ECE 478-578
Intelligent Robotics I

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Lecture 14

Introduction to OpenCV 3

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Open CV

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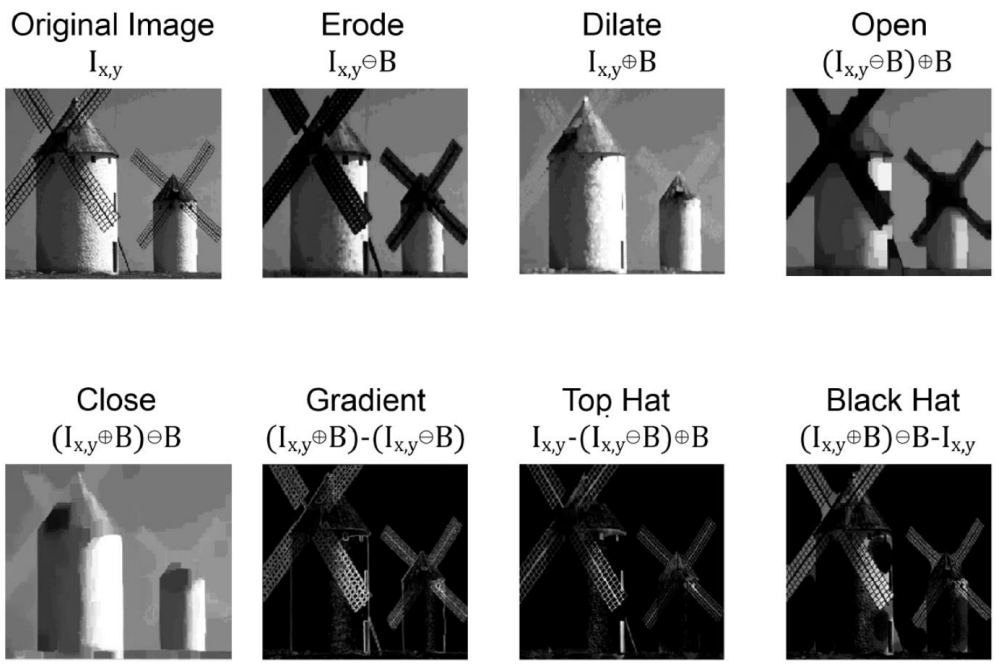
Morphological Operations Review

- Morphological operators often take a binary image and a structuring element as input and combine them using a set operator (intersection, union, inclusion, complement).

- They process objects in the input image based on characteristics of its shape, which are encoded in the structuring element.

- Dilation
- Erosion
- Opening
- Closing
- Top Hat
- Black Hat



https://homepages.inf.ed.ac.uk/rbf/HIPR2/morops.htm

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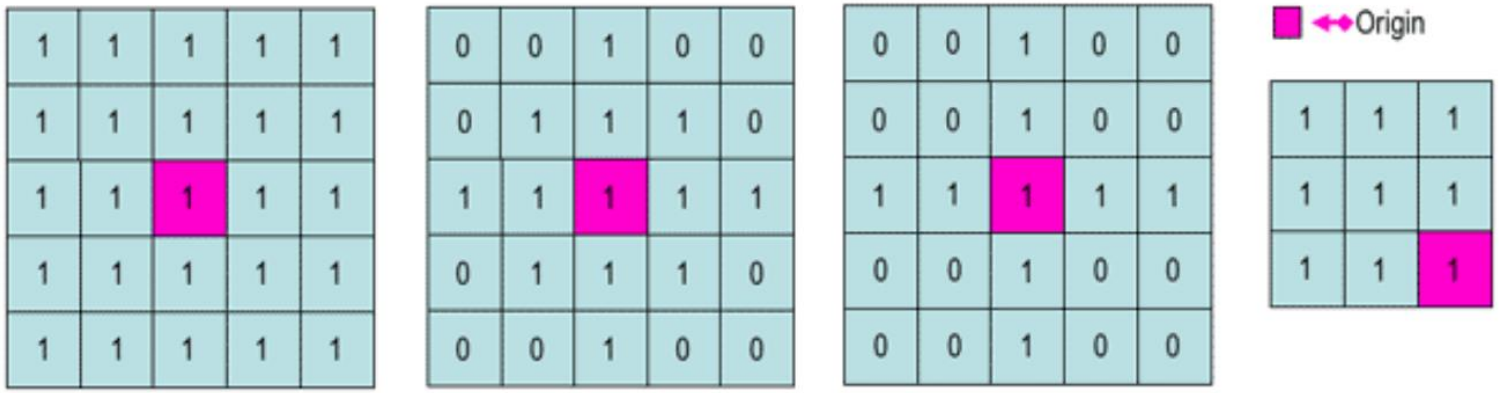
Basic Structuring Element

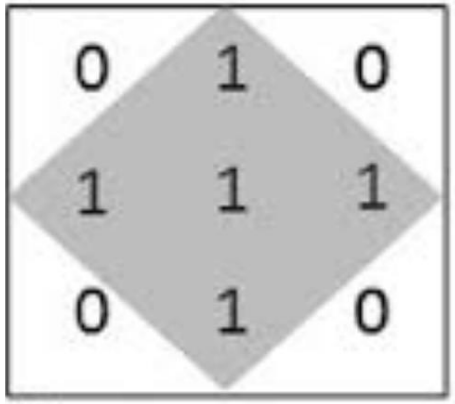
- Simply a binary image
- The matrix dimensions specify the *size* of the structuring element.
- The pattern of ones and zeros specifies the *shape* of the structuring element.
- An *origin* of the structuring element is usually one of its pixels, although generally the origin can be outside the structuring element.



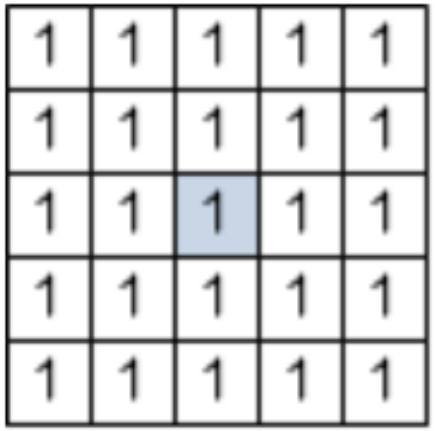
Examples of simple structuring elements.

https://www.cs.auckland.ac.nz/courses/compsci773s1c/lectures/ImageProcessing-html/topic4.htm

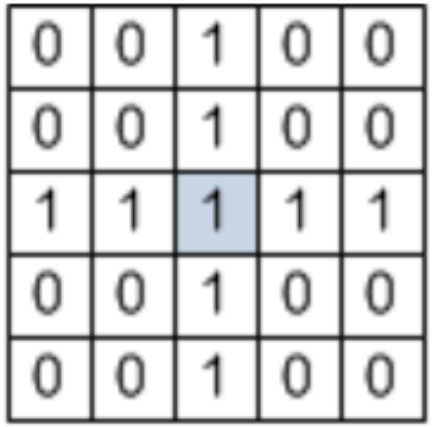
Different Shape Structuring Elements



Diamond



Square



Cross

```
[1 0 0 0 1]
[0 1 0 1 0]
[0 0 1 0 0]
[0 1 0 1 0]
[1 0 0 0 1]
```

X

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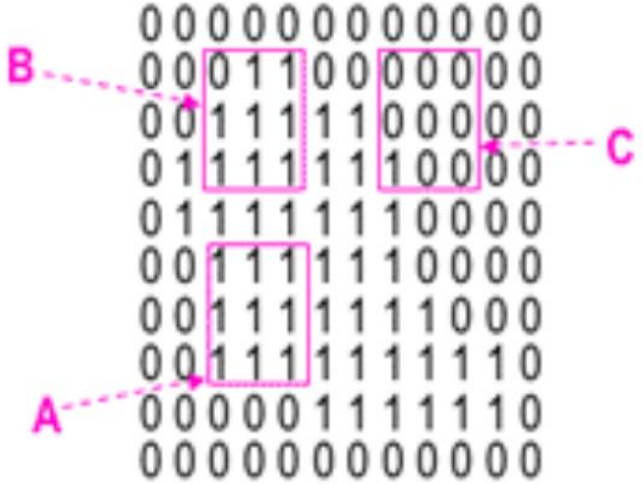
Hit and Fit

When a structuring element is placed in a binary image, each of its pixels is associated with the corresponding pixel of the neighborhood under the structuring element.

- The structuring element is said to **fit** the image if, for each of its pixels set to 1, the corresponding image pixel is also 1.
- Similarly, a structuring element is said to **hit**, or intersect, an image if, at least for one of its pixels set to 1 the corresponding image pixel is also 1.



$$s_1 = \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}$$

$$s_2 = \begin{pmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

		A	B	C
fit	s_1	yes	no	no
	s_2	yes	yes	no
hit	s_1	yes	yes	yes
	s_2	yes	yes	no

Fitting and hitting of a binary image with structuring elements s_1 and s_2.

https://www.cs.auckland.ac.nz/courses/compsci773s1c/lectures/ImageProcessing-html/topic4.htm

Grayscale Morphology

Dilation:

$$(I \oplus H)(u,v) = \max_{(i,j)\in H} \{I(u+i, v+j) + H(i,j)\}$$

Erosion:

$$(I \ominus H)(u,v) = \min_{(i,j)\in H} \{I(u+i, v+j) + H(i,j)\}$$

http://www.coe.utah.edu/~cs4640/slides/Lecture11.pdf

Morphological Operations - Dilation

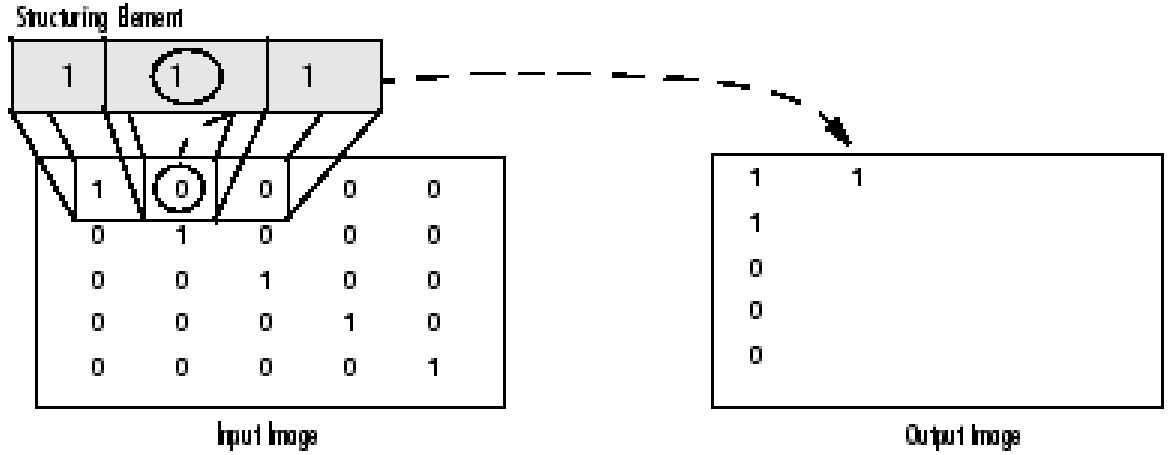
- Enlarges object by adding boundary pixels to object
- Fill in small holes in object

