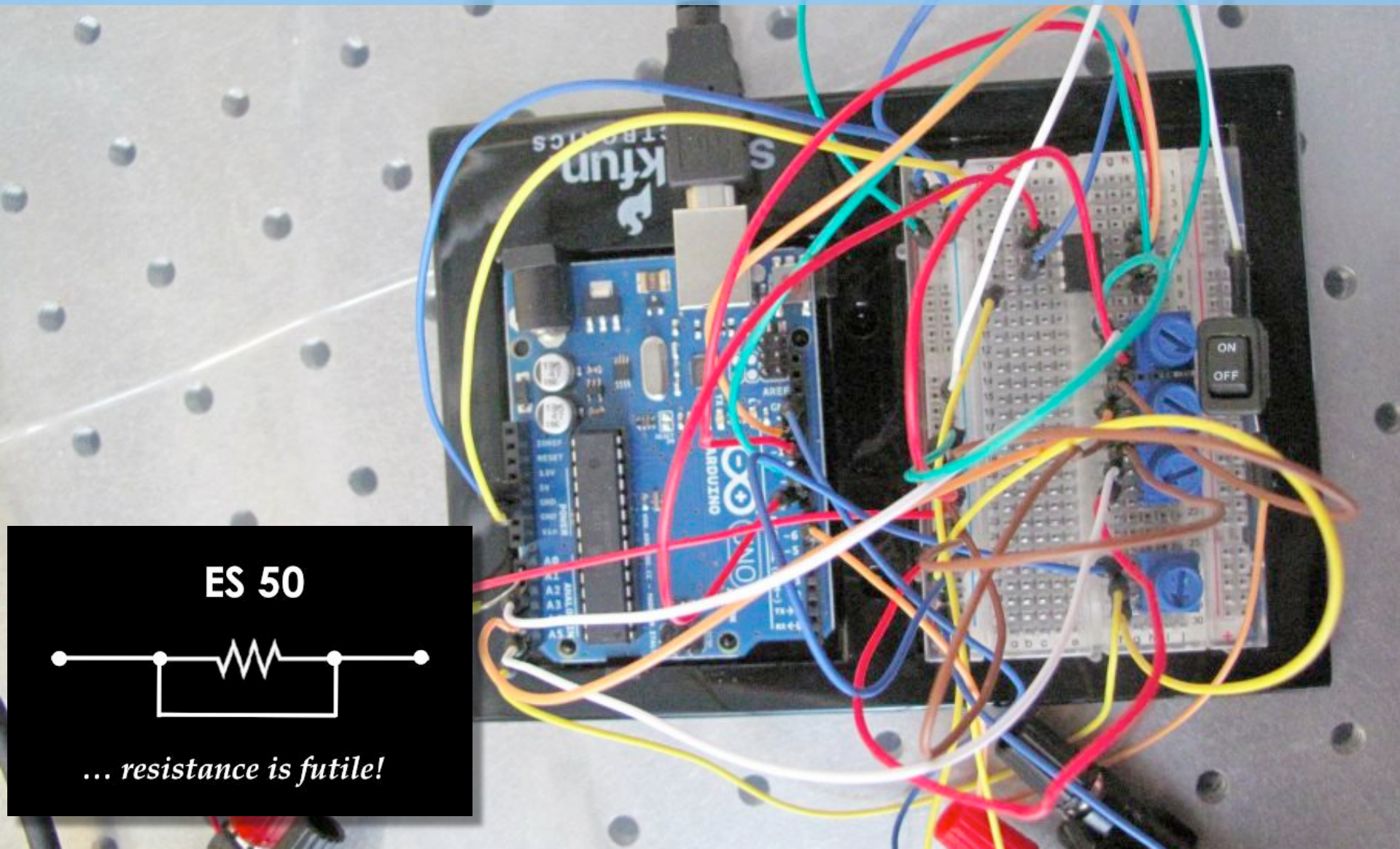
ES 50: Introduction to Electrical Eng.

Explore EE, satisfy a Gen Ed requirement & have fun



ES 50

… resistance is futile!

Lecture 15: 2D Signals & Images

November 9, 2015

HARVARD
School of Engineering and Applied Sciences

Announcements

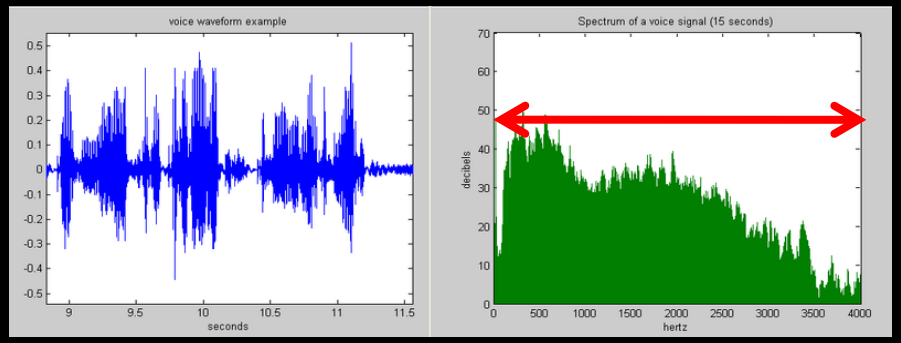
Parts List

- Please update your parts list with everything you need
  - Please list Arduino Unos, resistors, capacitors, etc.

Office Hours

- My Office hours will be tomorrow 330-430, in Pierce 287
- Thursday normal time

The important issues of signals 'good enough'; let's go back to audio



Waveform of speech

Response to AMPLITUDE of Audio Signal, in decibel (dB) Sound Power Level, a logarithmic scale

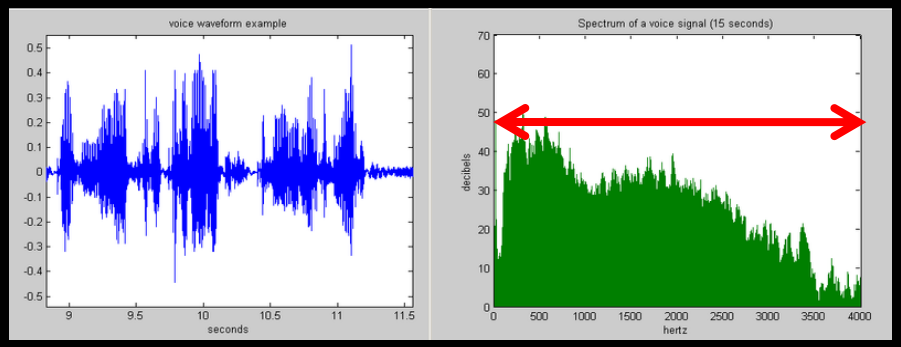
For us.....

- Difference between *loudest* and *faintest* sounds: 120 dB
- Can distinguish between 1 dB (12% change)
- But greatest sensitivity between 1-4 KHz
- So we DON'T necessarily need to 'quantize' amplitude equally into 12 one-dB intervals: use less bits, (8?) more judiciously

Watts/cm^2	Decibels SPL	Example sound
10^{-2}	140 dB	Pain
10^{-3}	130 dB	
10^{-4}	120 dB	Discomfort
10^{-5}	110 dB	Jack hammers and rock concerts
10^{-6}	100 dB	
10^{-7}	90 dB	OSHA limit for industrial noise
10^{-8}	80 dB	
10^{-9}	70 dB	
10^{-10}	60 dB	Normal conversation
10^{-11}	50 dB	
10^{-12}	40 dB	Weakest audible at 100 hertz
10^{-13}	30 dB	
10^{-14}	20 dB	Weakest audible at 10kHz
10^{-15}	10 dB	
10^{-16}	0 dB	Weakest audible at 3 kHz
10^{-17}	-10 dB	
10^{-18}	-20 dB	

Louder ↑ Softer ↓

The important issues of signals ‘good enough’; sacrificing quality for data rate



Waveform of speech

DVD Audio
- 48 kHz, 24 bit, 5.1 channel,
- 6144 kbit/sec

Blu-ray Audio
- 96 kHz, 24 bit, 7.1 channel
- 192 kHz, 24 bit, 5.1 channel
- 27 Mbit/sec

Sound Quality Required	Bandwidth	Sampling rate	Number of bits	Data rate (bits/sec)	Comments
High fidelity music (compact disc)	5 Hz to 20 kHz	44.1 kHz	16 bit	706k	Satisfies even the most picky audiophile. Better than human hearing.
Telephone quality speech	200 Hz to 3.2 kHz	8 kHz	12 bit	96k	Good speech quality, but very poor for music.
(with companding)	200 Hz to 3.2 kHz	8 kHz	8 bit	64k	Nonlinear ADC reduces the data rate by 50%. A very common technique.
Speech encoded by Linear Predictive Coding	200 Hz to 3.2 kHz	8 kHz	12 bit	4k	DSP speech compression technique. Very low data rates, poor voice quality.

