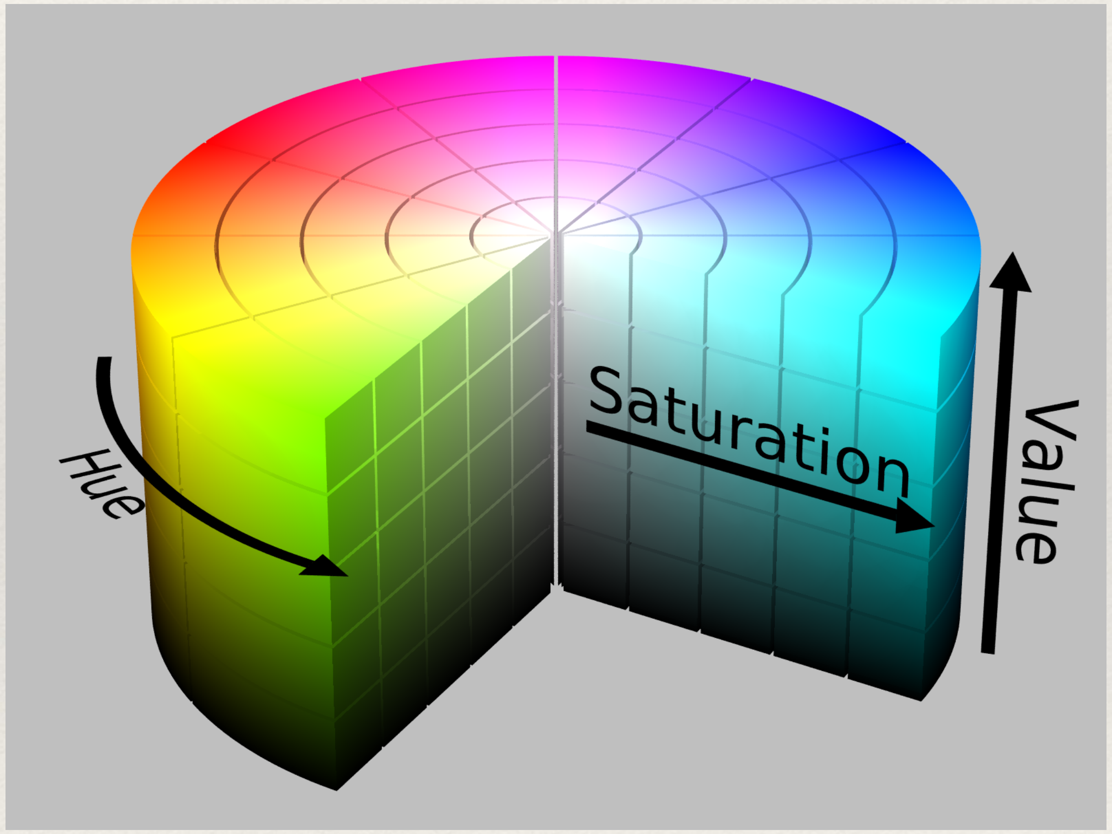
- RGB channels of pixel have the same value
- Content of image expressed through color **value** rather than hue or saturation
- How might we find a single value that captures the information of three color channels?