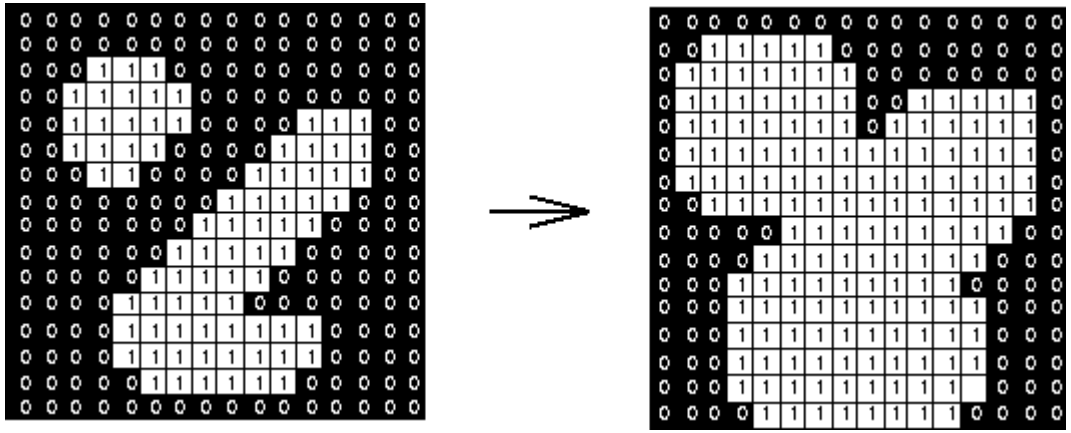
denoted by f ⊕ s

$$g(x,y) = \begin{cases} 1, & \text{if } s \text{ hits } f \\ 0, & \text{otherwise} \end{cases}$$

http://www.csie.nuk.edu.tw/~ayen/teach/cv/cv-note04.pdf

Morphological Operations - Dilation





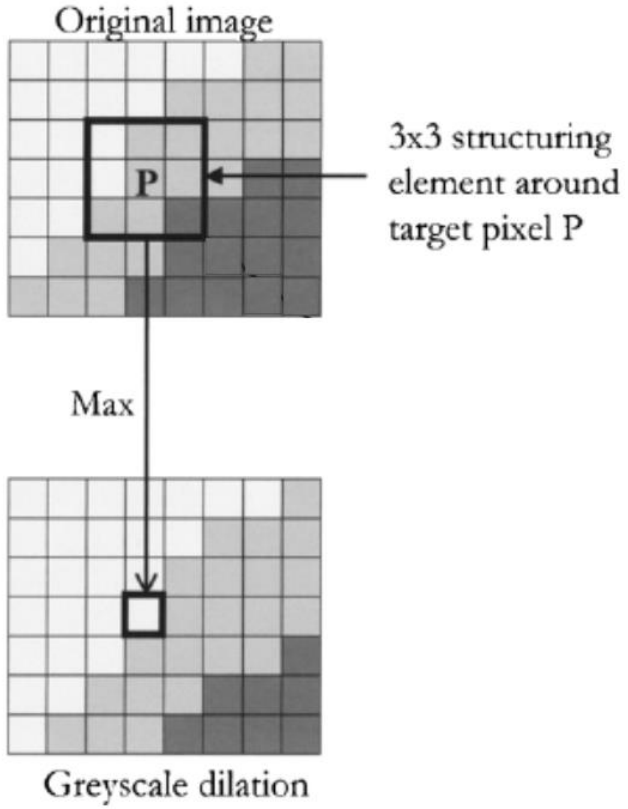


Image Source

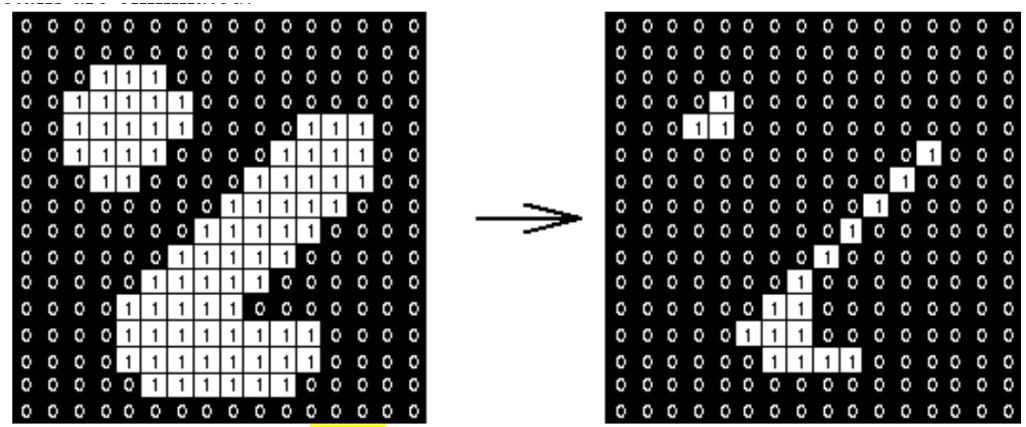
Morphological Operations - Erosion

- It has the effect of stripping away boundary pixels
- It enlarges holes in object
- It removes unwanted small-scale features
- It reduces size of other features

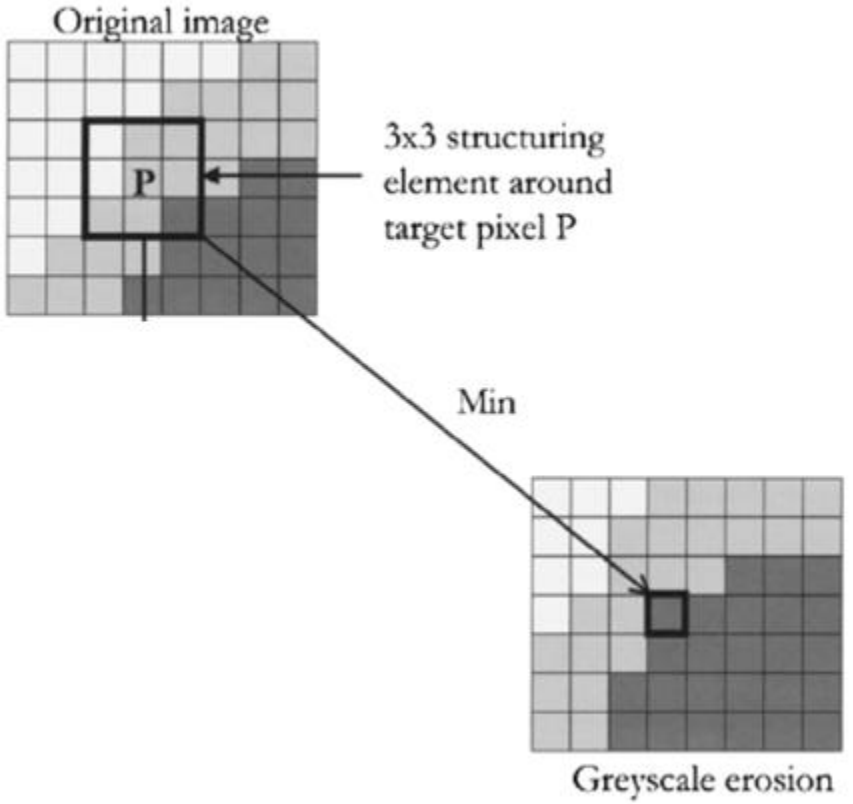
$$g(x, y) = \begin{cases} 1, & \text{if } s \text{ fits } f \\ 0, & \text{otherwise} \end{cases}$$

https://www.cs.auckland.ac.nz/courses/compsci773s1c/lectures/ImageProcessing-html/topic4.htm

Morphological Operations - Erosion



Erosion: a 3×3 square structuring element
(www.cs.princeton.edu/~pshilane/class/mosaic/).



https://www.cs.auckland.ac.nz/courses/compsci773s1c/lectures/ImageProcessing-html/topic4.htm

Morphological Operations - Opening

- An opening is defined as an erosion followed by a dilation using the same structuring element for both operations.
- Grayscale opening consists simply of a Grayscale erosion followed by a Grayscale dilation.
- Small bright regions are removed
- And white regions are more isolated

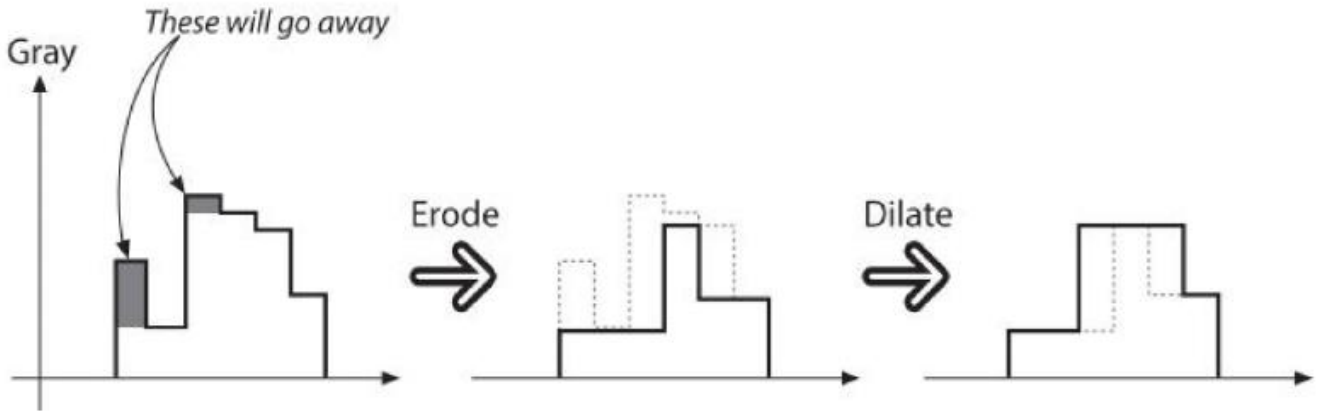


Figure 10-25. Morphological opening operation applied to a (one-dimensional) non-Boolean image: the upward outliers are eliminated

https://homepages.inf.ed.ac.uk/rbf/HIPR2/open.htm

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Morphological Operations - Closing

- An closing is defined as an dilation followed by a erosion using the same structuring element for both operations.
- Grayscale opening consists simply of a grayscale dilation followed by a grayscale erosion.
- Removes unwanted noisy segments
- Bright regions are joined but retain basic size