An image-processing icon

Lena Soderberg, 1972

‘ a nice mixture of detail, flat regions, shading, and texture that do a good job of testing various image processing algorithms…’
D.C. Munson

www.imageprocessingbasics.com

Lena today

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Munson, David C, Jr (January 1996). "A Note on Lena". *IEEE Transactions on Image Processing (archive)* **5** (1).

Quantization Effects

256 levels
8 bits
(1 byte)

16 levels
4 bits
(1 nibble)

4 levels
2 bits

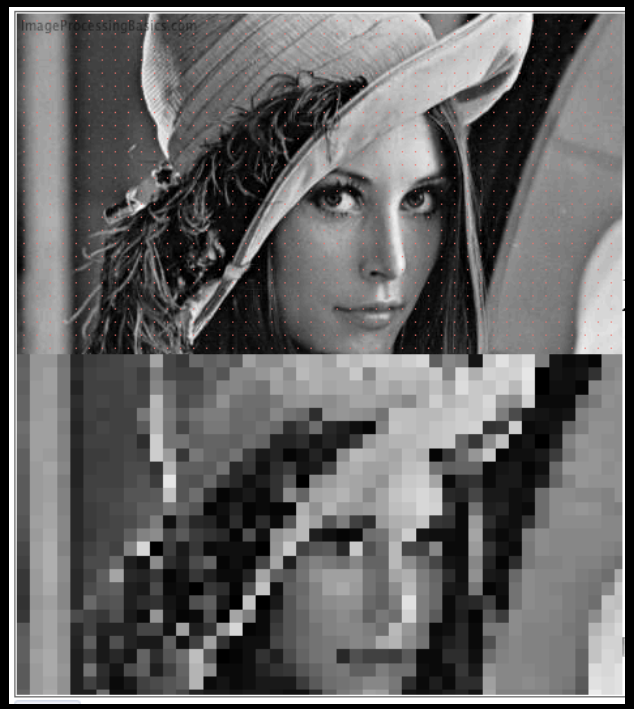
2 levels – Bitmap
1 bit

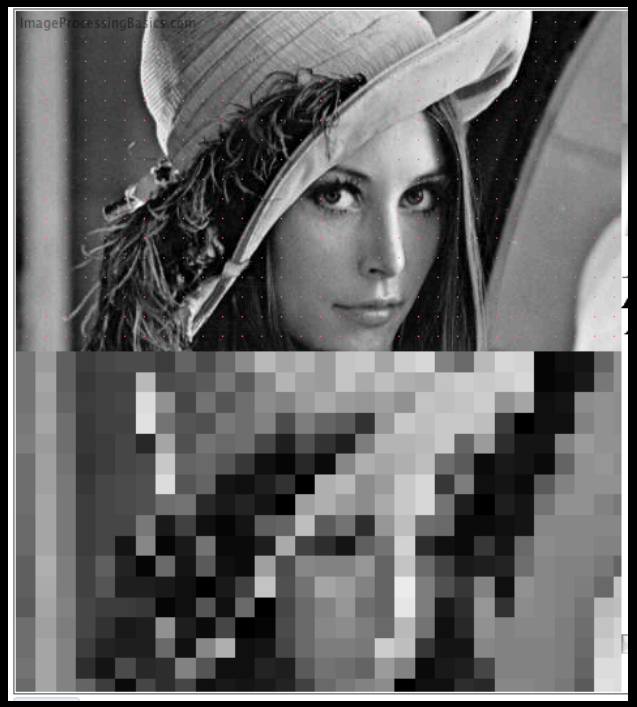
Sampling Effects

Sampling period is expressed in units length/sample: e.g. *meter/pixel*.

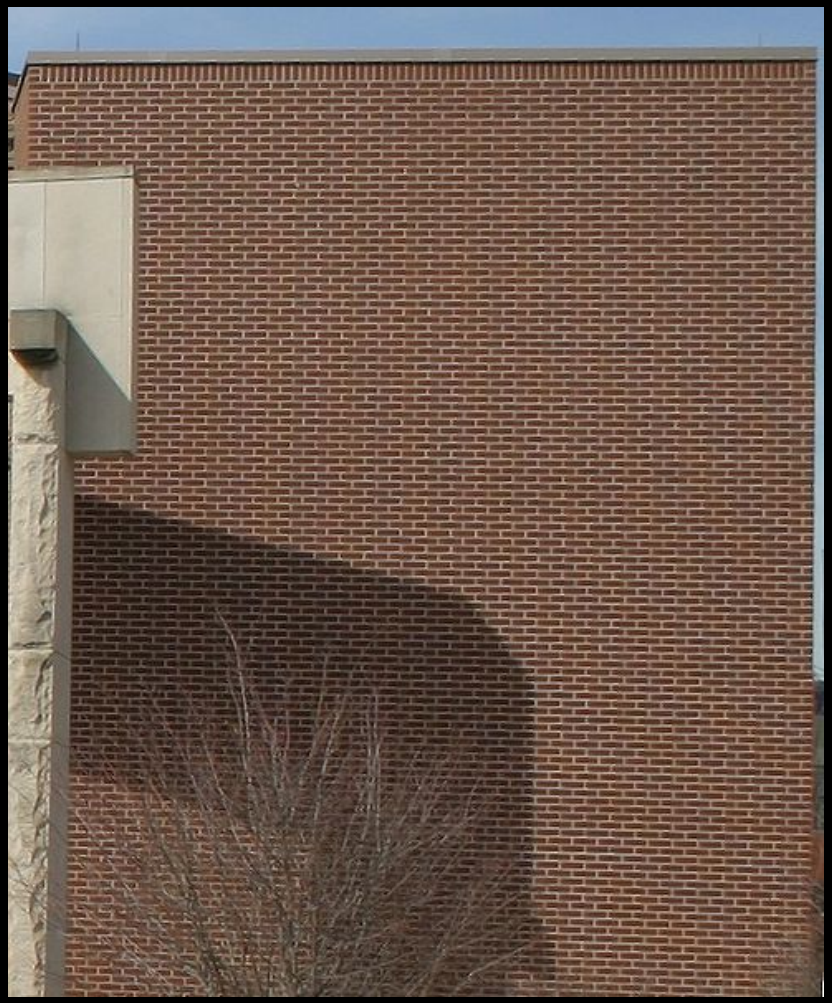
Sampling frequency is in units of samples/length: e.g. *pixels/meter*

How many pixels does your camera phone have? If you take an image of a car, for example, what would be the sampling frequency? What will happen to your image if you start reducing its resolution (number of pixels)? How would you reduce resolution?





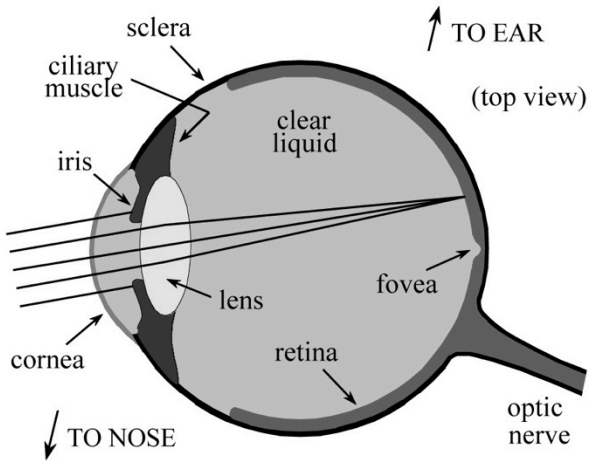
And they can also suffer from aliasing… Moire Effect!

