DIGITAL IMAGE PROCESSING

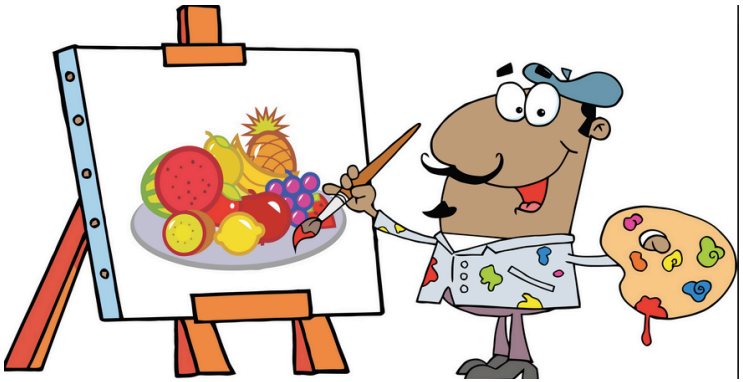
Lecture 1

Introduction

Tammy Riklin Raviv

Electrical and Computer Engineering

Ben-Gurion University of the Negev



Introduction to Digital Image Processing

- Lecturer: Dr. Tammy Riklin Raviv
- Teaching assistants: Assaf Arbelle and Boris Kodner
- No.: 361-1-4751
- Time: Wednesday 14:00-17:00
- Location: Building 28 Room 204
- Prerequisites: Digital Signal Processing
  Introduction to Stochastic Processes
- Course website:

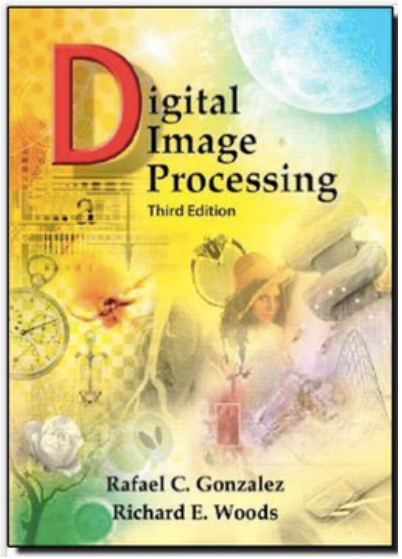
http://www.ee.bgu.ac.il/~rrtammy/DIP-2017/DIP

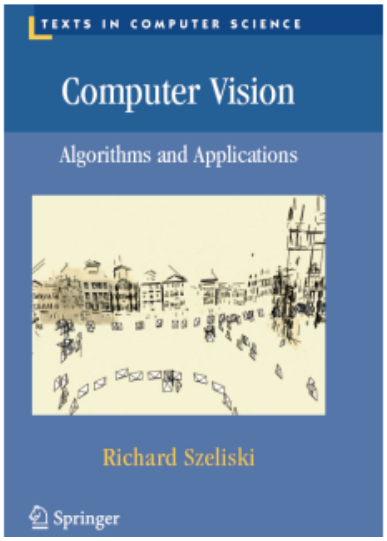
Course Objectives

- The primary objective of this course is to provide the students the necessary computational tools to:
  - Understand the main principles of image processing and computer vision.
  - Be familiar with different classical and commonly used algorithms and understand their mathematical foundation
  - Implement (Matlab) and test commonly used image analysis algorithms
  - Develop critical reading of computer vision and digital signal processing and analysis literature

Course Resources

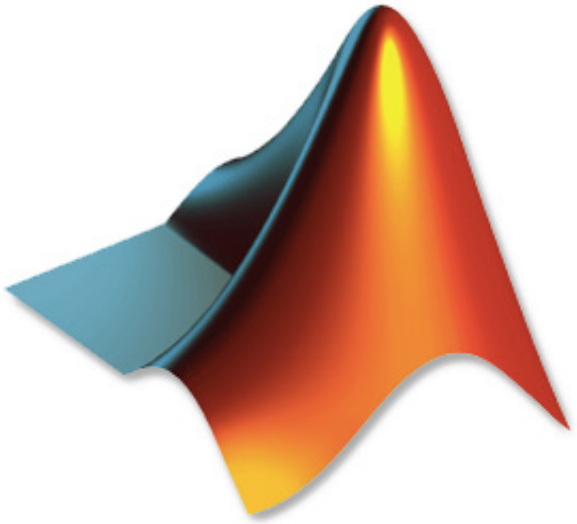
- Szeliski, Richard. Computer vision: algorithms and applications. Springer Science & Business Media, 2010.
- Gonzalez, Rafael C., and Richard E. Woods. "Image processing." Digital image processing 2 (2007).
- Forsyth, David A., and Jean Ponce. "A modern approach." Computer vision: a modern approach (2003).
- Duda, Richard O., Peter E. Hart, and David G. Stork. Pattern classification. John Wiley & Sons, 2012.
- Bishop, C. "Pattern Recognition and Machine Learning (Information Science and Statistics), 1st edn. 2006. corr. 2nd printing edn." Springer, New York(2007).





What should I do in order to succeed in the course?

- 6 Matlab assignments assignments, each 5% -> 30%
- Bonus assignments
- Final project and presentation 70%



MATLAB
The Language of Technical Computing

The instructor

- Tammy Riklin Raviv,
  Research interests:
  Signal processing: Biomedical Image Analysis, Computer Vision, Machine Learning
  Contact info:
  Telephone: 086428812
  Fax: 08-647 2949
  E-mail: rrtammy@ee.bgu.ac.il
  Office: 212/33
  Reception hours:
  please email
- Personal web page:

http://www.ee.bgu.ac.il/~rrtammy/

The Final Project

- A list of possible projects will be distributed around Passover
- Students can choose a subject out of this list or come up with their own ideas.
- It is the students responsibility to schedule a meeting with the teaching assistants to discuss the project of their choice.
- Students can work with a single or two team mates.
- Students are expected to based their project on a scientific publication, make sure they understand it and are able to implement it using Matlab.
- All students should present their final project. Date TBD.

List of topics (Tentative)

Overview on digital image processing,

Visual Perception

What is an image?

Sampling, quantizatiotion,

Histogram processing

Color image processing

Edge detection

Frequency domain analysis, Fourier transform

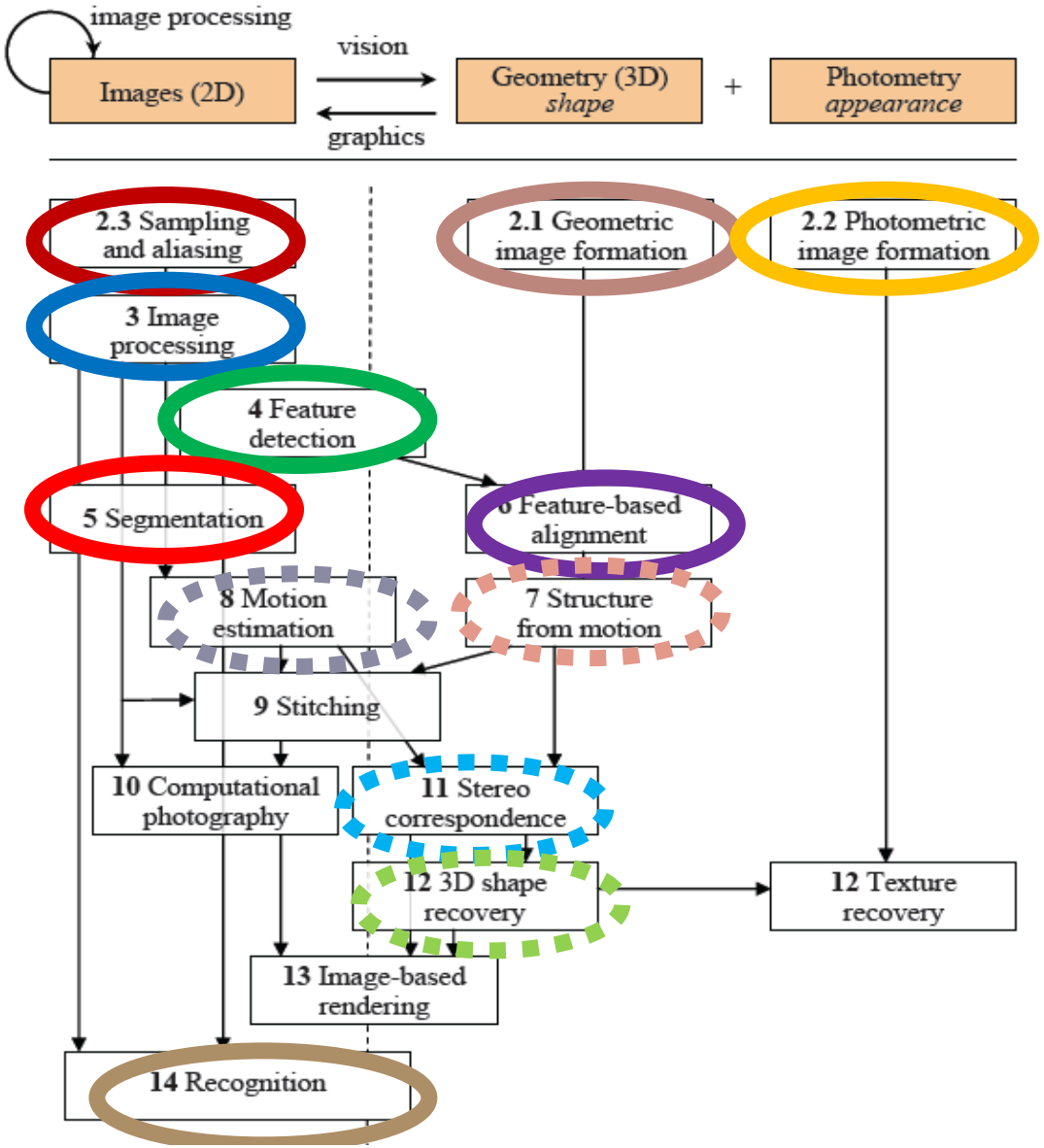
2D shape representation: Hough transform, pyramids, quad trees

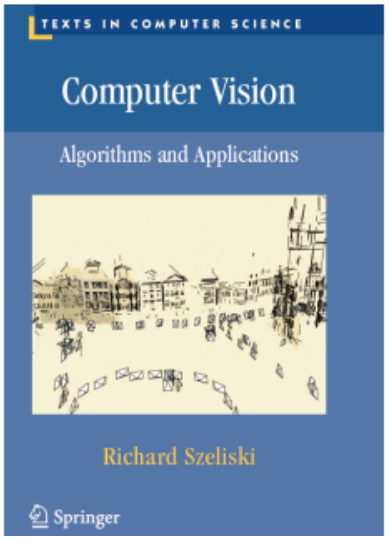
Imaging geometry: Scaling, rotation, camera model, pose estimation

List of topics (tentative)

- Photometry, shape from shading
- Image segmentation
- representation and descriptors, SIFTs and Hogs
- Stereo and Motion
- Face detection

A graphical view on the syllabus





The Rest of Today's Class

- Brief Overview
- Human Vision and Visual Perception
- What is an Image?

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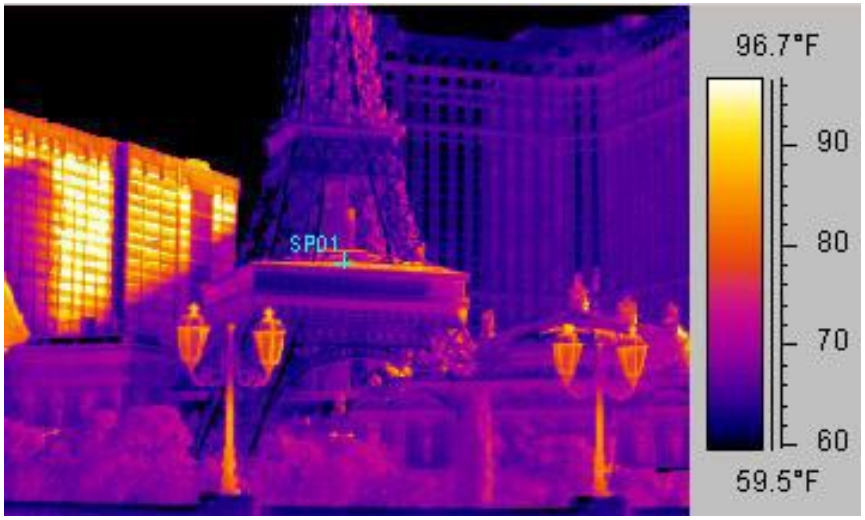
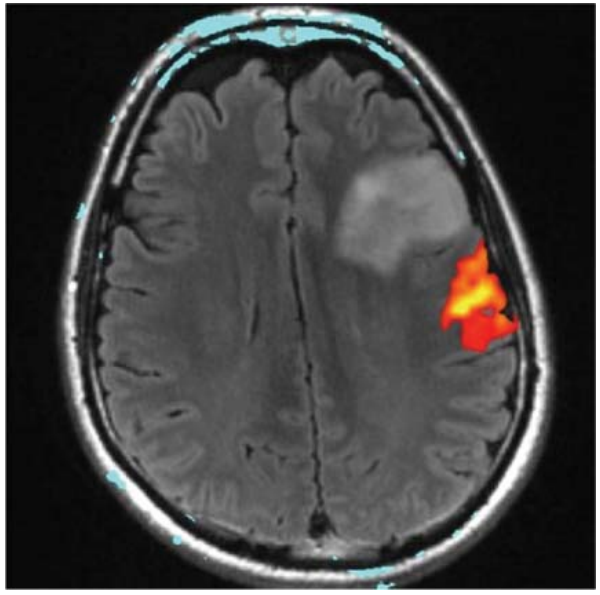
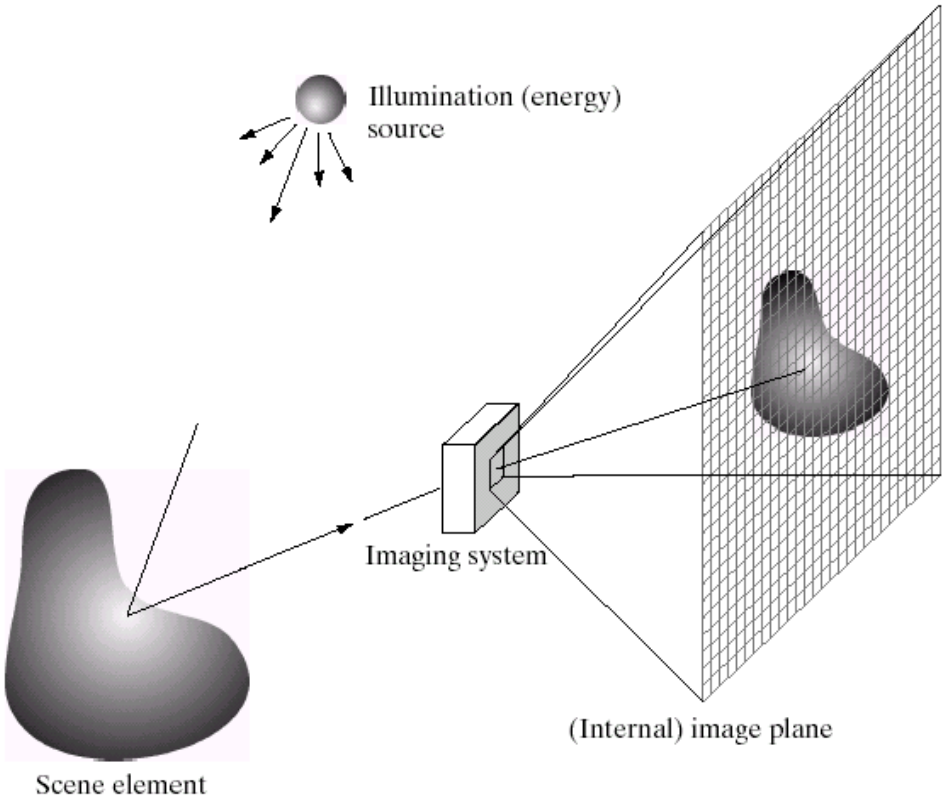
A brief overview: What is an Image?



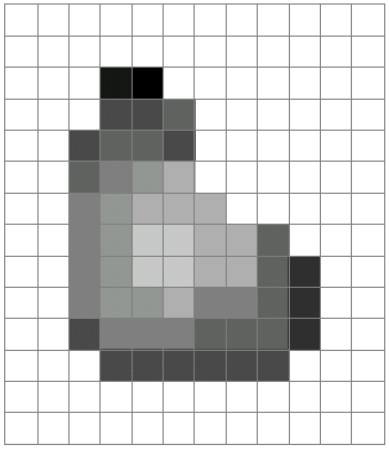


Brown's CV course

A Brief Overview: Image Formation

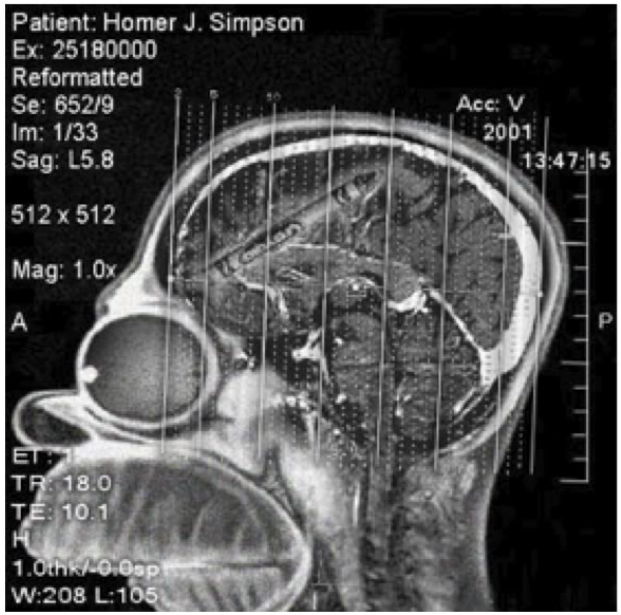


Camera Sensor



Output Image

A Brief Overview: Image Formation

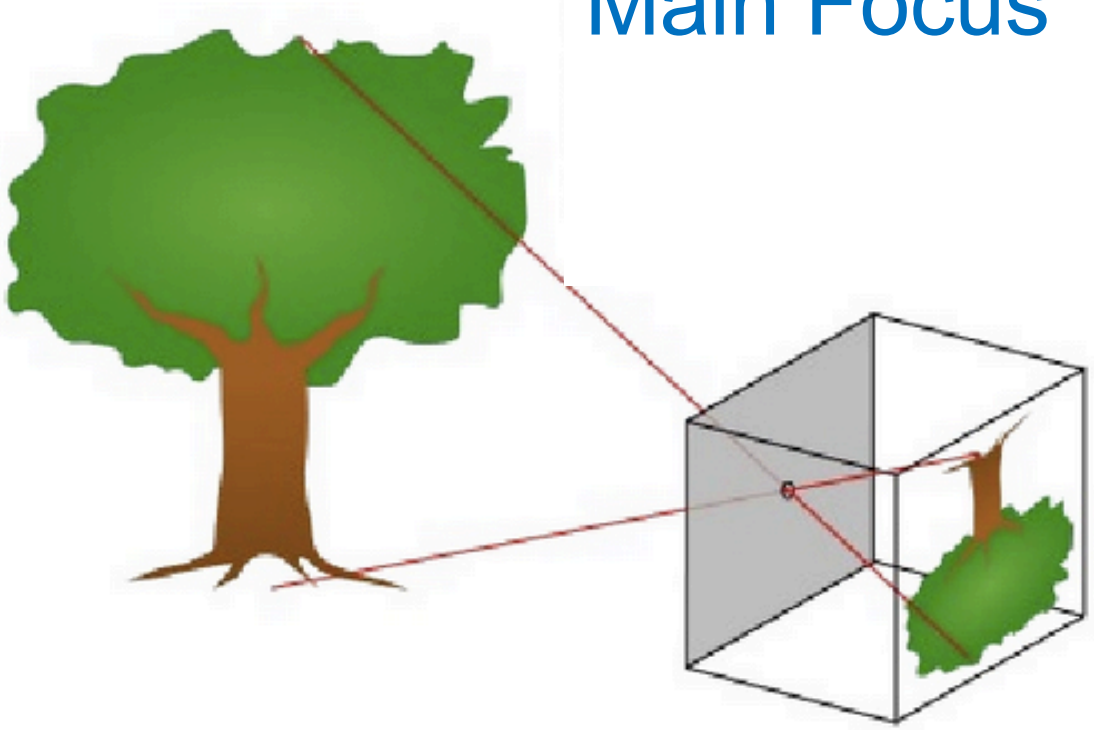


See: Introduction to Medical Imaging

Magnetic Resonance Imaging

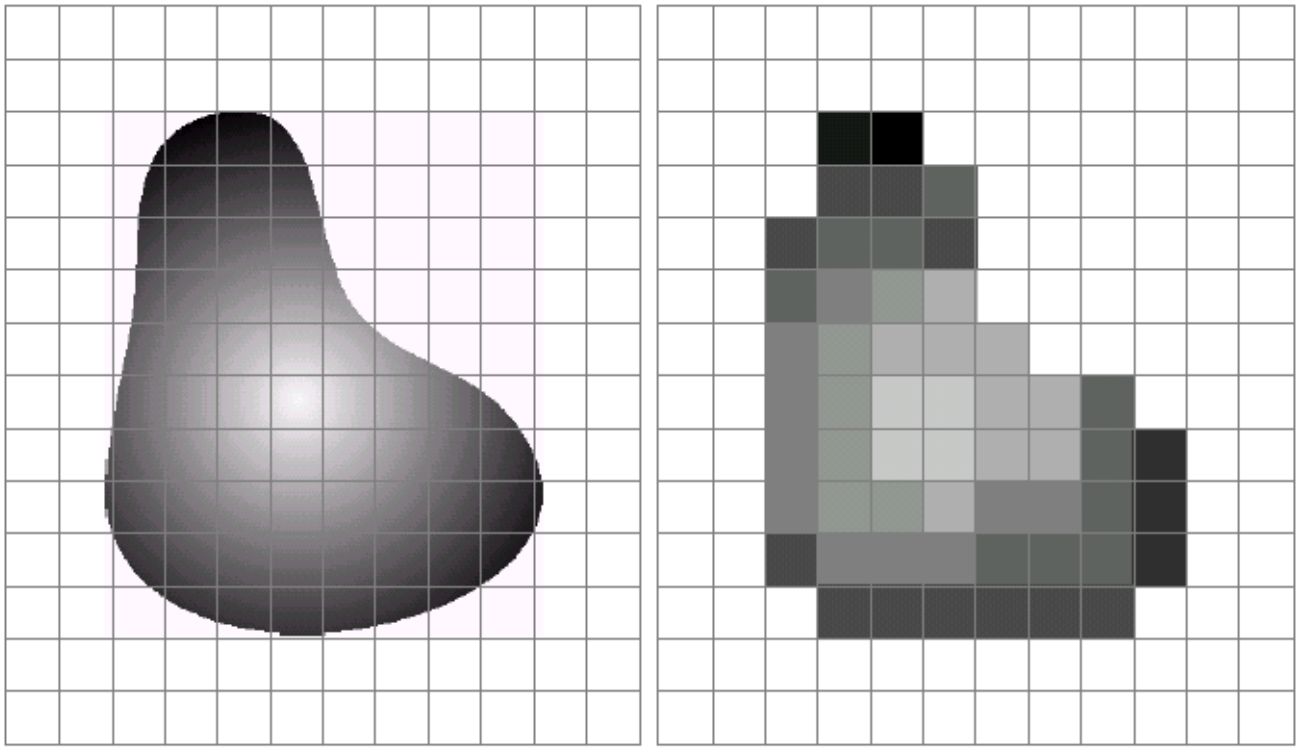
A Brief Overview: Image Formation

Main Focus



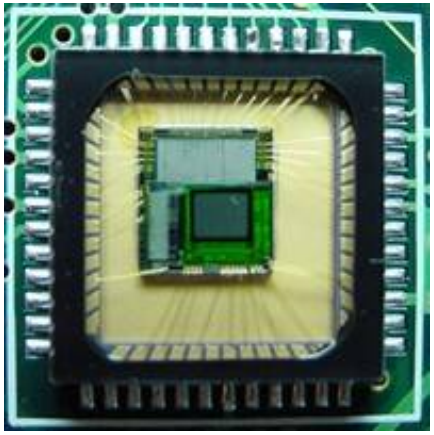
A Brief Overview: Image Formation

Sensor Array



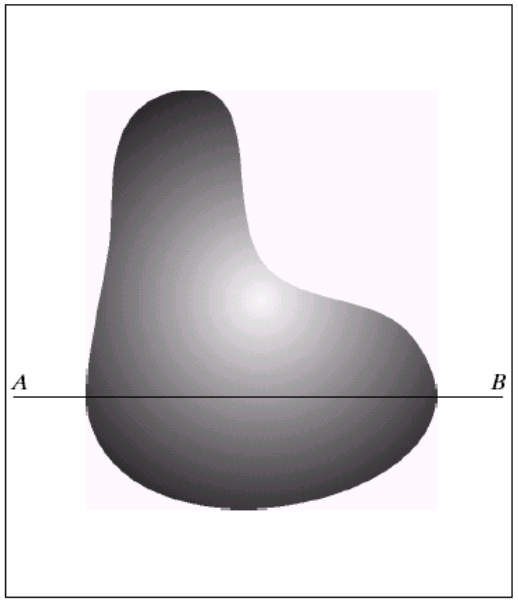
a b

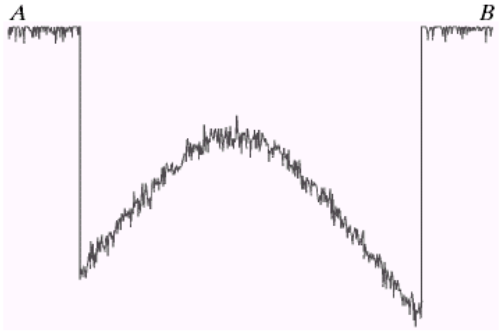
FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.



