Review

- Practice problems
- Image Processing
- Images – a 2D arrangement of colors
- Color – RGBA
- The color data type
- loadPixels(), getPixel(), setPixel(), updatePixels()
- immediateMode(), redraw(), delay()
- Animating with images
- PImage class, methods
- Examples that manipulate pixels
- Creative image processing – Pointillism

“Creative” Image Processing - Cat made of glyphs

```
# cat.py
from Processing import *

img = loadImage("cat.jpg")
w, h = img.width(), img.height()
window(w, h)
noStroke()
ellipseMode(CENTER)

# Cover with random shapes
img.loadPixels()
for i in xrange(30000):
    # Add a random colored glyphs to recreate the image
    x = int(random(w))
    y = int(random(h))
    c = img.getPixel(x, y)
    fill(c)

    # Choose a glyph
    text("C", x, y)
    #ellipse(x, y, 7, 7)
```


Calico

Convert a Color Image to Grayscale

- Average of RGB
  - Use the average of the red, green and blue color components as gray
- Lightness
  - Use the average of the max and min of (red + green + blue) as gray
- Luminance: a heuristic based on human perception
  - Humans are more sensitive to green, less sensitive to red, and even less sensitive to blue
  - Model used by HDTV:
  - gray = 0.2126 * red(c) + 0.7152 * green(c) + 0.0722 * blue(c)

Convert a Color Image to Grayscale

```
# Compute the "lightness" of a color
def lightness( c ):
    r = red(c)
    g = green(c)
    b = blue(c)
    return 0.5*(max(r, g, b) + min(r, g, b))


# Compute average of three color components
def average( c ):
    return (red(c) + green(c) + blue(c))/3.0


# Compute luminance with model used for HDTV
def luminance( c ):
    return 0.2126 * red(c) + 0.7152 * green(c) + 0.0722 * blue(c)
```

Convert a Color Image to Grayscale

```
# grayscale.py
# Convert color image to grayscale

from Processing import *

# Load the image to process
img = loadImage("kodim01.png")

# Create a window of the same size
w = int( img.width() )
h = int( img.height() )
window( w, h )

image( img, 0, 0)        # Draw the image
```

Convert a Color Image to Grayscale

```
# Perform the grayscale conversion
def grayscale(o, e):
    image( img, 0, 0)                   # Redraw the original image

    loadPixels()                        # Load pixels
    for i in range(w):                  # Loop over all pixels
        for j in range(h):
            c = getPixel(i, j)          # Get the color

            gray = lightness(c)         # Convert using lightness
            #gray = average(c)           # Convert using average
            #gray = luminance(c)         # Convert using luminance

            setPixel(i, j, color(gray))
    updatePixels()                      # Update pixels in image

# When the mouse is pressed, perform the conversion
onMousePressed += grayscale
```

Convert a Color Image to Grayscale - Lightness

grayscale.py

Convert a Color Image to Grayscale - Average

grayscale.py

Convert a Color Image to Grayscale - Luminance

grayscale.py

Thresholding

- Pixels below a cutoff value are set to black, white otherwise

threshold.py

```
# threshold.py
# Demonstrating the threshold function

from Processing import *

# Load the image to process
img = loadImage("kodim01.png")

# Compute luminance with model used for HDTV
def luminance( c ):
    return 0.2126 * red(c) + 0.7152 * green(c) + 0.0722 * blue(c)

# Create a window of the same size
w = int( img.width() )
h = int( img.height() )
window( w, h )

# Draw the image
image( img, 0, 0)
```

threshold.py

```
# Perform the threshold function
def threshold(o, e):
    image( img, 0, 0)                # Redraw the original image
    cutoff = mouseY()                # Get the cutoff as the y mouse position
    print( "cutoff =", cutoff )
    loadPixels()                     # Load pixels in preparation for processing

    # Loop over all pixels
    for i in range(w):
        for j in range(h):
            c = getPixel(i, j)       # Get the color

            gray = luminance( c )    # Convert the color to grayscale
            if gray >= cutoff:       # Compute threshold:
                gray = 255           # white if above cutoff
            else:
                gray = 0             # black if below cutoff
                                     # Reset color to threshold value
            setPixel(i, j, color(gray))

    updatePixels()                   # Update pixels in image

# When the mouse is pressed, perform the threshold function
onMousePressed += threshold
```

threshold.py

Creative Thresholding

```
# webicon.py
from Processing import *

# Define colors
darkBlue = color(0, 51, 76)
reddish = color(217, 26, 33)
lightBlue = color(112, 150, 158)
yellow = color(252, 227, 166)

# Load image
img = loadImage("obama.jpg")
w = int( img.width() )
h = int( img.height() )

# Open a window and draw the initial image
window( w, h )
image(img, 0, 0)

# Compute luminance with model used for HDTV
def luminance( c ):
    return 0.2126 * red(c) + 0.7152 * green(c) + 0.0722 * blue(c)

# Load pixels so they can be manipulated
loadPixels()
```

webicon.py

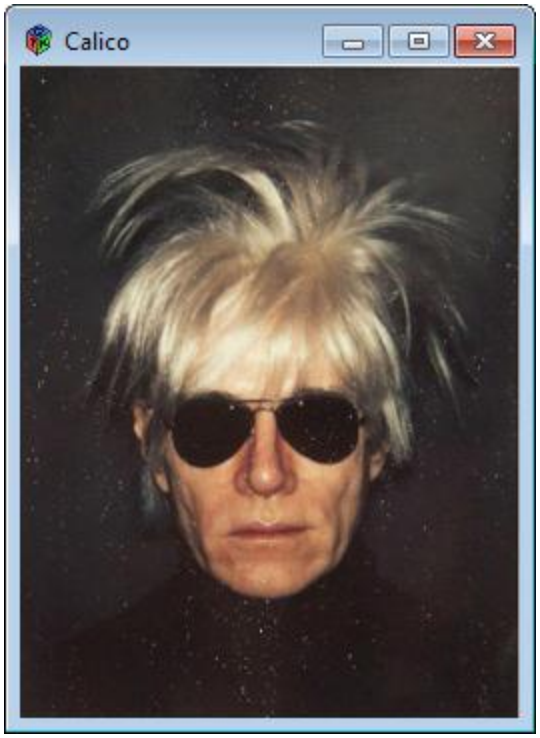
```
# Loop over all pixels in the images
for i in range(w):
    for j in range(h):

        c = getPixel(i, j)                  # Get pixel color
        total = luminance( c )              # Compute luminance

        if total < 60:                      # Remap to new color
            newColor = darkBlue
        elif total < 121:
            newColor = reddish
        elif total < 147:
            newColor = lightBlue
        else:
            newColor = yellow

        setPixel(i, j, newColor)            # Update to new color

updatePixels()                              # Update
```

webicon.py

Other Single-Pixel Filters

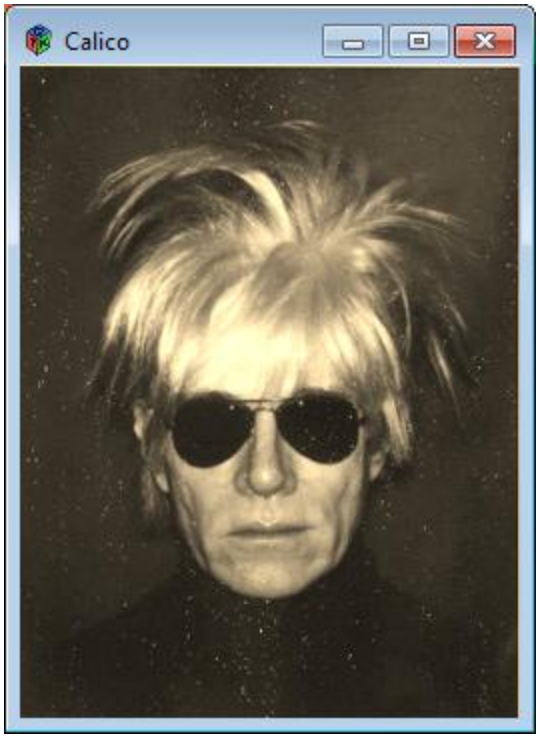
```
# Negative Filter
def negative( c ):
    return color(255-red(c), 255-green(c), 255-blue(c))

# Sepia Filter
def sepia( c ):
    r = int( red(c)*0.393 + green(c)*0.769 + blue(c)*0.189 )
    g = int( red(c)*0.349 + green(c)*0.686 + blue(c)*0.168 )
    b = int( red(c)*0.272 + green(c)*0.534 + blue(c)*0.131 )
    r = constrain( r, 0, 255 )
    g = constrain( g, 0, 255 )
    b = constrain( b, 0, 255 )
    return color(r, g, b)
```