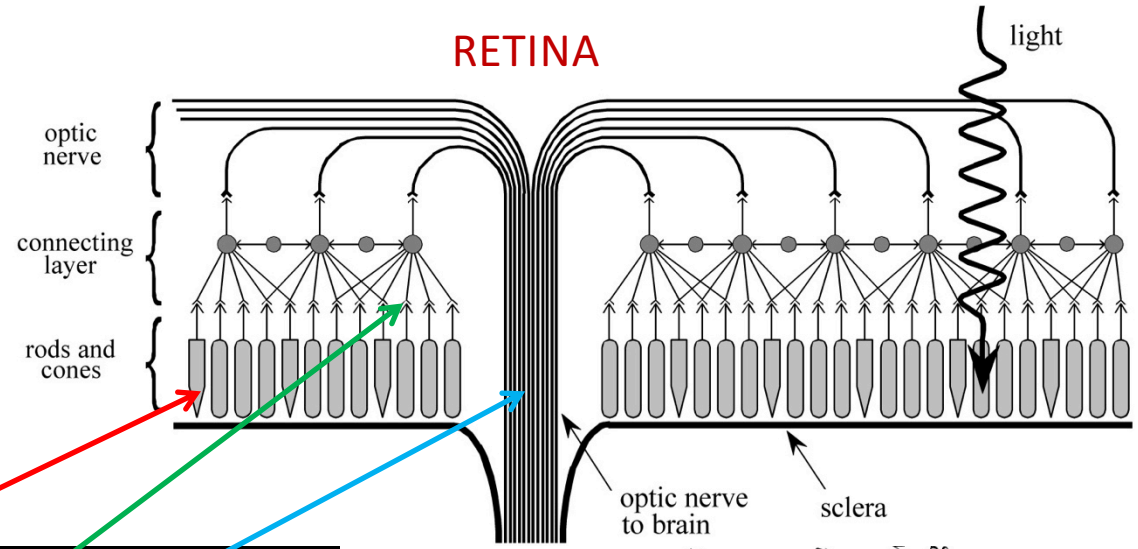


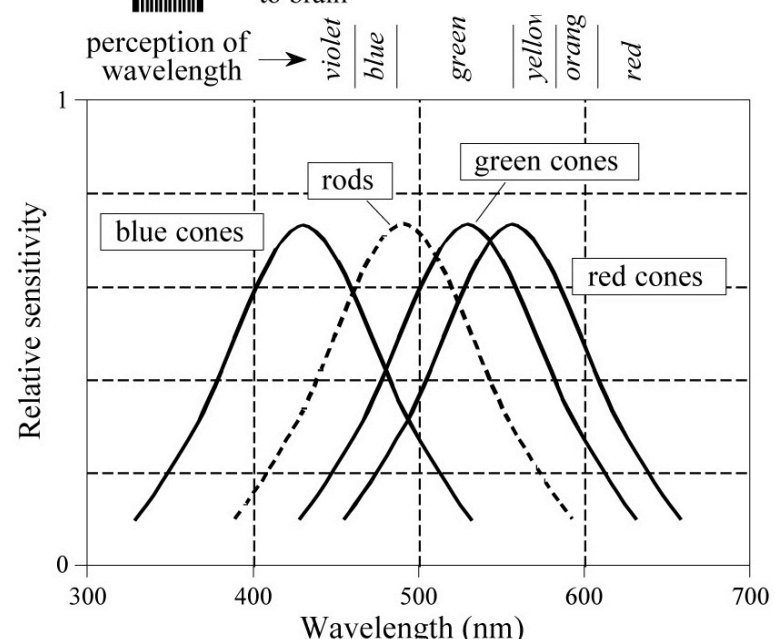
Properly Sampled

Undersampled

The important issues of signals ‘good enough’; visual detector







LIGHT SENSORS

Data reduction & image processing

Optic nerve fibers

RODS: low-light sensors

CONES: distinguish color, with higher incident light

RGB coding: rough sorting, ‘pre-processing’

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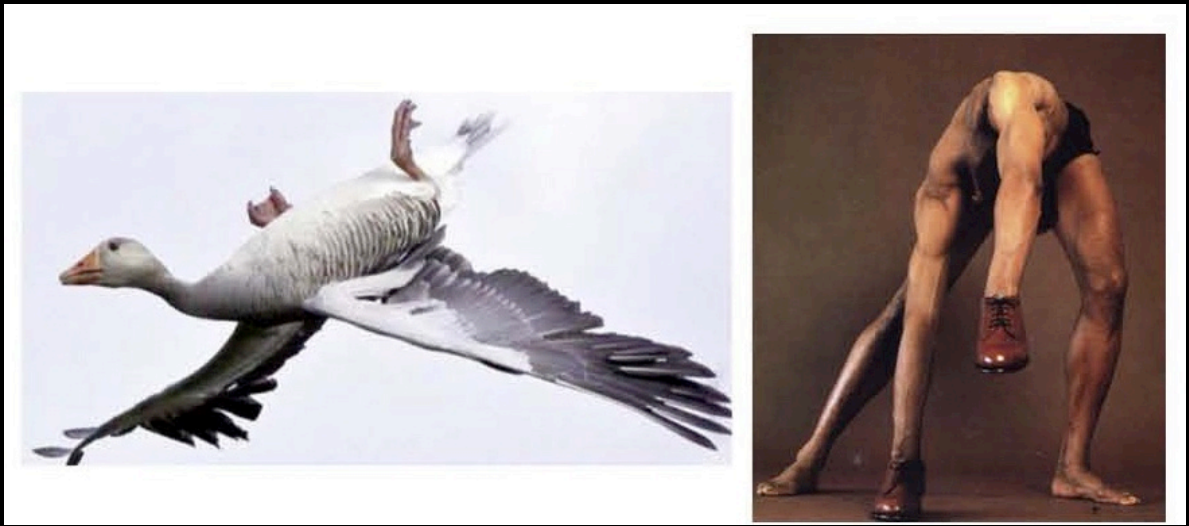
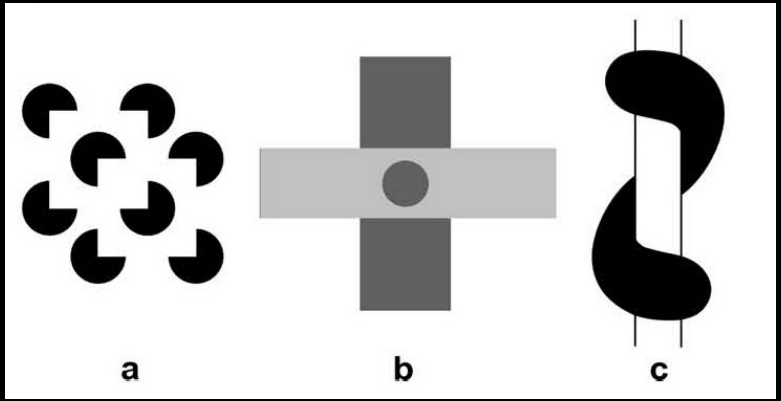
For visual signals, what is 'hardwired' or pre-processed? What INFERENCES do we make?

What is this image?



Can you make sense of these images?



How do we interpret these images?