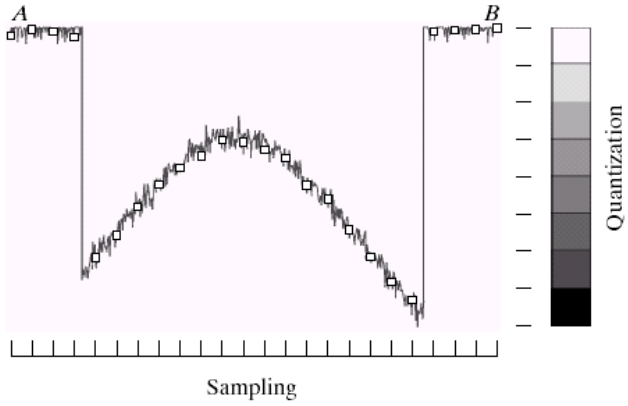
CMOS sensor

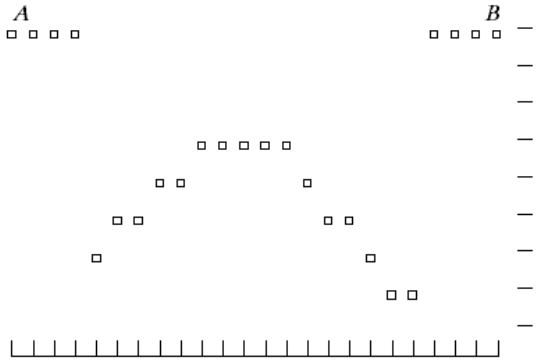
A Brief Overview: Image Processing





Quantization



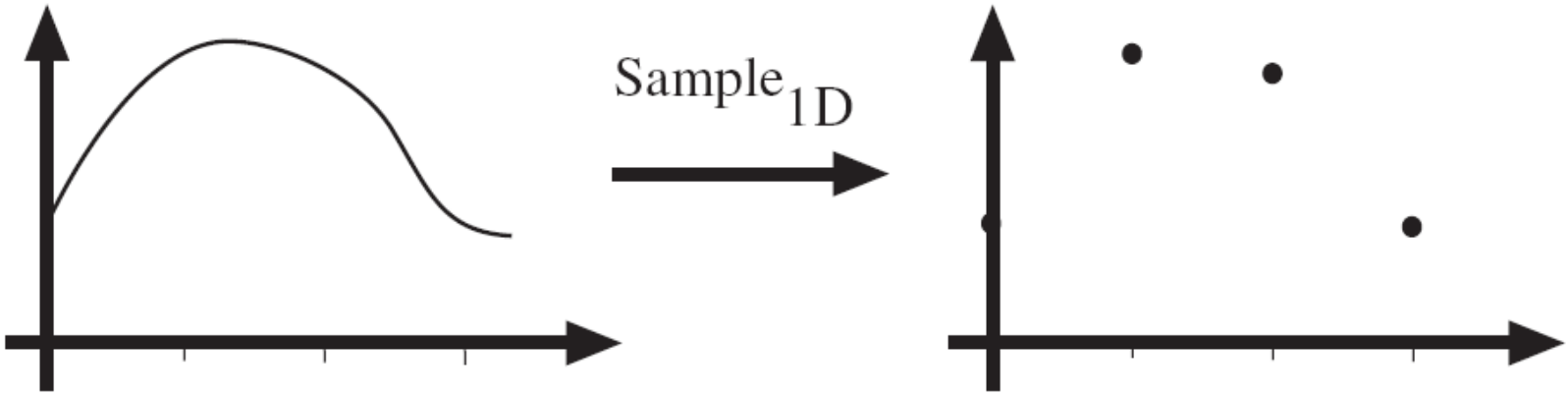


a b
c d

FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from *A* to *B* in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

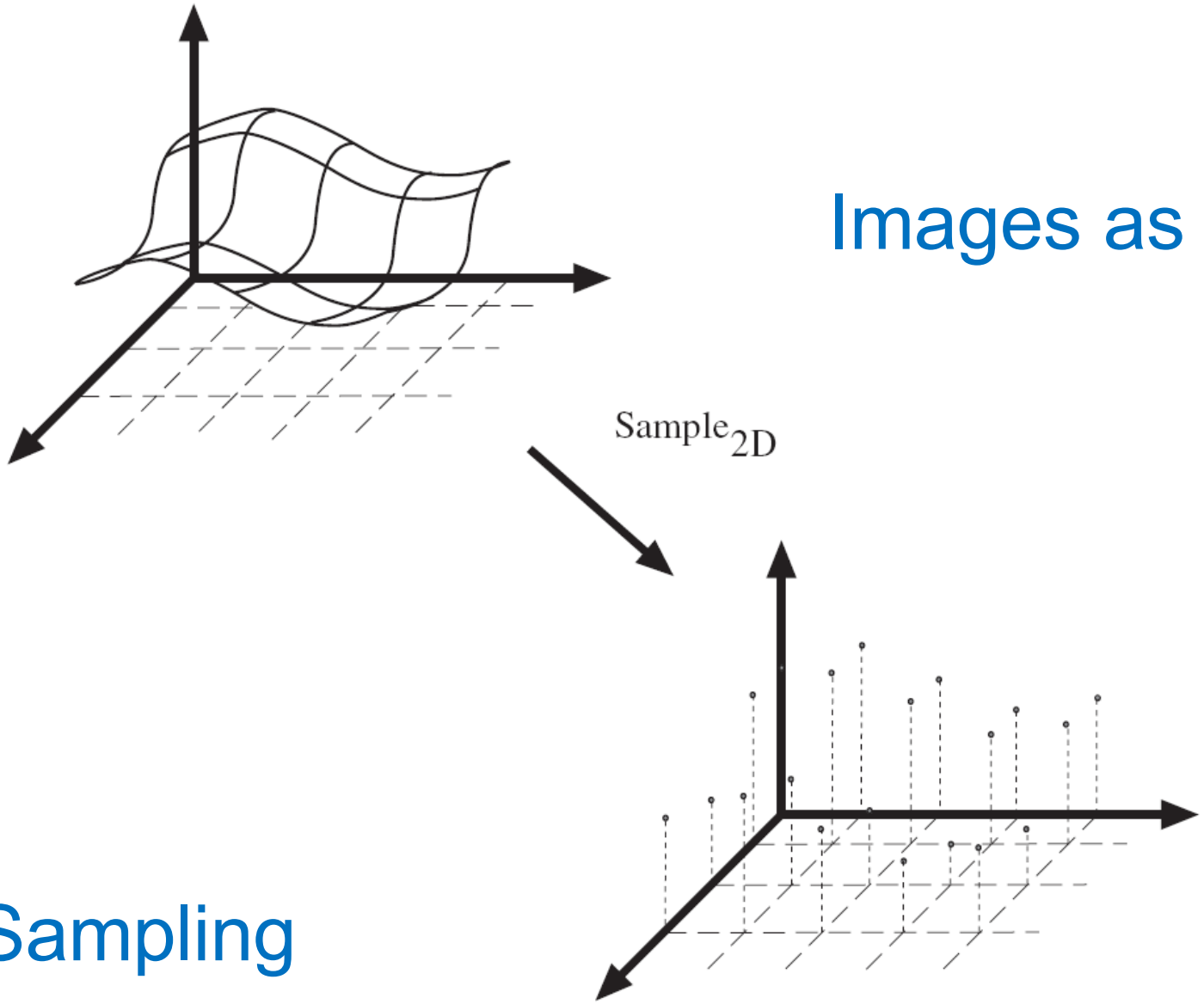
A Brief Overview: Image Processing

Images as 2D Signals



Sampling

A Brief Overview: Image Processing



Images as 2D Signals

Sampling

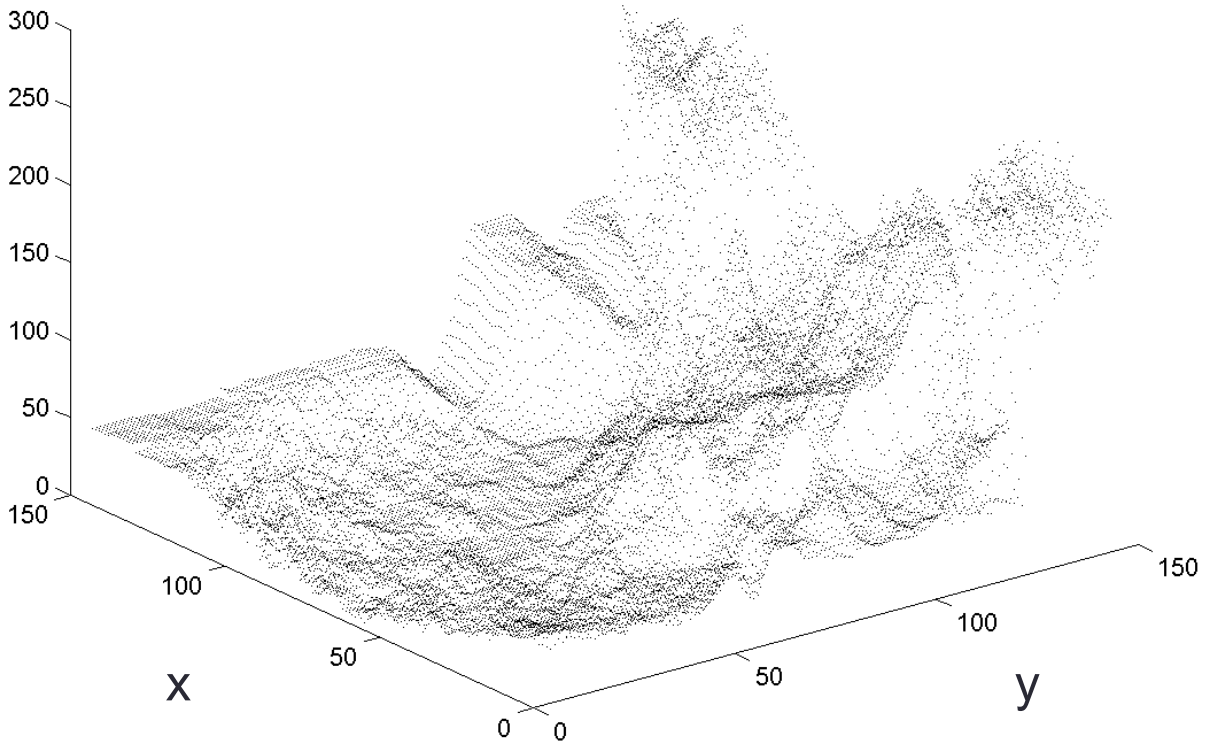
Resolution – geometric vs. spatial resolution