filter.py



Original

Negative



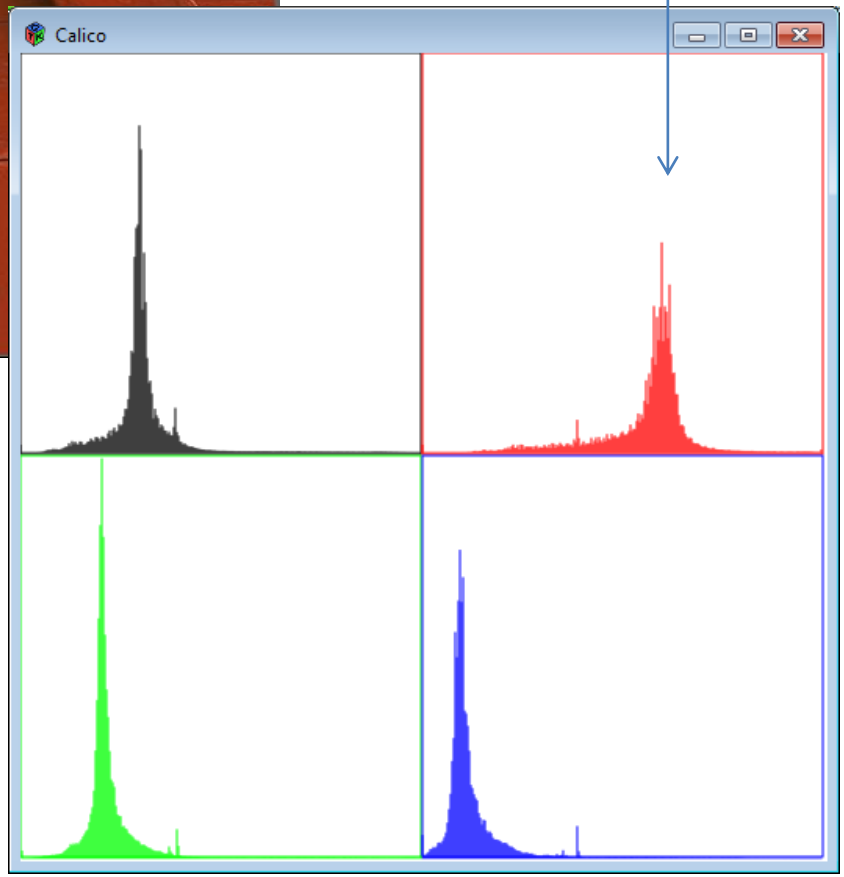
Sepia

filter.py

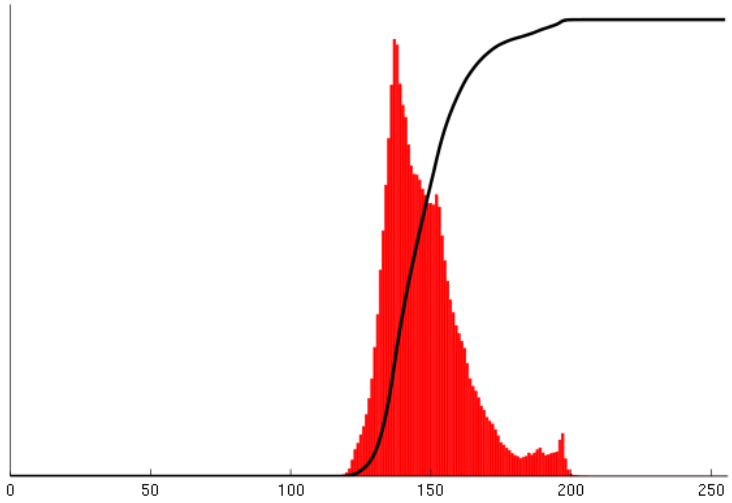
Histogram Equalization

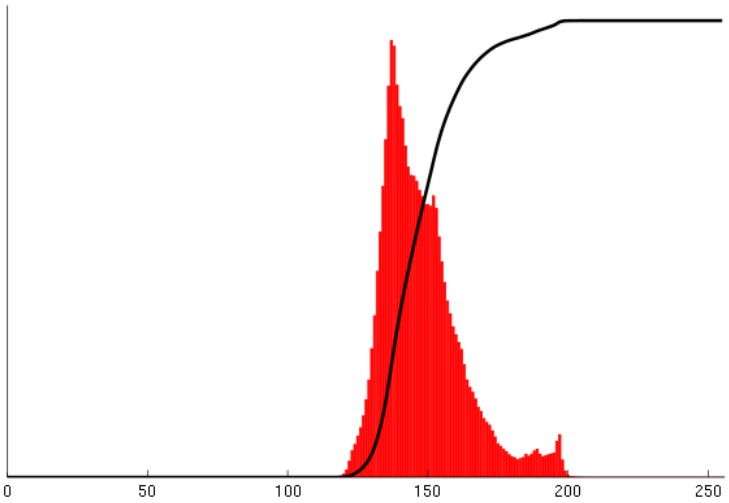
- Increases the global contrast of images
- Intensities are better distributed
- Reveals more details in photos that are over or under exposed
- Better views of bone structure in X-rays

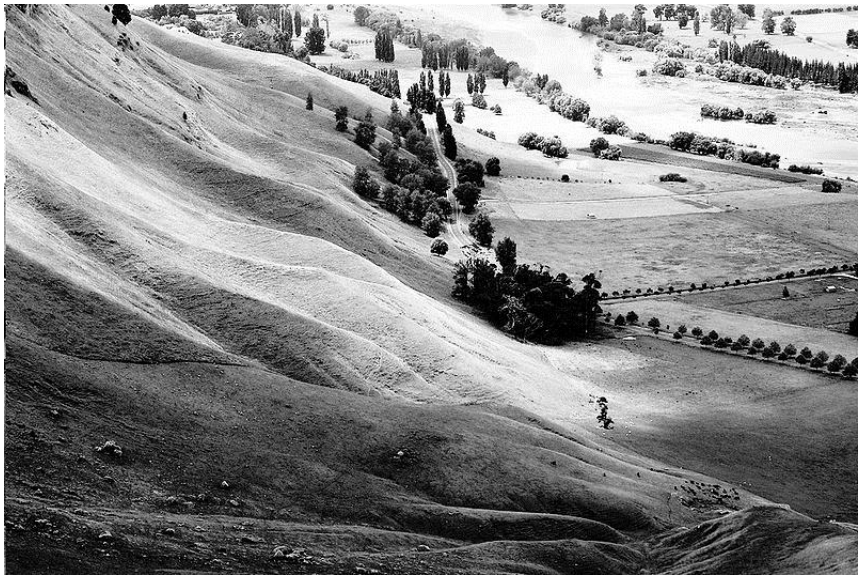
Shift to the right
implies brighter reds



histogram.py


0
50
100
150
200
250


0
50
100
150
200
250




0
50
100
150
200
250

Histogram Equalization

Procedure:

- Calculate color frequencies - count the number of times each pixel color appear in the image
- Calculate the cumulative distribution function (cdf) for each pixel color – the number of times all smaller color values appear in the image
- Normalize over (0, 255)

Spatial Filtering (aka Area-Based Filters)