'Visual cognition', P. Cavanagh, *Vision Research* (2011)

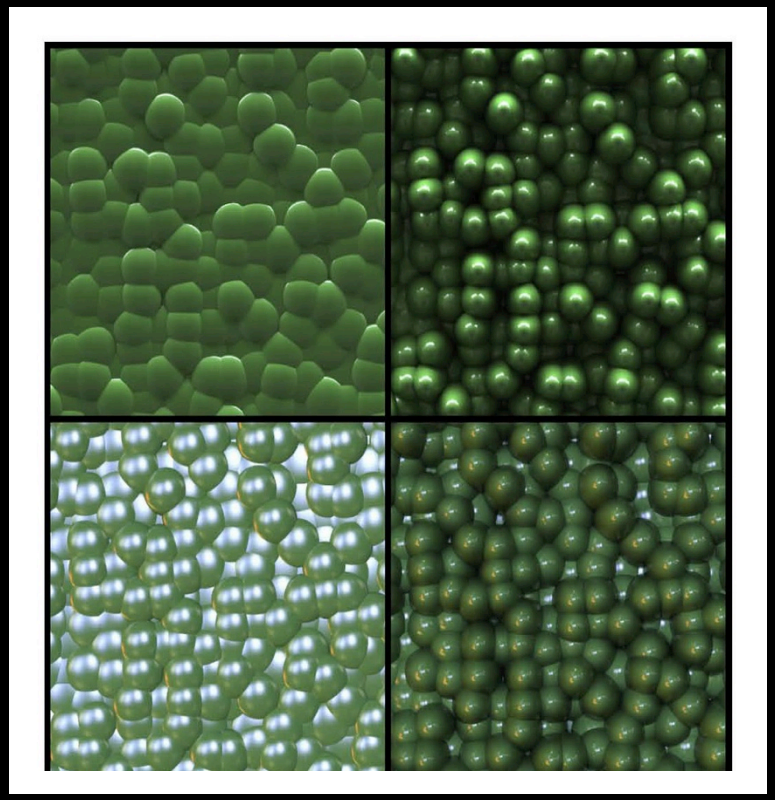
For visual signals, what is 'hardwired' or pre-processed? What INFERENCES do we make?

Are these the same, different? Are there critical pieces of information here?

Surface depth →

Oblique illumination

Direct illumination

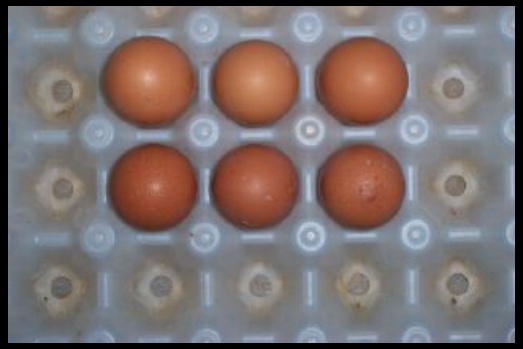


Identical reflectance properties

'Visual perception of materials & their properties', R. Fleming, *Vision Research* (2014)

A first attempt at Image Processing

Color images can be hard to process. Often, color images are converted to gray scale and then *thresholding* is used to realize binary images. Binary images can easily be "digested" by computers.

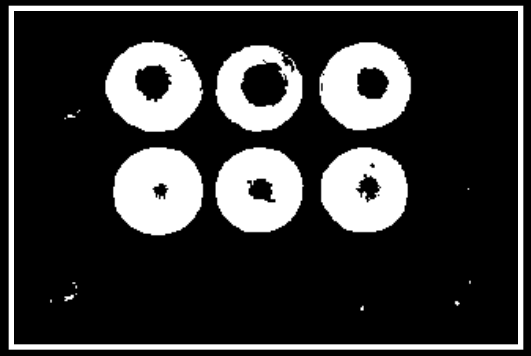


Binary Image & Thresholding

- $J(x,y) = 1$, if $I(x,y) \geq T$ (T is desired threshold)
- $J(x,y) = 0$, if $I(x,y) < T$
  - MATLAB code: >> J = (I>=T);

Examples

- automatic detection of eggs in egg factory:
  - egg counting, detection of broken eggs, etc.
- medical images (CT scan, X-ray, ultrasound, etc)



How do we know which threshold to use?

- That is, how does computer know what is an egg & what is a container?

Going Binary & Setting a Threshold

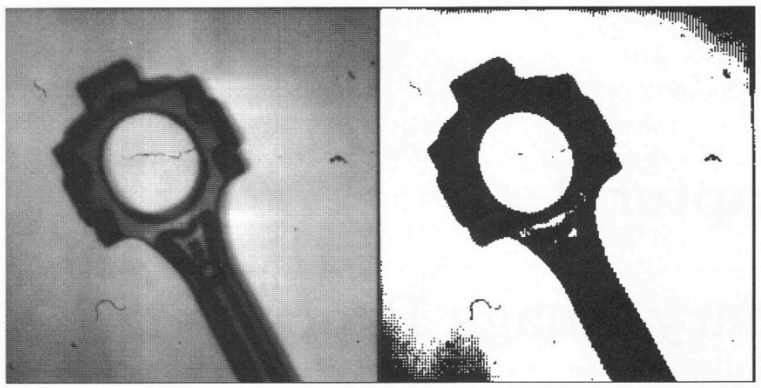
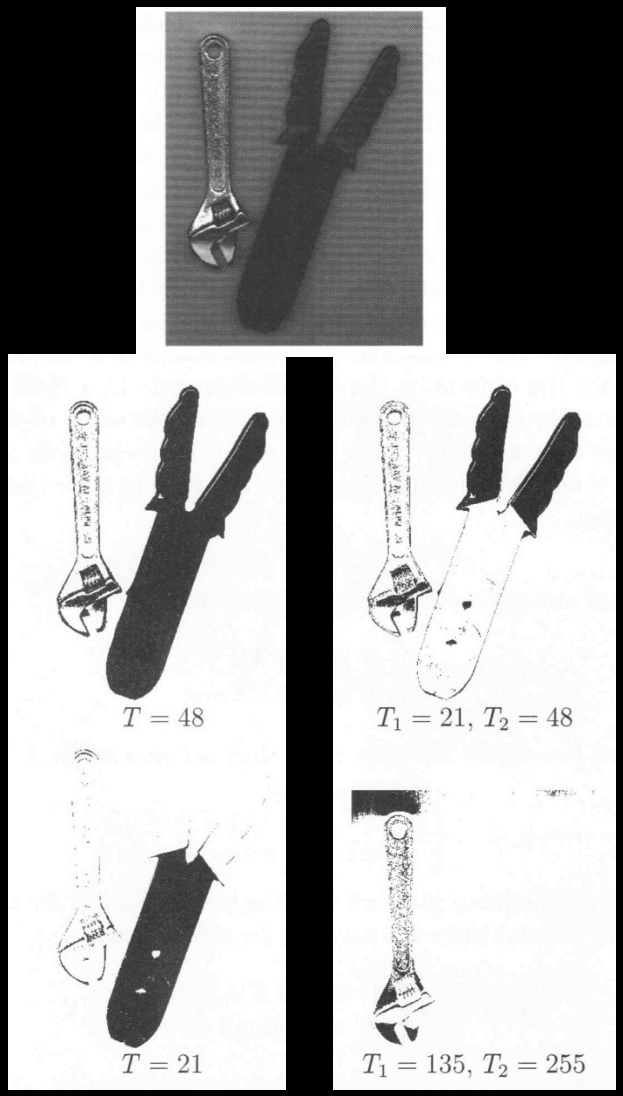


Figure 2.1: A gray level image and its corresponding binary image.



Is there a slightly more sophisticated approach?