Both images are ~500x500 pixels

A Brief Overview: Image Representation

Grayscale Digital Image

Brightness or intensity

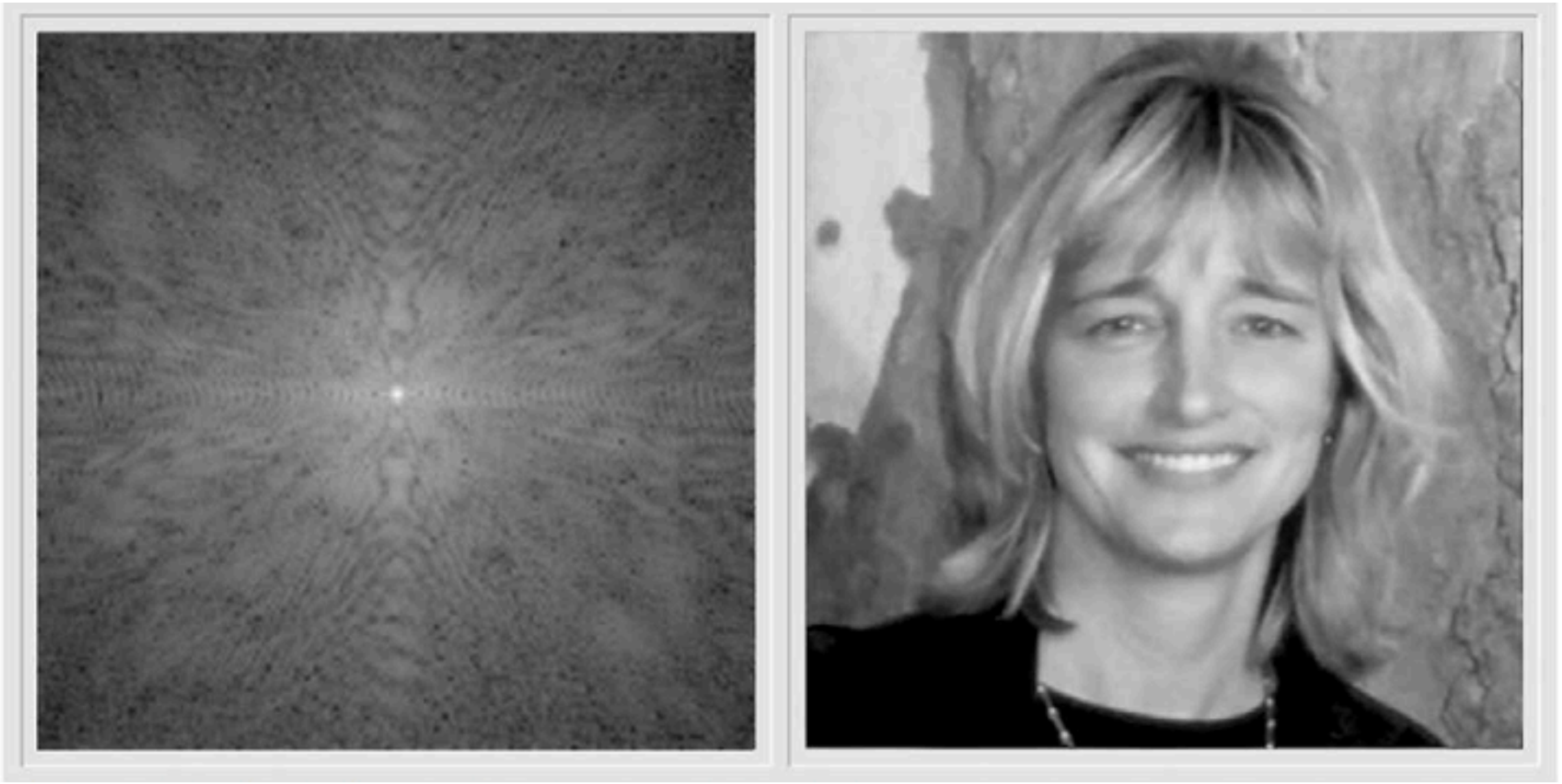


A Brief Overview: Light and Color

Danny Alexander

A Brief Overview: Edge detection

A Brief Overview: Frequency Analysis



Fourier domain

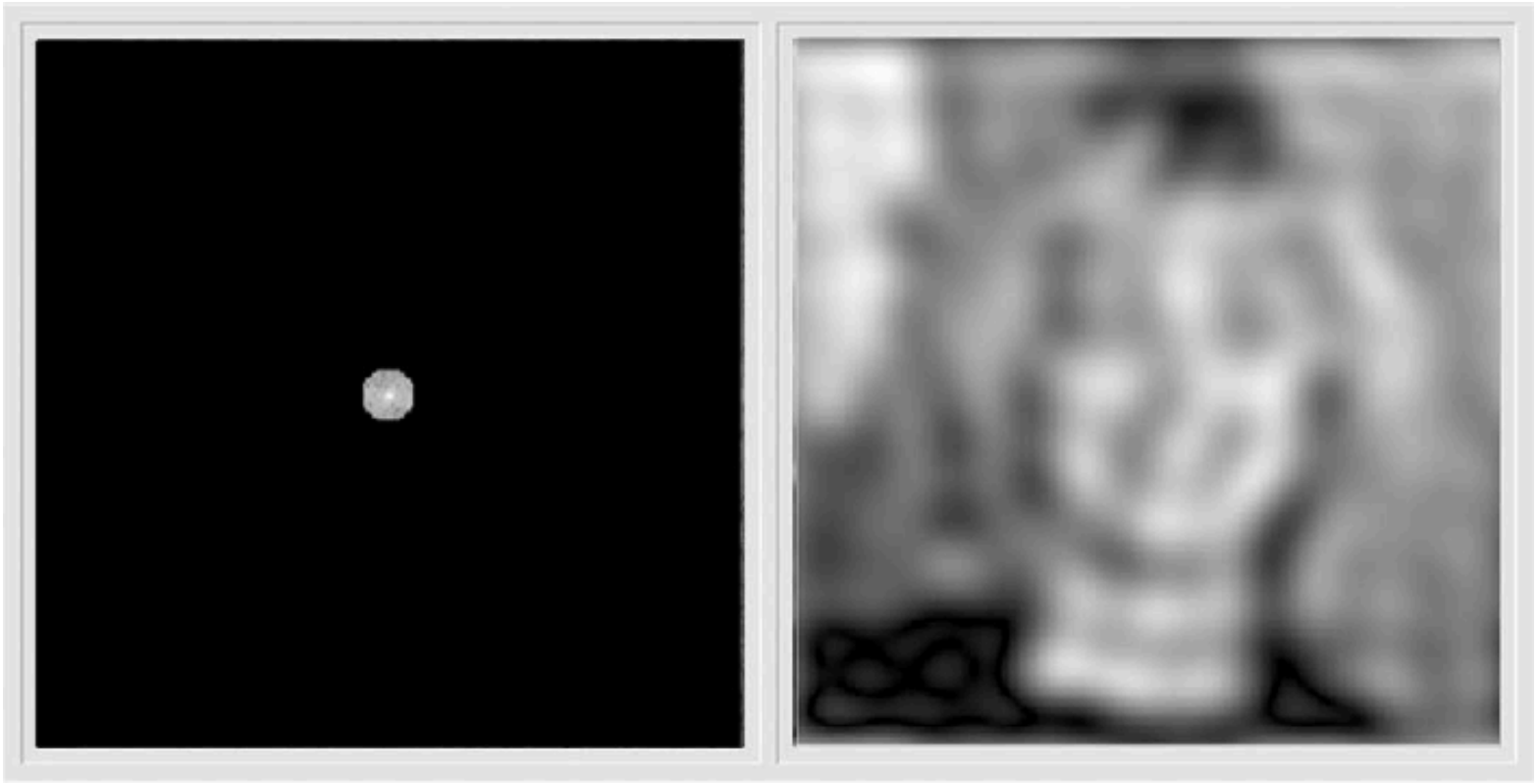
Image domain

A Brief Overview: Frequency Analysis

Fourier domain

Image domain

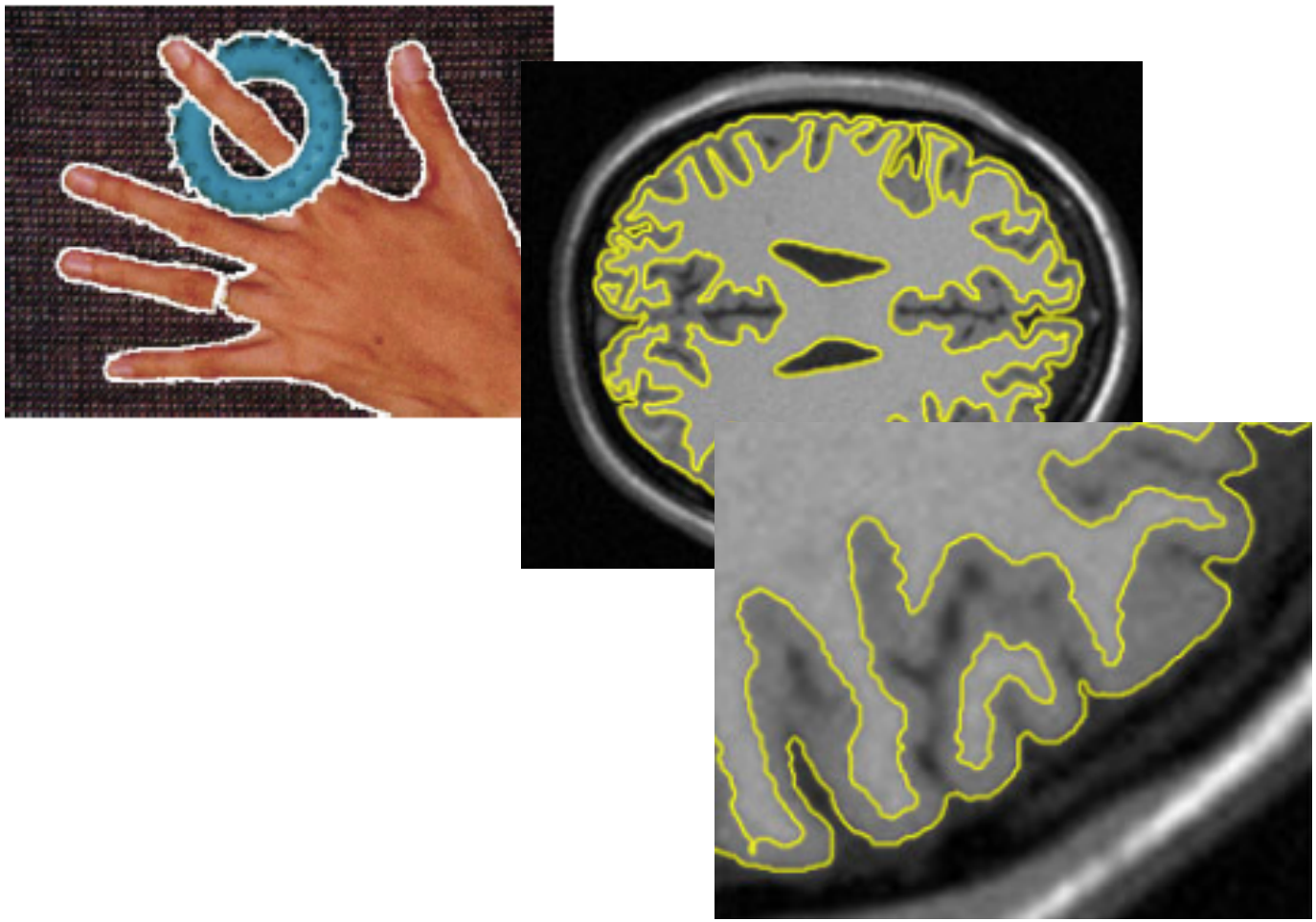
A Brief Overview: Frequency Analysis



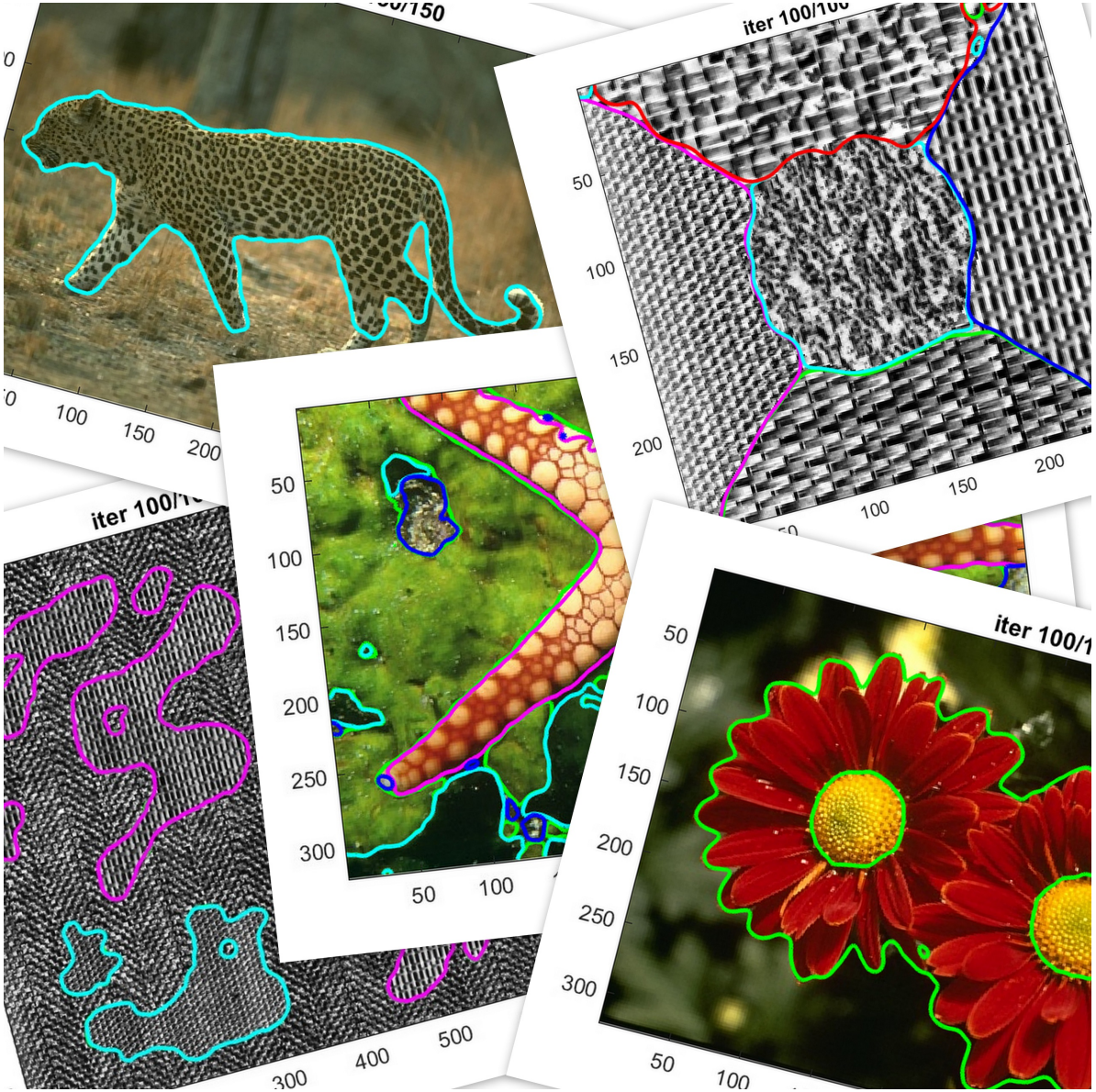
Fourier domain

Image domain

A Brief Overview: Image Segmentation

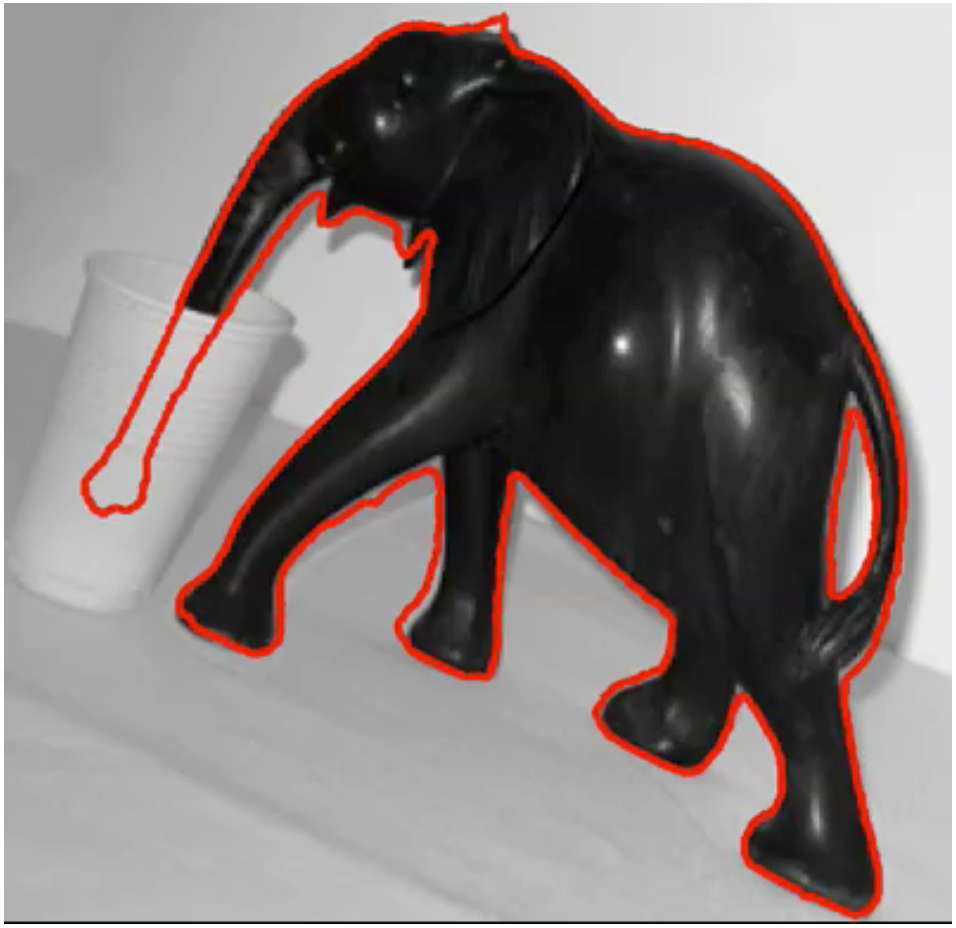


A Brief Overview: Image Segmentation



Texture segmentation

A Brief Overview: Image Segmentation



Prior based segmentation

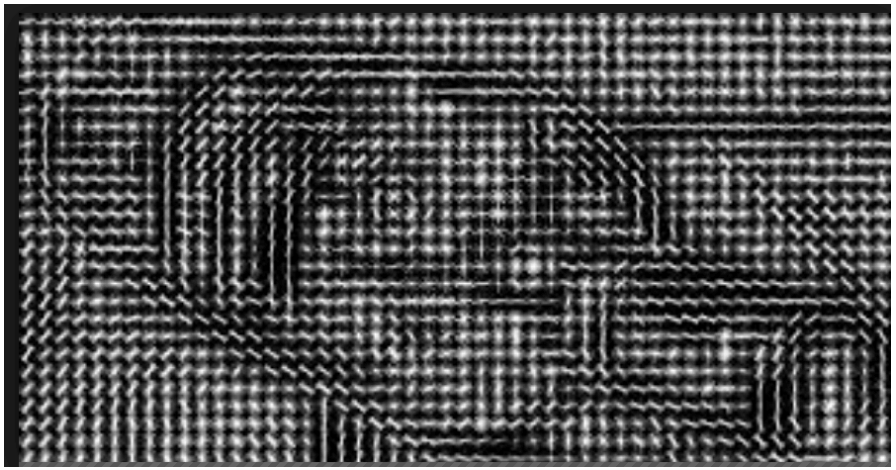
Riklin Raviv et al, IJCV 2007

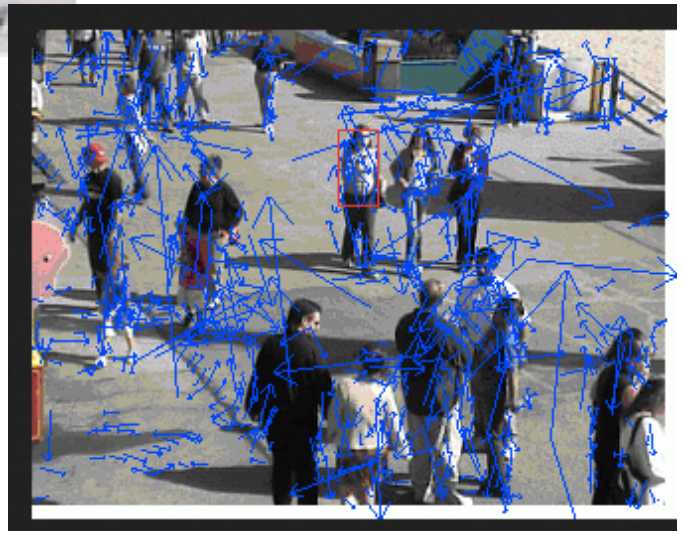
A Brief Overview: Image Segmentation

Symmetry based segmentation

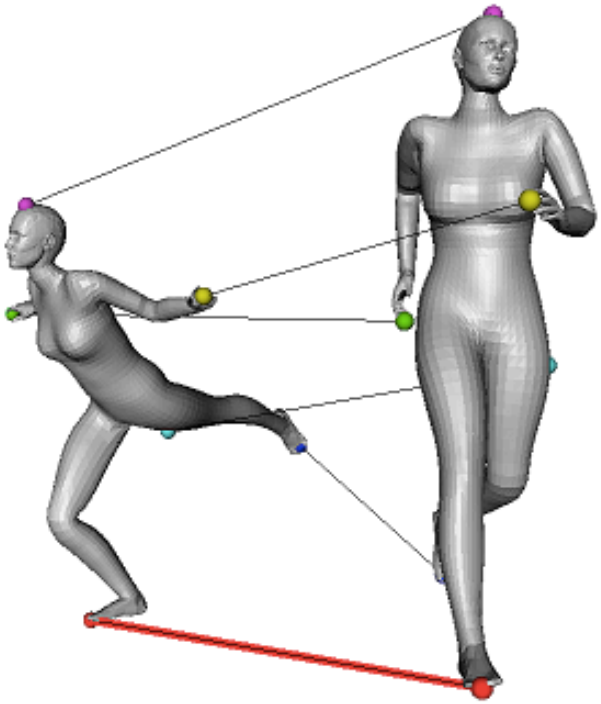
Riklin Raviv et al, TPAMI 2009

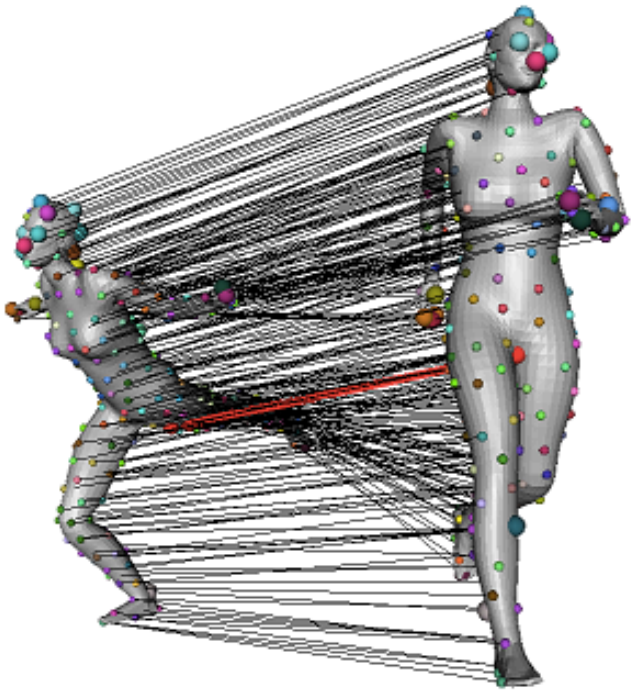
A Brief Overview: Feature Detection

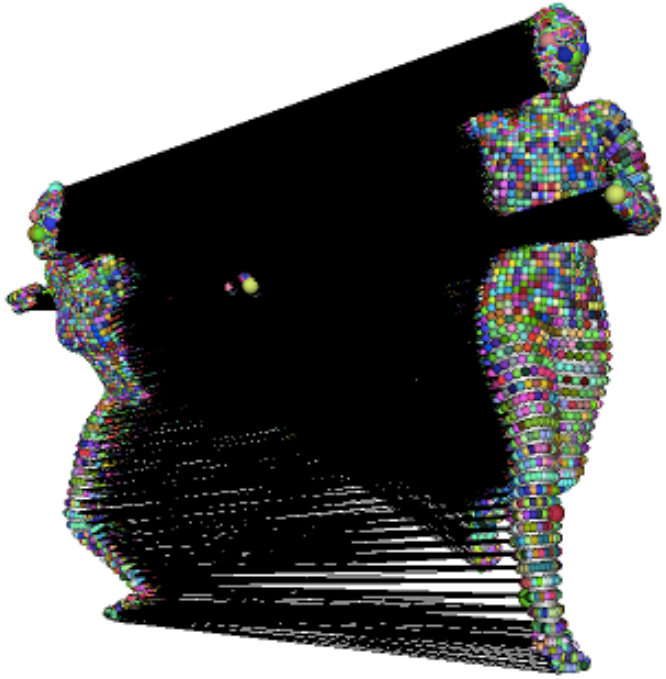




A Brief Overview: Correspondences







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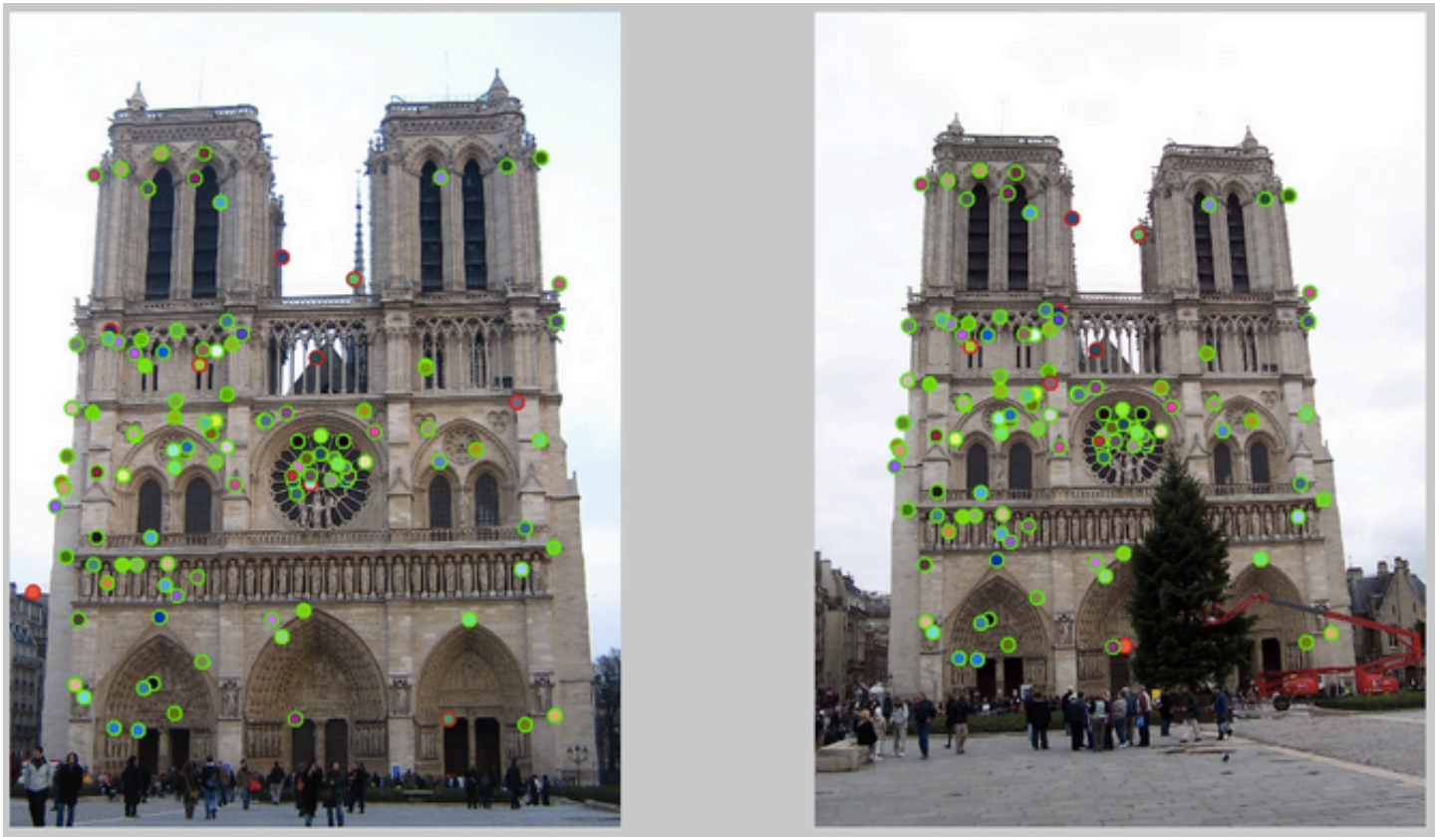
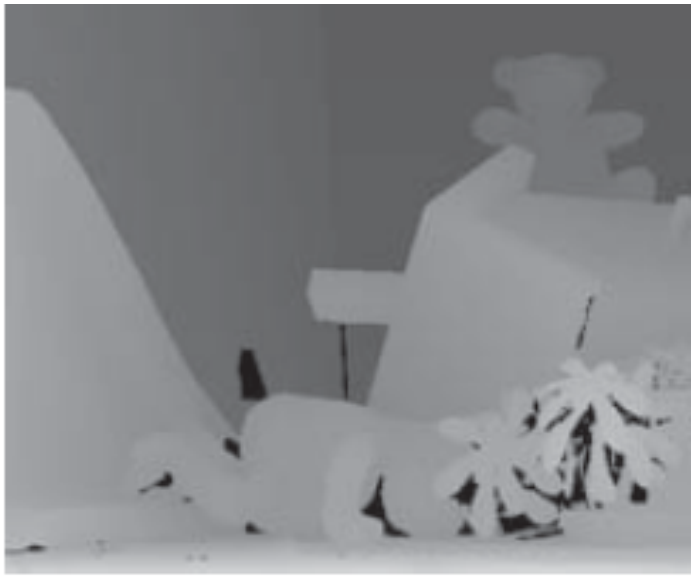
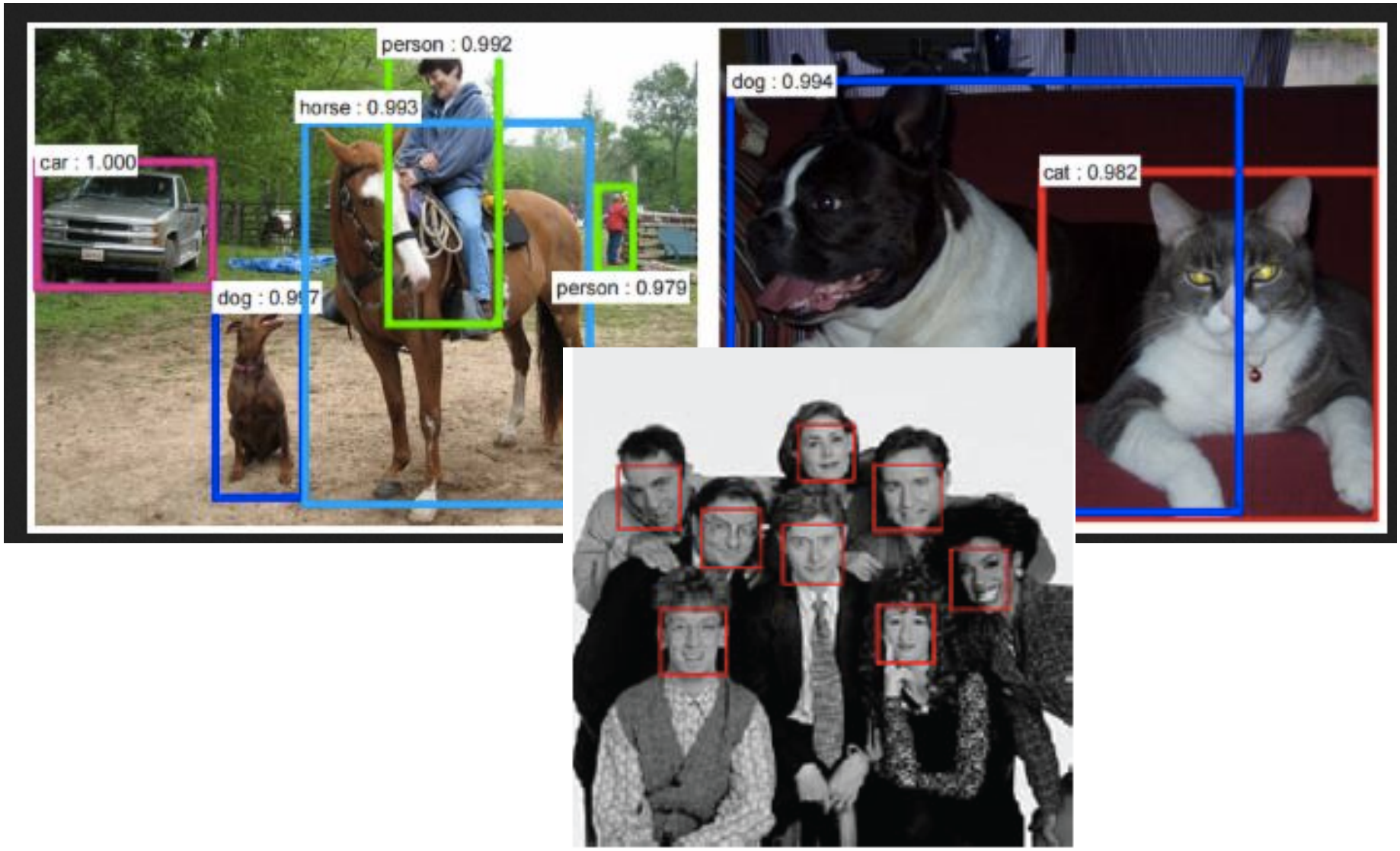