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



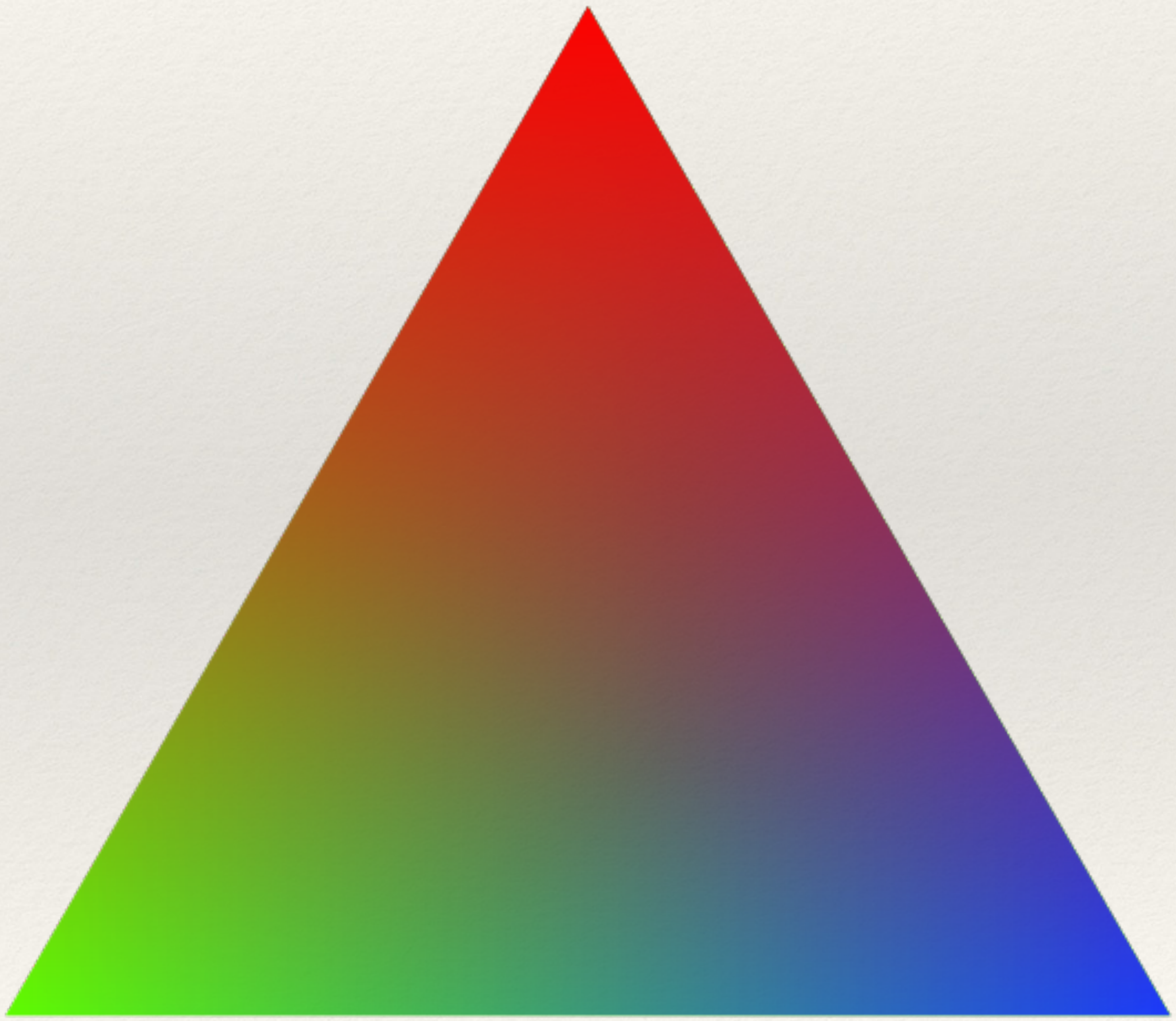
Setting Color Mode

- `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);
```

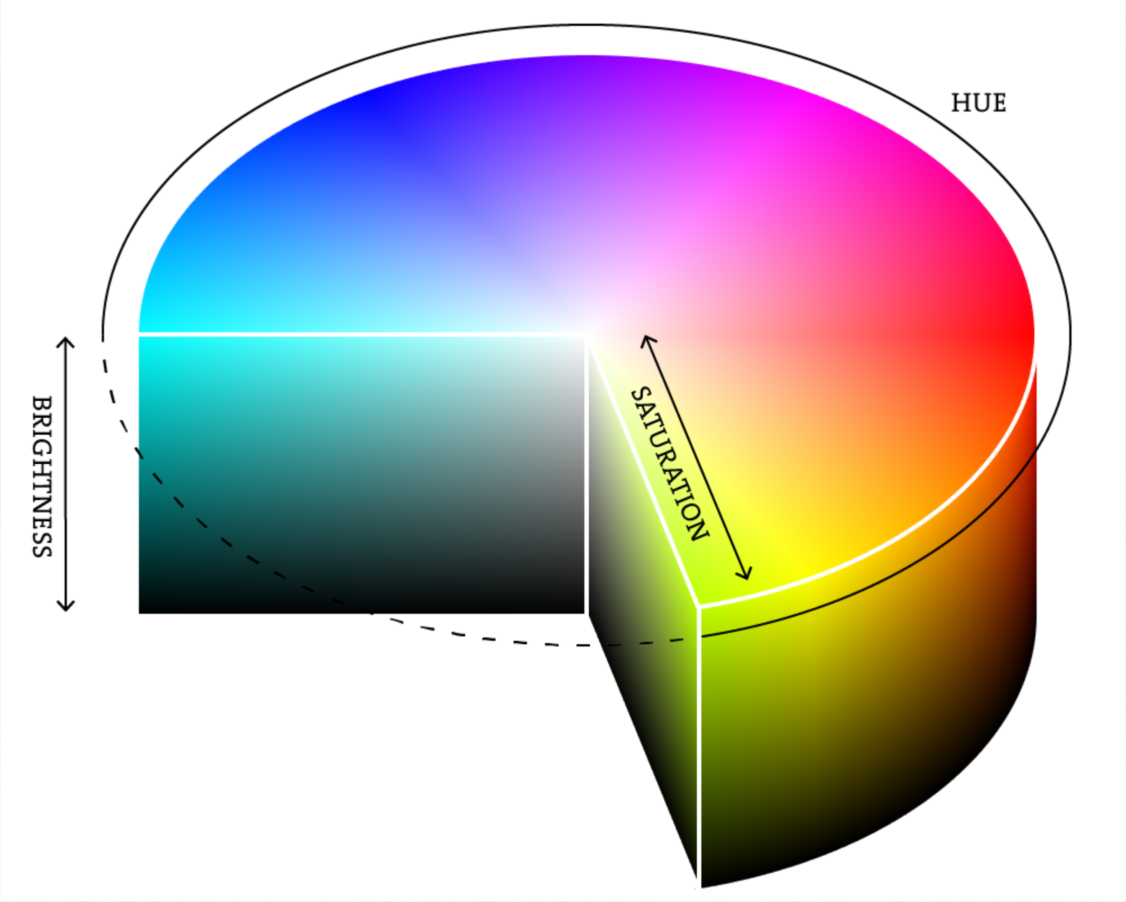
RGB Methods

- 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
```