Chapter 2. *Binary Image Processing*
www.cse.usf.edu/.../MachineVision_Chapter2

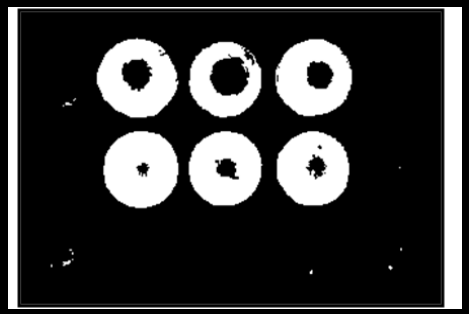
Forming a Histogram of Intensities

Histogram: a plot of the number of pixels at each intensity level

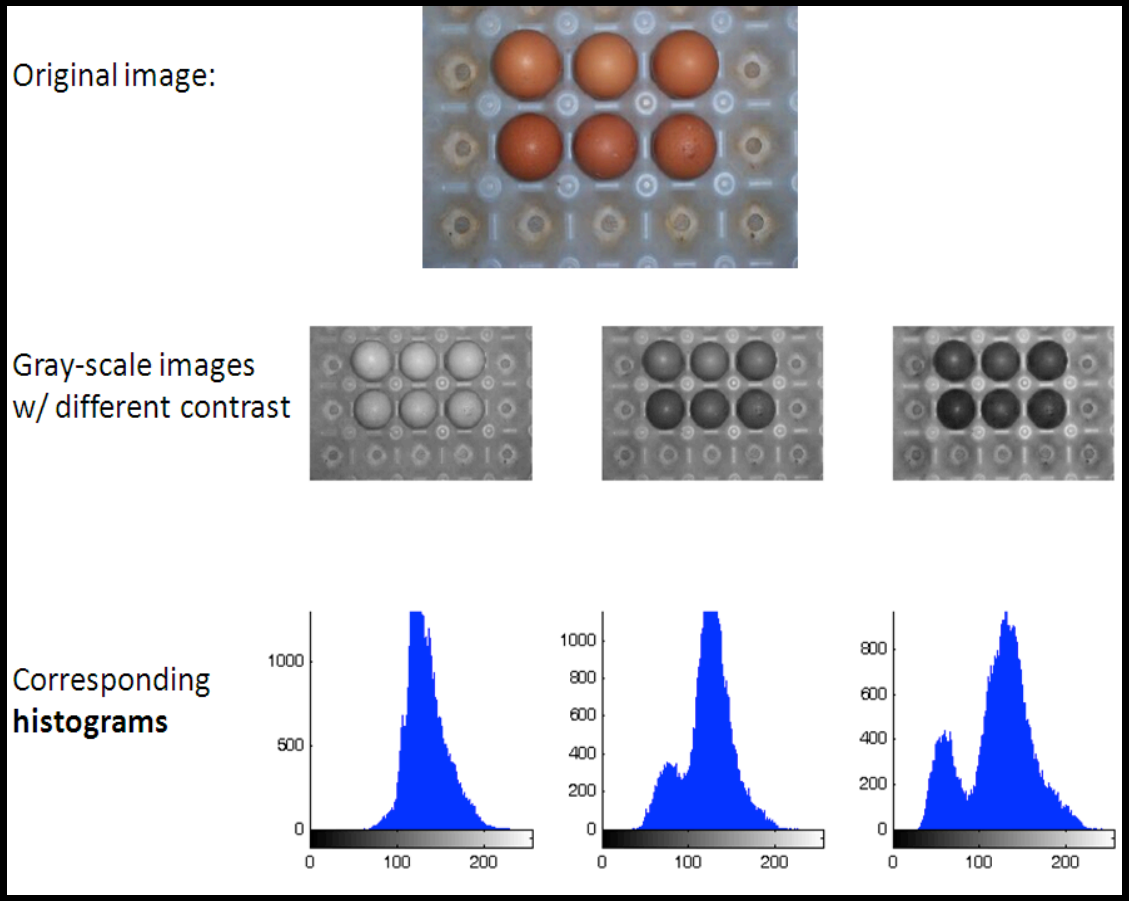
H(r) = # of pixels with intensity level r

Which threshold/histogram to pick?

1. Are the eggs below broken?
2. How many eggs are there?
3. What is 'inside' and what is 'boundary'?
4. DO WE HAVE ENOUGH INFORMATION?

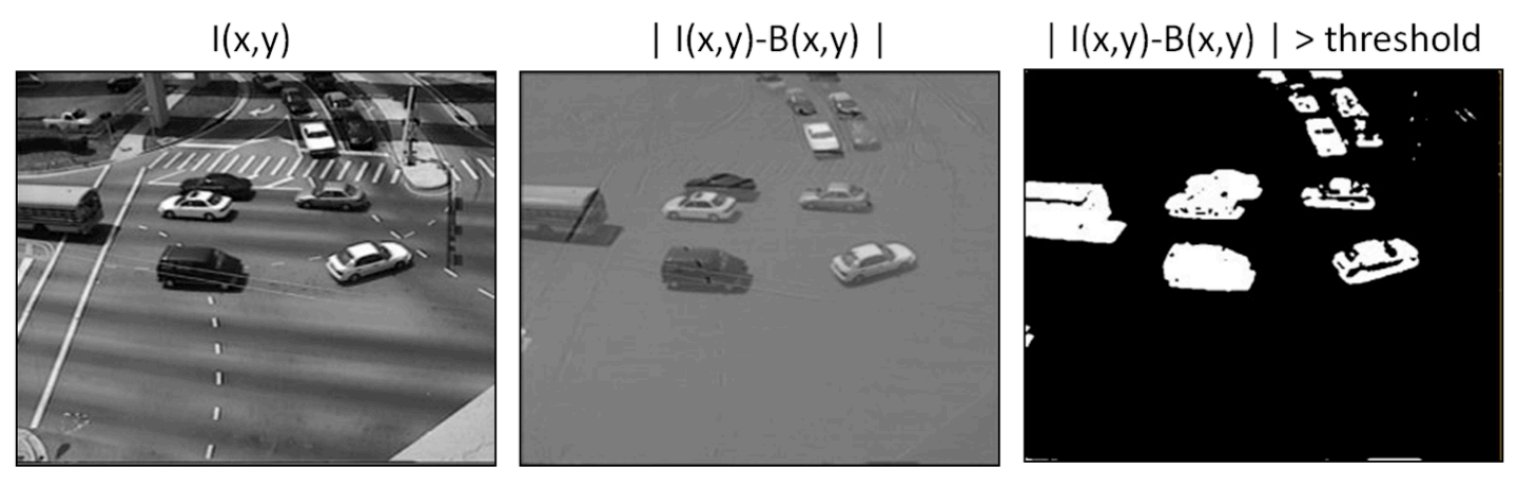


MATLAB:
BitMap=(Original < threshold)



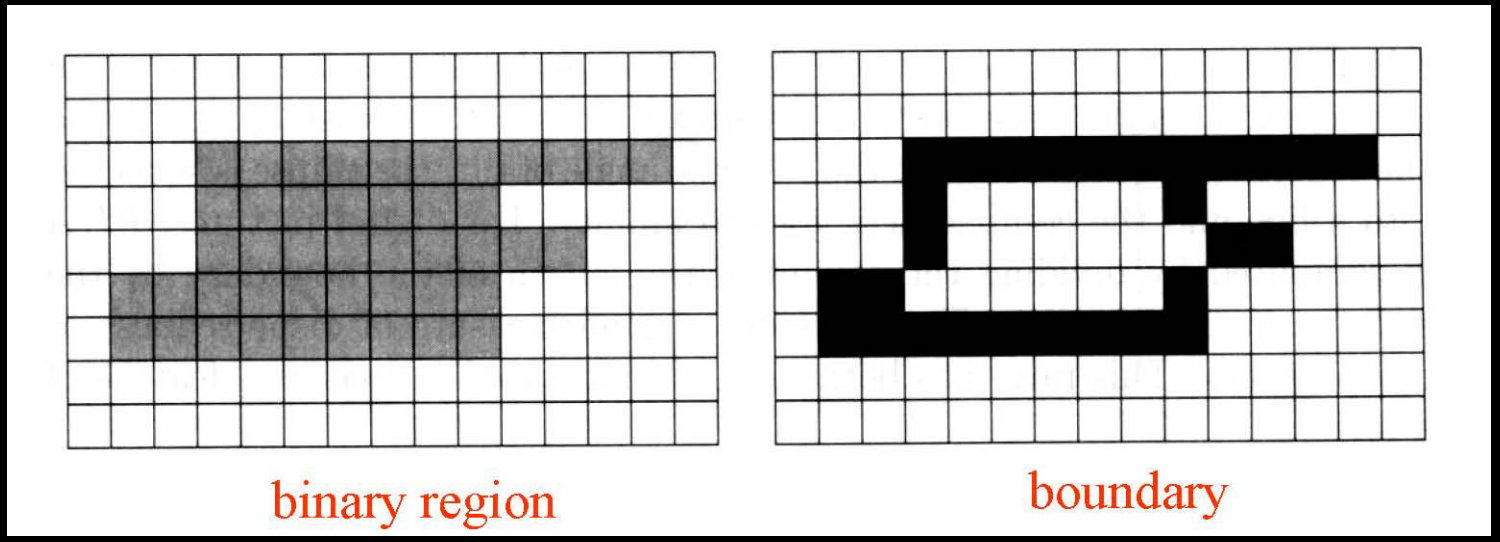
Background Subtraction & Addition

Background subtraction $J(x,y) = |I(x,y) - B(x,y)|$



Background addition

Finding the boundary



Find pixels that are adjacent to the background and are connected

Select a starting pixel and track the boundary until it comes back to the starting pixel