Original

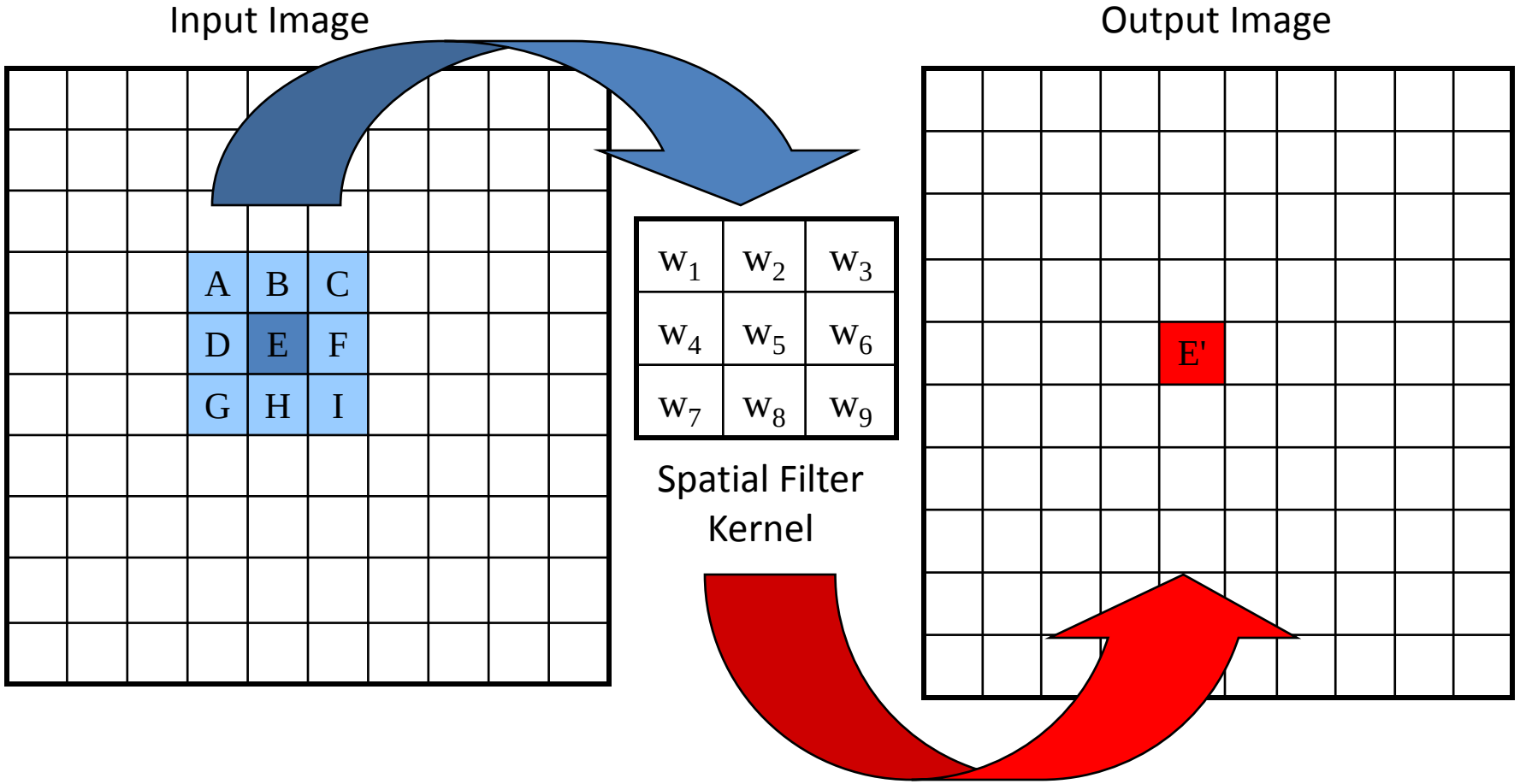
Sharpen

Edge Detection

Gaussian Blur

spatial.py

Spatial Filtering (aka Area-Based Filters)



$$E' = w_1A+w_2B+w_3C+w_4D+w_5E+w_6F+w_7G+w_8H+w_9I$$

Spatial Kernel Filters - Identity

- No change

0	0	0
0	1	0
0	0	0

Average – smooth

- Set pixel to the average of all colors in the neighborhood
- Smooths out areas of sharp changes.

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

Blur – Low Pass Filter

- Softens significant color changes in image
- Creates intermediate colors
- aka Gaussian Blur

1/16	2/16	1/16
2/16	4/16	2/16
1/16	2/16	4/16

Sharpen – High Pass Filter

- Enhances the difference between neighboring pixels
- The greater the difference, the more change in the current pixel

-1	-1	-1
-1	9	-1
-1	-1	-1

0	-2/3	0
-2/3	11/3	-2/3
0	-2/3	0

```
# spatial.py
from Processing import *

# Sharpen
matrix = [[ -1., -1., -1. ],
          [ -1.,  9., -1. ],
          [ -1., -1., -1. ]]

# Load image and open a window
img = loadImage("moon.jpg")

w = int( img.width() )
h = int( img.height() )
window( w, h )
keepAbove(True)

# Draw the image on the window
img.loadPixels()
image(img,0,0)

# Filter rectangle
loadPixels()

# Apply filter
for r in range( 1, h-1):
    for c in range( 1, w-1):
        clr = spatialFilter(c, r, matrix, img)
        setPixel(c, r, clr)

updatePixels()
```

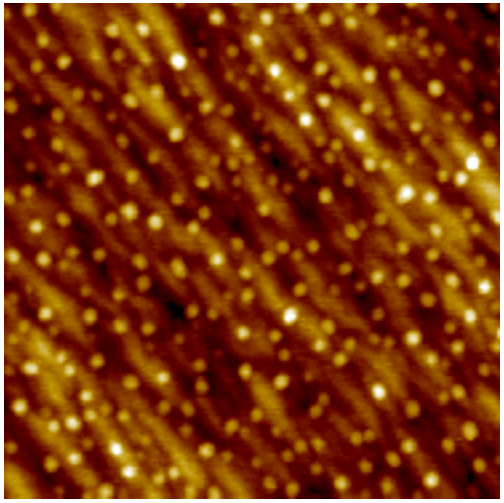
spatial.py

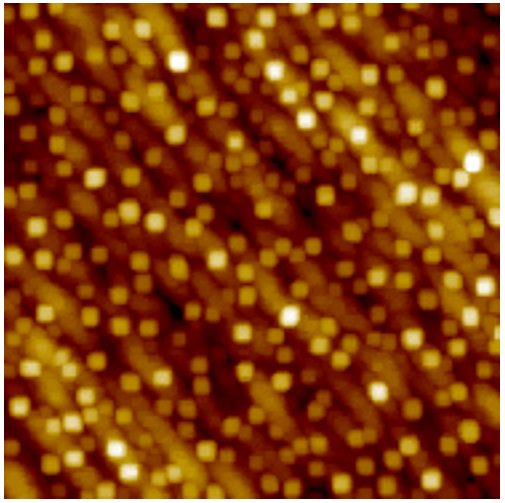
```
# Perform spatial filtering on one pixel location
def spatialFilter(c, r, matrix, img):
    rtotal = 0.0
    gtotal = 0.0
    btotal = 0.0

    # Loop through filter matrix
    for i in range(3):
        for j in range(3):

            # Get the weight position in the filter
            cc = c + j - 1
            rr = r + i - 1

            # Apply the filter
            pix = img.getPixel(cc, rr)
            mul = matrix[i][j]
            rtotal += red(pix) * mul
            gtotal += green(pix) * mul
            btotal += blue(pix) * mul

    # Make sure RGB is within range
    rtotal = constrain(rtotal,0,255)
    gtotal = constrain(gtotal,0,255)
    btotal = constrain(btotal,0,255)

    # Return resulting color
    return color(rtotal, gtotal, btotal)
```

spatial.py

Dilation - Morphology

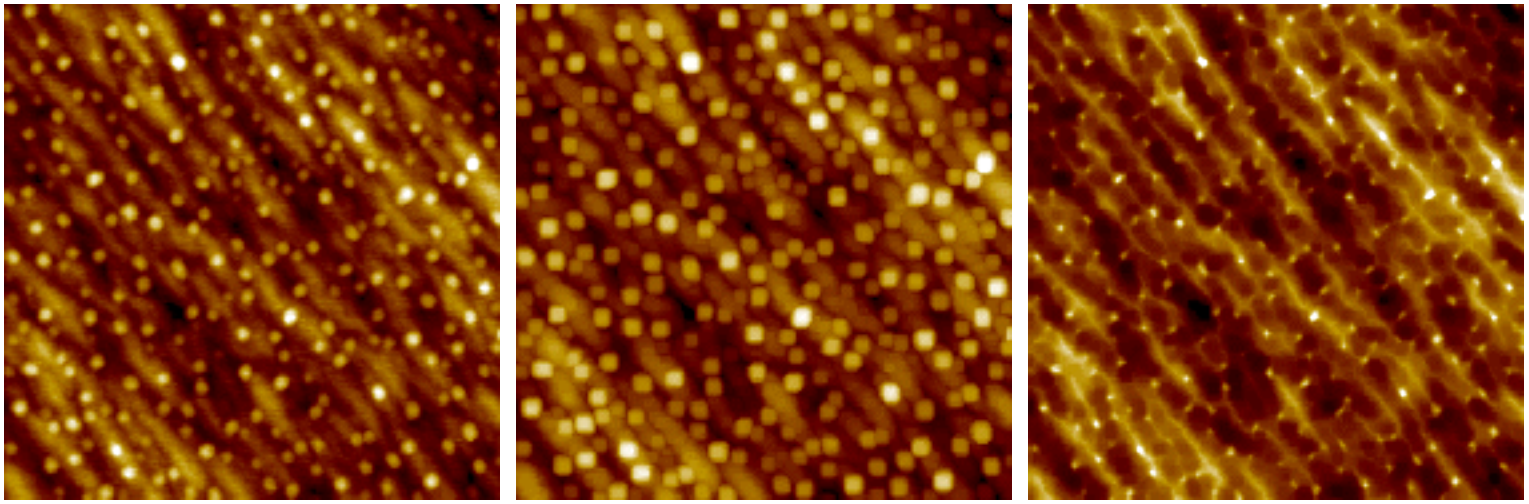
- Set new pixel color to the max color value within a 3x3 window around original pixel color
- Causes objects to grow in size.
- Brightens and fills in small holes





Erosion - Morphology

- Set new pixel color to the min color value within a 3x3 window around original pixel color
- Causes objects to shrink.
- Darkens and removes small objects