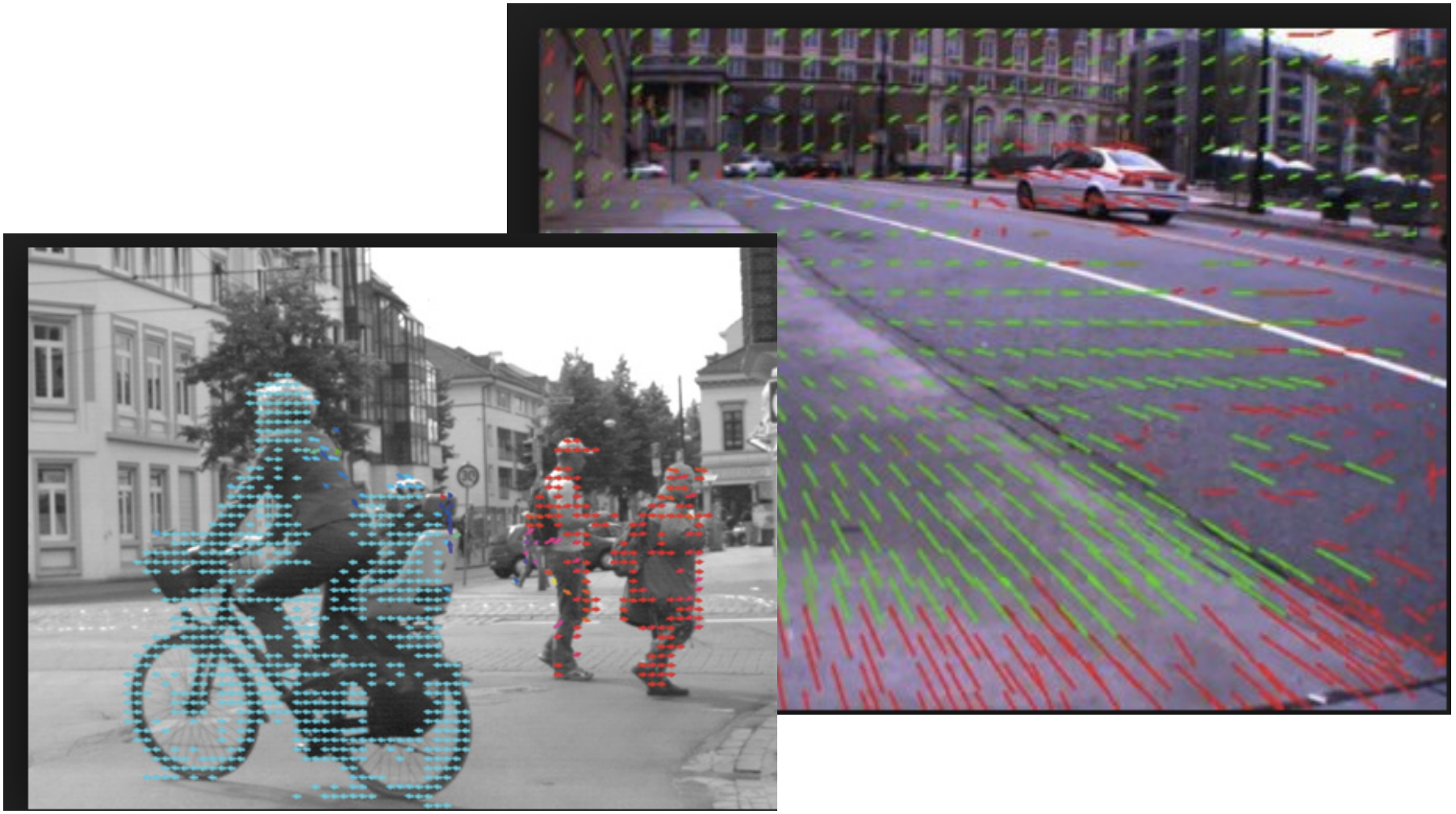
A Brief Overview: Stereo and 3D reconstruction



A Brief Overview: Object Detection and Recognition

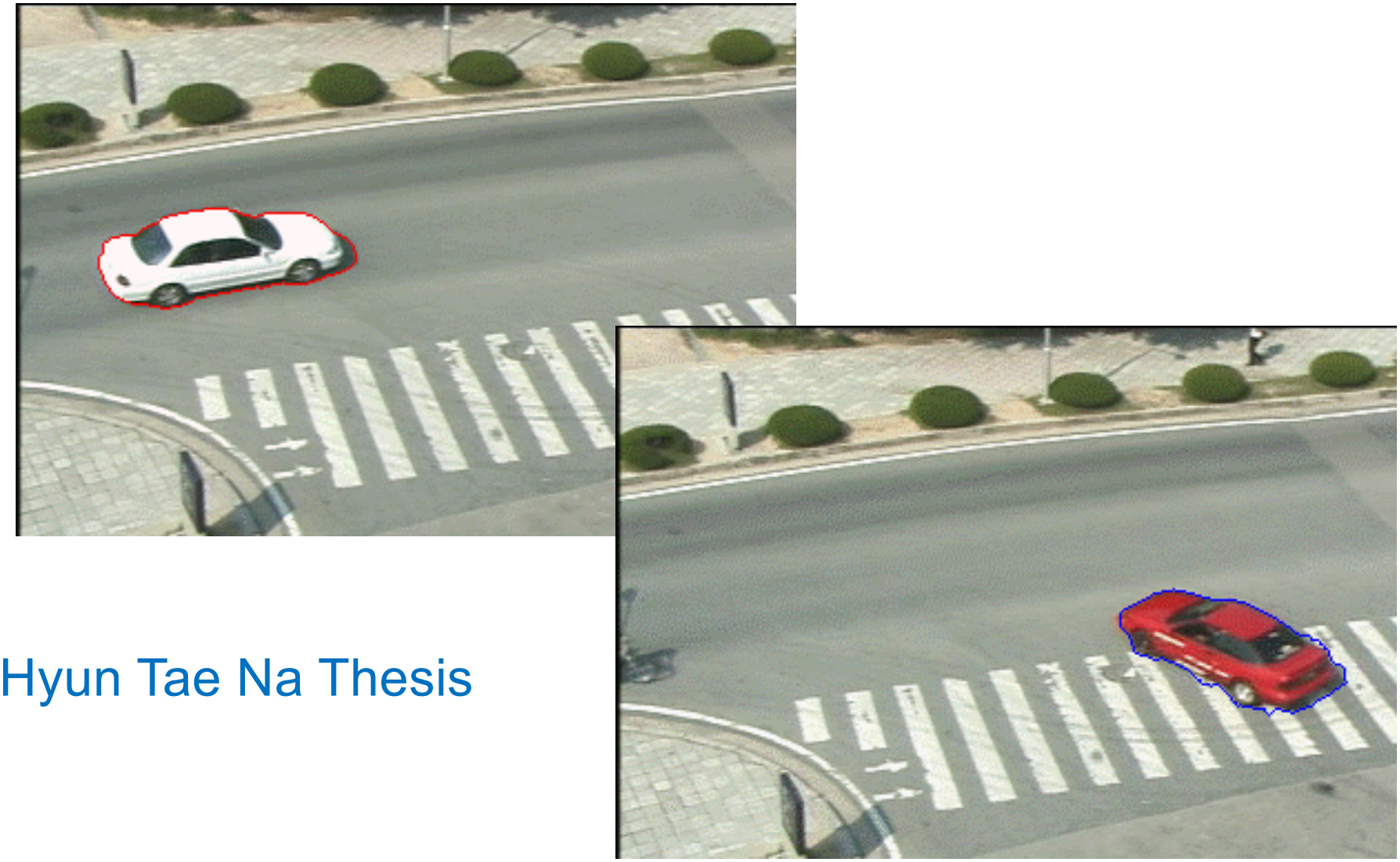


A Brief Overview: Motion



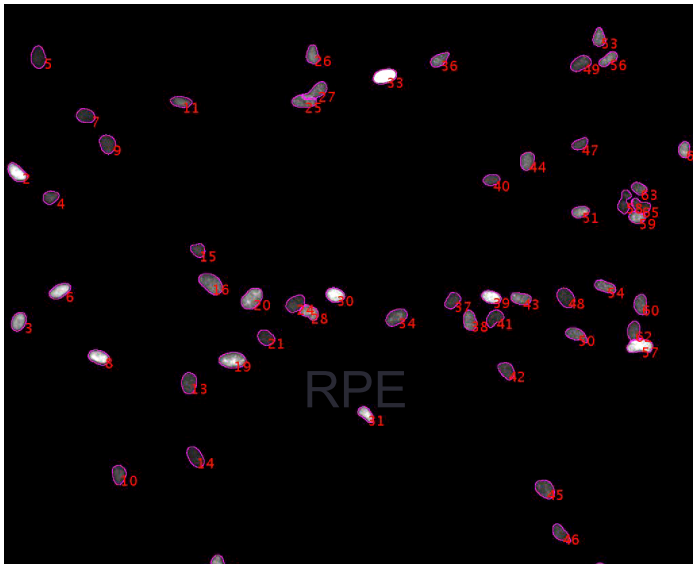
Optical Flow

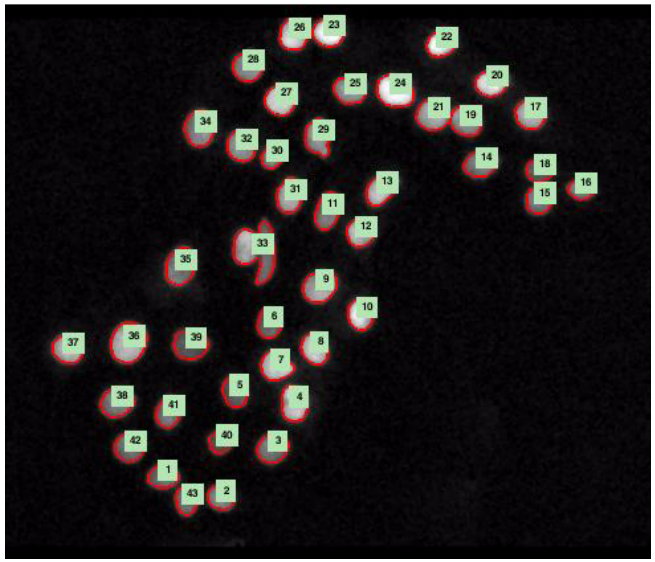
A Brief Overview: Tracking

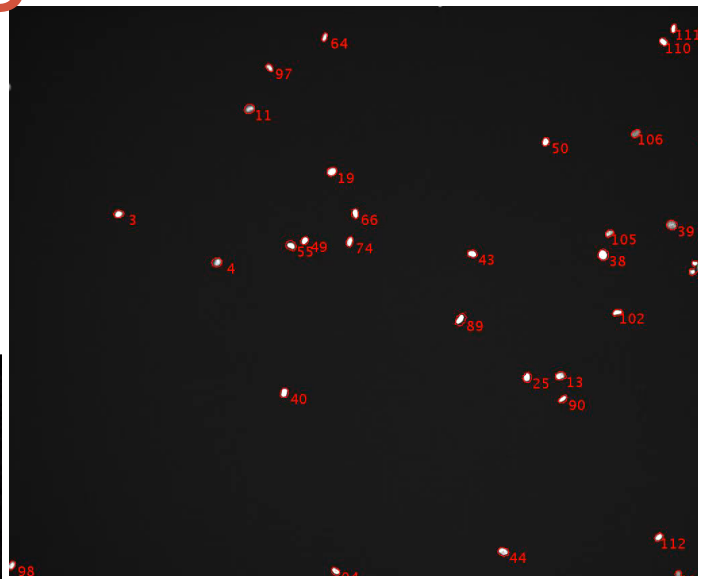


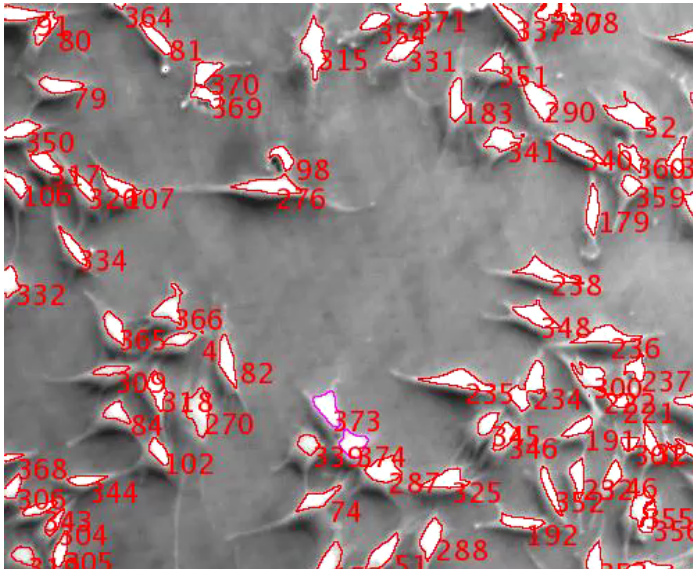
Hyun Tae Na Thesis

A Brief Overview: Tracking

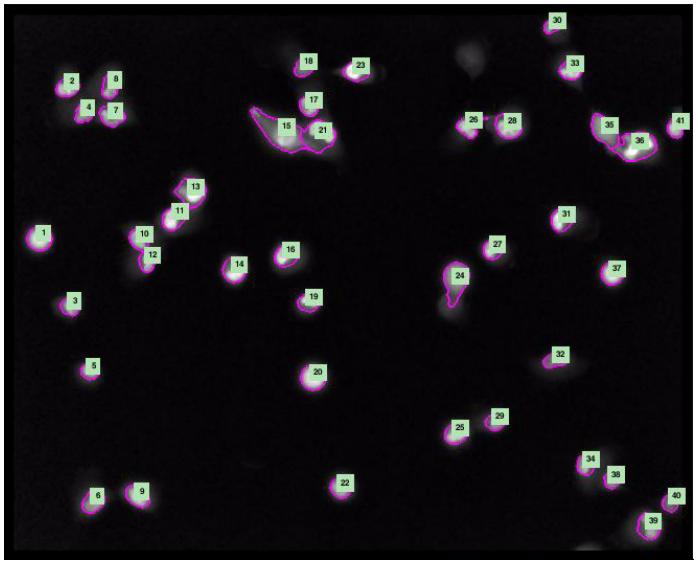








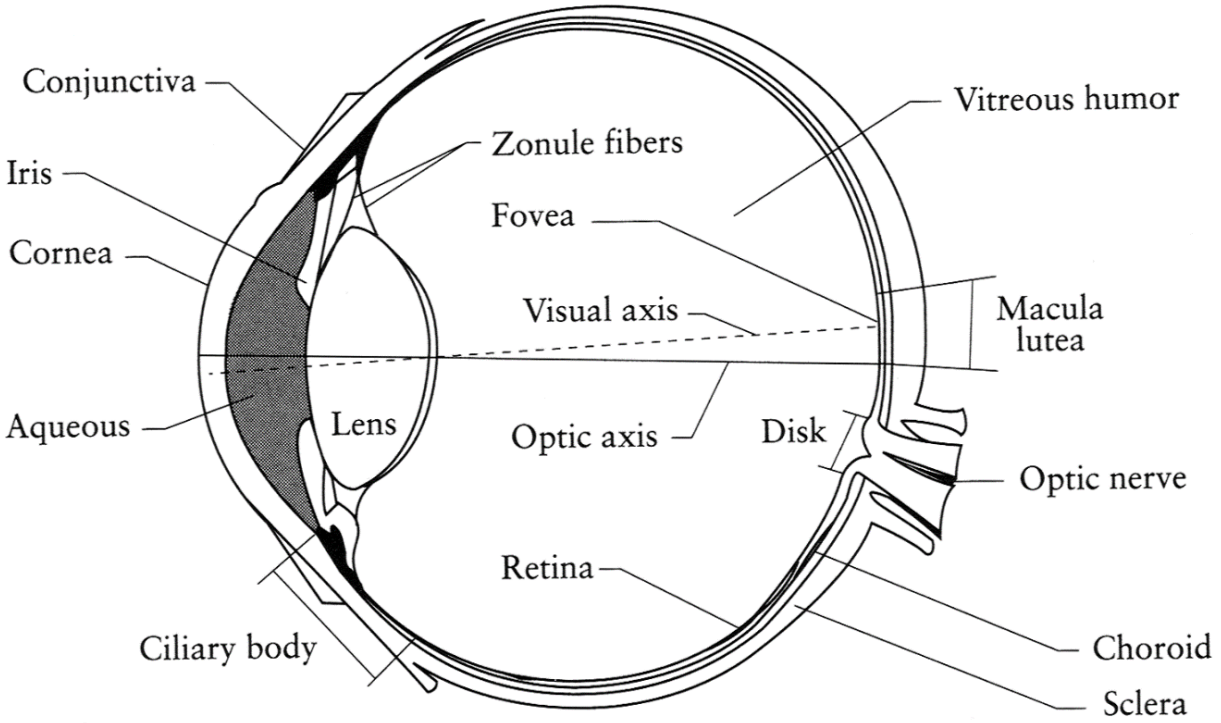
Arbelle's Thesis



The Rest of Today's Class

- Brief Overview
- Human Vision and Visual Perception
- What is an Image?

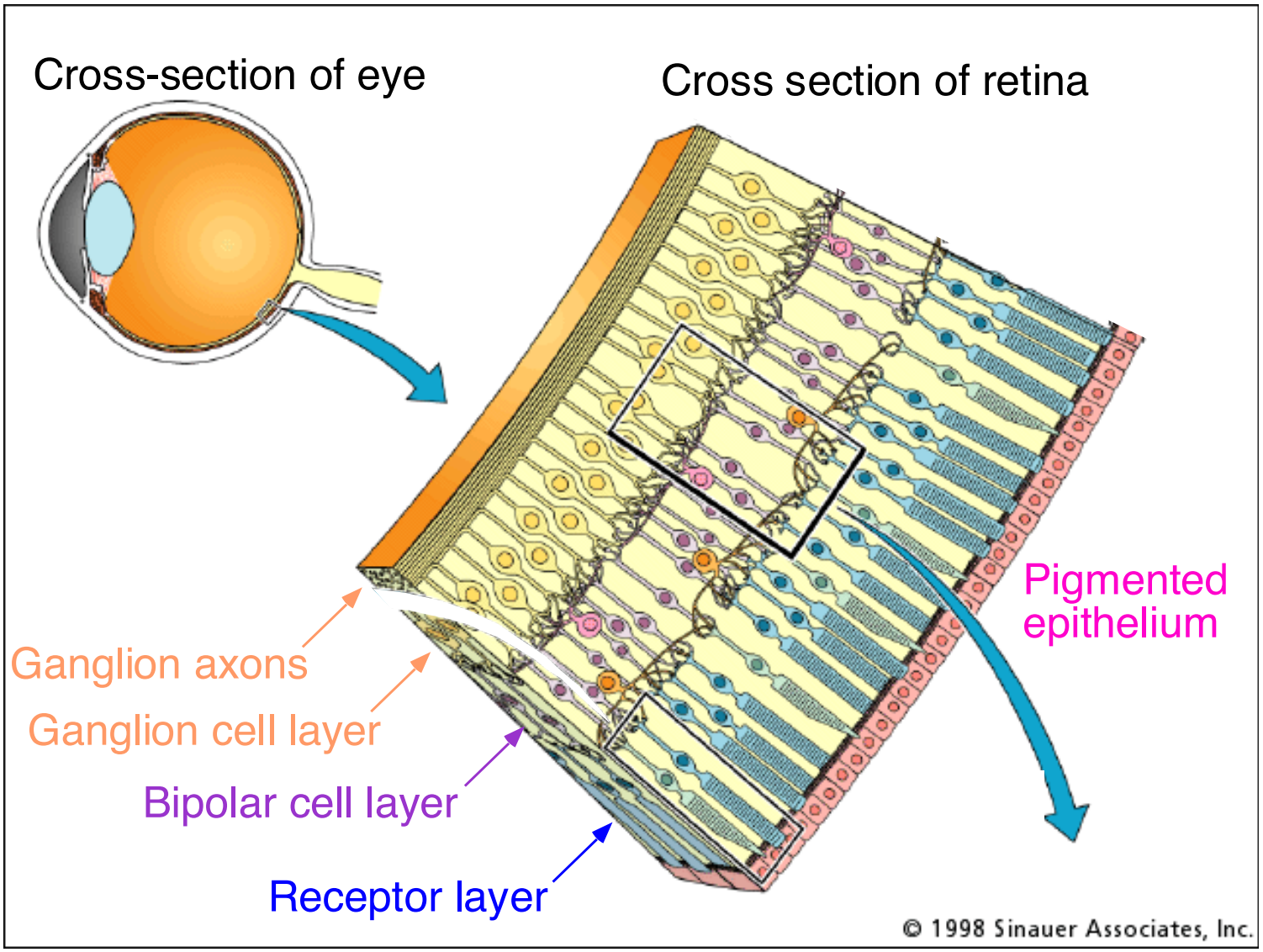
Human Vision/ Visual Perception



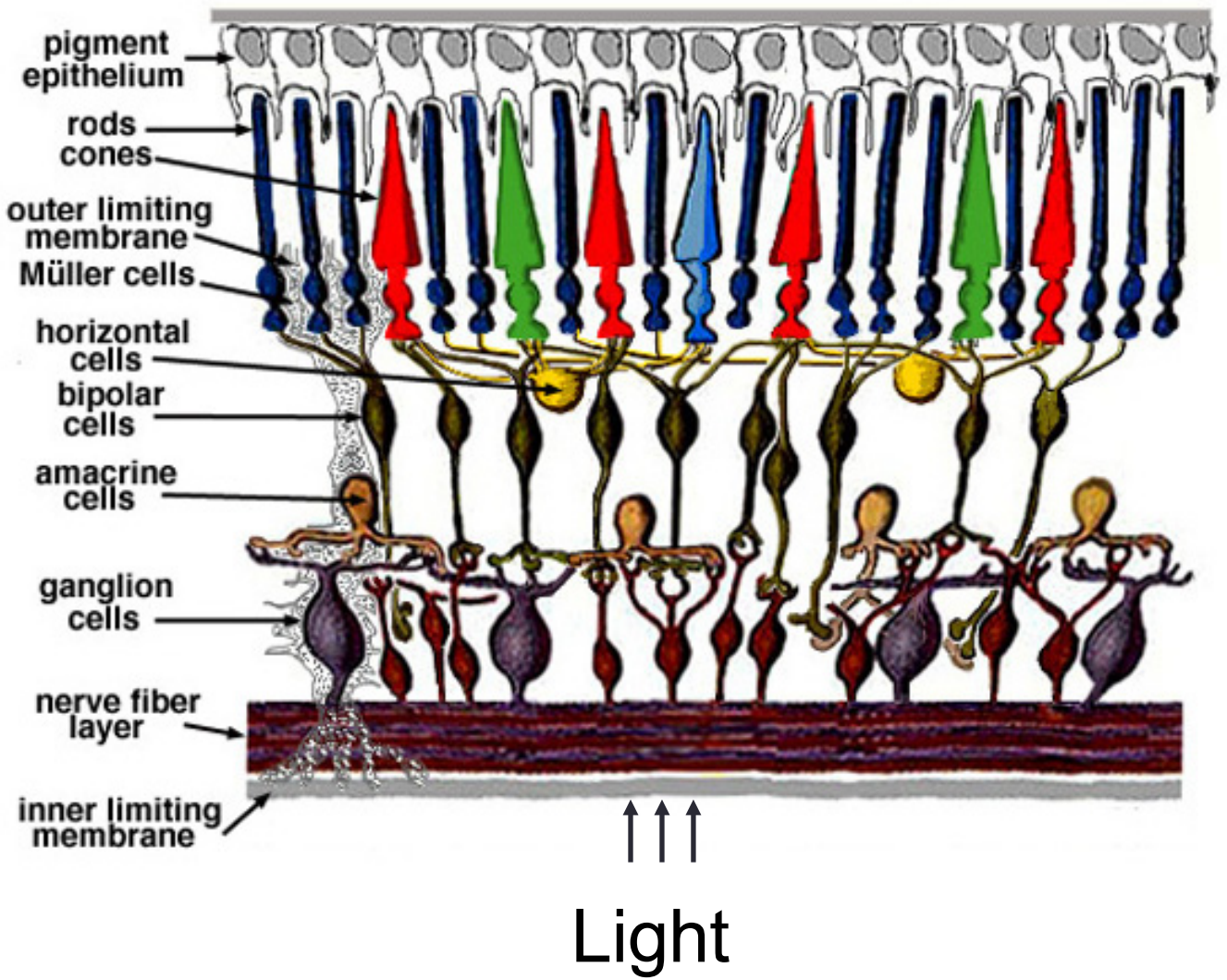
- The human eye is a camera
  - **Iris** - colored annulus with radial muscles
  - **Pupil** - the hole (aperture) whose size is controlled by the iris
  - What's the sensor?
    - photoreceptor cells (rods and cones) in the **retina**