Image Processing: filters to clean up the image

NOISE

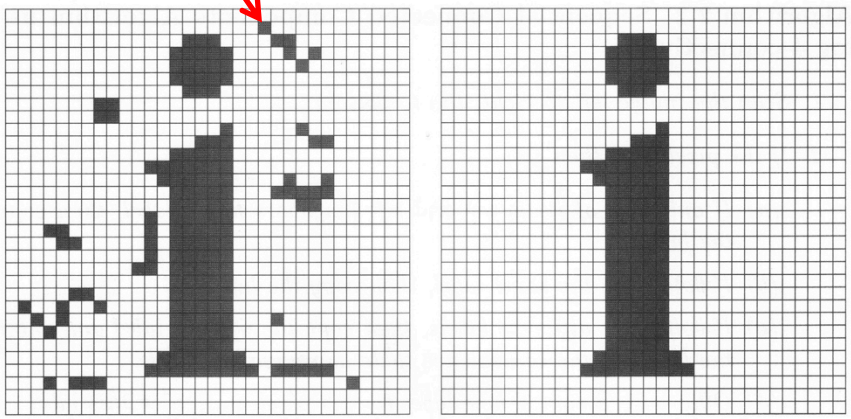


Figure 2.13: A noisy binary image of the letter "i" (left) and the resulting image after the application of a size filter (right). $T = 10$.

Use a 'size' filter to remove regions below a certain pixel size ('T')

- If 'T' is too small, noise remains
- If 'T' is too large, the image is corrupted

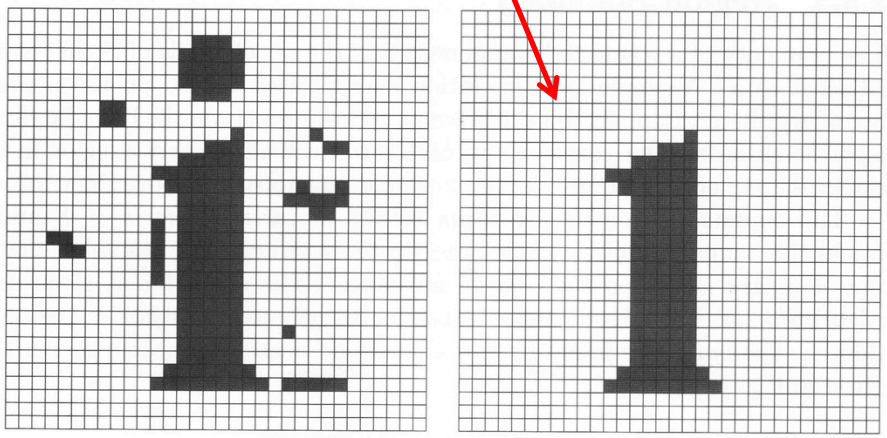


Figure 2.14: The possible error resulting from a poor choice of threshold for the size filter ($T = 25$). Note that the "dot" is missing from the letter "i."

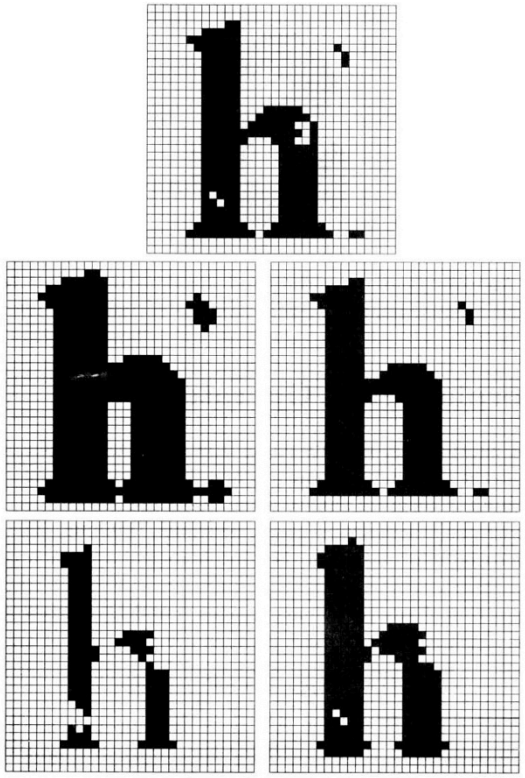
Still Noisy?

‘Filtering’ the image:

Close, but ‘no cigar’…..

Try to expand the region to fill the gaps

Try to shrink the region to remove noise



noisy image

expanding followed by shrinking filled holes but did not eliminate noise

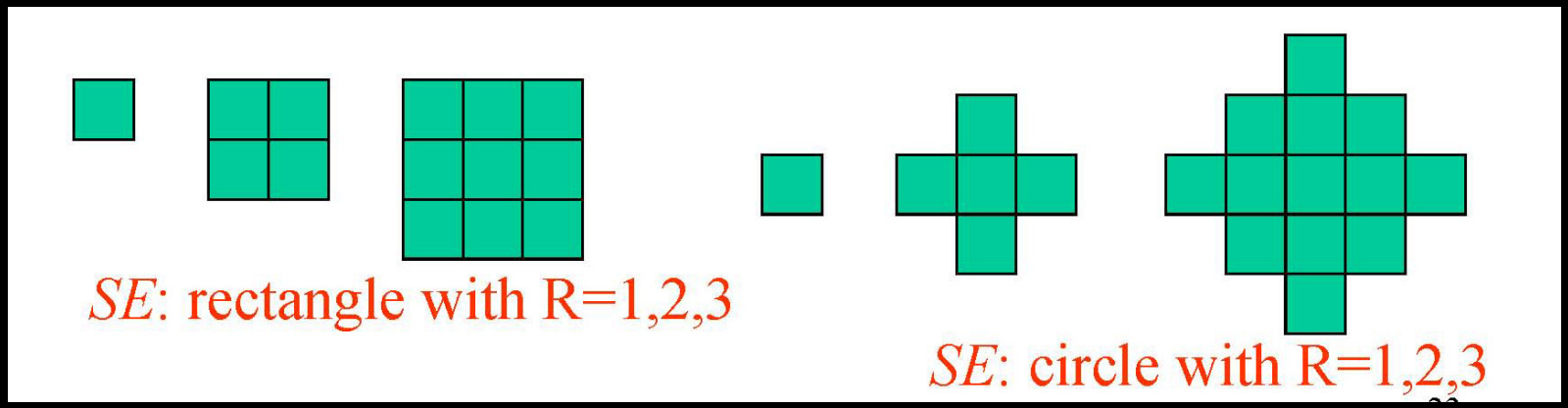
shrinking followed by expanding eliminated noise but did not fill the holes

‘Morphological’ filtering

‘Expand’ & ‘shrink’, but use a *structuring element* & some rules

- Expand → DILATION
- Shrink → EROSION

STRUCTURING ELEMENTS CAN BE CHOSEN TO ‘MATCH’ THE IMAGE



Erosion and Dilation

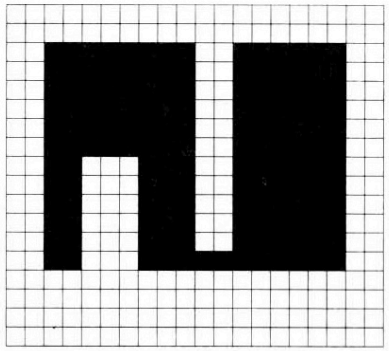
EROSION

- Apply the SE to every pixel (i, j) of the image, f
  - (i, j) is at the center of the SE
  - If the entire SE is included in the region, then $f(i, j) = 1$
  - Otherwise, $f(i, j) = 0$

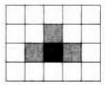
DILATION

- Same procedure as above, but…
  - If at least one pixel of the SE is inside the region, $f(i, j) = 1$