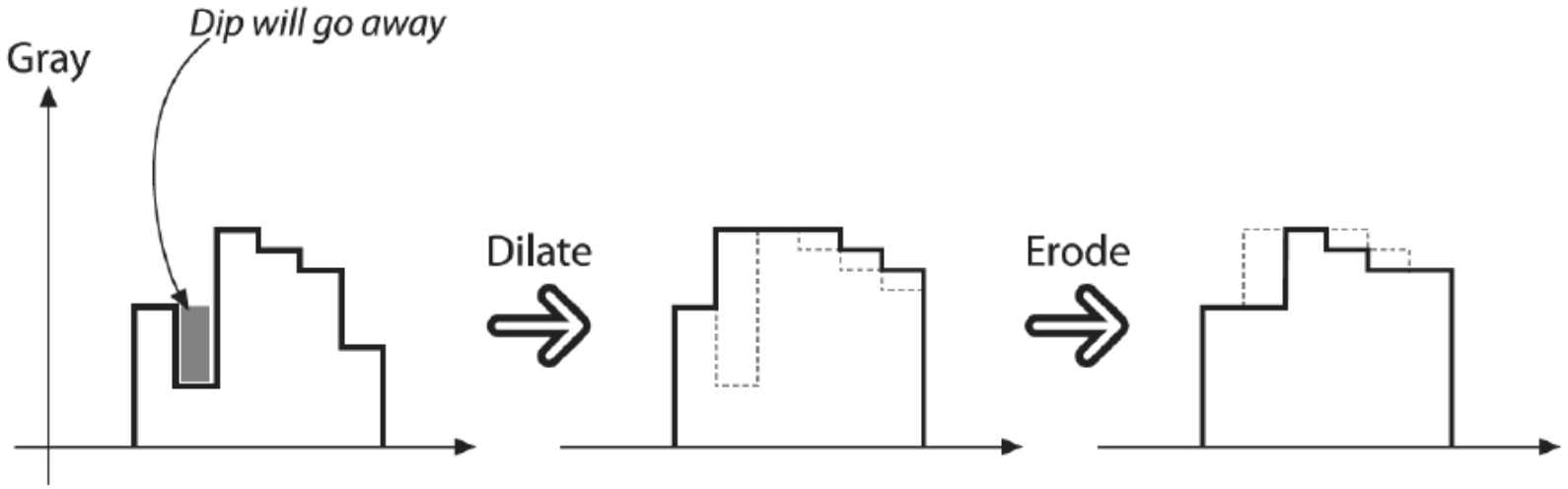


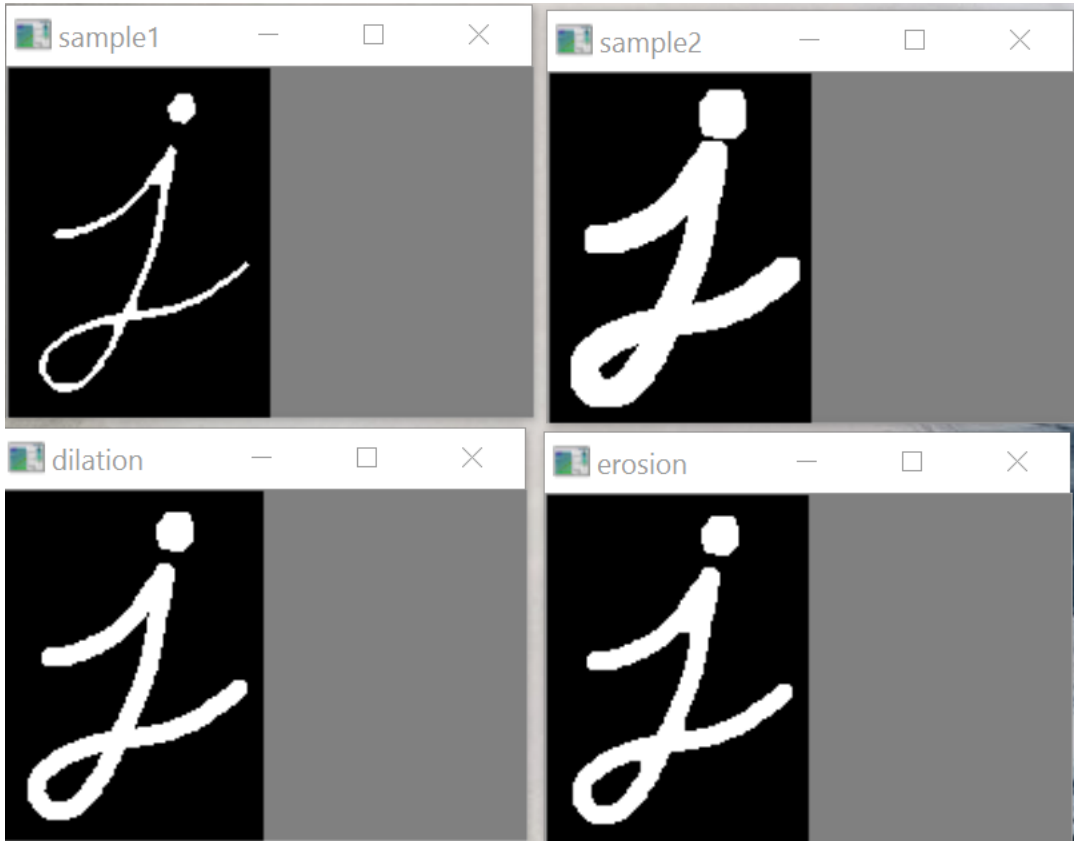
Figure 5-12. Morphological closing operation: the downward outliers are eliminated as a result

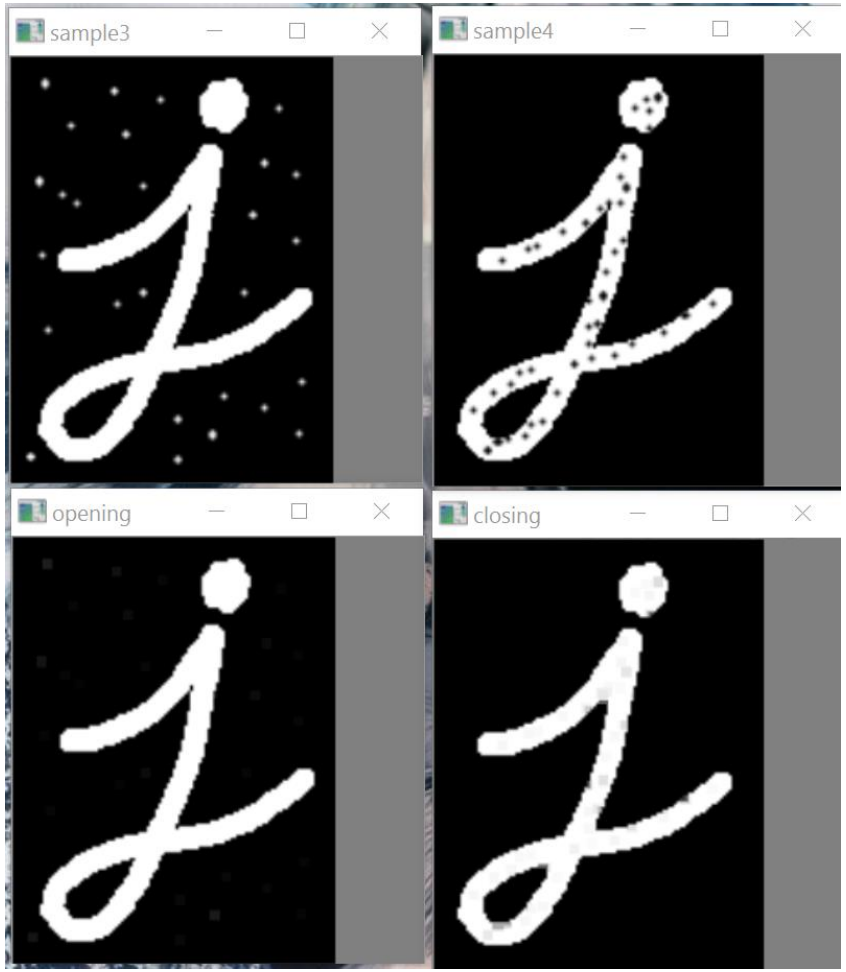
Morphological Operations

```
import cv2
import numpy as np

img1 = cv2.imread('sample1.png',0)
cv2.imshow("sample1", img1)

img2 = cv2.imread('sample2.png',0)
cv2.imshow("sample2", img2)

img3 = cv2.imread('sample3.png',0)
cv2.imshow("sample3", img3)

img4 = cv2.imread('sample4.png',0)
cv2.imshow("sample4", img4)

#5x5 structuring elemnent all ones
kernel = np.ones((5,5),np.uint8)

#dilation
dilation = cv2.dilate(img1,kernel,iterations = 1)
cv2.imshow("dilation", dilation)

#erosion
erosion = cv2.erode(img2,kernel,iterations = 1)
cv2.imshow("erosion", erosion)
```

```
#opening
opening = cv2.morphologyEx(img3, cv2.MORPH_OPEN, kernel)
cv2.imshow("opening", opening)

#closing
closing = cv2.morphologyEx(img4, cv2.MORPH_CLOSE, kernel)
cv2.imshow("closing", closing)

cv2.waitKey(0)
cv2.destroyAllWindows()
```

Morphological Operations





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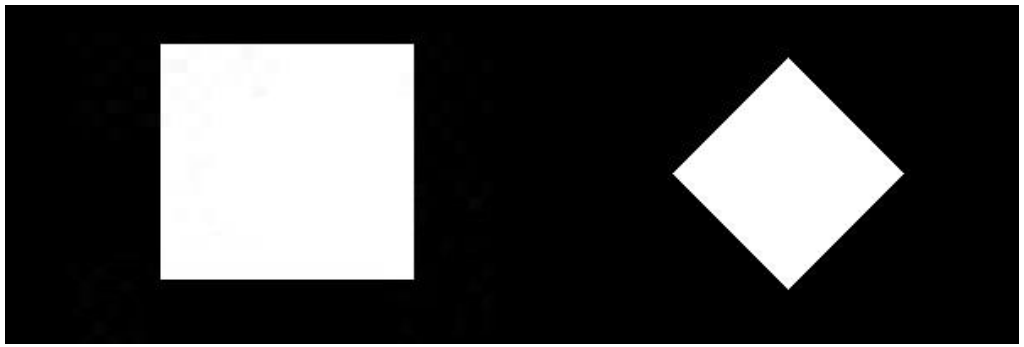
Finding Corners

```
import cv2
import numpy as np
# global variables
img = None
ret = None
threshold = None
se_square = None
se_cross = None
se_diamond = None
se_x = None
# load the image and conver it to a binary image
def load_images():
    global img, ret, threshold
    img = cv2.imread('corner_binary.jpg')
    cv2.imshow('original image',img)
    ret, threshold = cv2.threshold(img, 127, 255, cv2.THRESH_BINARY)
```



Finding Corners – Cont.

```
# create structing elements for the morphological operations
def create_structuring_elements():
    global se_square, se_cross, se_diamond, se_x

    se_square= np.matrix([[1, 1, 1, 1, 1], [1, 1, 1, 1, 1], [1, 1, 1, 1, 1], [1, 1, 1, 1, 1], [1, 1, 1, 1, 1]])
    print "se_square"
    print se_square
    se_cross= np.matrix([[0, 0, 1, 0, 0], [0, 0, 1, 0, 0], [1, 1, 1, 1, 1], [0, 0, 1, 0, 0], [0, 0, 1, 0, 0]])
    print "se_cross"
    print se_cross
    se_diamond= np.matrix([[0, 0, 1, 0, 0], [0, 1, 1, 1, 0], [1, 1, 1, 1, 1], [0, 1, 1, 1, 0], [0, 0, 1, 0, 0]])
    print "se_diamond"
    print se_diamond
    se_x= np.matrix([[1, 0, 0, 0 ,1], [0, 1, 0, 1, 0], [0, 0, 1, 0, 0], [0, 1, 0, 1, 0], [1, 0, 0, 0, 1]])
    print "se_x"
    print se_x
```