Erode + Dilate to Despeckle

erodedilate.py

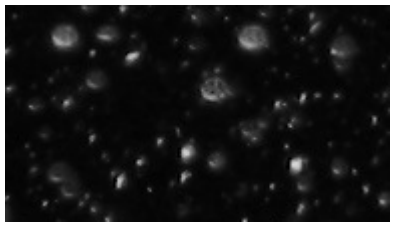
```
# erodedilate.py
from Processing import *

# Compute luminance with model used for HDTV
def luminance( c ):
    return 0.2126 * red(c) + 0.7152 * green(c) + 0.0722 * blue(c)

# Load image three times and open a window
img1 = loadImage("andy-warhol2.jpg")
img2 = loadImage("andy-warhol2.jpg")
img3 = loadImage("andy-warhol2.jpg")
w = img1.width()
h = img1.height()

window( w, h )
keepAbove(True)

image( img1,0,0 )       # Draw the first image on the window

print("Eroding...")
erode( img1, img2 )     # Erode image
image( img2,0,0 )       # Draw eroded image

print("Dilating...")
dilate( img2, img3 )    # Dilate image
image( img3,0,0 )       # Draw dilated image

print("Done")
```

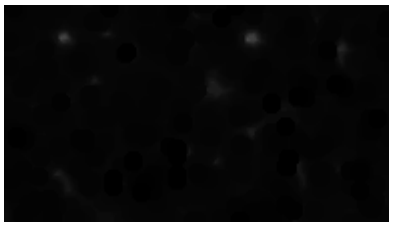
```
# Perform erosion on img1 and save to img2
def erode(img1, img2):
    # Load pixels and get dimensions
    img1.loadPixels()
    img2.loadPixels()
    w = img1.width()
    h = img1.height()

    # Loop over all pixels
    for r in range( 1, h-1 ):
        for c in range( 1, w-1 ):

            # Init min luminance and color
            minlum = 255
            minclr = color(255)

            # Loop over analysis region
            for i in range(3):
                for j in range(3):
                    # Compute indexes of adjacent pixels
                    cc = c + j - 1
                    rr = r + i - 1

                    # Update if luminance is lower
                    clr = img1.getPixel(cc, rr)
                    lum = luminance( clr )
                    if lum < minlum:
                        minlum = lum
                        minclr = clr

            # Set minimum color in img2
            img2.setPixel(c, r, minclr)

    # Copy modified pixels from buffer to image
    img2.updatePixels()
```

```
# Perform dilation on img1 and save to img2
def dilate(img1, img2):
    # Load pixels and get dimensions
    img1.loadPixels()
    img2.loadPixels()
    w = img1.width()
    h = img1.height()

    # Loop over all pixels
    for r in range( 1, h-1):
        for c in range( 1, w-1):

            # Init max luminance and color
            maxlum = 0
            maxclr = color(0)

            # Loop over analysis region
            for i in range(3):
                for j in range(3):
                    # Compute indexes of adjacent pixels
                    cc = c + j - 1
                    rr = r + i - 1

                    # Update if luminance is lower
                    clr = img1.getPixel(cc, rr)
                    lum = luminance( clr )
                    if lum > maxlum:
                        maxlum = lum
                        maxclr = clr

            # Set maximum color in img2
            img2.setPixel(c, r, maxclr)

    # Copy modified pixels from buffer to image
    img2.updatePixels()
```

Applications - Feature Extraction

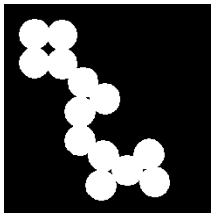
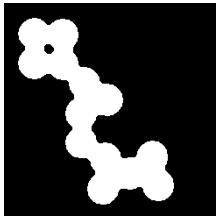
- Region detection – morphology manipulation
  - Dilate and Erode



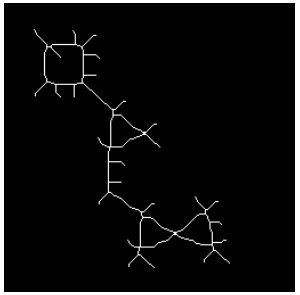
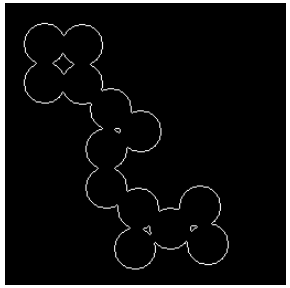


  - Open
    - Erode → Dilate
    - Small objects are removed

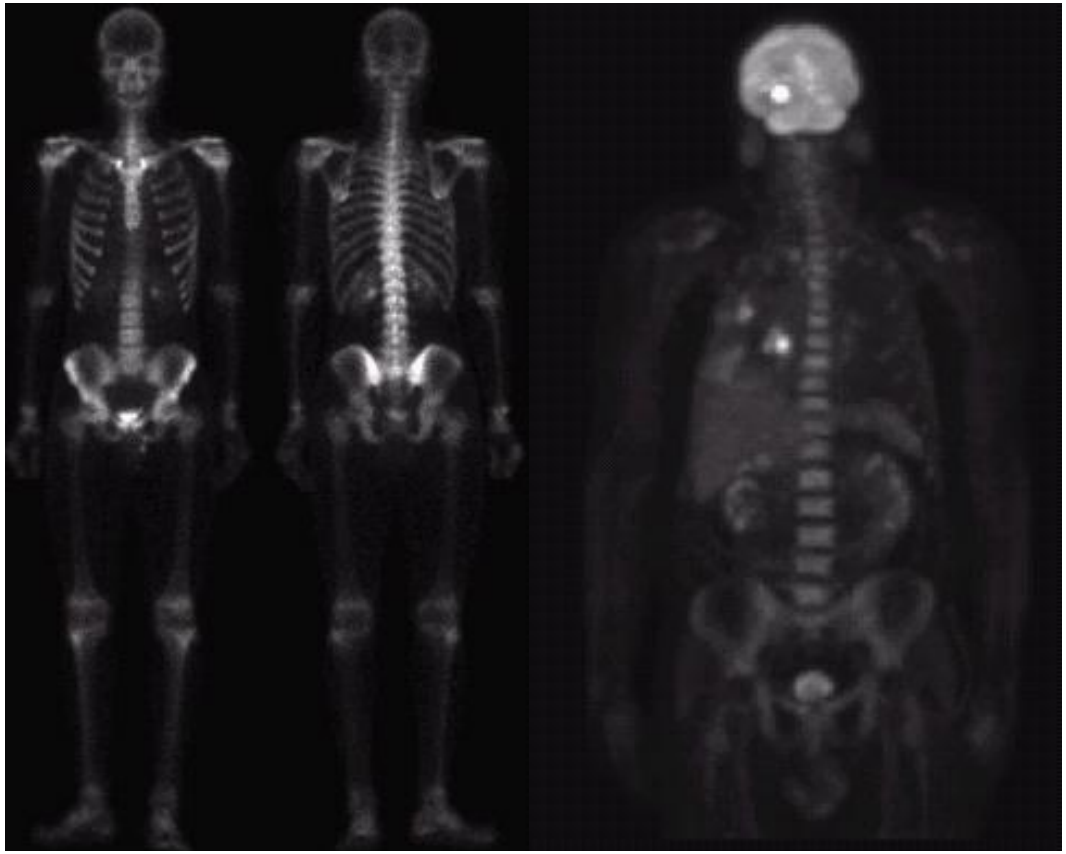
  - Close
    - Dilate → Erode
    - Holes are closed