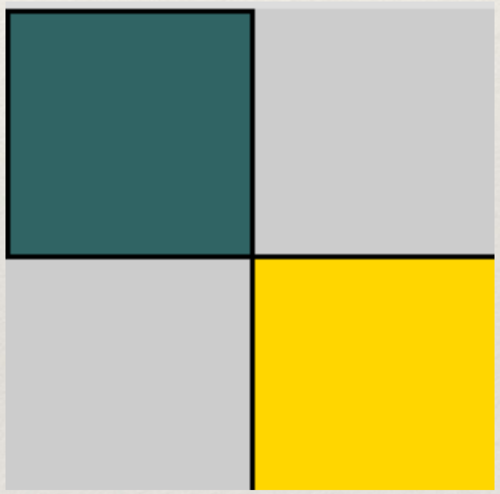


Image Kernels

- 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
- **Note: not a matrix multiply!!**

Convolution

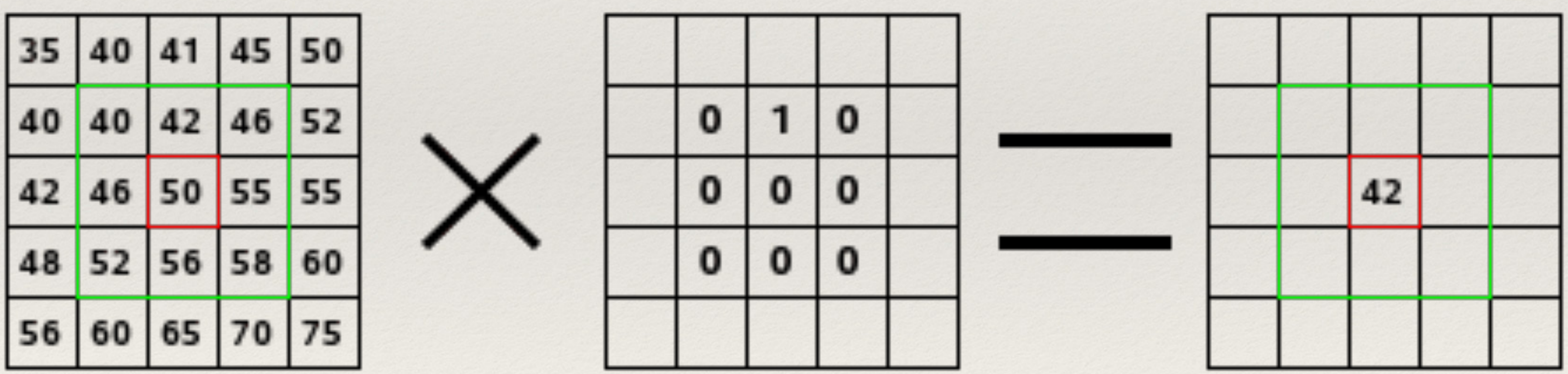
- Matrix convolution
  1. Multiplication of corresponding cells
  2. Summation of these values