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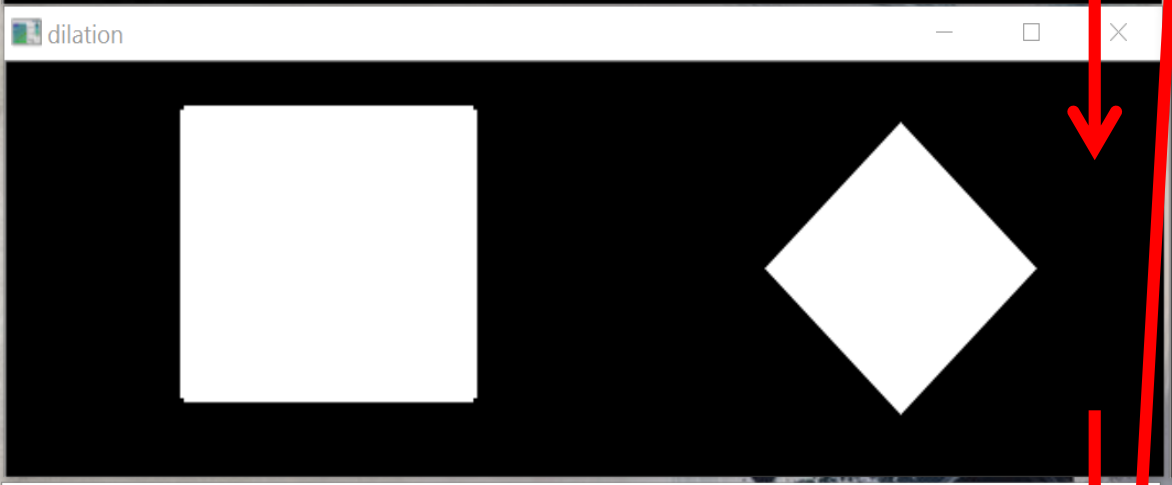
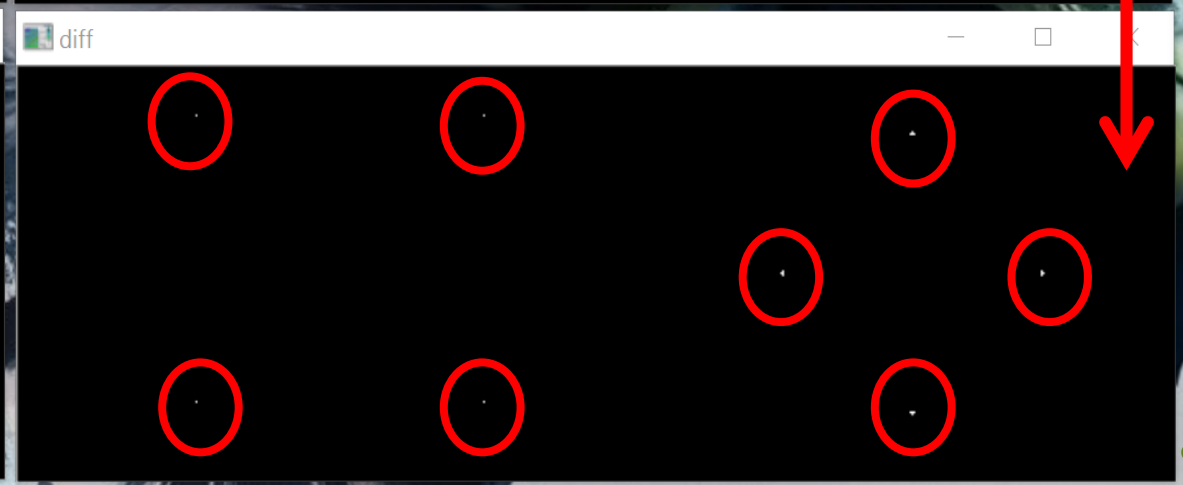
Finding Corners – Cont.

```
# detect corners by morphological operations
def corner_detection():
    #global ret, threshold
    result1 = cv2.dilate(threshold,se_cross,iterations = 1)
    cv2.imshow('dilation',result1)

    result1 = cv2.erode(result1,se_diamond,iterations = 1)
    cv2.imshow('erode',result1)

    result2 = cv2.dilate(threshold,se_x,iterations = 1)
    cv2.imshow('dilation2', result2)

    result2 = cv2.erode(result2,se_square,iterations = 1)
    cv2.imshow('erode2',result2)

    diff = cv2.absdiff(result1,result2);
    cv2.imshow('diff',diff)

load_images()
create_structuring_elements()
corner_detection()

cv2.waitKey(0)
cv2.destroyAllWindows()
```





*Python 2.7.13 S

File Edit Shell

```
Python 2.7.13
AMD64)] on wi
Type "copyrig
>>>
 RESTART: C:/
ind_corners.p
se_square
[[1 1 1 1 1]
 [1 1 1 1 1]
 [1 1 1 1 1]
 [1 1 1 1 1]
 [1 1 1 1 1]]
se_cross
[[0 0 1 0 0]
 [0 0 1 0 0]
 [1 1 1 1 1]
 [0 0 1 0 0]
 [0 0 1 0 0]]
se_diamond
[[0 0 1 0 0]
 [0 1 1 1 0]
 [1 1 1 1 1]
 [0 1 1 1 0]
 [0 0 1 0 0]]
se_x
[[1 0 0 0 1]
 [0 1 0 1 0]
 [0 0 1 0 0]
 [0 1 0 1 0]
 [1 0 0 0 1]]
```

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Filters

- Filtering is a technique for modifying or enhancing an image.
- You can filter an image to emphasize certain features or remove other features.
- Image processing operations implemented with filtering include smoothing, sharpening, and edge enhancement.
- Filtering is a *neighborhood operation,* in which the value of any given pixel in the output image is determined by applying some algorithm to the values of the pixels in the neighborhood of the corresponding input pixel. A pixel's neighborhood is some set of pixels, defined by their locations relative to that pixel.

Correlation and Convolution

Correlation and Convolution

- Correlation: $G = H \otimes F$

$$G[i,j] = \sum_{u=-k}^{k} \sum_{v=-k}^{k} H[u,v]F[i+u, j+v]$$

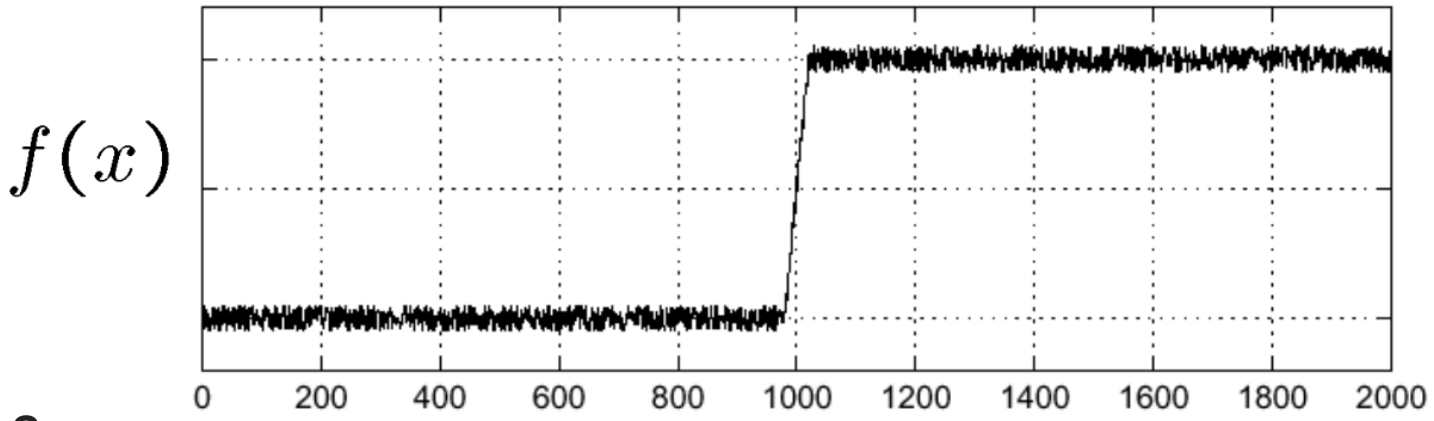
- Convolution: $G = H * F$

$$G[i,j] = \sum_{u=-k}^{k} \sum_{v=-k}^{k} H[u,v]F[i-u, j-v]$$

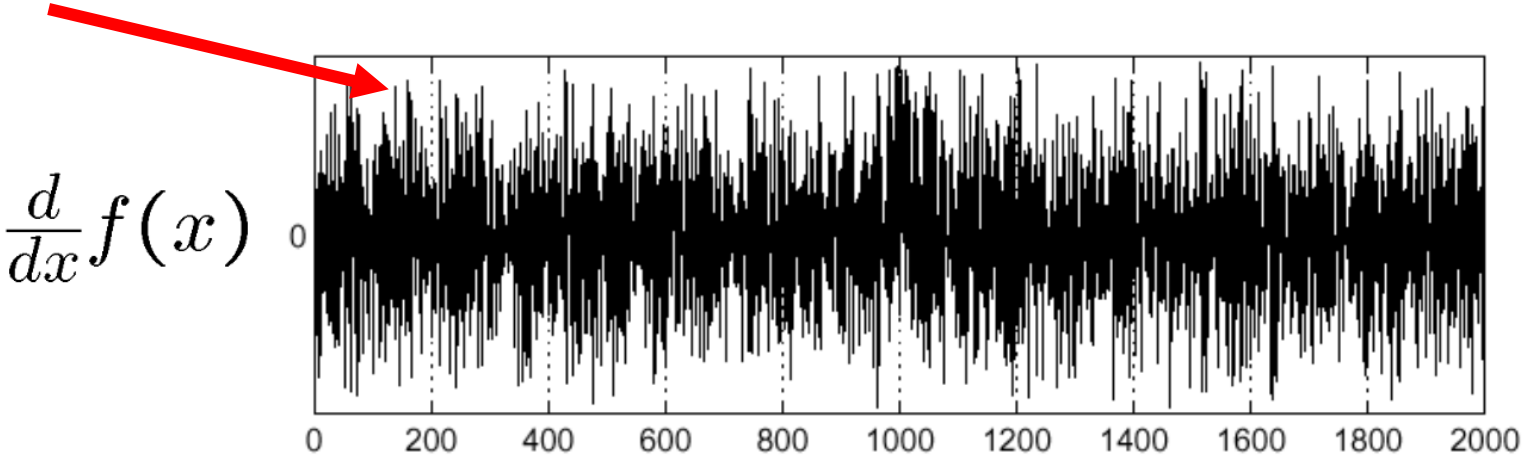
- If you want to learn more about correlation and convolution
  - http://www.cs.umd.edu/~djacobs/CMSC426/Convolution.pdf

https://web.eecs.umich.edu/~jjcorso/t/598F14/files/lecture_0924_filtering.pdf

Effects of Noise



Where is the edge?



High Pass and Low Pass Filters

- A low-pass filter is a filter that passes low-frequency signals and attenuates signals with frequencies higher than the cut-off frequency. The actual amount of attenuation for each frequency varies depending on specific filter design.

- A high-pass filter is a filter that passes high frequencies well, but attenuates frequencies lower than the cut-off frequency. Sharpening is fundamentally a high pass operation in the frequency domain.

http://research.ijcaonline.org/volume109/number14/pxc3900999.pdf

Mean and Median Filter

Mean Filter

Median Filter

http://www.bogotobogo.com/Matlab/Matlab_Tutorial_Digital_Image_Processing_6_Filter_Smoothing_Low_Pass_fspecial_filter2.php

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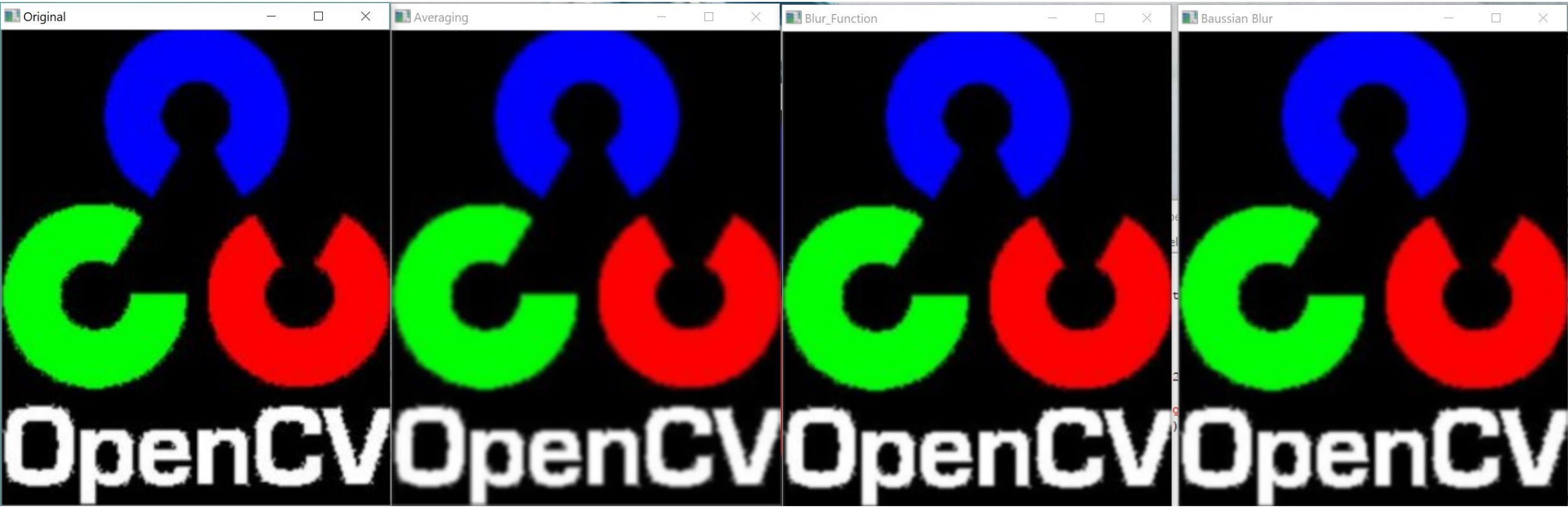
Blurring

```
import cv2
import numpy as np
from matplotlib import pyplot as plt

img = cv2.imread('input.png')

#Create a kernel
kernel = np.ones((5,5),np.float32)/25

#Apply custom-made filter to theimage
custom = cv2.filter2D(img,-1,kernel)

# Use blur function
blur = cv2.blur(img,(3,3))

# Use Gaussian Blur function
gaussianblur = cv2.GaussianBlur(img,(5,5),0)

cv2.imshow('Original', img)
cv2.imshow('Averaging', custom)
cv2.imshow('Blur_Function', blur)
cv2.imshow('Baussian Blur', gaussianblur)

cv2.waitKey(0)
cv2.destroyAllWindows()
```