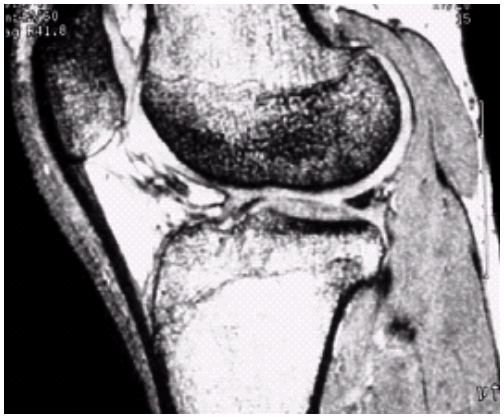



  - Skeleton and perimeter

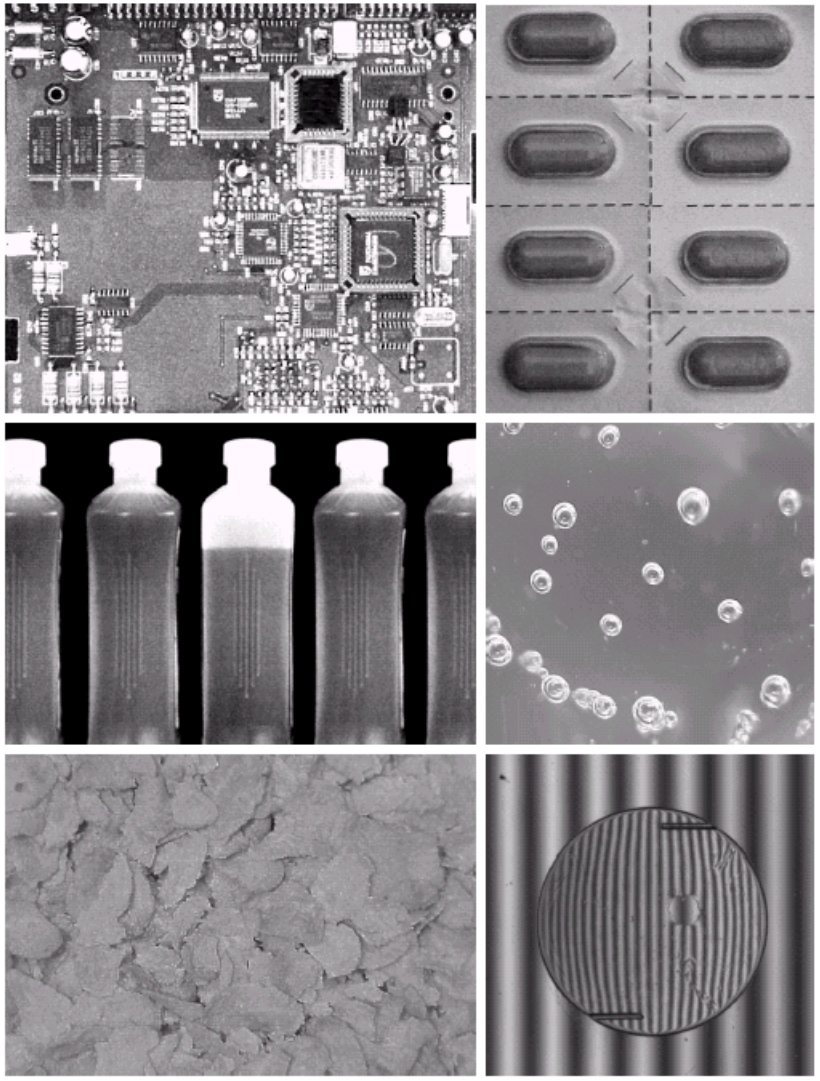




Applications - Medical Images





Applications - Manufacturing



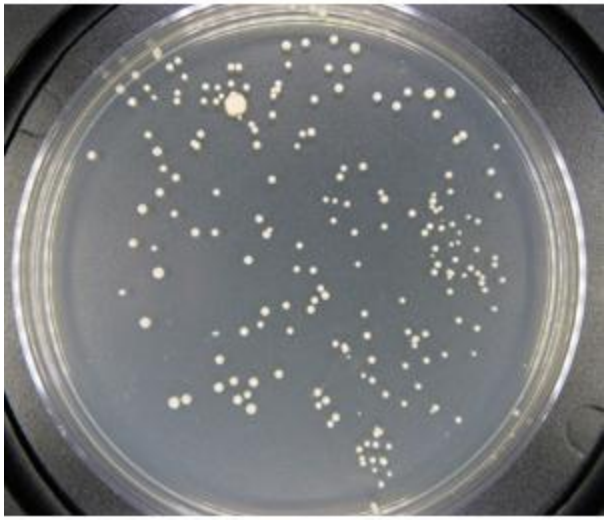
a b
c d
e f

FIGURE 1.14
Some examples of manufactured goods often checked using digital image processing. (a) A circuit board controller. (b) Packaged pills. (c) Bottles. (d) Bubbles in clear-plastic product. (e) Cereal. (f) Image of intraocular implant. (Fig. (f) courtesy of Mr. Pete Sites, Perceptics Corporation.)

Measuring Confluency in Cell Culture Biology

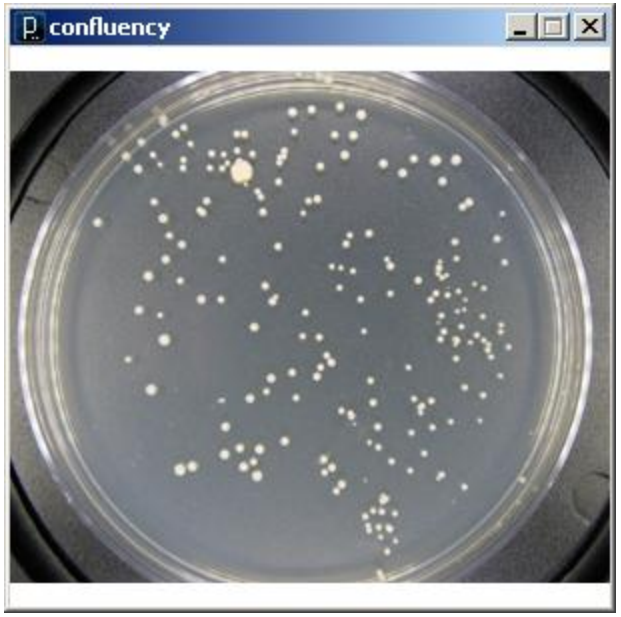
- Refers to the coverage of a dish or flask by cell colonies
- 100% confluency = completely covered

- Image Processing Method
  1. Mask off unimportant parts of image
  2. Threshold image
  3. Count pixels of certain color