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

$$\otimes \begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix} = \begin{Bmatrix} 1\cdot 34 & 2\cdot 36 & 1\cdot 33 \\ 2\cdot 33 & 4\cdot 36 & 2\cdot 34 \\ 1\cdot 36 & 2\cdot 35 & 1\cdot 36 \end{Bmatrix} = \{139 + 278 + 142\} = 559$$

Kernel Application

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



Hands-on: Understanding Convolutions

- Today's activities:
  1. Complete your `tint` method if it's not finished (do not resubmit)
  2. Experiment with `colorMode`, switching between RGB and HSB
  3. Use RGB and HSB methods to extract a color's information
  4. Construct this kernel* in Processing:

0	-1	0
-1	5	-1
0	-1	0

*You do not need to use it yet!

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:

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

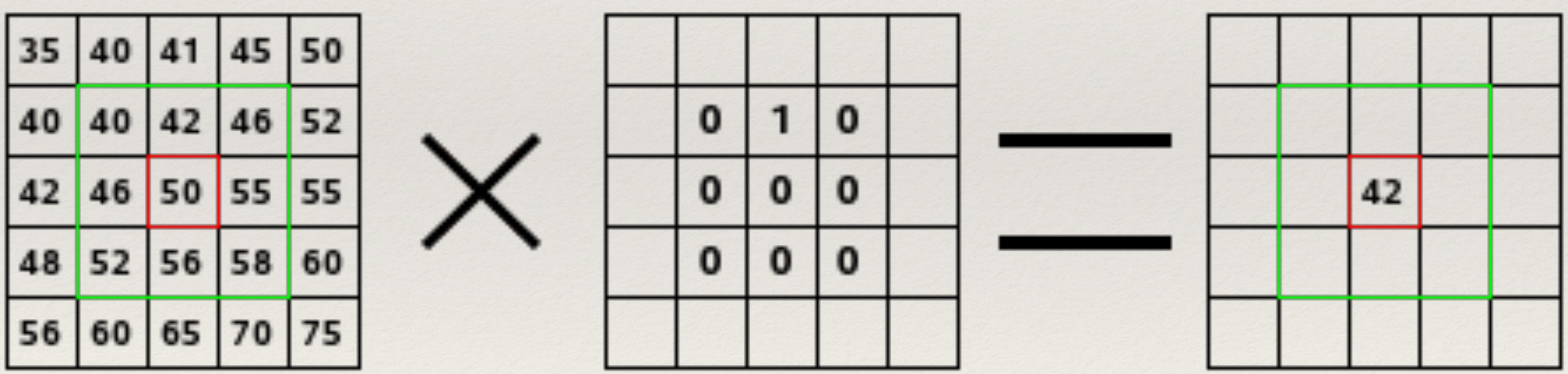
- Provides an *offset* to the target pixel
- Based on i and j values, offset reaches certain number of neighboring pixels in the x and y directions

Sharpen Example Code

```
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

   }

}

red = constrain(abs(red), 0, 255);

...  //Clamp green and blue
```

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:
  - `loadImage(image_file); //load twice`
- Or can create a blank image:
  - `createImage(width, height, ARGB);`
- Then copy pixel values from one buffer to another
  - `copy(img, x, y, width, height, x, y, width, height);`

Copying an Image

- Shallow copy:

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

- Deep copy*:

```
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:

```
1/9 * {{1, 1, 1},
         {1, 1, 1},
         {1, 1, 1}}
```

or approximately:

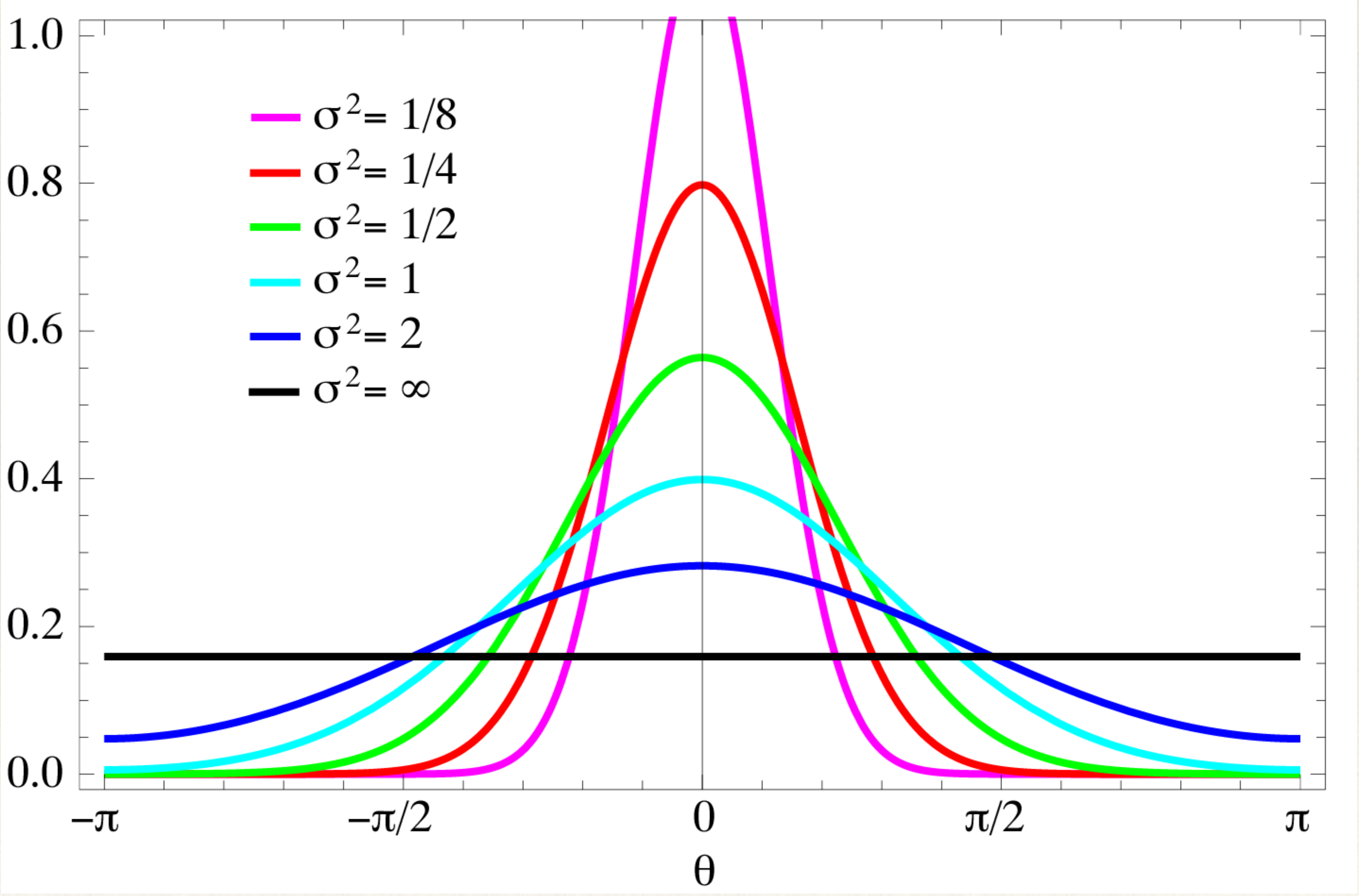
```
{{0.11, 0.11, 0.11},
 {0.11, 0.11, 0.11},
 {0.11, 0.11, 0.11}}
```

Gaussian Blur

- Use of Gaussian function for convolution:

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

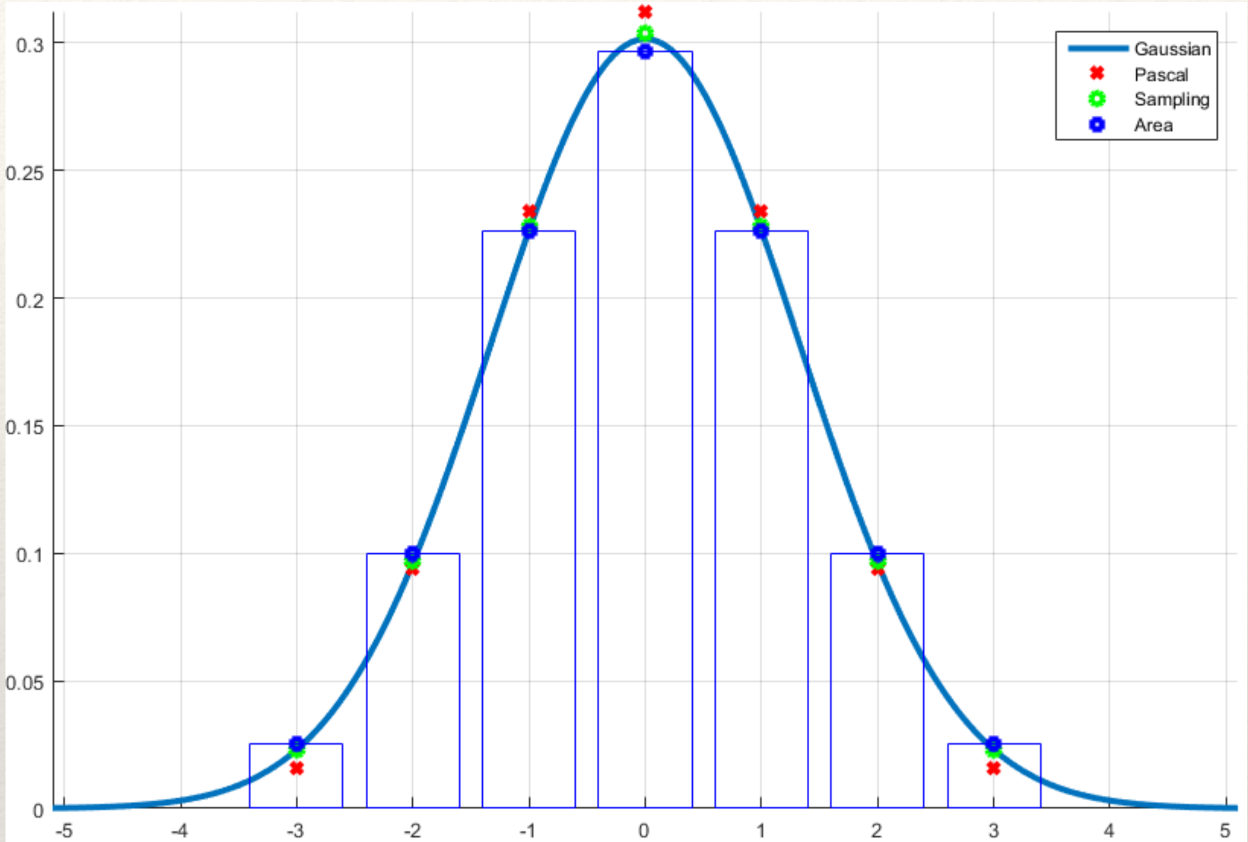
- Low-pass filter that reduces high frequency features including noise
- Weighted average better preserves features



1D Gaussian distribution

Approximate Gaussian Blur

- Same idea as a Gaussian blur but now discretized
- Apply weights to neighbors in kernel based on distance from the center
- Total weight must still equal 1