Blurring



$$K = \frac{1}{25}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

```
blur = cv2.blur(img,(3,3))
```

```
gaussianblur = cv2.GaussianBlur(img,(5,5),0)
```

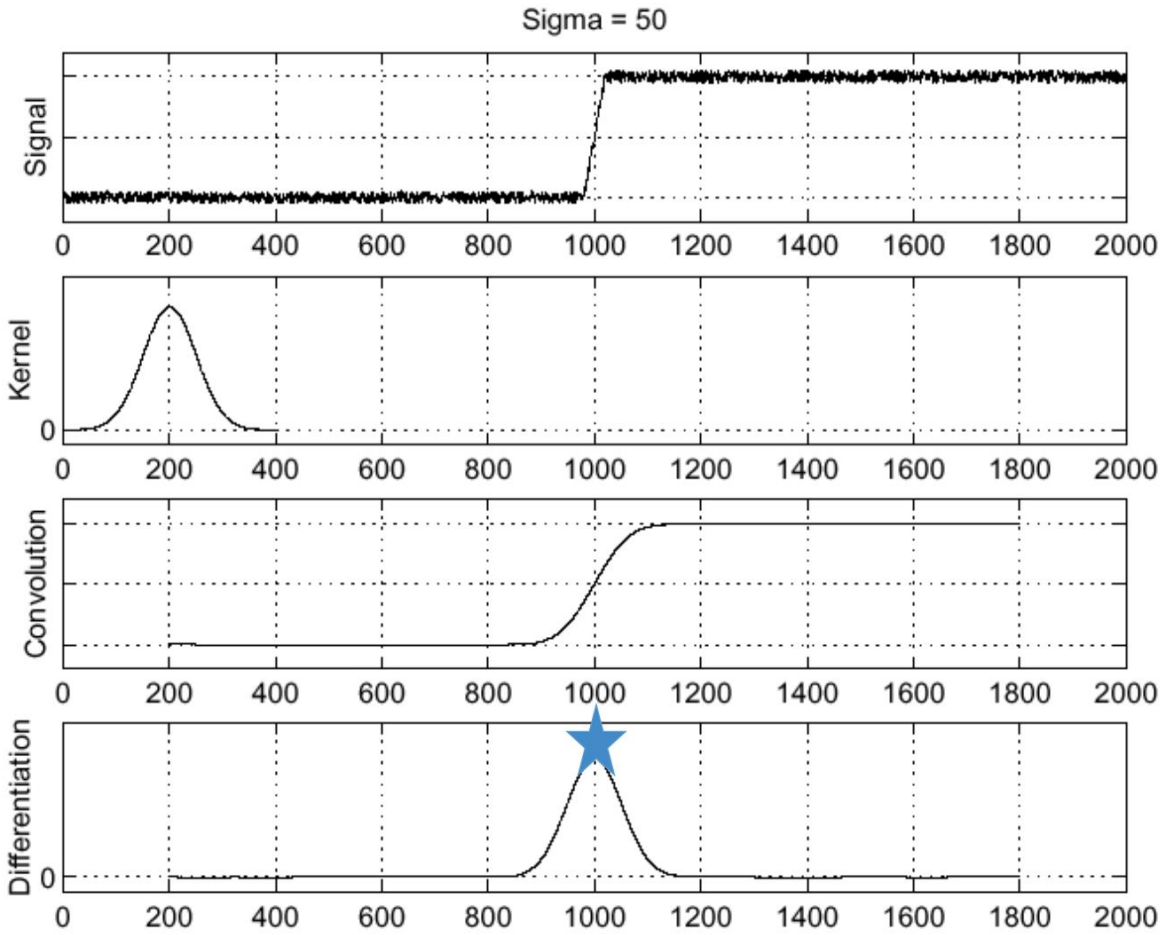
Low Pass Filters - Gaussian

f

h

$h \star f$

$\frac{\partial}{\partial x}(h \star f)$



Where is the edge?

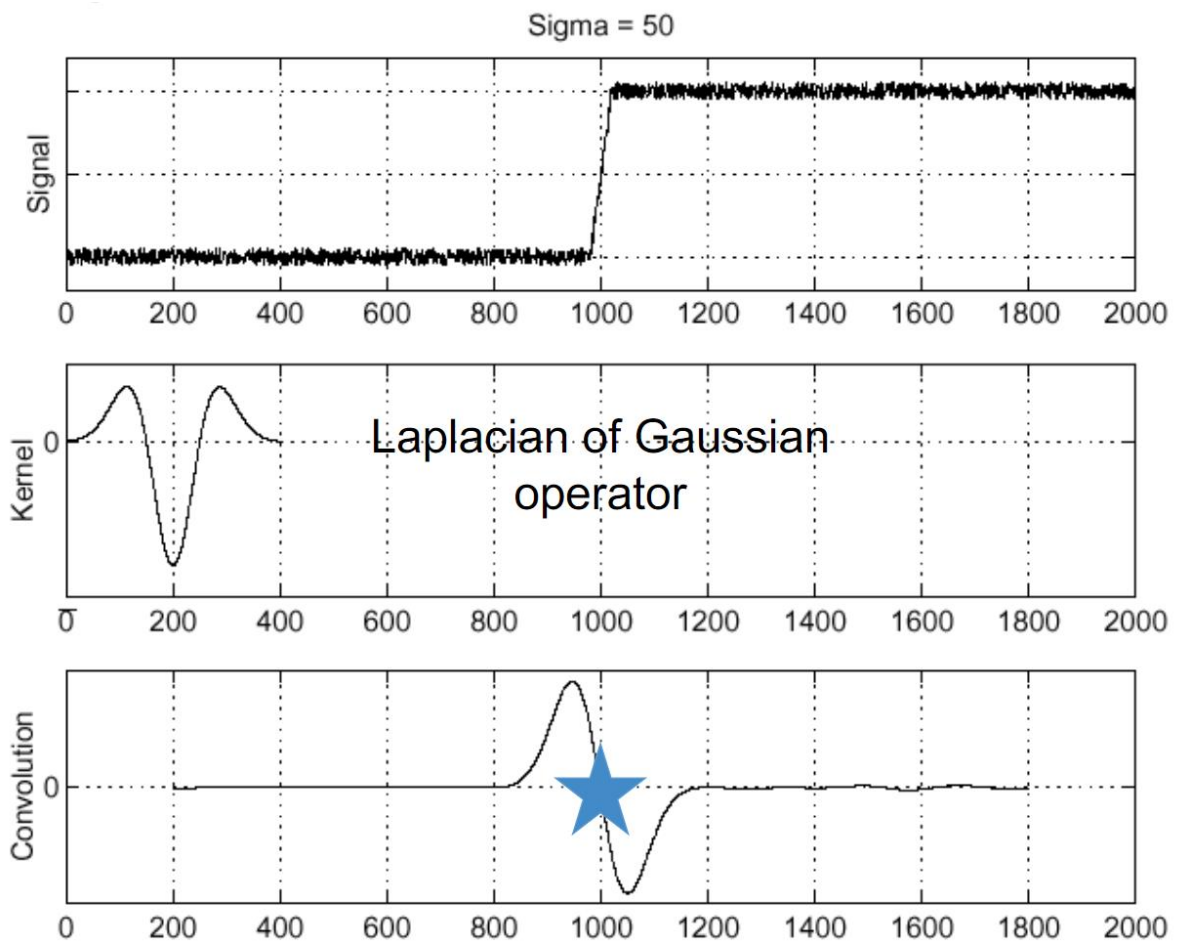
Look for peaks in $\frac{\partial}{\partial x}(h \star f)$

Low Pass Filters – Laplacian of Gaussian

f

$\frac{\partial^2}{\partial x^2} h$

$(\frac{\partial^2}{\partial x^2} h) \star f$



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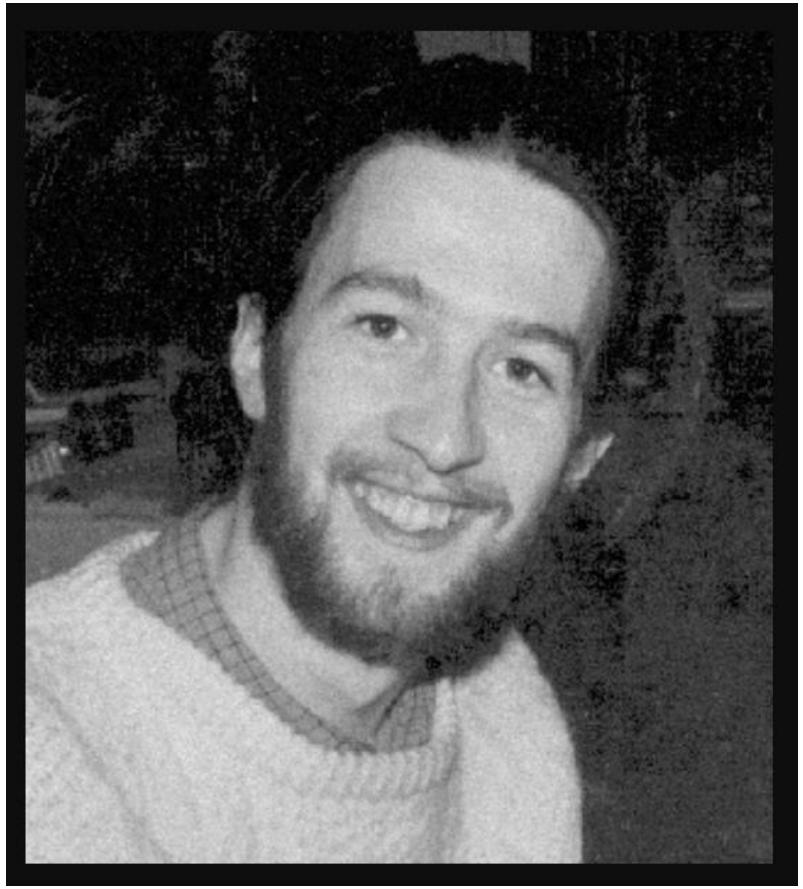
Low Pass Filters - Gaussian