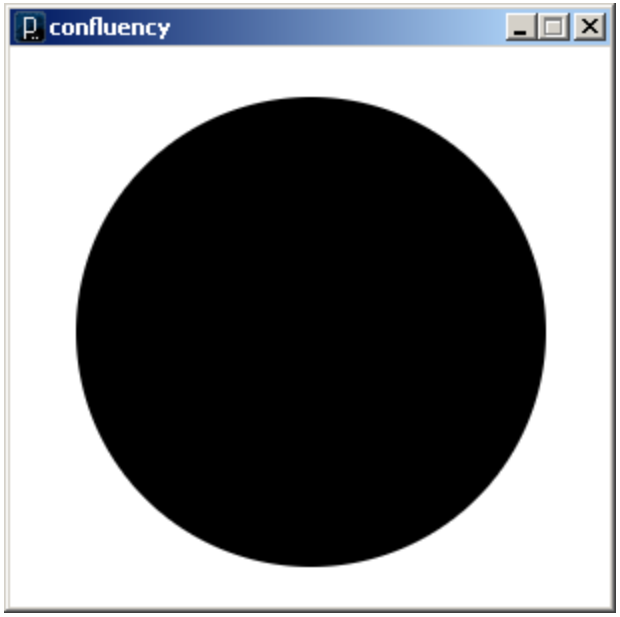


Blend: Subtract

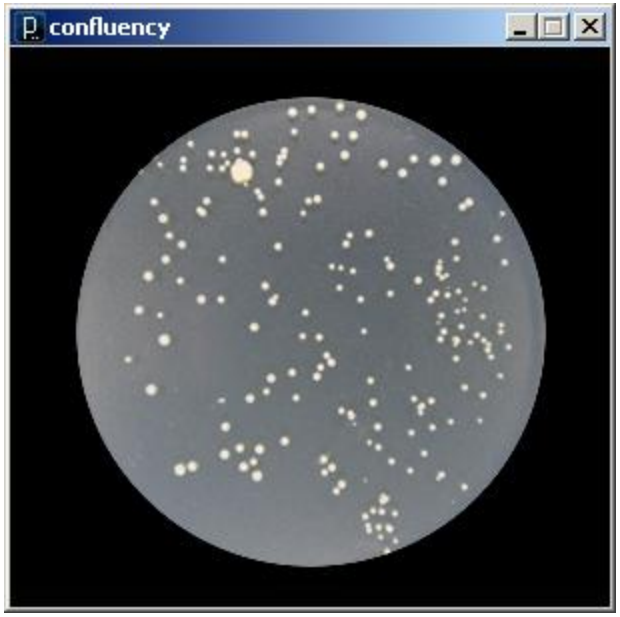
Original



Mask

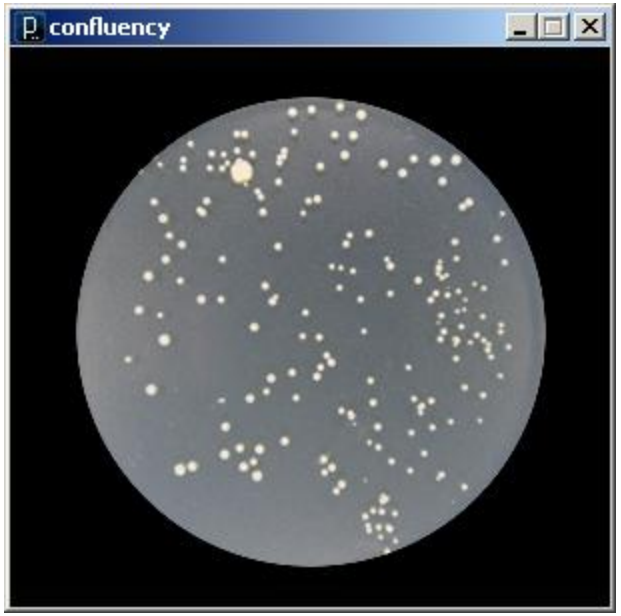


Subtracted

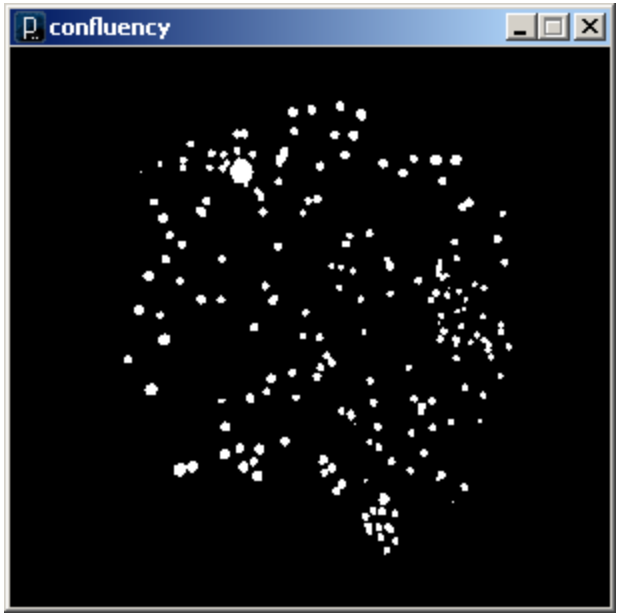


Filter: Theshold

Subtracted



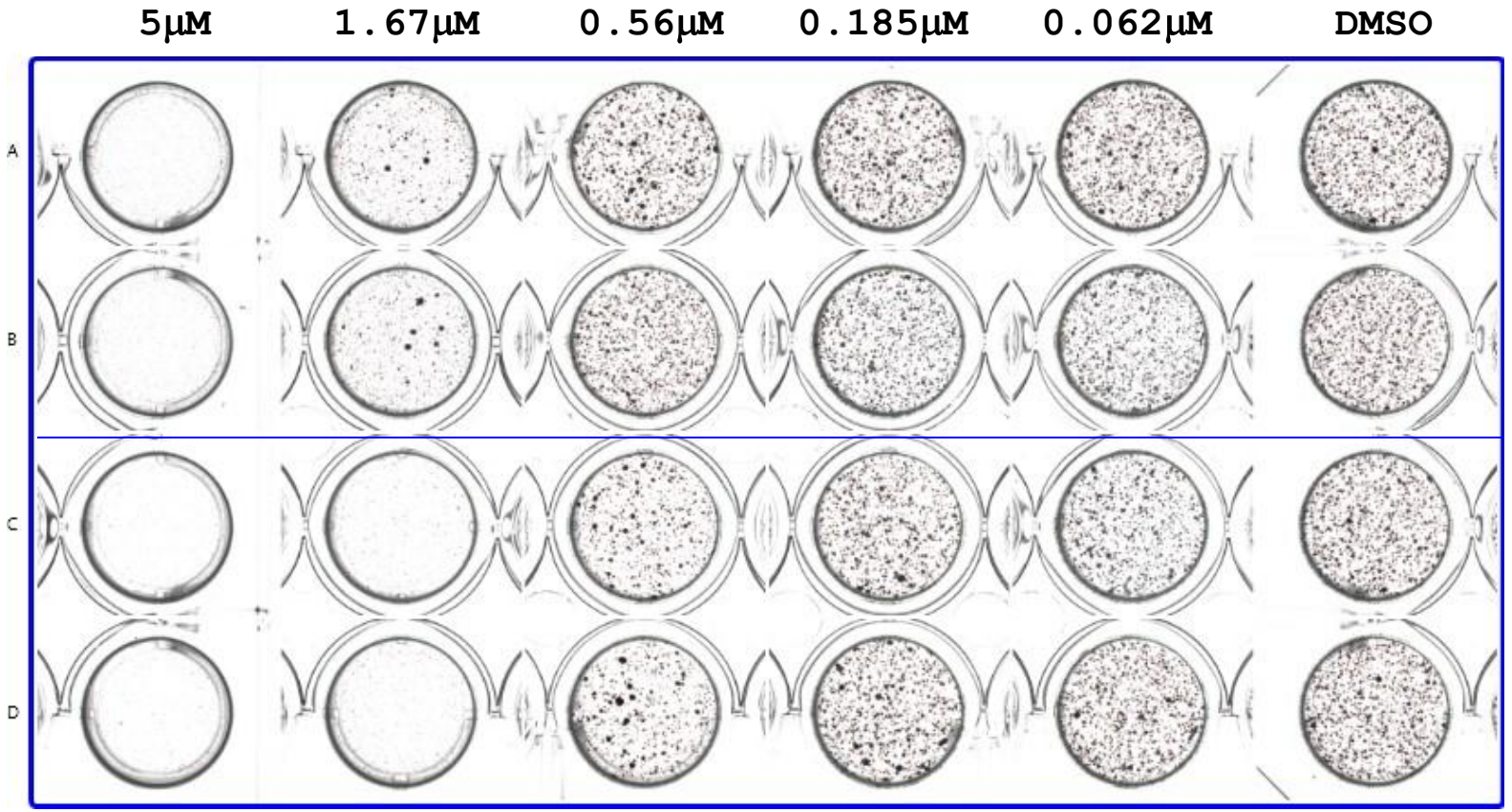
Threshold



Count Fraction of Pixels to Quantify

5.3% Confluency

IC_{50} determination



Vision Guided Robotics
Colony Picking

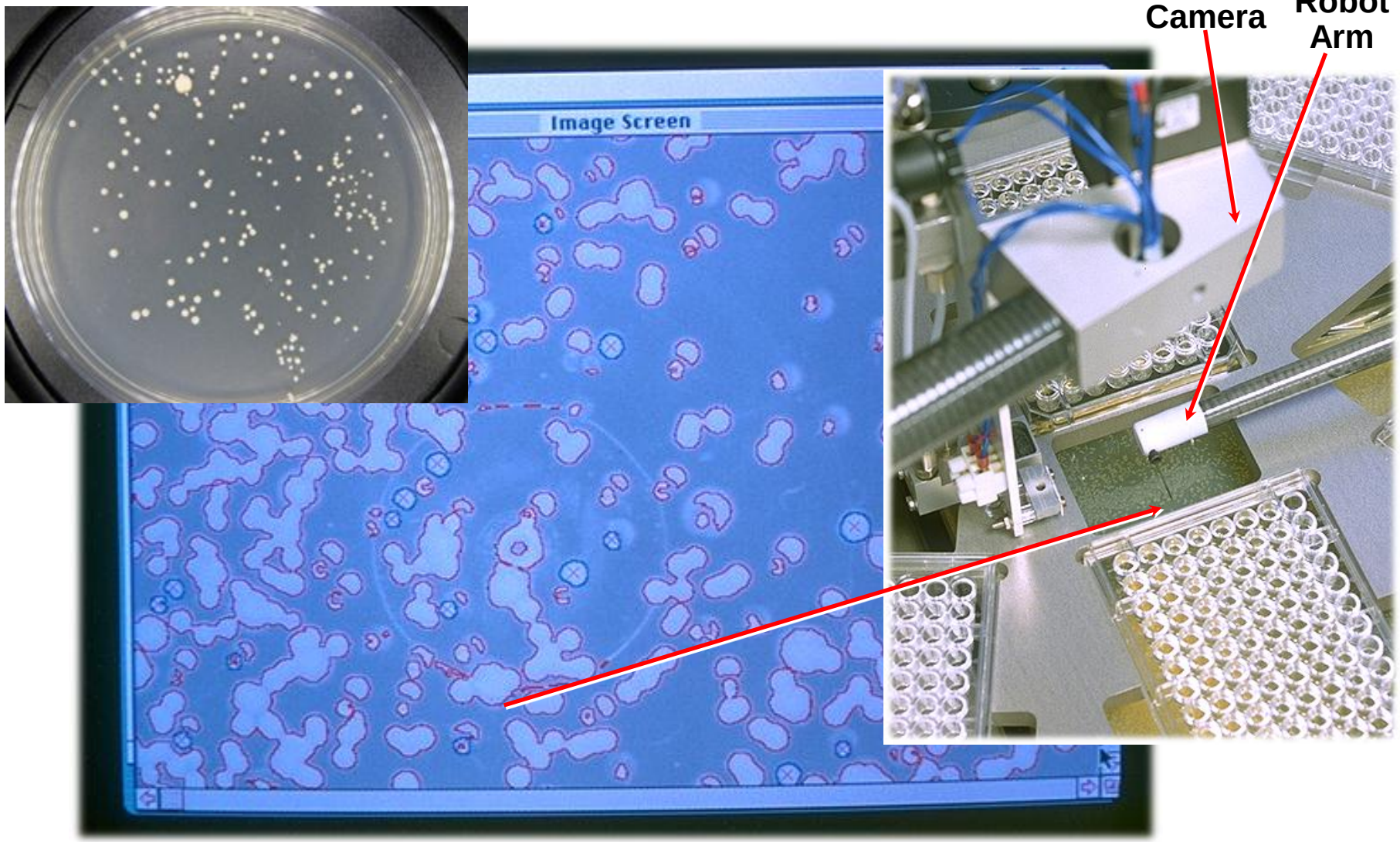
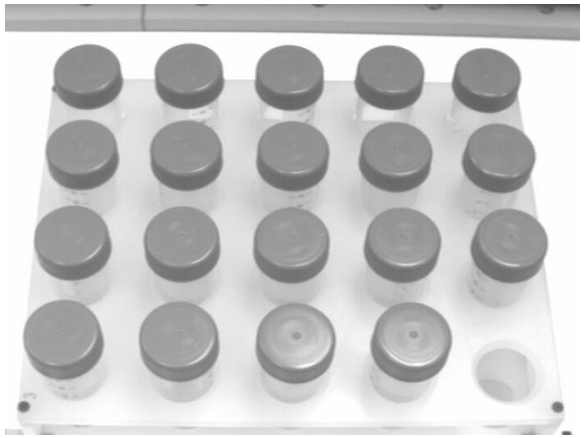
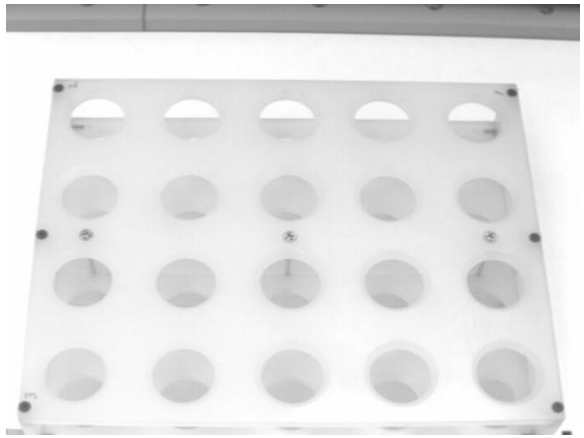