Slide by Steve Seitz

Human Vision: the Retina



Human Vision: Retina up-close



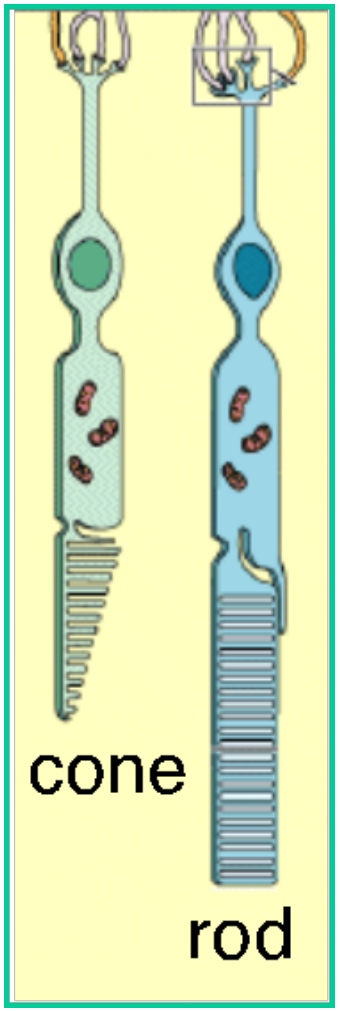
Human Vision: Retina up-close

Cones

cone-shaped
less sensitive
operate in high light
color vision

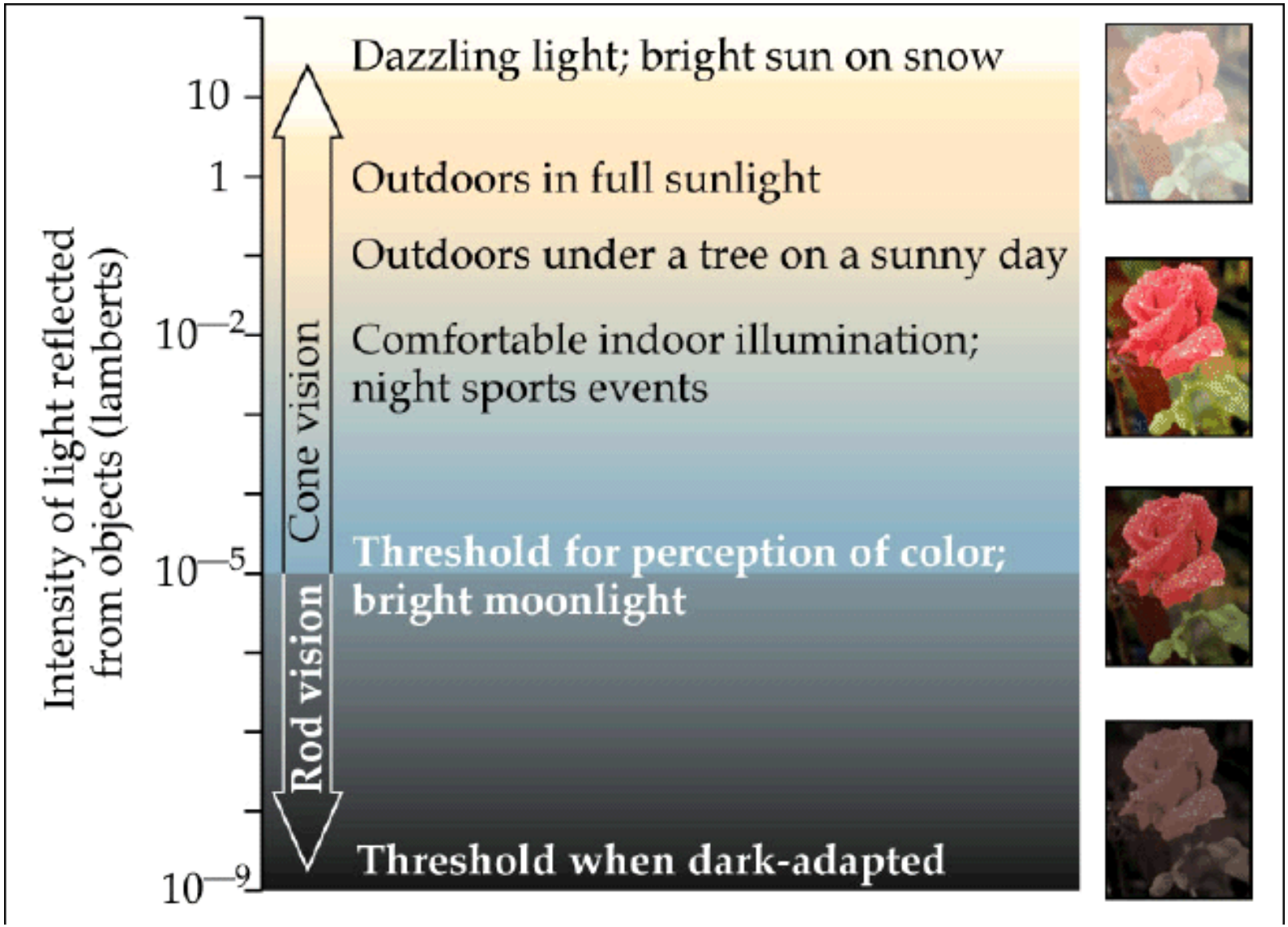
Rods

rod-shaped
highly sensitive
operate at night
gray-scale vision

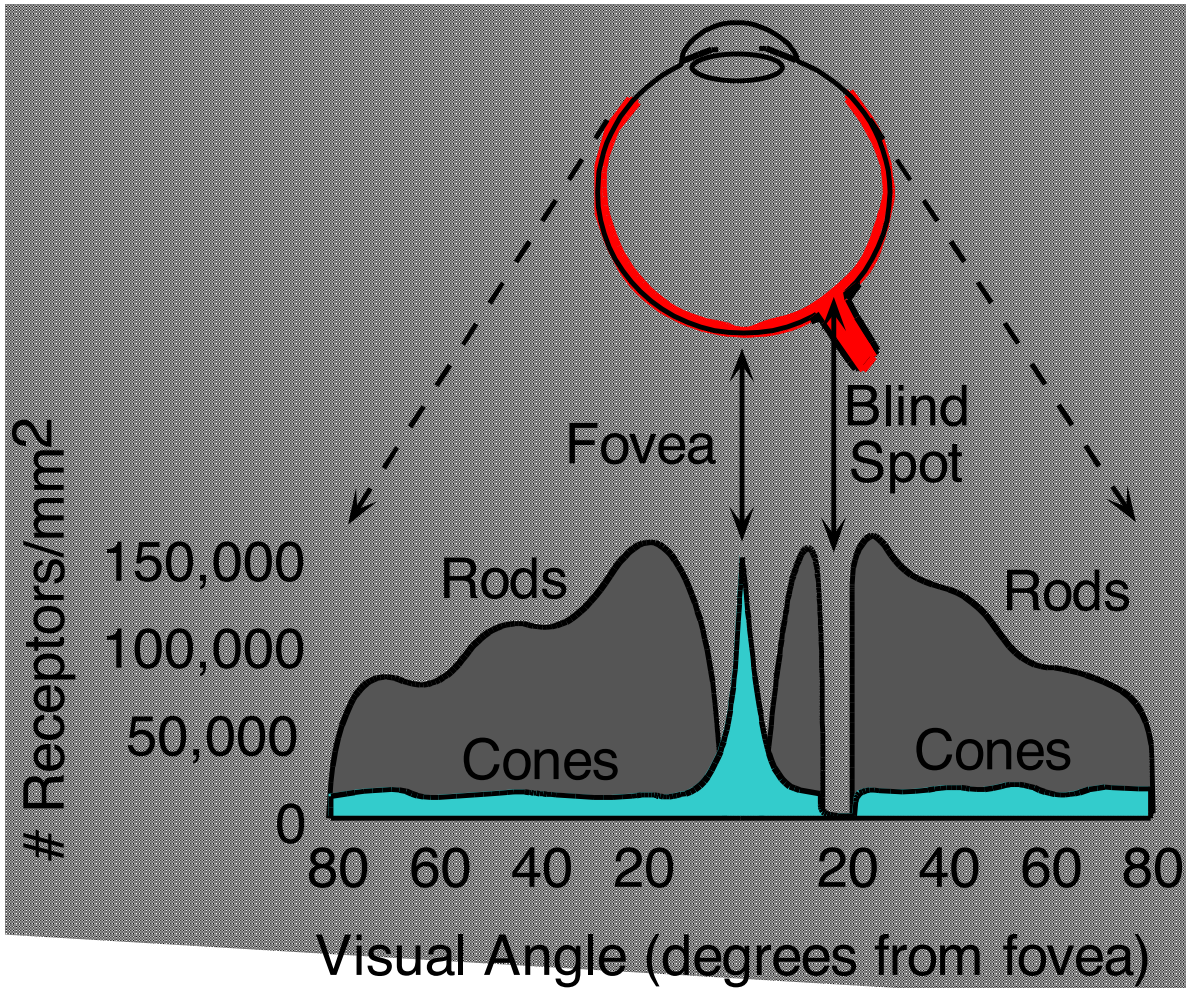


Two types of light-sensitive receptors

Rod / Cone sensitivity



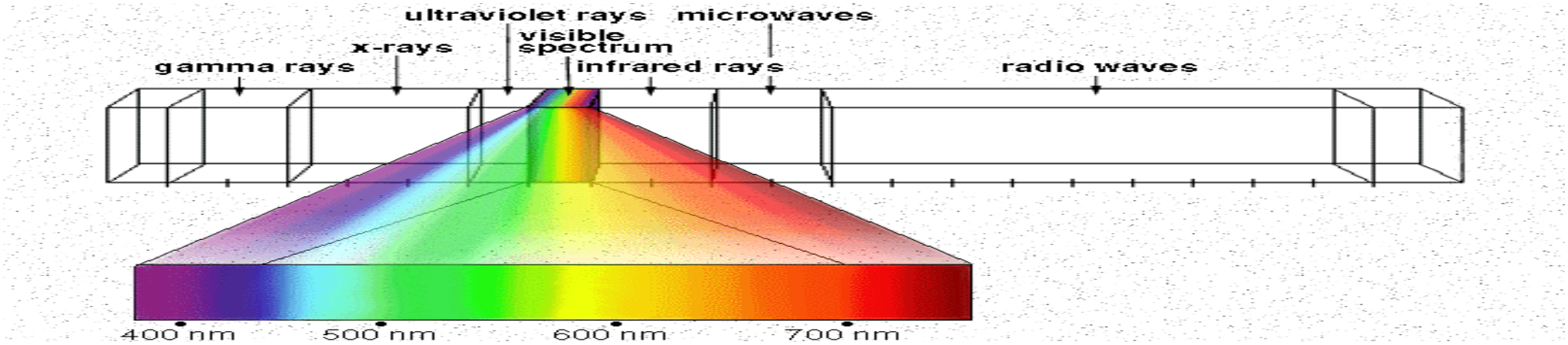
Distribution of Rods and Cones

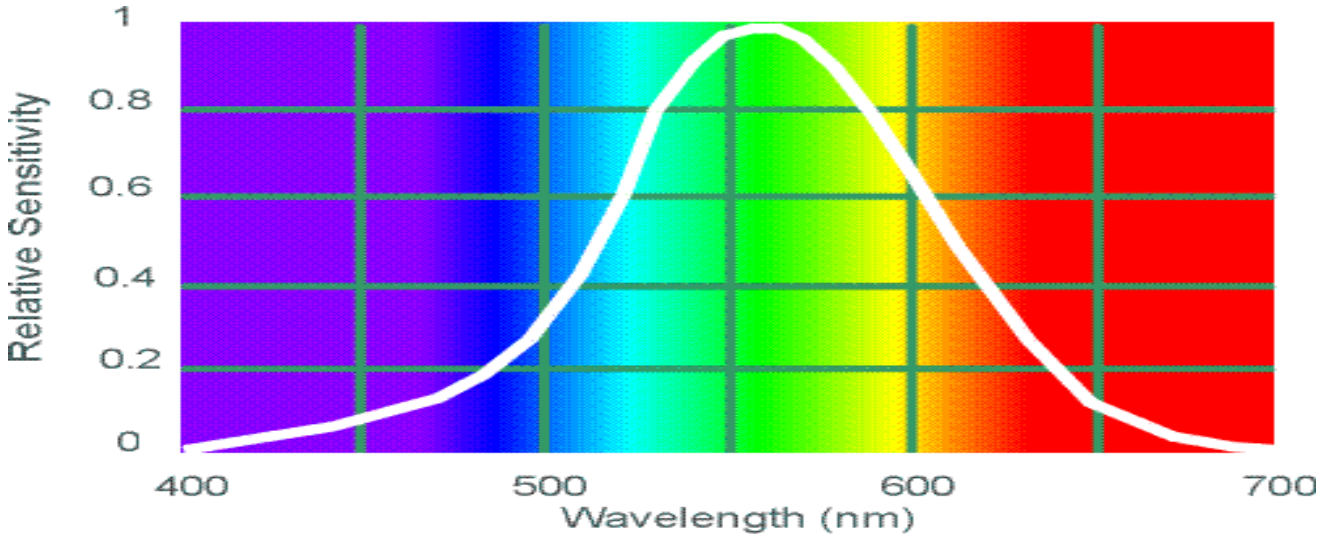


Night Sky: why are there more stars off-center?

Averted vision: http://en.wikipedia.org/wiki/Averted_vision

Electromagnetic Spectrum



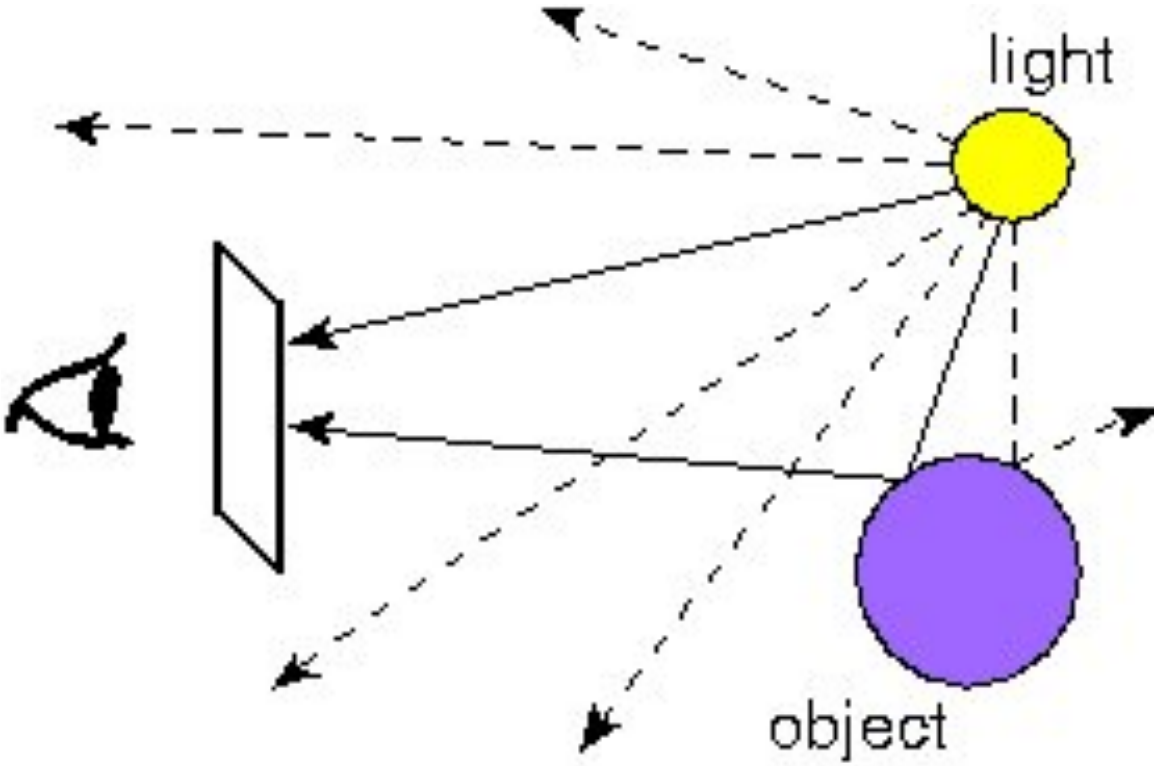


Human Luminance Sensitivity Function

http://www.yorku.ca/eye/photopik.htm

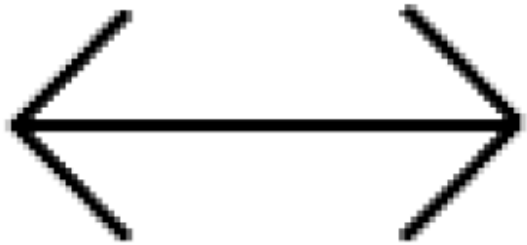
Human Visual Perception

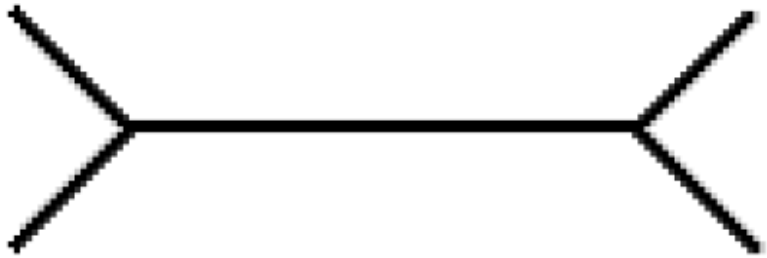
What can we learn from human visual perception?