https://homepages.inf.ed.ac.uk/rbf/HIPR2/gsmooth.htm

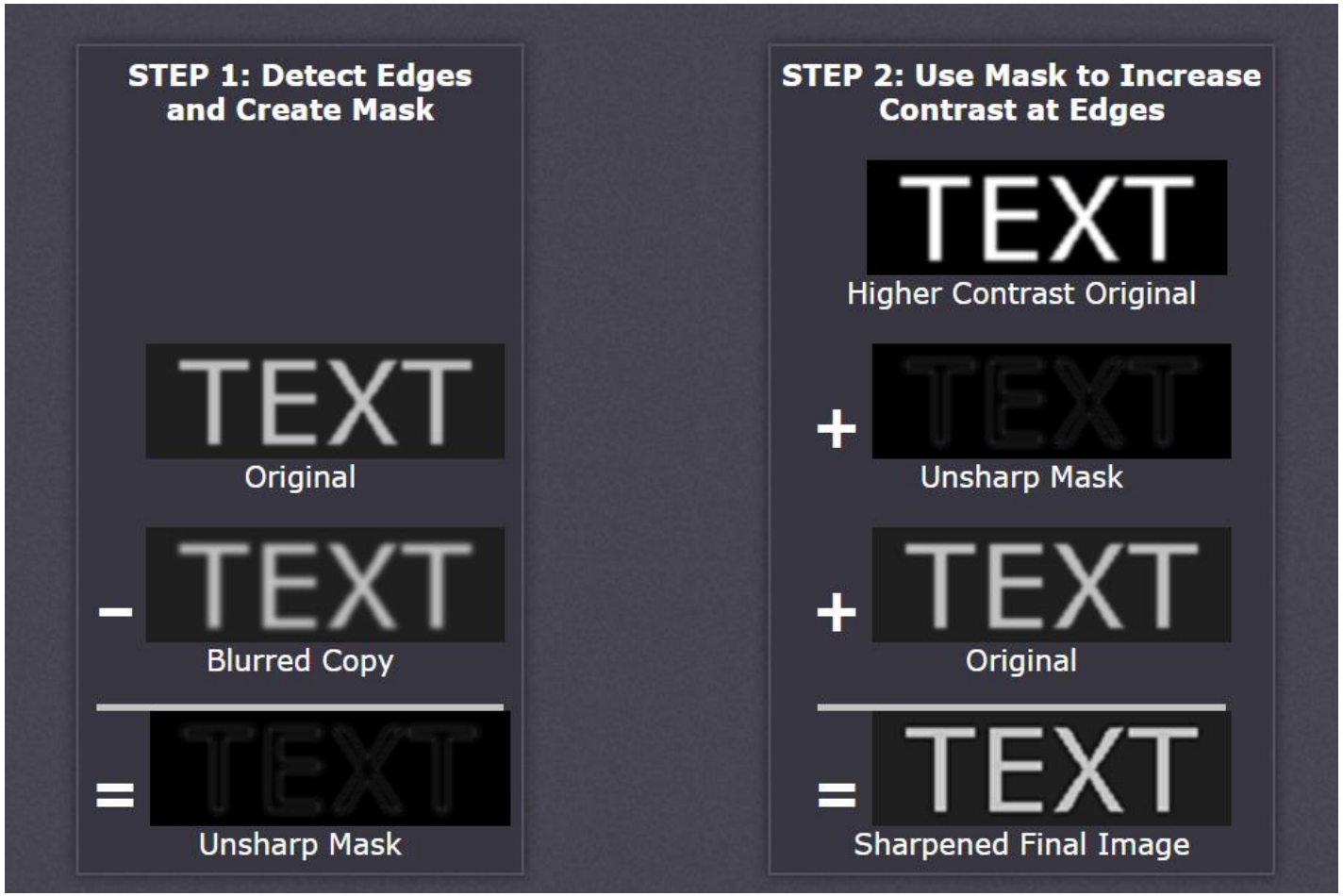
Sharpening (Edge Enhencement)

- To enhance line structures or other details in an image
- A high-pass filter can be used to make an image appear sharper.
- These filters emphasize fine details in the image
- While low-pass filtering smooths out noise, high-pass filtering does just the opposite: it *amplifies noise*.
- You can get away with this if the original image is not too noisy; otherwise the noise will overwhelm the image.

$$\begin{bmatrix} -1/9 & -1/9 & -1/9 \\ -1/9 & 1 & -1/9 \\ -1/9 & -1/9 & -1/9 \end{bmatrix}$$

https://pdfs.semanticscholar.org/fcbf/0322f336f5d2470b623fe4115dd4efbea9b7.pdf
https://diffractionlimited.com/help/maximdl/High-Pass_Filtering.htm

Sharpening - Unsharp Mask



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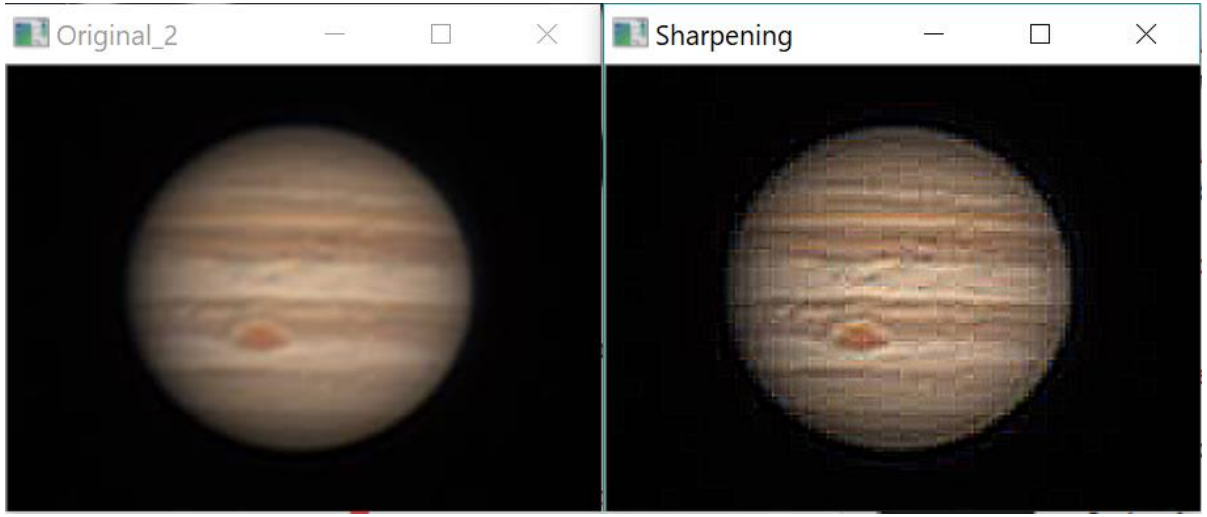
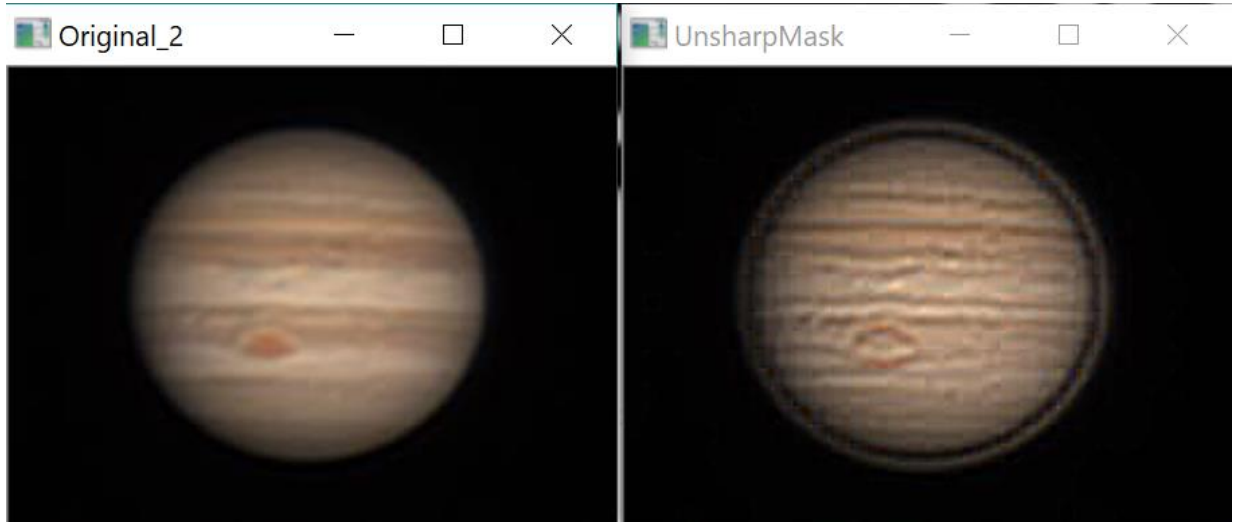
Sharpening

```
# Use Sharpening
kernel = np.array([[-1,-1,-1], [-1,9,-1], [-1,-1,-1]])
sharp = cv2.filter2D(img2, -1, kernel)

# Unsharp Masking
mask = cv2.GaussianBlur(img2,(0, 0), 3);
unsharp = cv2.addWeighted(mask, 4, img2, -3, 0);
```





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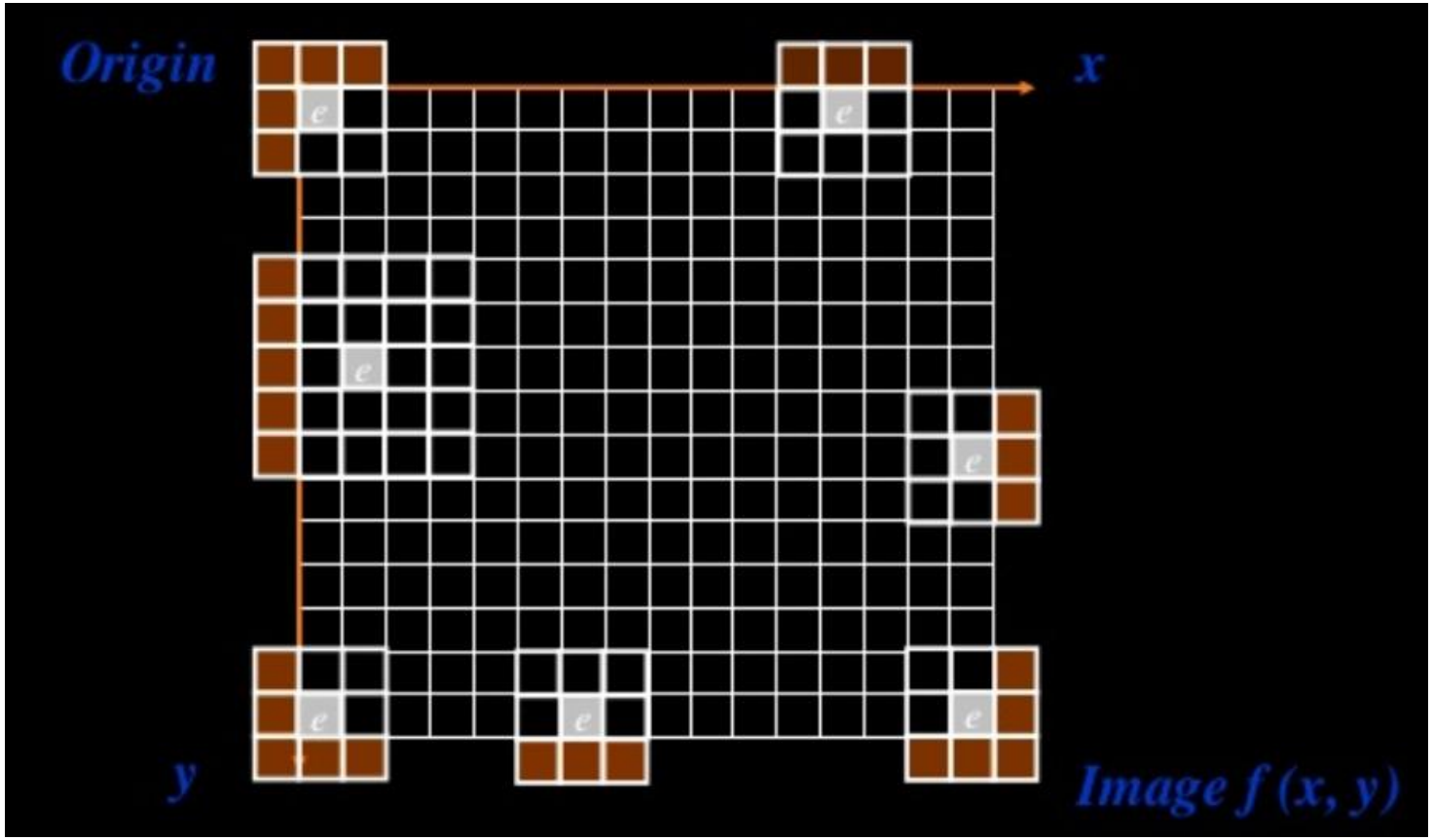
Border Extrapolation and Boundary Conditions