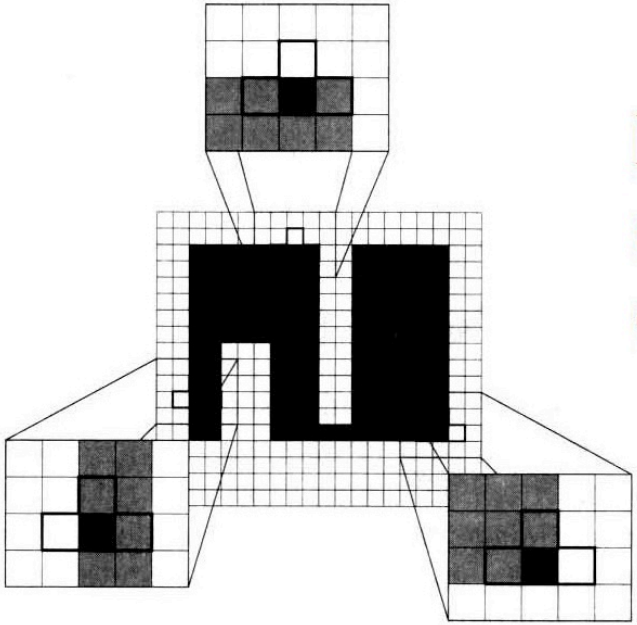
Erosion and Dilation



original image

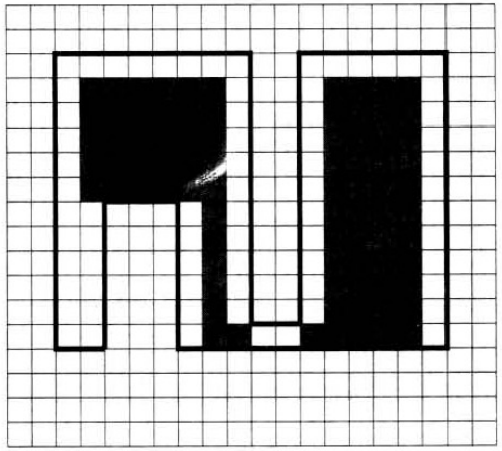


Structuring Element (*SE*)



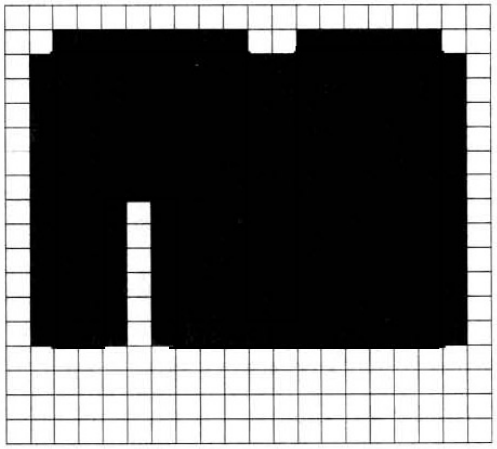
Erosion with the *SE* at various positions of the original image

Erosion and Dilation



the erosion of the original image with the *SE*

the bold line shows the border of the original image



the dilation of the original image with the *SE*

the bold line shows the border of the original image

Opening and Closing

OPENING: erosion followed by dilation with the same SE

- Smooth boundaries are preserved
- Jagged boundaries are smoothed
- Thin connections are broken
- Small objects and protrusions are removed

CLOSING: dilation followed by erosion with the same SE

- Smooth boundaries are preserved
- Jagged boundaries are smoothed
- Narrow breaks are joined
- Small holes and long gulfs are filled

Opening and Closing

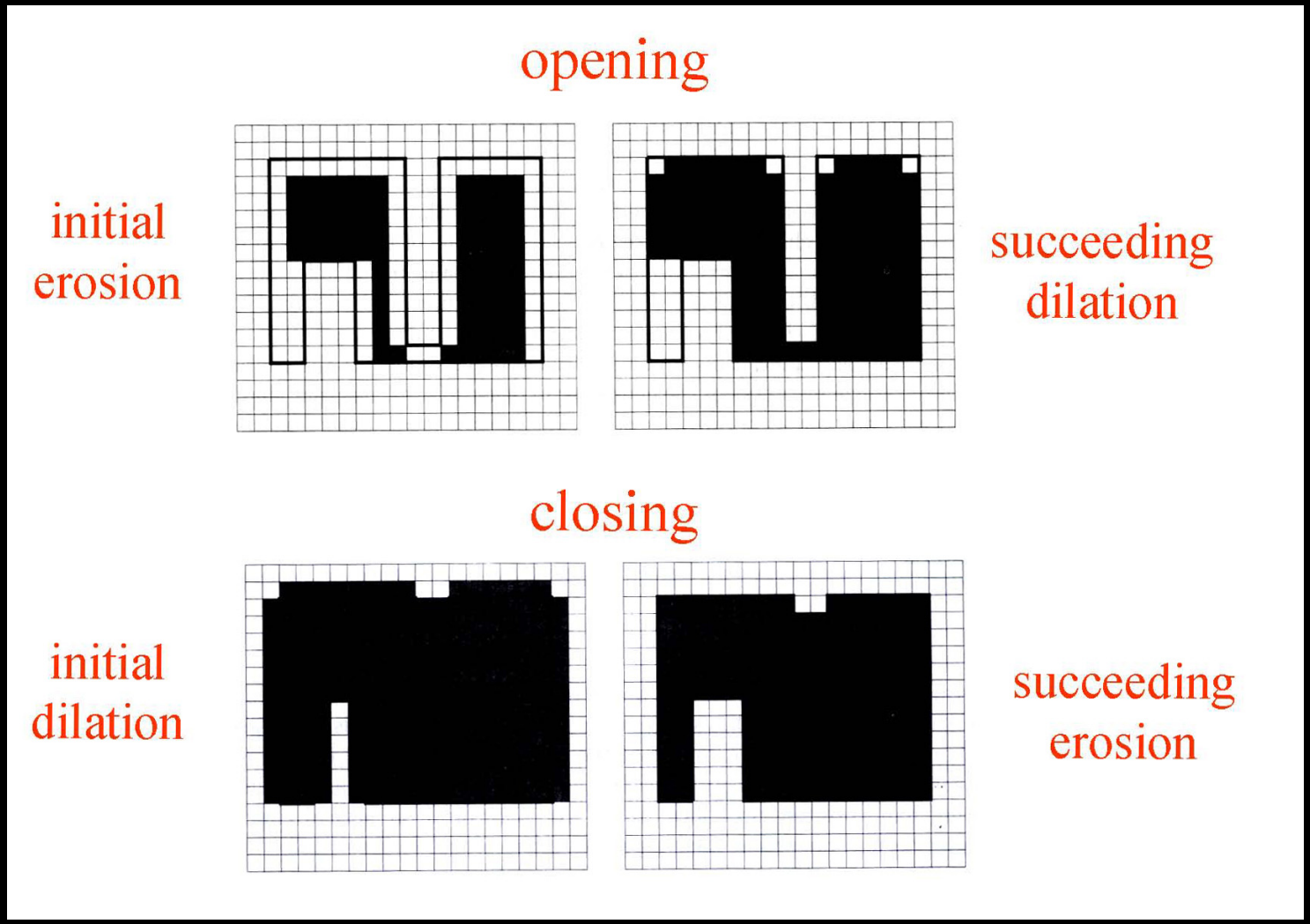
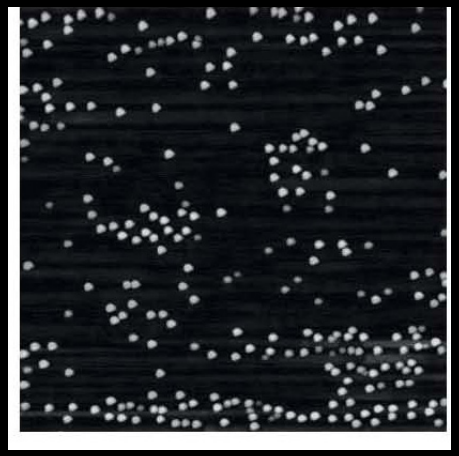
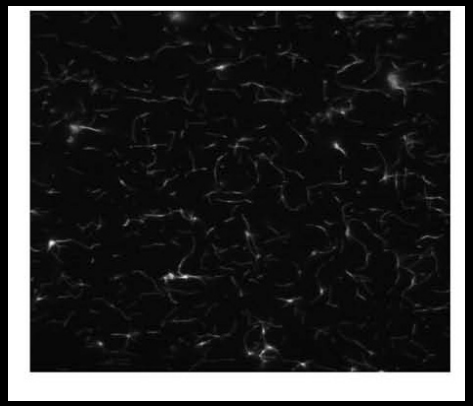