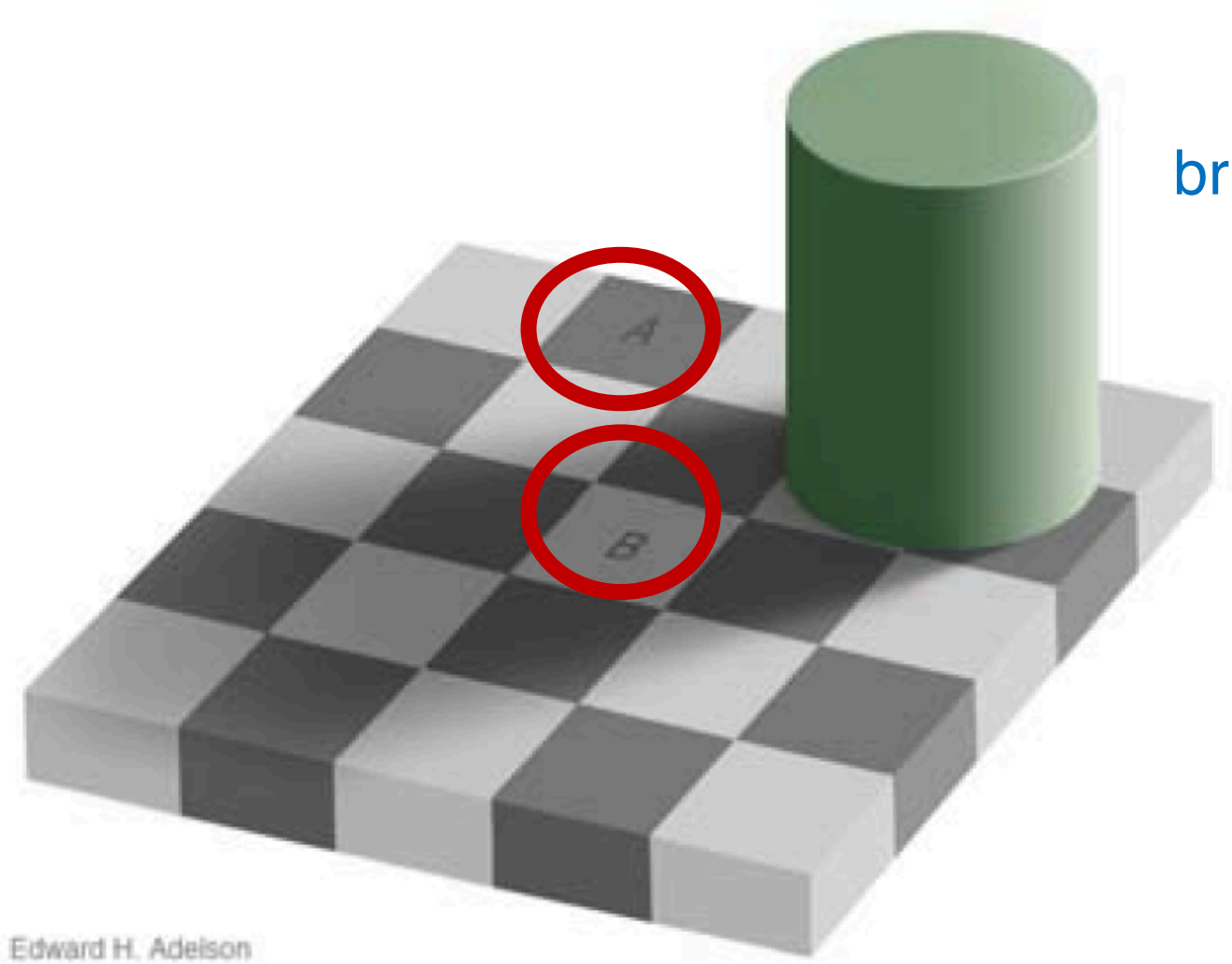
Human Perception

Muller-Lyer illusion





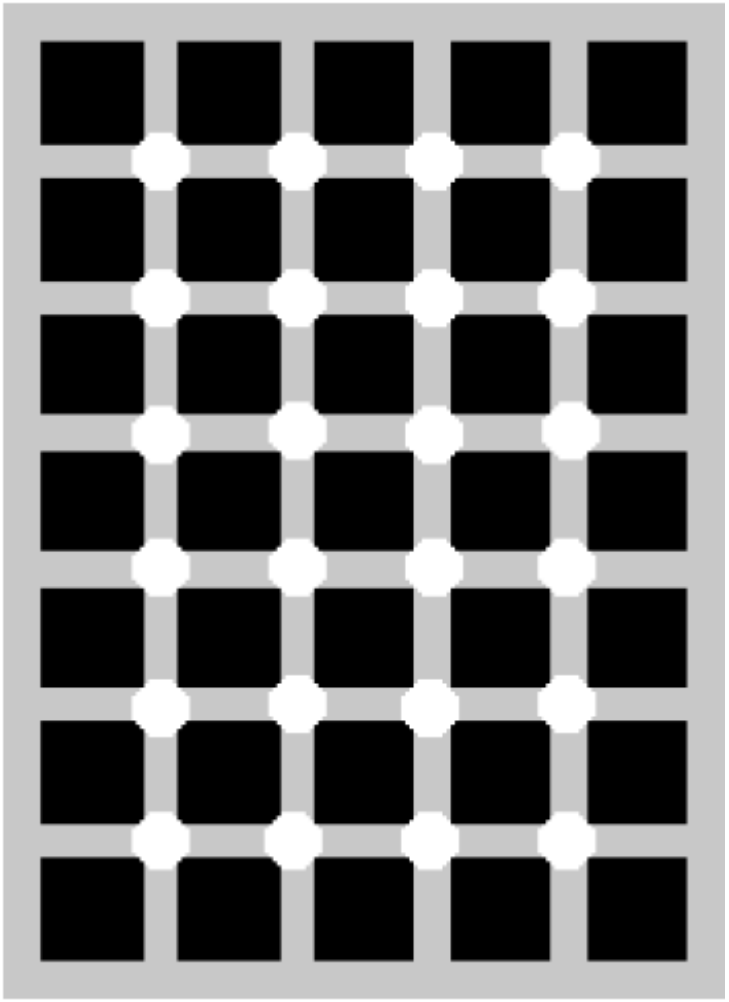
Human Perception



brightness constancy

Ted Adelson, http://web.mit.edu/persci/people/adelson/checkershadow illusion.html

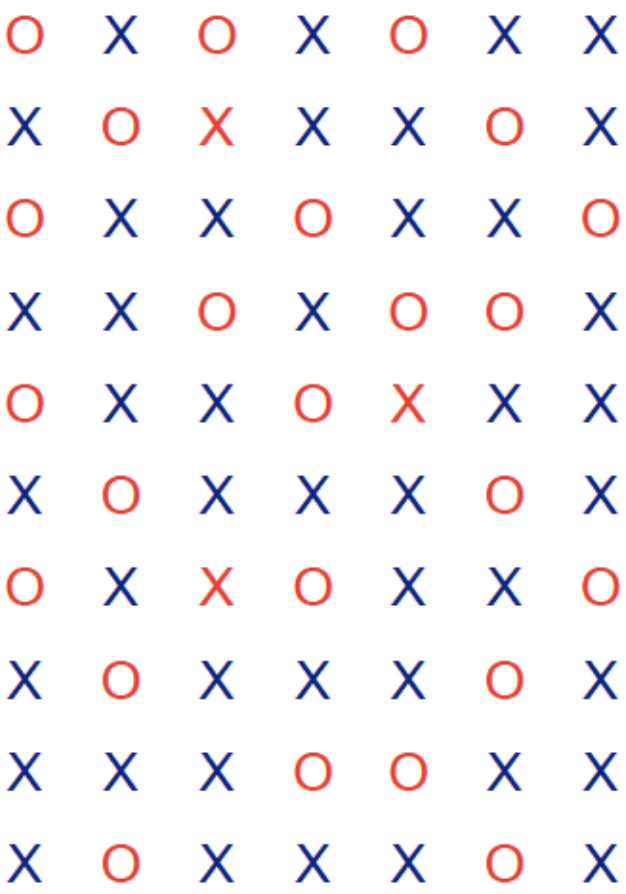
Human Perception



Hermann grid illusion

Hany Farid, http://www.cs.dartmouth.edu/farid/illusions/hermann.html

Human Perception



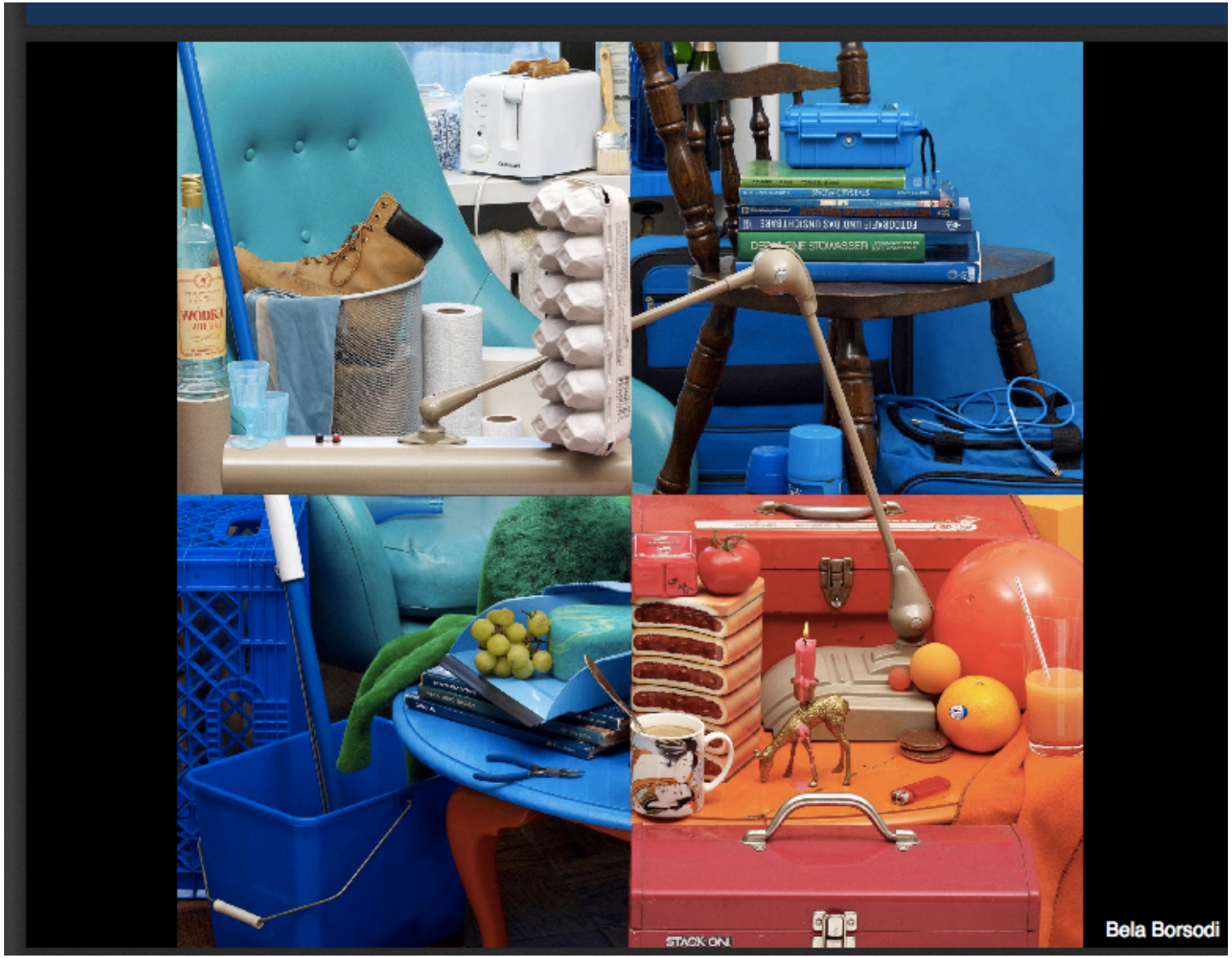
Count the red X

pop-out effect (Treisman 1985)

The Rest of Today's Class

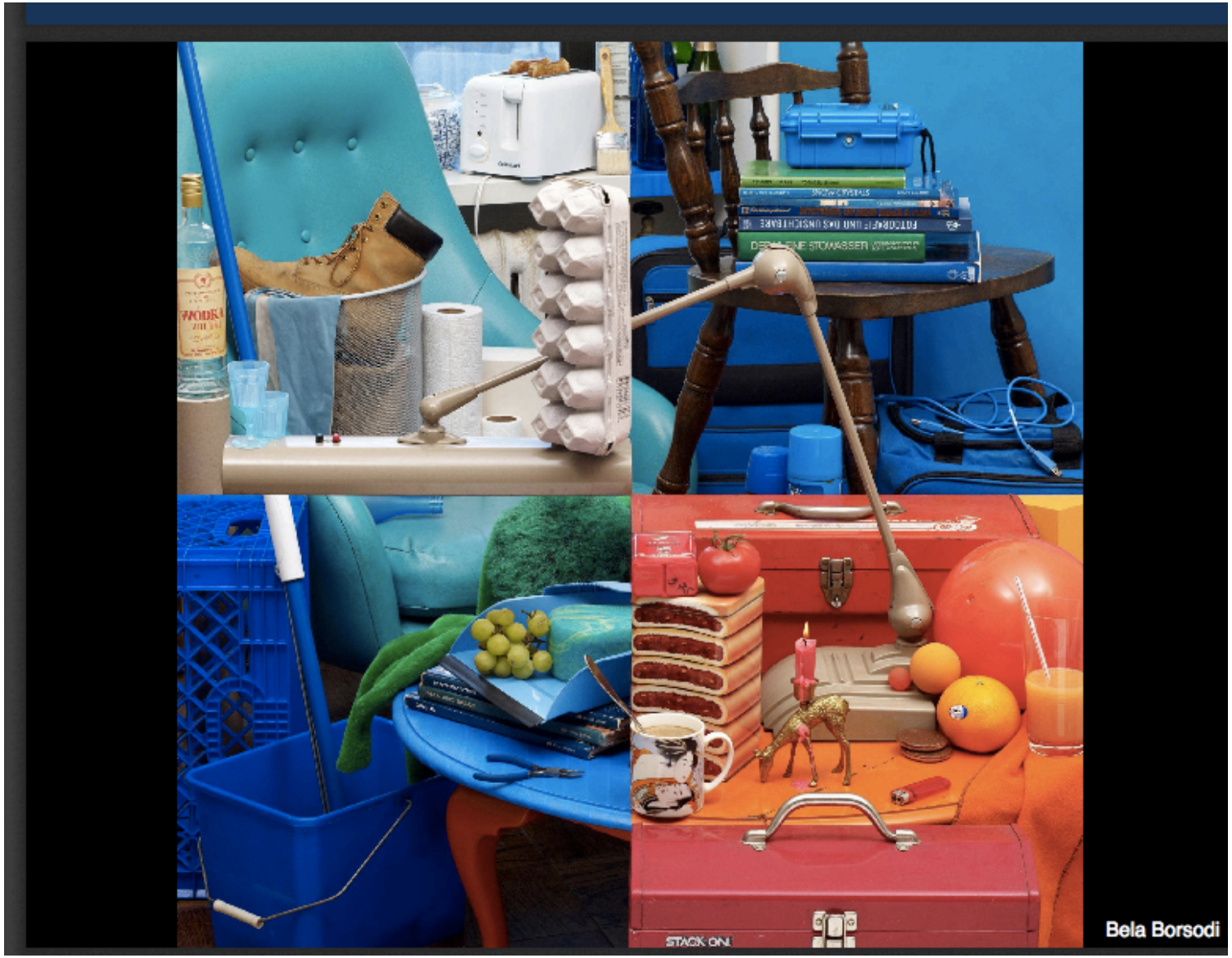
- Brief Overview
- Human Vision and Visual Perception
- What is an Image?

What is an Image?

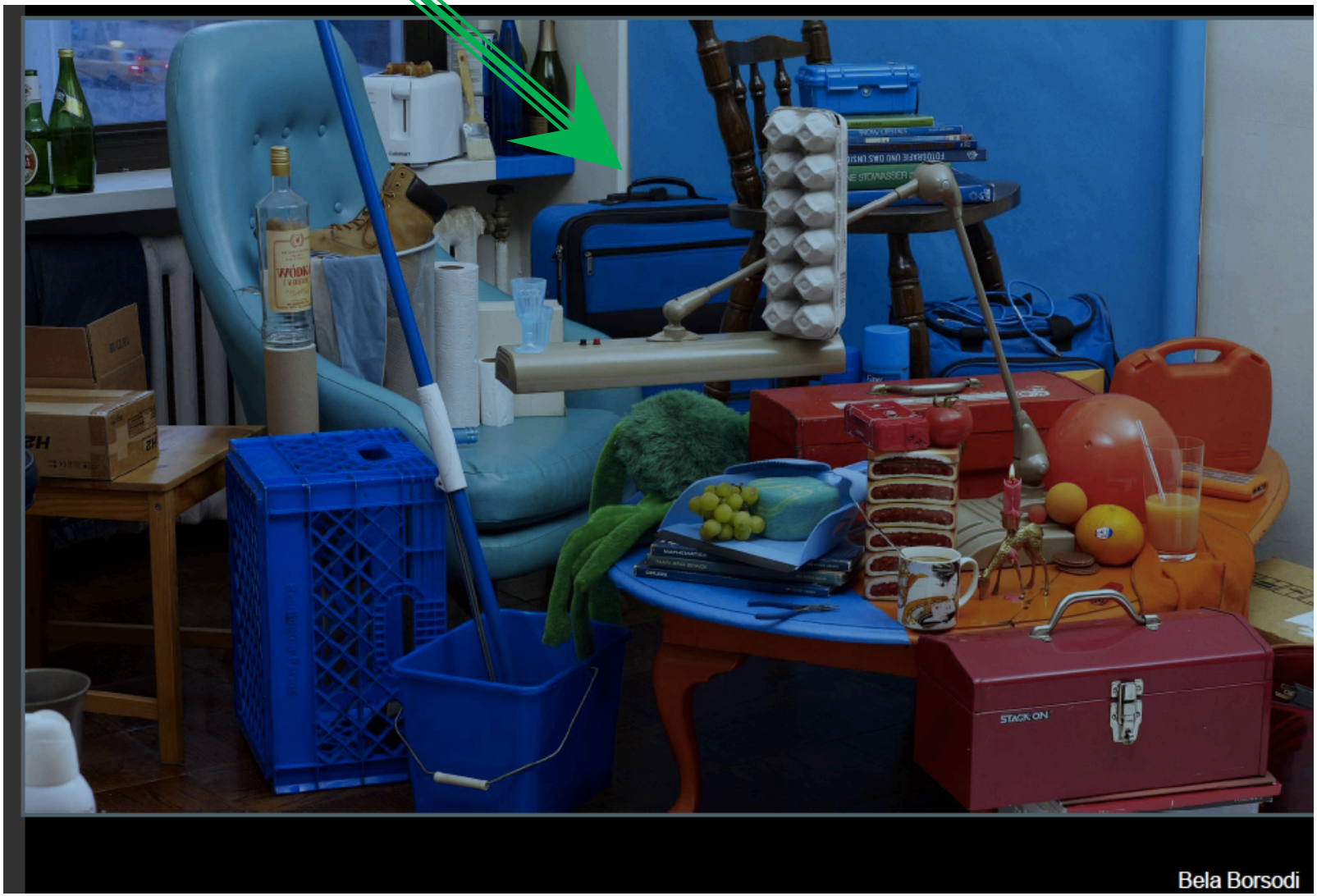


This Image is taken from Brown's Computer Vision Course

How would it look through the “computer’s eyes” ?

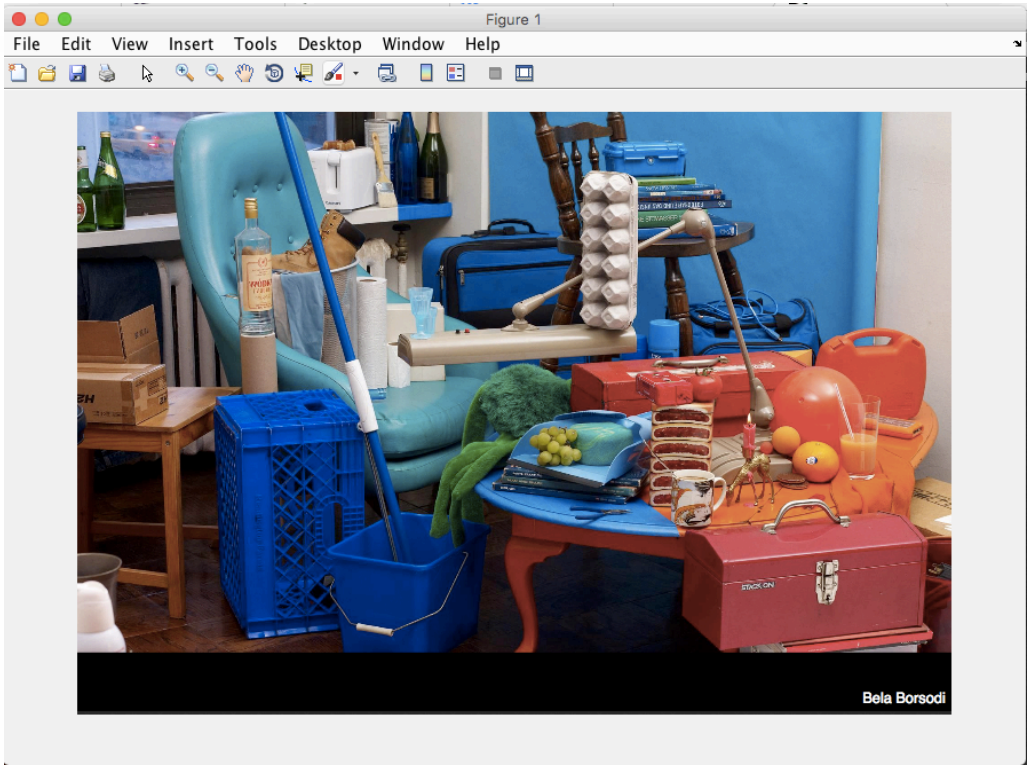


Why is this an image?



Hello Word !

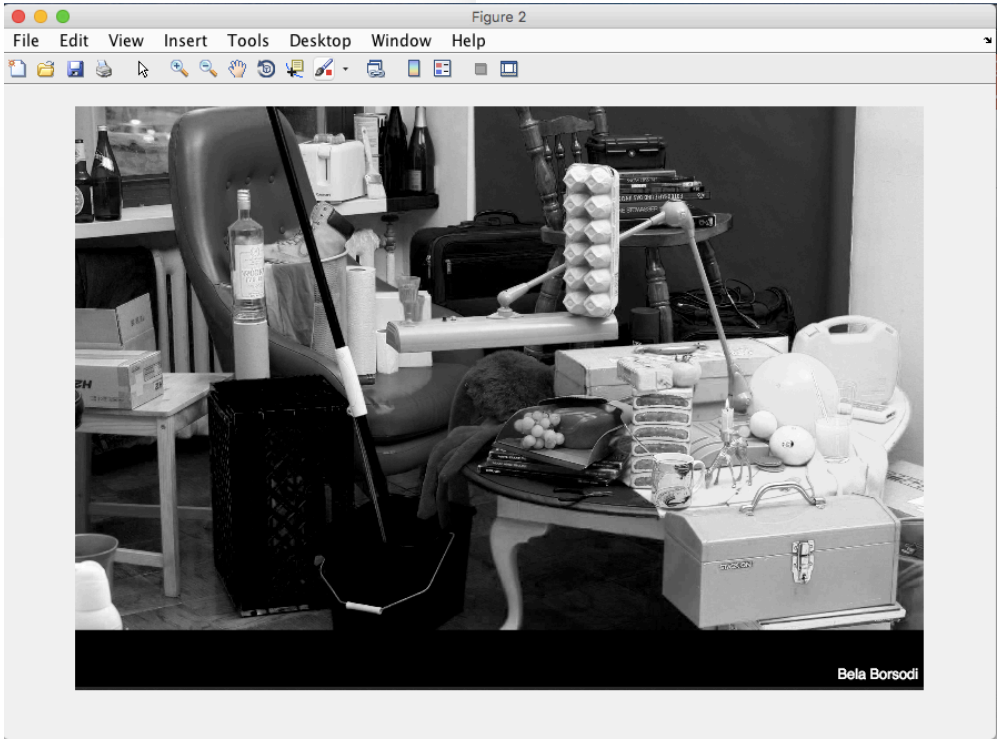

```
>>
>>
>> myFirstImage = imread('someImage.png');
>> whos
  Name                 Size                    Bytes  Class

  ans                526x764x3                1205592  uint8
  myFirstImage       526x764x3                1205592  uint8

>> imshow(myFirstImage);
```



Hello Word !

```
>>
>> myFirstImage = imread('someImage.png');
>> whos
  Name                 Size                    Bytes  Class

  ans                526x764x3                1205592  uint8
  myFirstImage       526x764x3                1205592  uint8

>> imshow(myFirstImage);
>> I1 = myFirstImage(:,:,1);
>> figure;imshow(I1)
>>
```