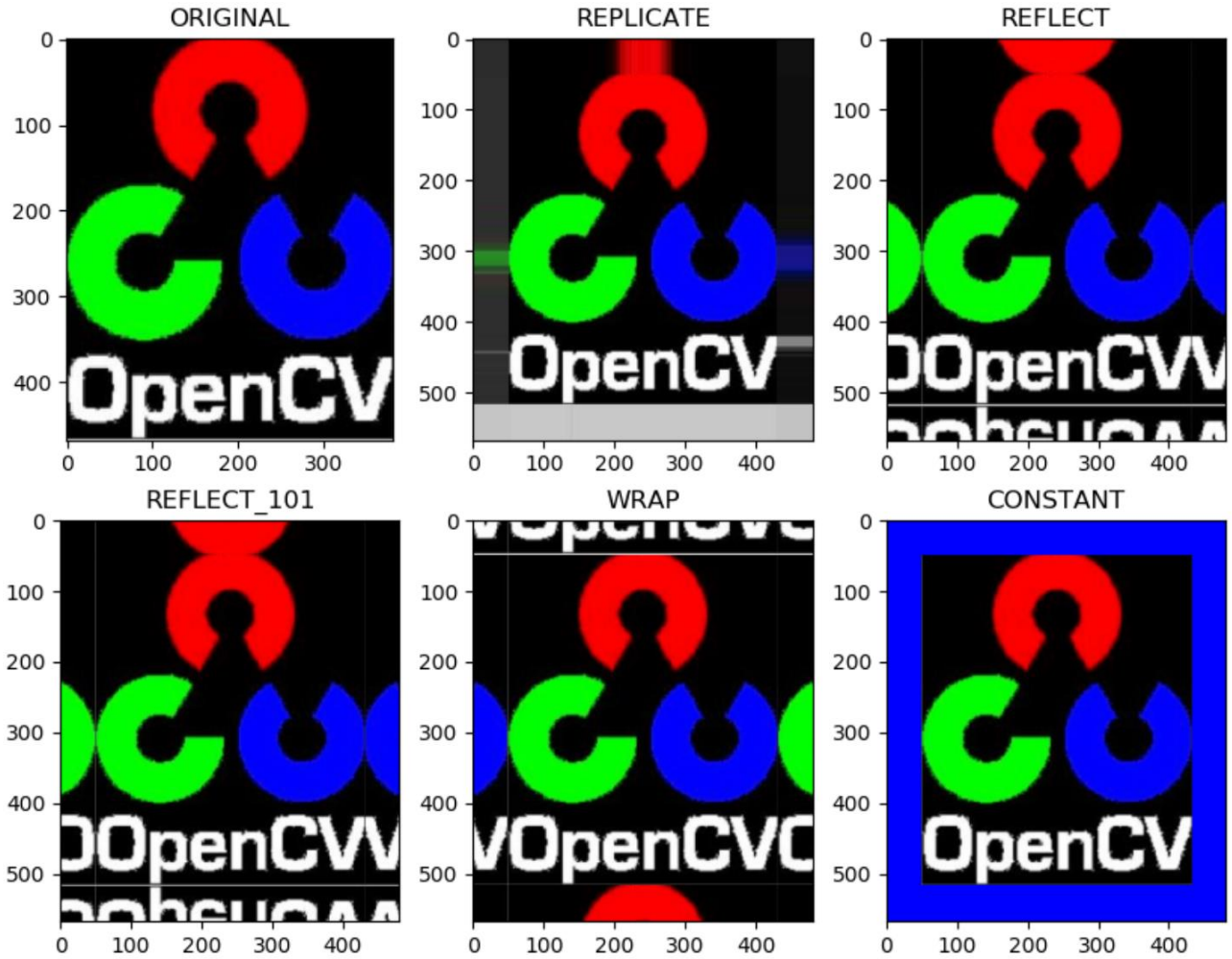


https://www.slideshare.net/anujarora3304/spatial-filtering-using-image-processing-32890033

Border Extrapolation and Boundary Conditions

```
import cv2
import numpy as np
from matplotlib import pyplot as plt

red = [0,0,255]

img1 = cv2.imread('opencv.png')

#create boarders
replicate = cv2.copyMakeBorder(img1,50,50,50,50,cv2.BORDER_REPLICATE)
reflect = cv2.copyMakeBorder(img1,50,50,50,50,cv2.BORDER_REFLECT)
reflect101 = cv2.copyMakeBorder(img1,50,50,50,50,cv2.BORDER_REFLECT_101)
wrap = cv2.copyMakeBorder(img1,50,50,50,50,cv2.BORDER_WRAP)
constant= cv2.copyMakeBorder(img1,50,50,50,50,cv2.BORDER_CONSTANT,value=red)

# print results
# subplot (rows - columns - plot number)
plt.subplot(231),plt.imshow(img1,'gray'),plt.title('ORIGINAL')
plt.subplot(232),plt.imshow(replicate,'gray'),plt.title('REPLICATE')
plt.subplot(233),plt.imshow(reflect,'gray'),plt.title('REFLECT')
plt.subplot(234),plt.imshow(reflect101,'gray'),plt.title('REFLECT_101')
plt.subplot(235),plt.imshow(wrap,'gray'),plt.title('WRAP')
plt.subplot(236),plt.imshow(constant,'gray'),plt.title('CONSTANT')

plt.show()
```

Border Extrapolation and Boundary Conditions



Thresholding

- The simplest segmentation method

- Application example: **Separate out regions** of an image corresponding to objects **which we want to analyze**. This separation is based on the variation of intensity between the object pixels and the background pixels.

- **To differentiate the pixels we are interested** in from the rest (which will eventually be rejected), we perform a comparison of each pixel intensity value with respect to a *threshold* (determined according to the problem to solve).

- Once we have separated properly the important pixels, we can set them with a determined value to identify them (i.e. we can assign them a value of (black), white) or any value that suits your needs).