Image Processing





Compute the presence of objects or “particles”

Image Processing

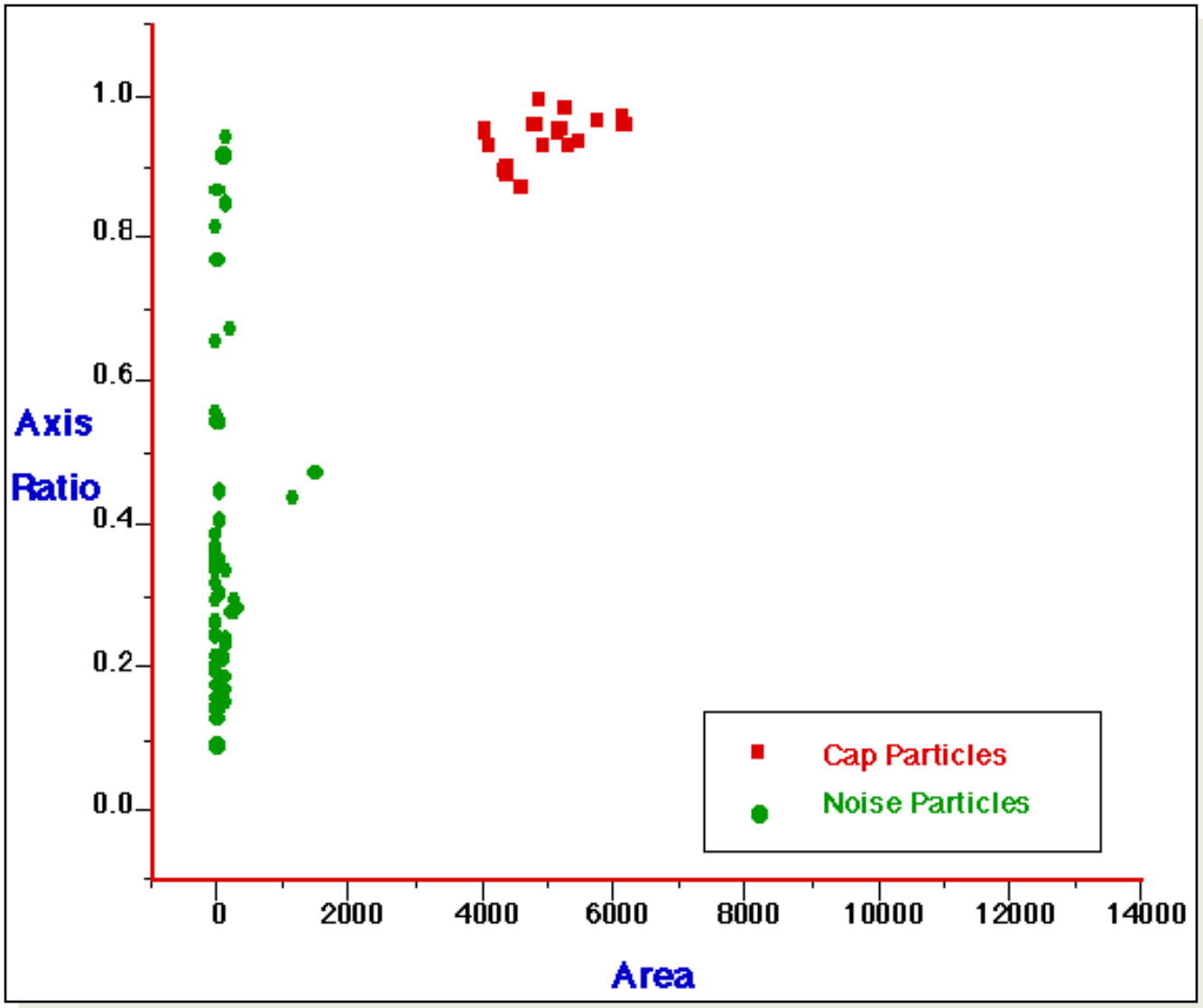


Image Processing

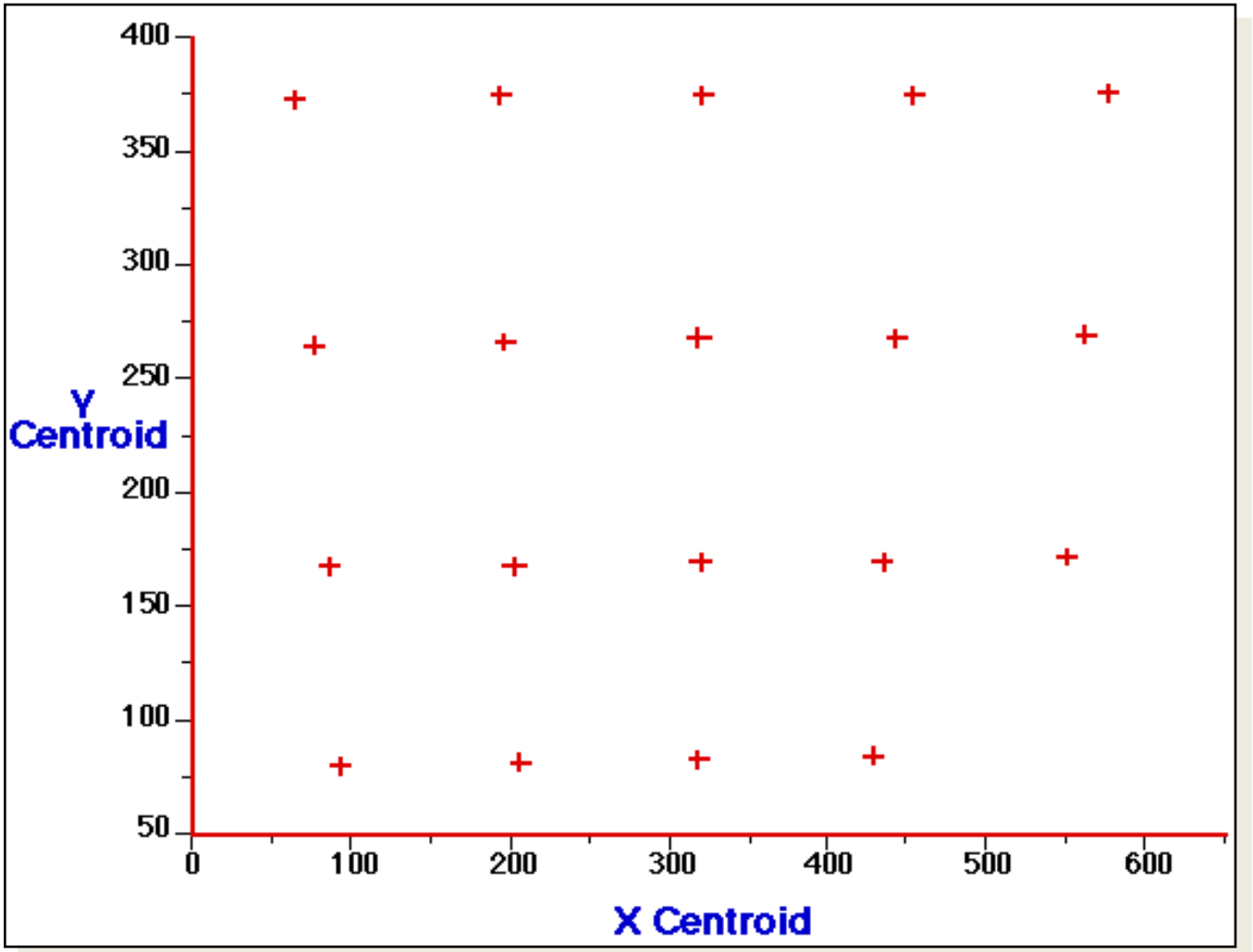
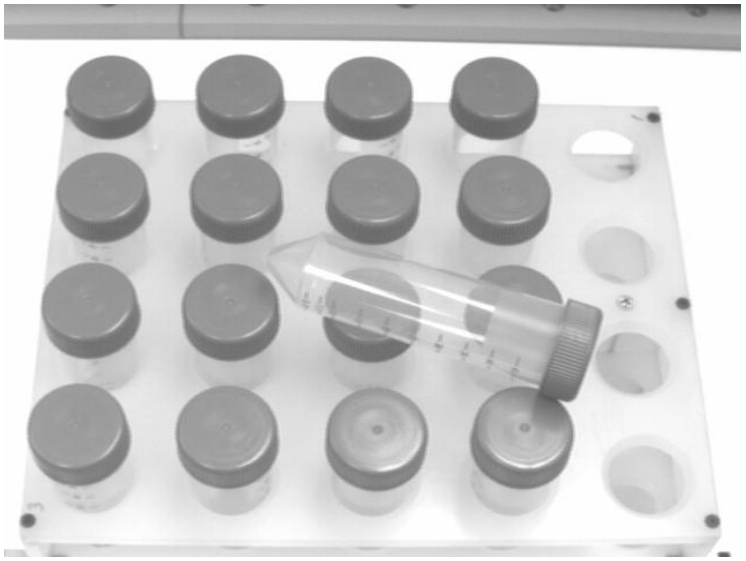