MATLAB
The Language of Technical Computing



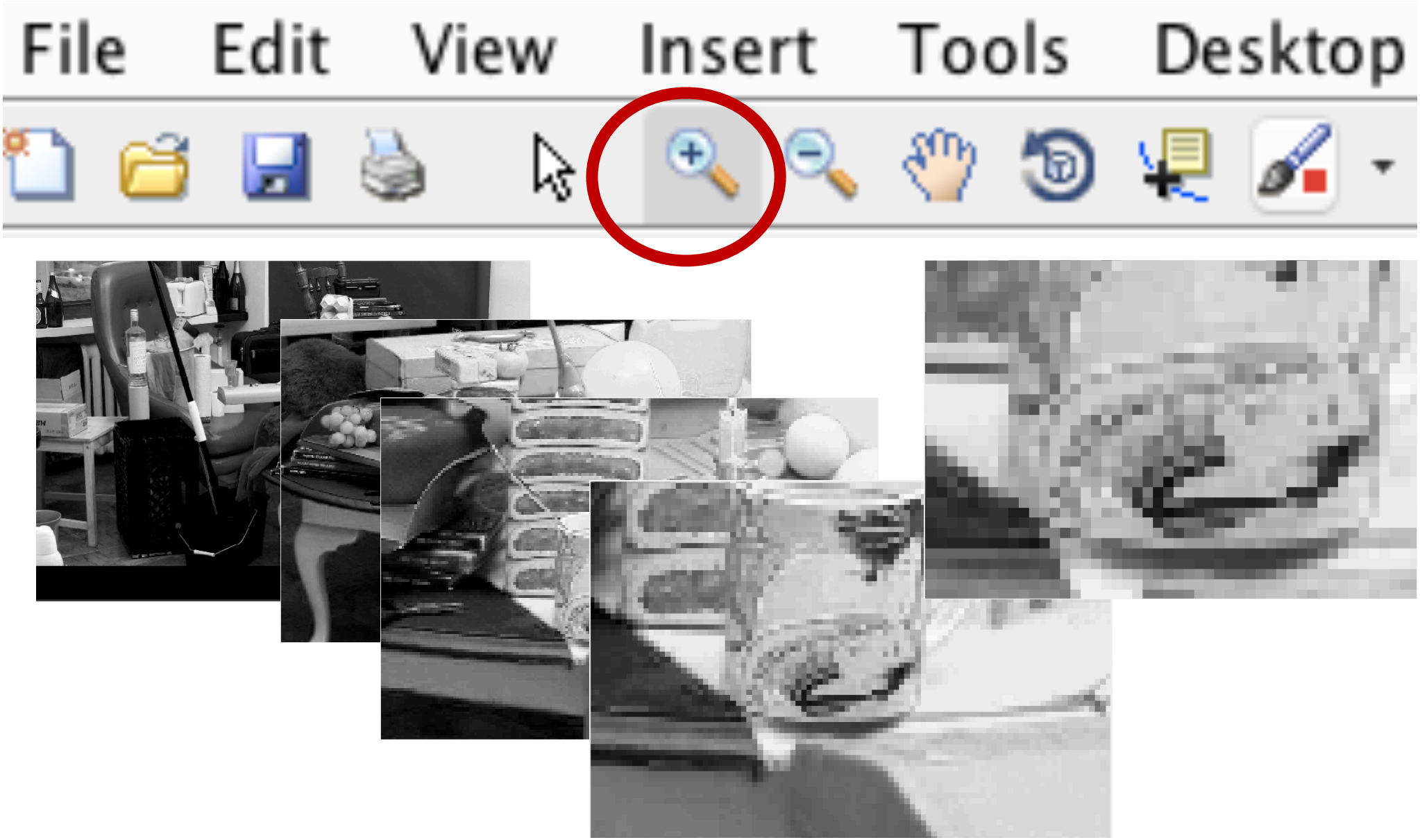
Hello Word !

```
>> I1 = myFirstImage(:,:,1);
>> figure;imshow(I1)
>> colorbar
>>
```

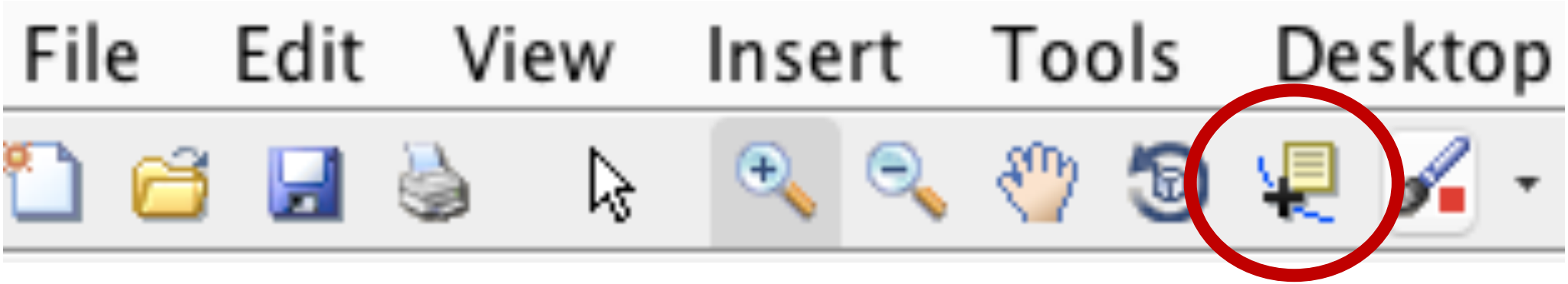
Hello World ☺ RGB

```
>> imshow(myFirstImage);
>> I1 = myFirstImage(:,:,1);
>> figure;imshow(I1)
>> I2 = myFirstImage(:,:,2);
>> figure;imshow(I2)
>> I3 = myFirstImage(:,:,3);
>> figure;imshow(I3)
```

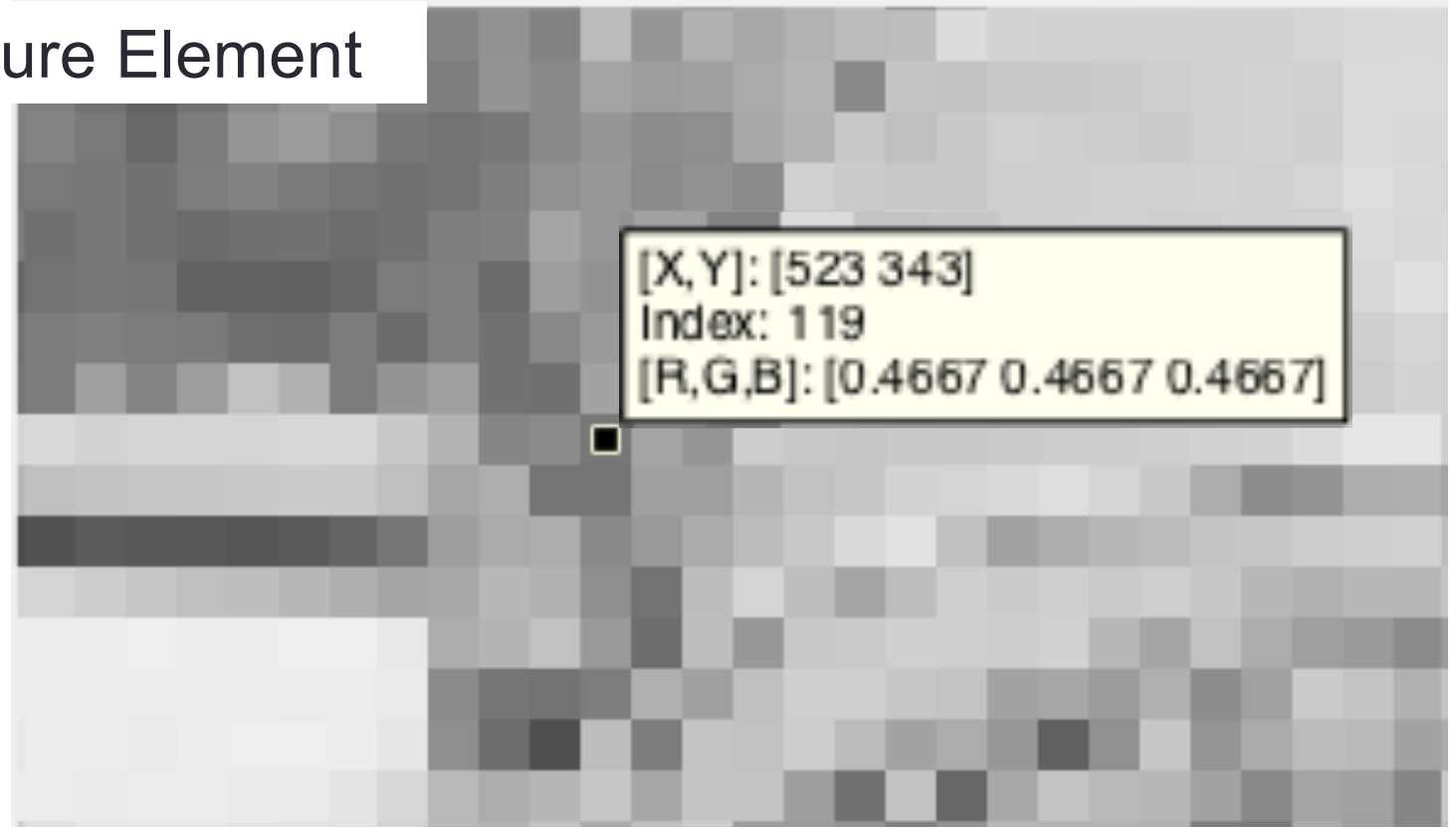
Let's zoom in



Let's Pixel



Pixel = Picture Element



Let's Pixel

220	218	214	224	224	179	223	208	230	237	210
211	217	191	215	192	187	221	213	232	223	231
212	219	188	229	181	189	221	212	208	230	235
217	214	220	198	190	194	205	187	221	236	222
202	210	175	154	187	221	200	206	244	229	226
173	196	218	137	201	226	195	241	241	238	242
201	207	210	199	180	183	207	245	247	249	245
208	206	211	199	170	184	216	252	250	244	219
204	177	211	211	189	178	206	244	238	217	224
207	137	203	212	193	151	207	227	221	230	236
203	159	207	209	208	143	209	221	231	236	235

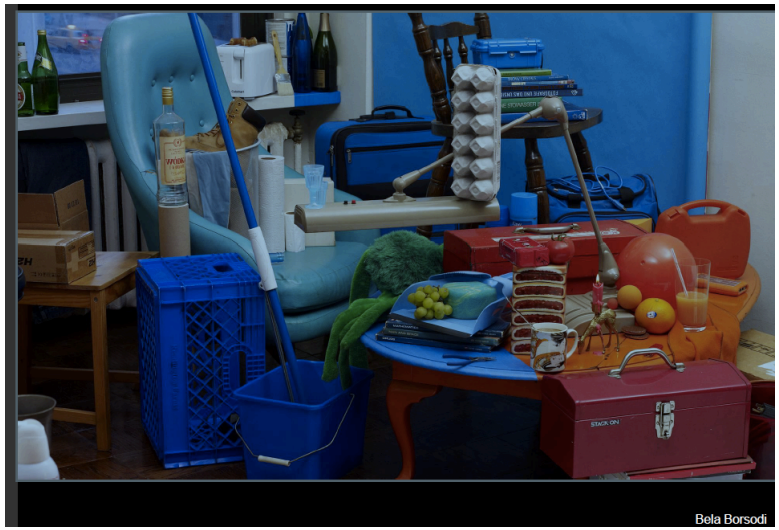
Let's count

1 Pixel = 8 bits (UINT 8) = 1 Byte

```
>> whos myFirstImage
  Name                  Size                    Bytes  Class

  myFirstImage        526x764x3               1,205,592  uint8
```

myFirstImage worth maybe 1000 words

but costs much more ….



What is an Image?

An image I is a two dimensional (2D) function

that maps the image domain Ω to $[0, 255]$

$$I : \Omega \rightarrow [0, 255]$$

or (for RGB)

$$I(\mathbf{x}) = I(x, y) = \vec{v}, \;\; v \in [0, 255]^3$$

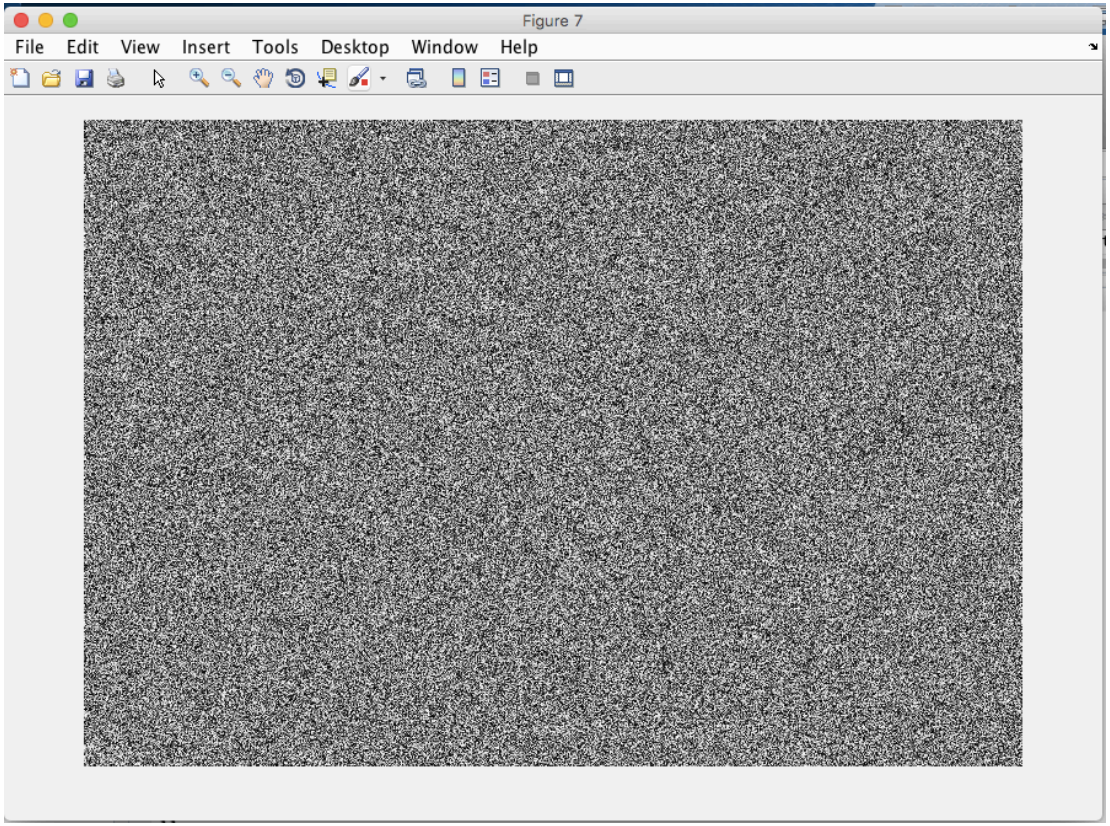
and the value of a single pixel is:

$$I(\mathbf{x}) = I(x, y) = v, \;\; v \in [0, 255]$$ Gray Level Pixel

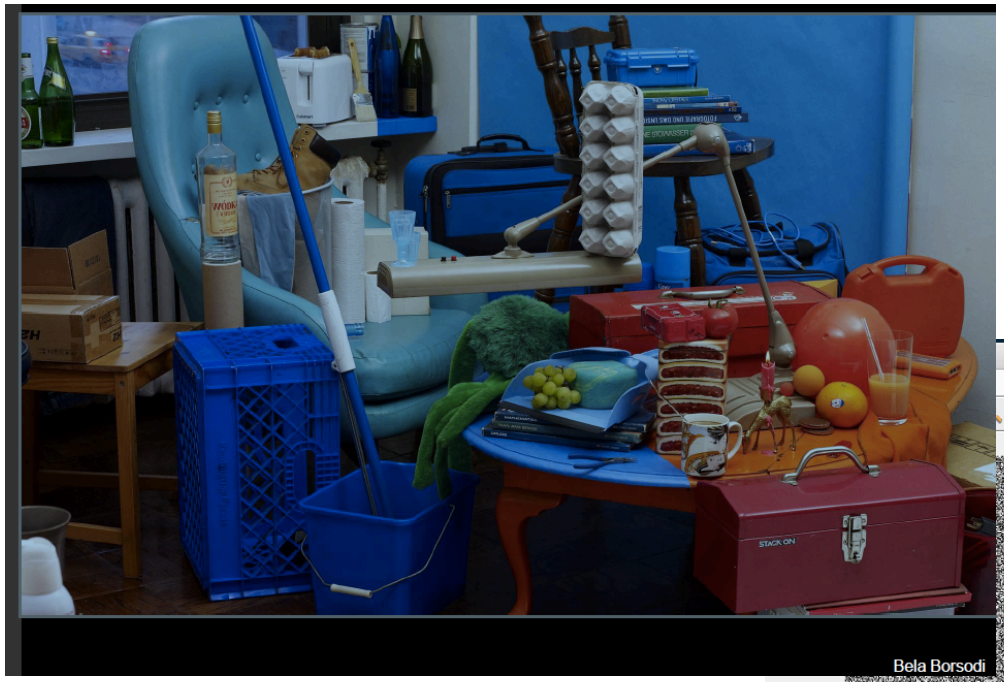
$$I(\mathbf{x}) = I(x, y) = (v_R, v_G, v_B)$$ RGB pixel

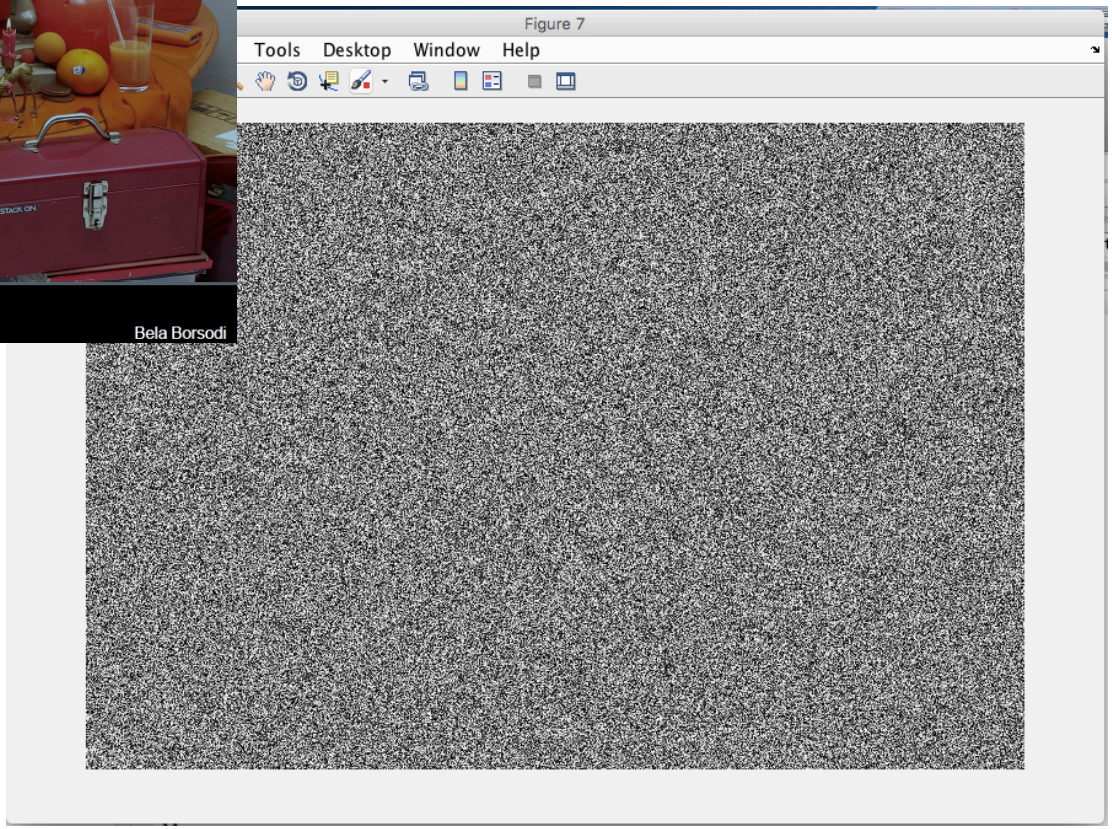
Is this an image?

```
>>
>> I = uint8(255*rand(526,764));
>> I = uint8(255*rand(size(I1)));
>> figure ; imshow(I);
>>
```

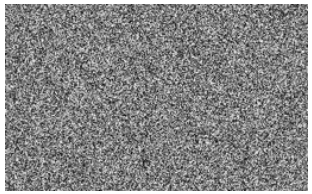


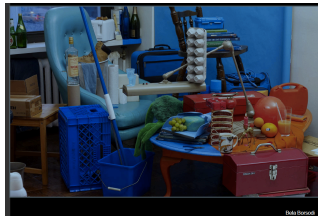
What's the difference?