$$K = \frac{1}{256}\begin{bmatrix} 1 & 4 & 6 & 4 & 1 \\ 4 & 16 & 24 & 16 & 4 \\ 6 & 24 & 36 & 24 & 6 \\ 4 & 16 & 24 & 16 & 4 \\ 1 & 4 & 6 & 4 & 1 \end{bmatrix}$$

A 5x5 kernel

Edge Detection

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

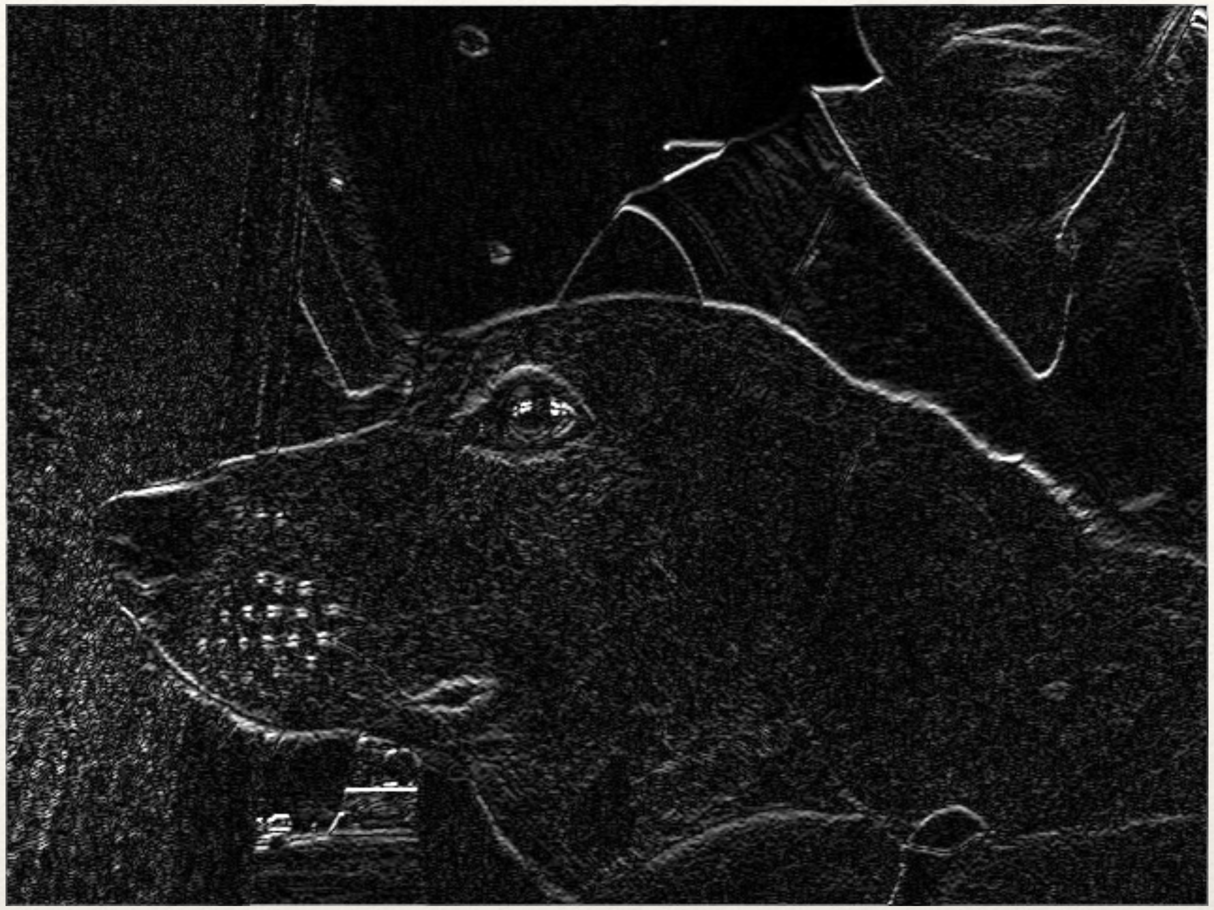
Sobel Operator

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

$$\mathbf{G}_x = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix} * \mathbf{A} \quad \text{and} \quad \mathbf{G}_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ +1 & +2 & +1 \end{bmatrix} * \mathbf{A}$$

- Horizontal and vertical convolutions performed *independently*

- Gradient magnitude (i.e. rate of change in both directions) 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 (easiest)
    - Fill in missing pixels with 0 or 255
    - Wrap missing pixels (from the other side of the image)
    - Mirror missing pixels (from the other side of the kernel)
- How do these choices affect the image appearance?

Hands-on: Using Convolutions

- Today's activities:
  1. Take your "sharpen" kernel and place it in a 3x3 2D array in Processing
  2. Create an image buffer to store the final, convolved image data
  3. Apply the sharpen kernel to an image and store the convolved data into your secondary image buffer (this should display to the screen)