Image Processing



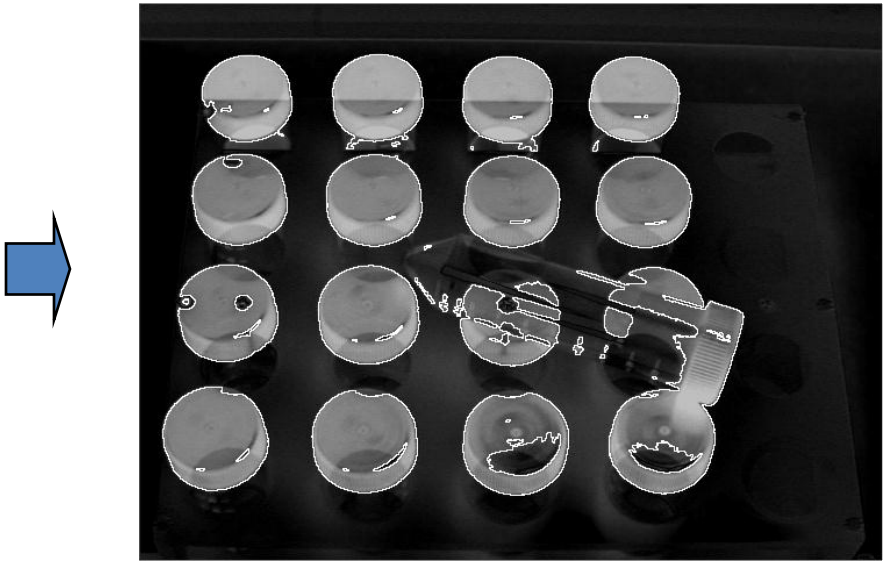
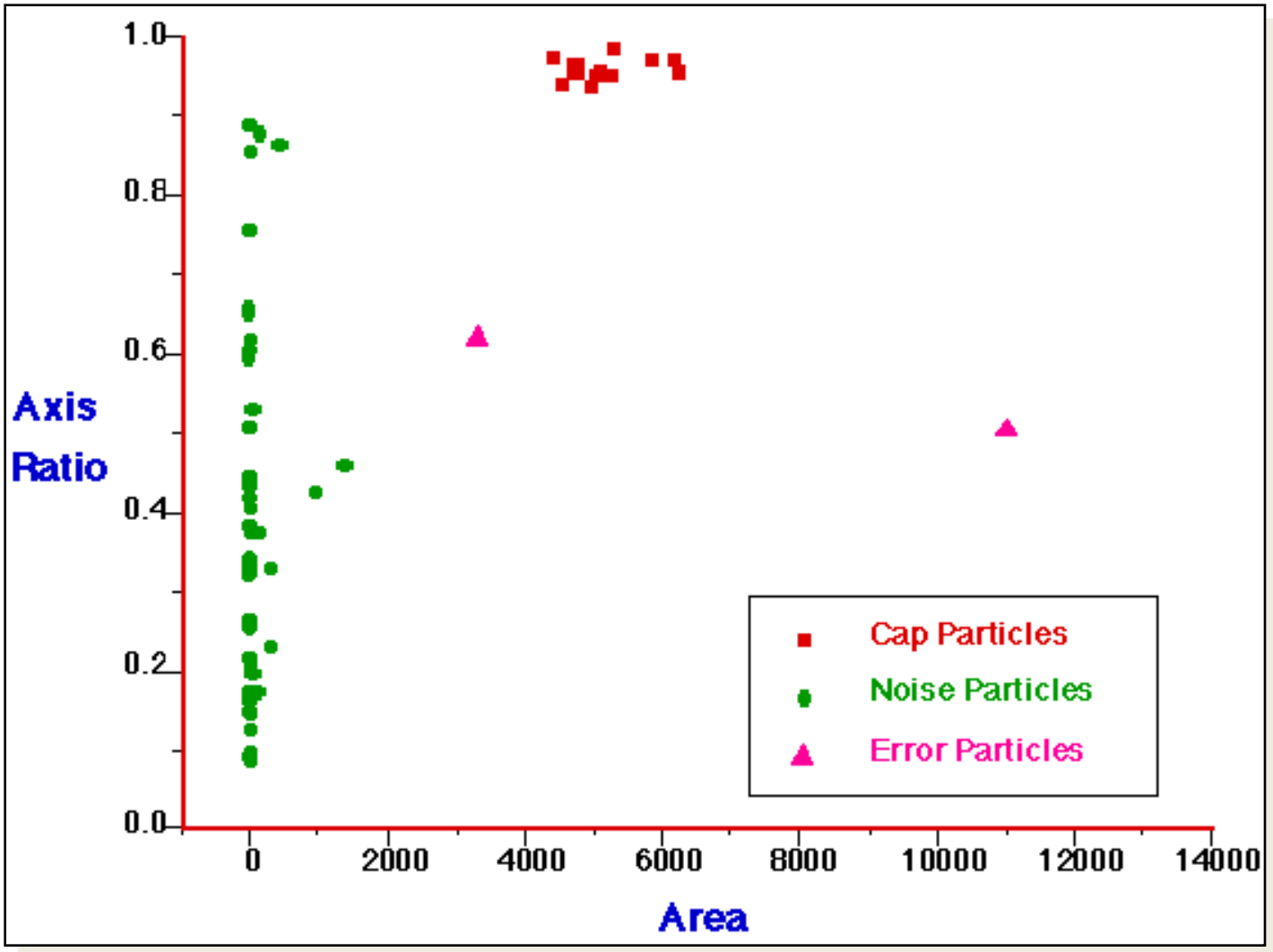


Image Processing



What can you do with Image Processing?

Inspect, Measure, and Count using Photos and Video
http://www.youtube.com/watch?v=KsTtNWVhpgI

Image Processing Software
http://www.youtube.com/watch?v=1WJp9mGnWSM

Manual Colony Counter
http://www.youtube.com/watch?v=7B-9Wf6pENQ

Automated Colony counter
http://www.youtube.com/watch?v=qtJmQqRHHag

Predator algorithm for object tracking with learning
http://www.youtube.com/watch?v=1GhNXHCQGsM

FACEDEALS
http://player.vimeo.com/video/47133014

Video Processing, with Processing
http://www.niklasroy.com/project/88/my-little-piece-of-privacy/
http://www.youtube.com/watch?v=rKhbUjVyKIc