https://docs.opencv.org/2.4/doc/tutorials/imgproc/threshold/threshold.html

Thresholding

- cv2.THRESH_BINARY
- cv2.THRESH_BINARY_INV
- cv2.THRESH_TRUNC
- cv2.THRESH_TOZERO
- cv2.THRESH_TOZERO_INV

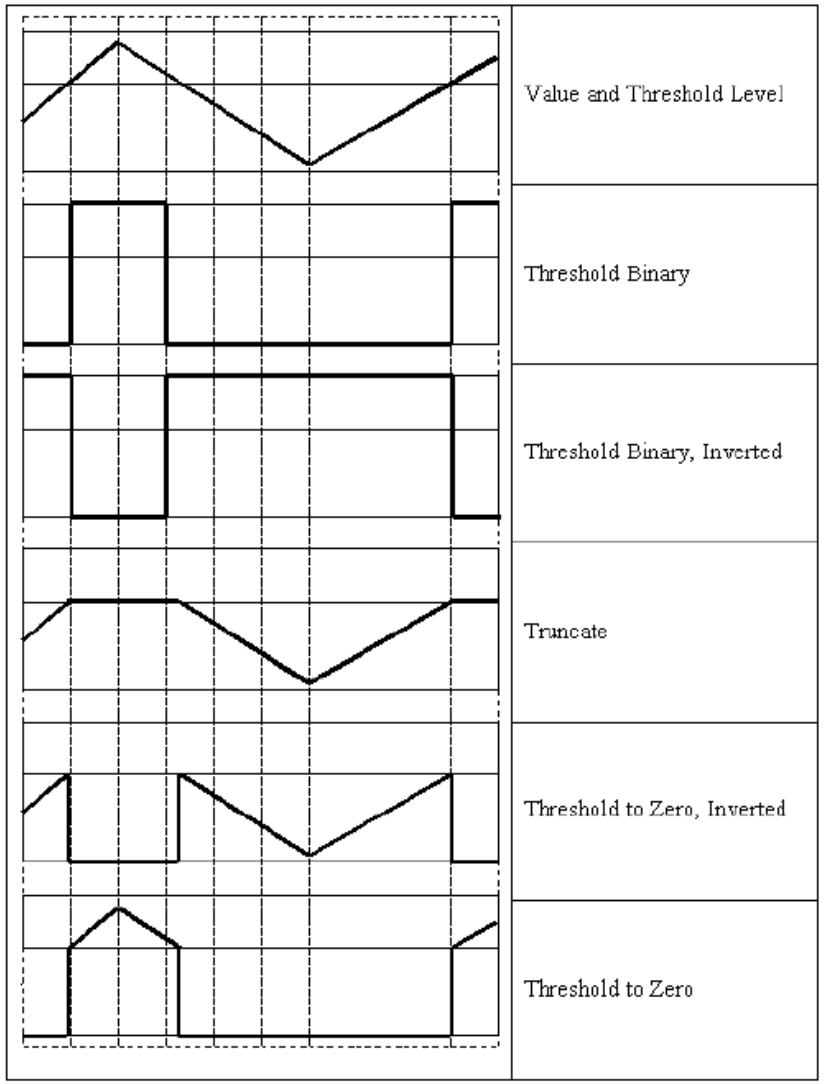


Image Source

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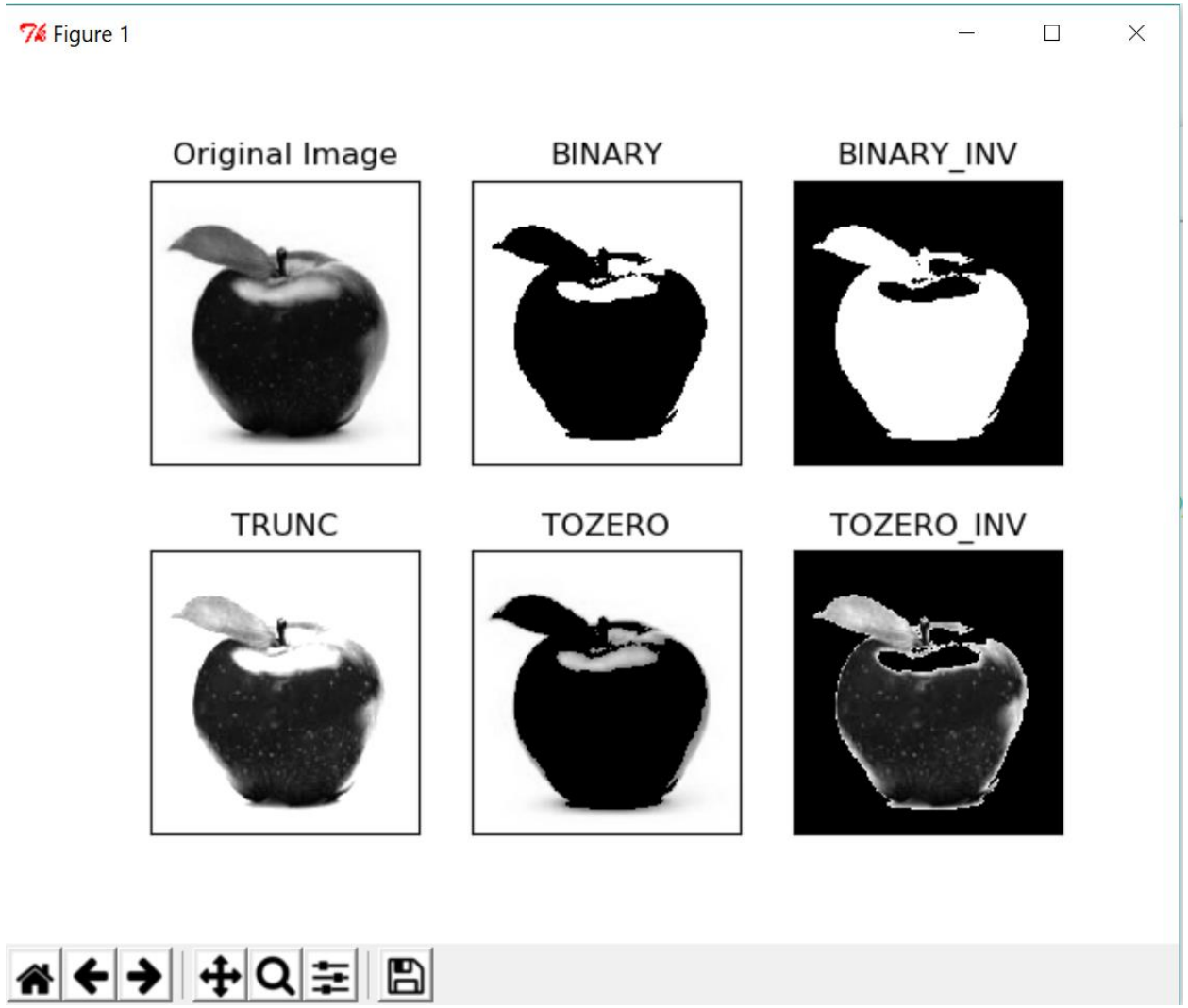
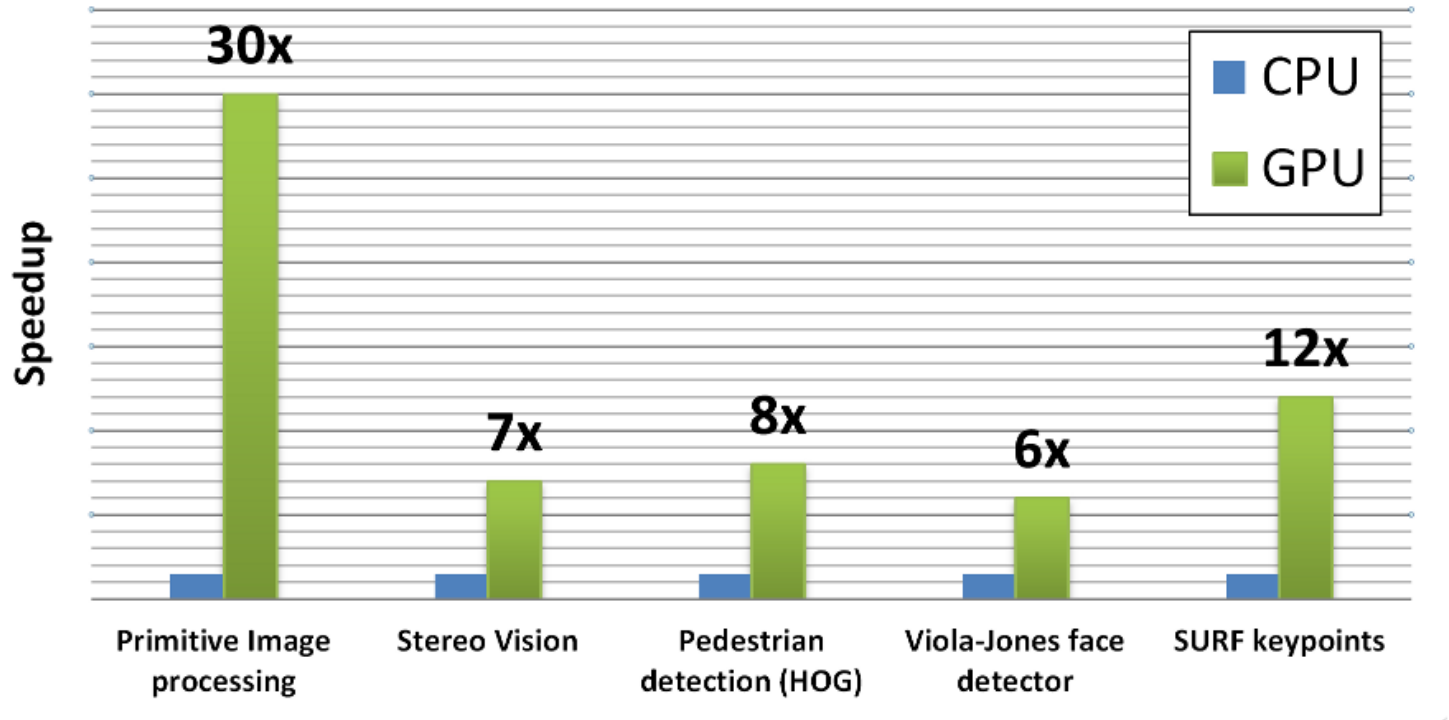
Thresholding

```
import cv2
import numpy as np
from matplotlib import pyplot as plt

# Load input image
img = cv2.imread('input.png',0)

# Use different tresholds
ret,thresh1 = cv2.threshold(img,127,255,cv2.THRESH_BINARY)
ret,thresh2 = cv2.threshold(img,127,255,cv2.THRESH_BINARY_INV)
ret,thresh3 = cv2.threshold(img,127,255,cv2.THRESH_TRUNC)
ret,thresh4 = cv2.threshold(img,127,255,cv2.THRESH_TOZERO)
ret,thresh5 = cv2.threshold(img,127,255,cv2.THRESH_TOZERO_INV)

# show the results
titles = ['Original Image','BINARY','BINARY_INV','TRUNC','TOZERO','TOZERO_INV']
images = [img, thresh1, thresh2, thresh3, thresh4, thresh5]
for i in xrange(6):
    plt.subplot(2,3,i+1),plt.imshow(images[i],'gray')
    plt.title(titles[i])
    plt.xticks([]),plt.yticks([])
plt.show()
```

Thresholding



OpenCV and CUDA



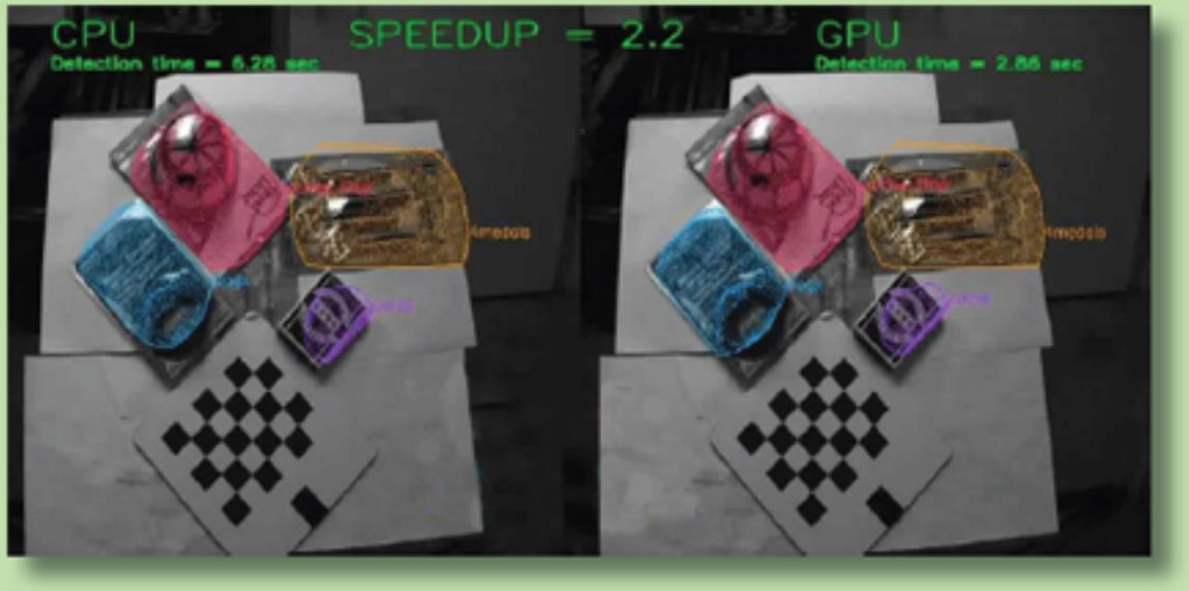
https://opencv.org/platforms/cuda.html

OpenCV and CUDA

FIGURE 3

Texture Object Detection Application: CPU and GPU

Objects
- coffee filter
- medals
- clog remover
- playing cards



https://opencv.org/platforms/cuda.html

Python + Raspberry Pi + Open CV

What you need.

- Raspberry Pi 3
- Pi Cam

https://www.codemade.io/programming-a-raspberry-pi-robot-using-python-and-opencv-2/

A good instruction guide:

https://www.pyimagesearch.com/2016/04/18/install-guide-raspberry-pi-3-raspbian-jessie-opencv-3/

Warning! It takes time. About 2-3 hours.

Recommendation: When you successfully install OpenCV, create a copy of your micro SD card.

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Raspberry Pi Camera Review

There are two ways to use the pi cam.

raspistill

- *Take a picture*
  - *raspistill -o picture.jpg*

```
import picamera

camera = picamera.PiCamera() # create a camera object
camera.capture('image.jpg') # take a picture
camera.start_preview() # show preview
camera.stop_preview() # stop preview
```

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Raspberry Pi Camera and OpenCV

```
# import the necessary packages
from picamera.array import PiRGBArray
from picamera import PiCamera
import time
import cv2

# initialize the camera and grab a reference to the raw camera capture
camera = PiCamera()
camera.resolution = (480, 288)

rawCapture = PiRGBArray(camera)

# allow the camera to warmup
time.sleep(0.1)

# grab a single frame from the camera
camera.capture(rawCapture, format="bgr")
frame = rawCapture.array

# image processing
frame = cv2.cvtColor(frame, cv2.COLOR_BGR2GRAY)

# display the image on screen and wait for a keypress
cv2.imwrite("result1.jpg", frame)

cv2.waitKey(0)
```

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OpenCV and Raspberry Pi Cam Video Demo

```
# import the necessary packages
from picamera.array import PiRGBArray
from picamera import PiCamera
import numpy as np
import time
import cv2

# initialize the camera and grab a reference to the raw camera capture
camera = PiCamera()
camera.resolution = (640, 480)
camera.framerate = 32
rawCapture = PiRGBArray(camera, size=(640, 480))

# allow the camera to warmup
time.sleep(0.1)

# Define codec
fourcc = cv2.VideoWriter_fourcc(*'DIVX')
out =  cv2.VideoWriter('video.avi', fourcc, 20.0, (640, 480), False)

# capture frames from the camera
for frame in camera.capture_continuous(rawCapture, format="bgr", use_video_port=True):

    # grab the raw NumPy array representing the image
    image = frame.array

    # show the frame
    cv2.imshow("Original", image)

    # color conversion
    grayscale = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)

    # show the frame
    cv2.imshow("Grayscale", grayscale)

    #Canny edge detection
    edges = cv2.Canny(grayscale, 30, 90)

    # show the frame
    cv2.imshow("Edges", edges)

    #write the frame to a video
    out.write(edges)

    # clear the stream in preparation for the next frame
    rawCapture.truncate(0)

    key = cv2.waitKey(1) & 0xFF

    # if the `q` key was pressed, break from the loop
    if key == ord("q"):
        break

out.release()
print("done")
cv2.destroyAllWindows()
```

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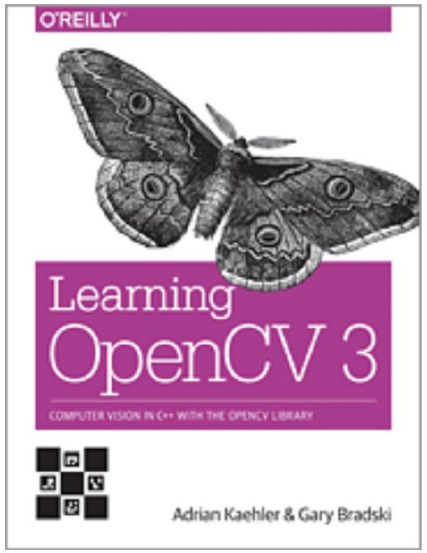
Books

- Learning OpenCV 3 Computer Vision in C++ with the OpenCV Library
- OpenCV 2 Computer Vision Application Programming Cookbook
- Learning OpenCV 3 Computer Vision with Python



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Questions?

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