Image processing you *could do* with MATLAB



Find number, height of quantum dots



Find average actin filament length, number of filaments

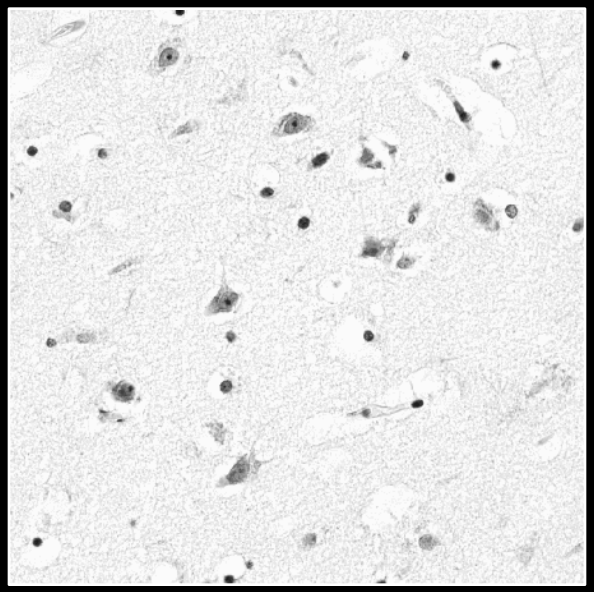
Find boundary of cell

We will analyze simpler objects in a future lab!

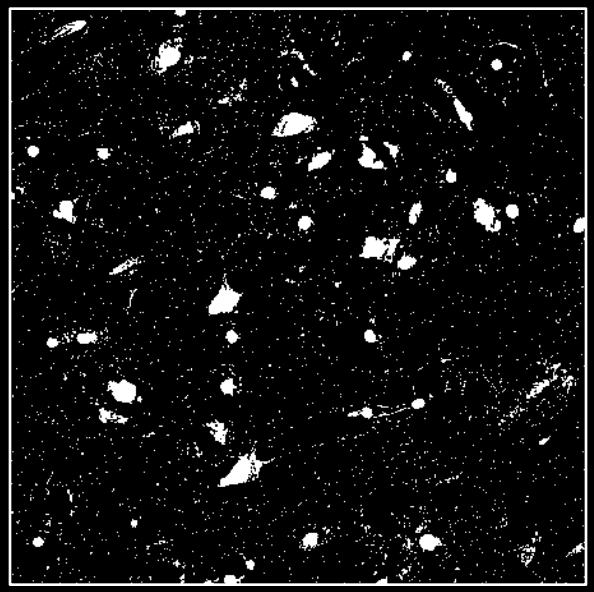
Opening: Real-life Example ☺

How many big cells are there?

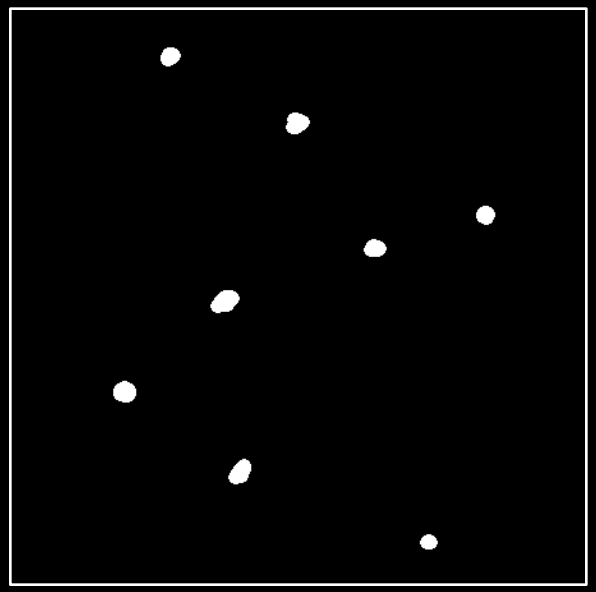
Microscope image



Thresholded image



"Opened" thresholded image

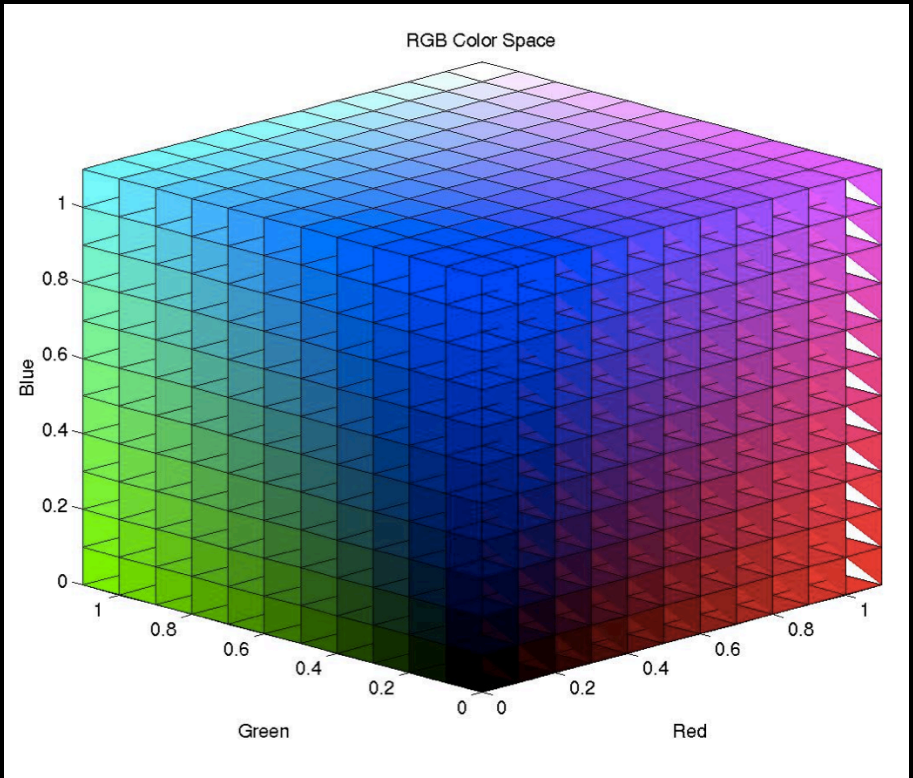
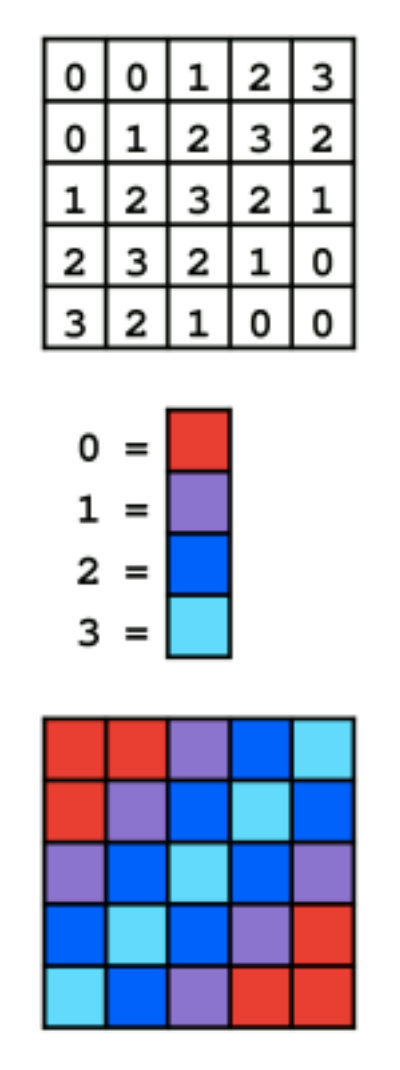


Next Time

More Image Processing

Color

- RGB
- Indexed

Compression

- JPEG
- MPEG