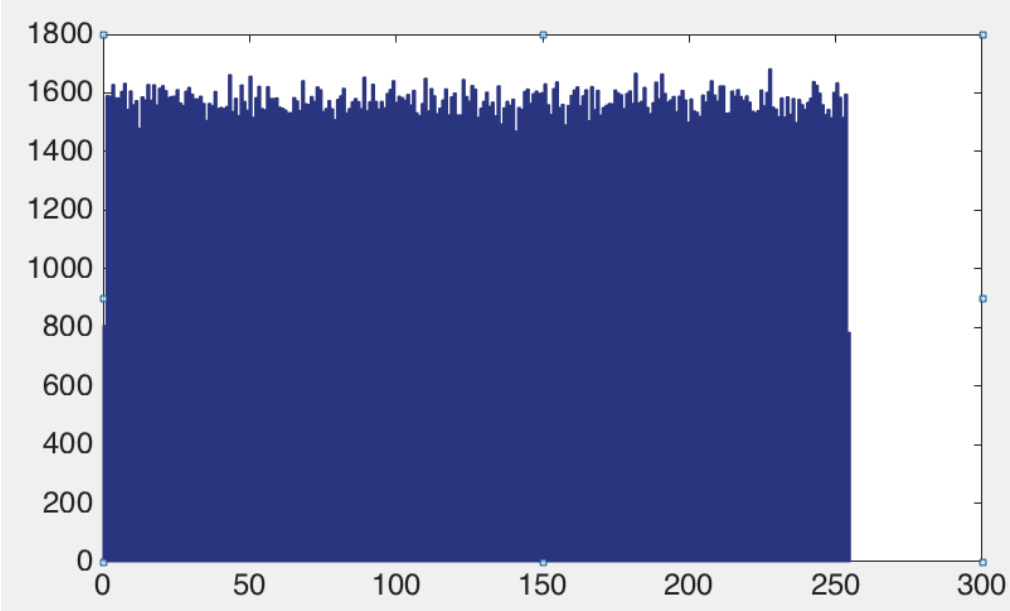
Building an histogram

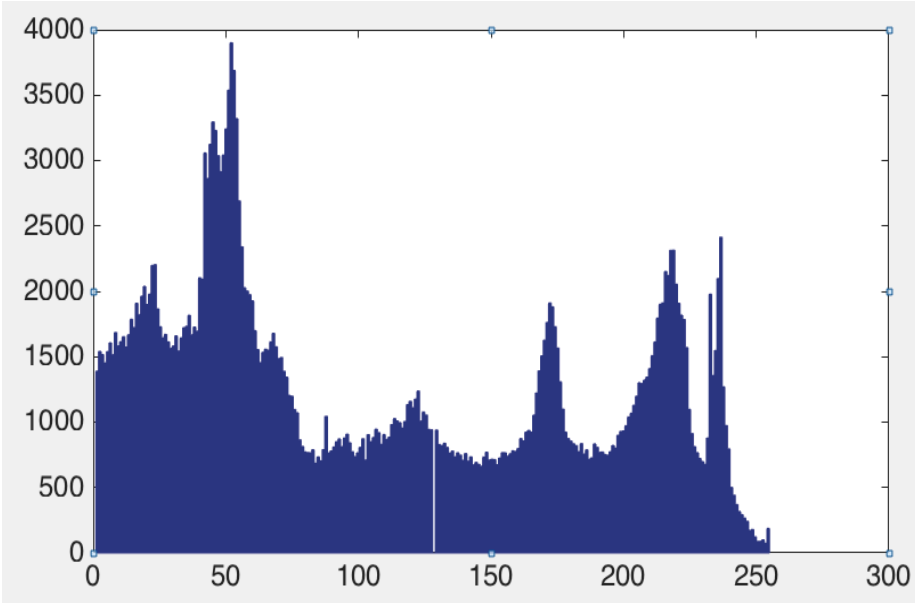




```
>>
>> I=double(I);
>> figure;hist(I(:),256);
>>
```

```
>>
>> I1 = double(I1);
>> figure;hist(I1(I1~=0),256)
>>
```

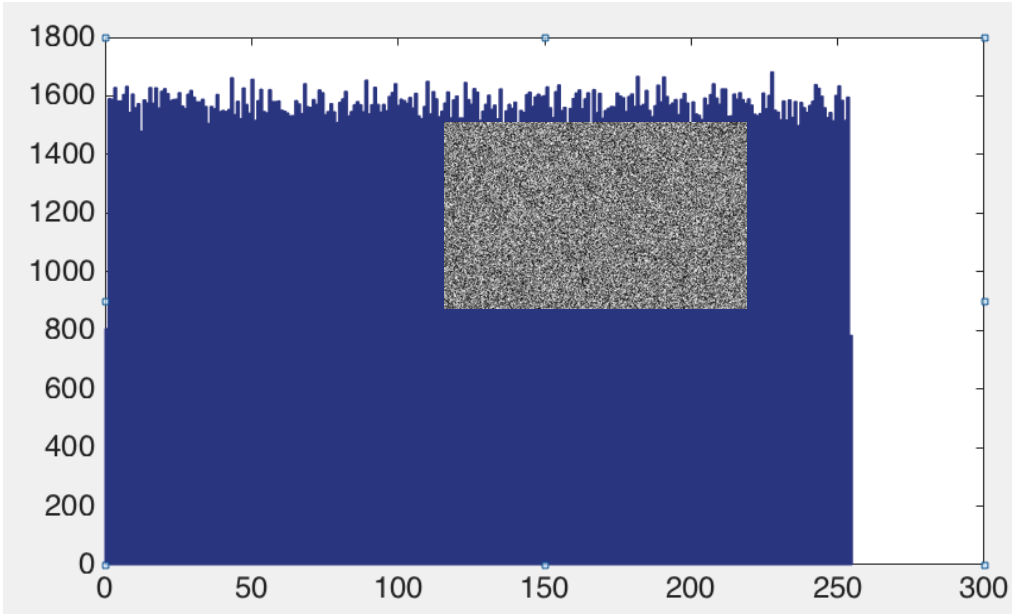


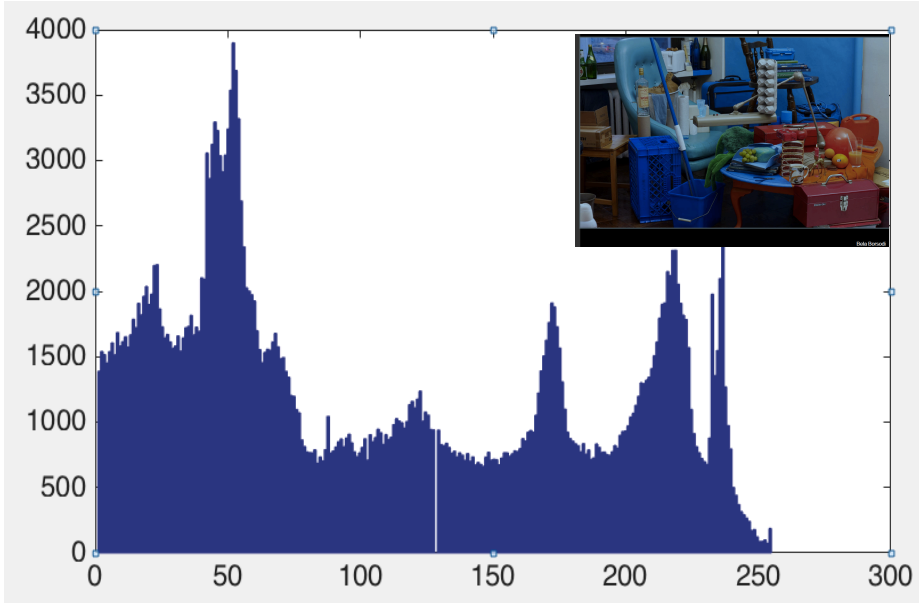


Can we measure the differences?

```
>>
>> I=double(I);
>> figure;hist(I(:),256);
>>
```

```
>> I1 = double(I1);
>> figure;hist(I1(I1~=0),256)
>>
```





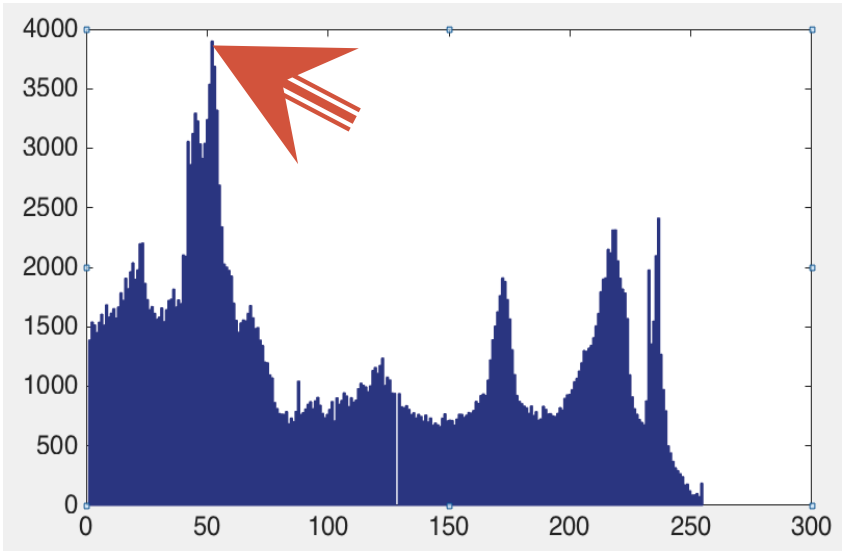
A bit on information theory

(in the context of images)

$\{0, 1\}$

Choose an arbitrary pixel in an image, can you guess its value?

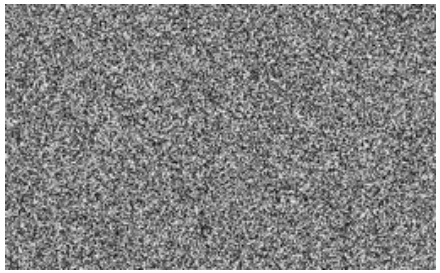
Well, we can build an histogram and gamble on the value with the highest frequency



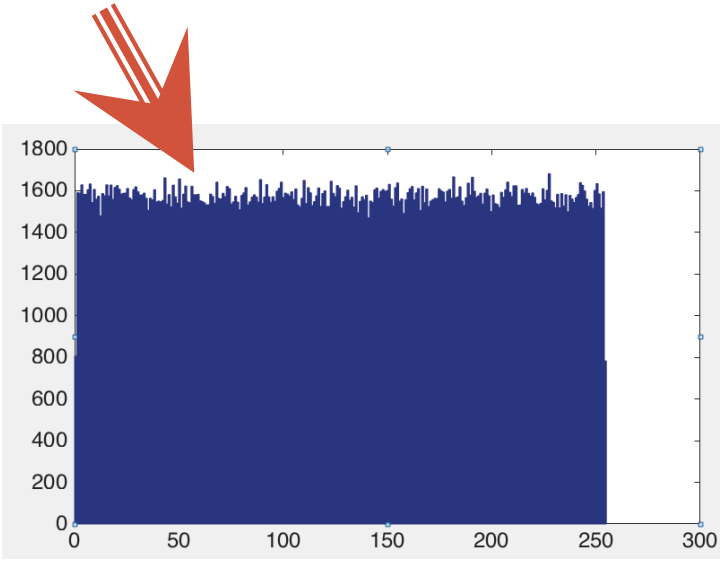
A bit on information theory

$\{0, 1\}$

Choose an arbitrary pixel in an image, can you guess its value?



Well, we can build an histogram and gamble on the value with the highest frequency



A bit on information theory

(in the context of images)

By normalizing an histogram, one can get the probability p_i for the occurrence of the i-th value.

The Shannon entropy (measured in bits) is given by:

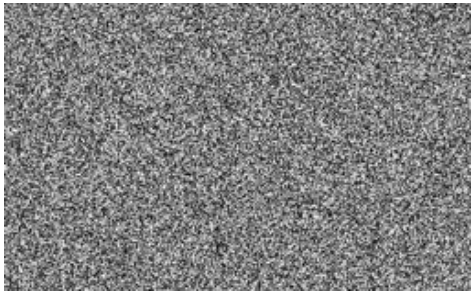
$$H = -\sum_i p_i log_2(p_i)$$

where $-log_2(p_i)$ is the self-information,

which is the entropy contribution of an individual pixel.

Entropy of an Image

What does it mean ? Does it mean anything?

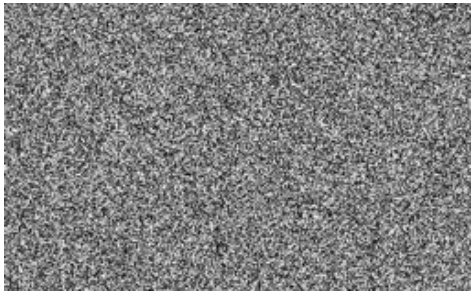


Entropy = 7.98

Entropy = 6.98

Entropy of an Image

What does it mean ? Does it mean anything?



Entropy = 7.98

Entropy = 6.98

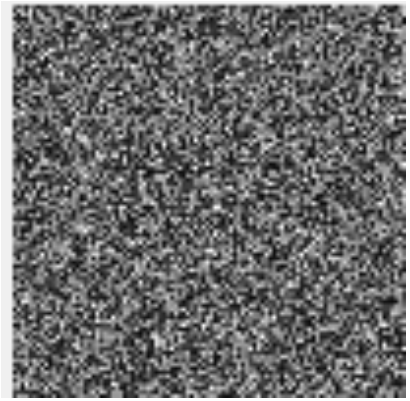
But

```
>>
>> Isame = uint8(100*ones(size(I1)));
>> figure; imshow(Isame)
```

Entropy = 0

Entropy of an Image

What does it mean ? Does it mean anything?

Entropy () = Entropy ()

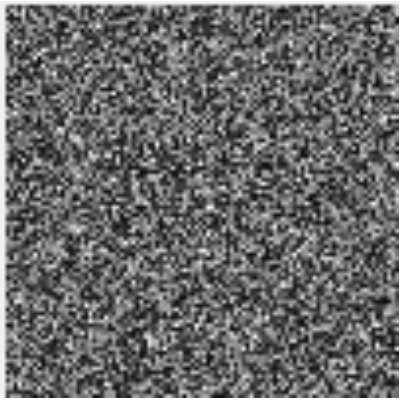
Obtained by pixel permutation

Entropy of an Image

What does it mean ? Does it mean anything?

SmallI1

SmallI1im



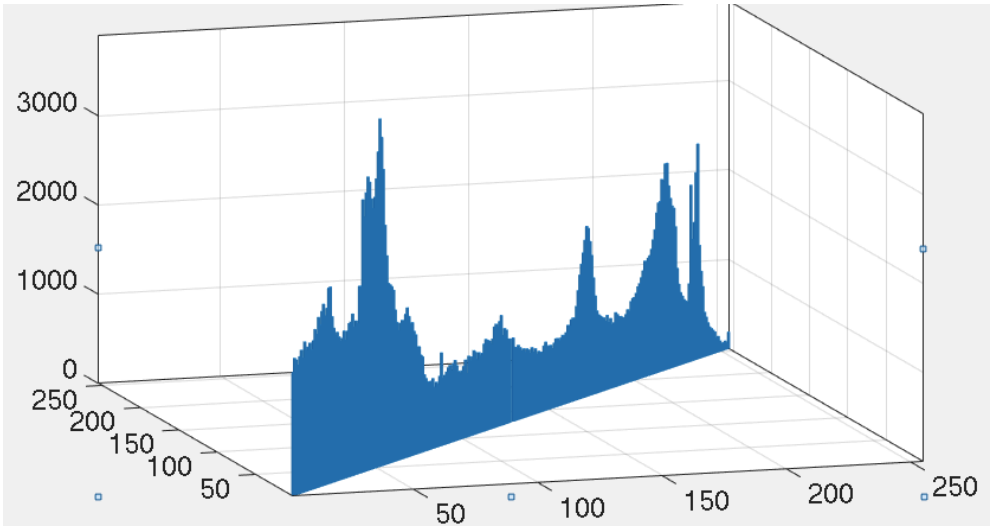
```
>>
>> myFirstImage = imread('someImage.png');
>> I1 = myFirstImage(:,:,1);
>> smallI1 = I1(1:100,1:100);
>> figure;imshow(smallI1)
>> randOrd = randperm(numel(smallI1));
>> permSI1 = smallI1(randOrd);
>> whos
  Name                  Size                    Bytes  Class

  I1                  526x764                   401864  uint8
  myFirstImage        526x764x3                1205592  uint8
  permSI1               1x10000                   10000  uint8
  randOrd               1x10000                   80000  double
  smallI1             100x100                     10000  uint8

>> permSI1im = reshape(permSI1,size(smallI1));
>> figure;imshow(permSI1im)
```

Next-door neighbors

You have chosen a pixel and you know its value.

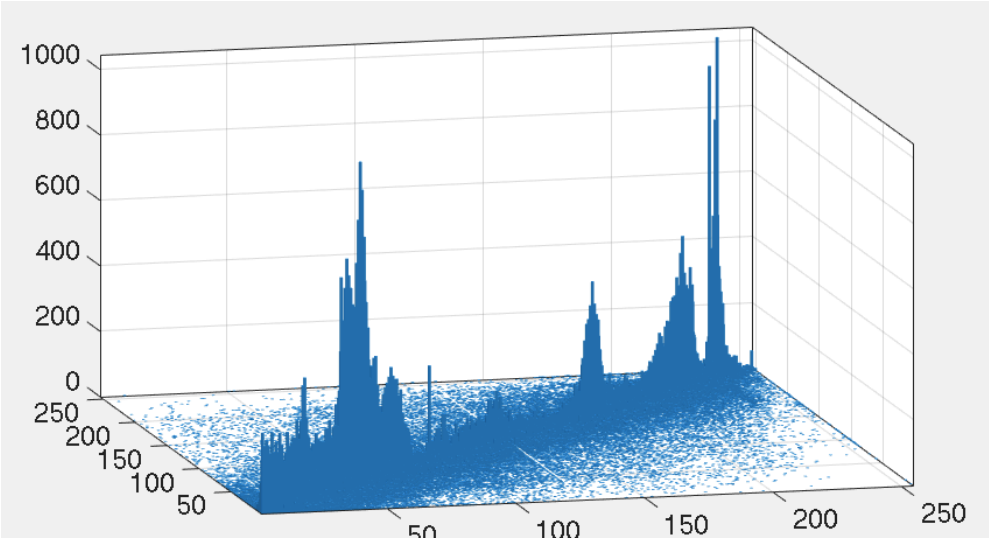
What can you say about the value of its next-door neighbor?

Next-door neighbors



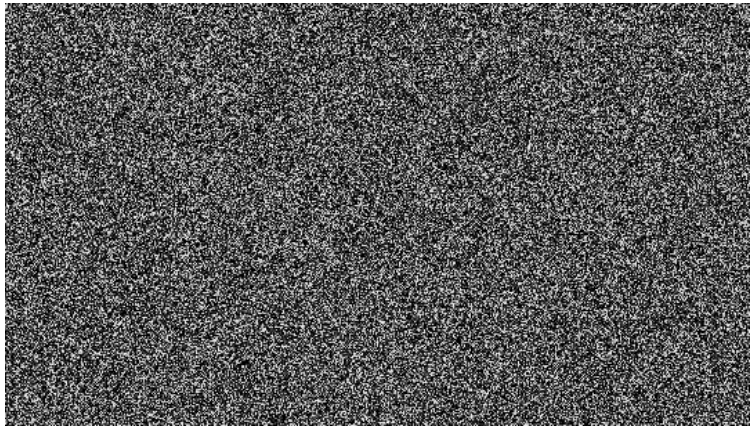

```
figure;histogram2(I1(I1~=0),I1(I1~=0),256)
```

Next-door neighbors

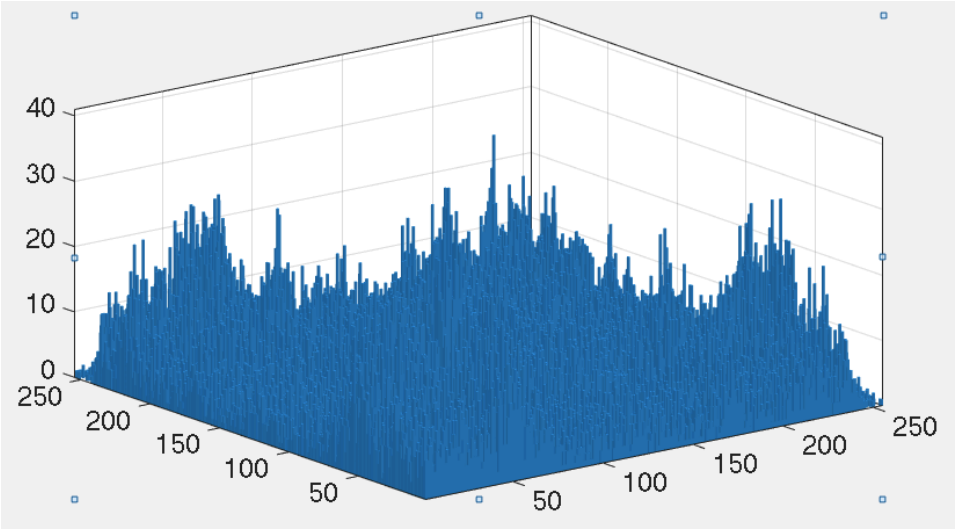



```
>> figure;histogram2(I1L(I1L~=0 & I1R~=0),I1R(I1L~=0 & I1R~=0),256)
```

Next-door neighbors



Random permutation of the
red channel of myFirstImage




```
>> figure;histogram2(permI1L(permI1L~=0 & permI1R~=0),permI1R(permI1L~=0 & permI1R~=0),256)
```

Mutual Information

(a little bit more on information theory)

- The Mutual Information of two random variables is a measure of the variables' mutual dependence.
- The most common unit of measurement of mutual information is the bit.

Mutual Information

(a little bit more on information theory)

- The Mutual Information of two random variables is a measure of the variables' mutual dependence.

$$\mathcal{I}(X;Y) = \sum_{y \in Y} \sum_{x \in X} p(x,y) \log \left(\frac{p(x,y)}{p(x)p(y)} \right)$$

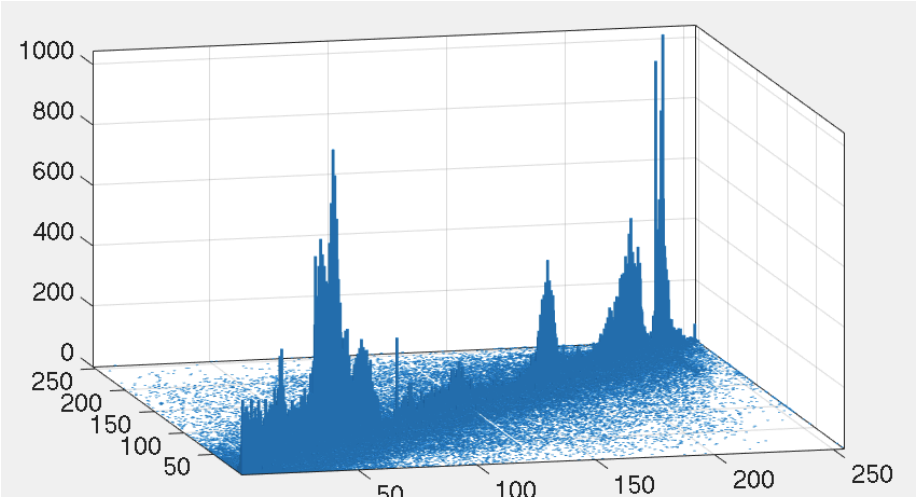
$p(x,y)$ is the joint probability function of X and Y.

$p(x), p(y)$ are the marginal probability distribution functions of X and Y (respectively).

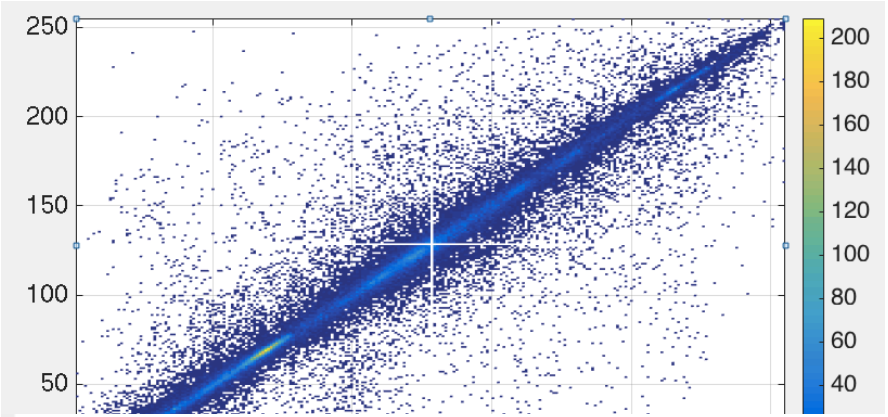
Mini-assignment #1 (bonus)

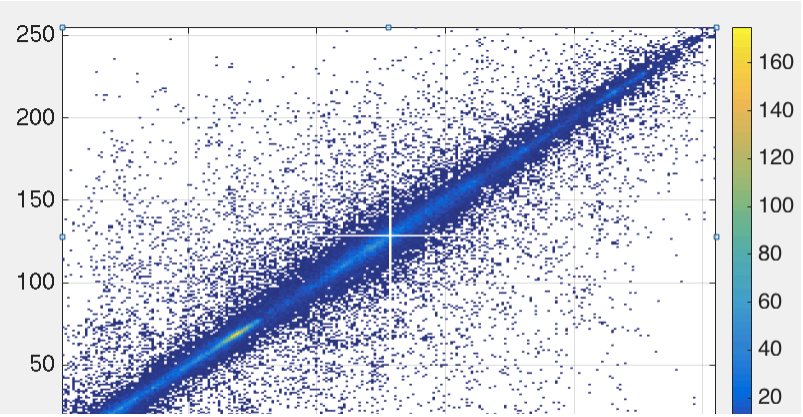
- Read an image (any image)
- Present one of its RGB channels – I1
- Permute I1 and present it.
- Present the histogram of I1.
- Calculate its entropy
- Calculate the Mutual Information between I1 pixels and their respective left-neighbors
- Calculate the Mutual Information between the permutation image's pixels and their respective left-neighbors

Is it enough?



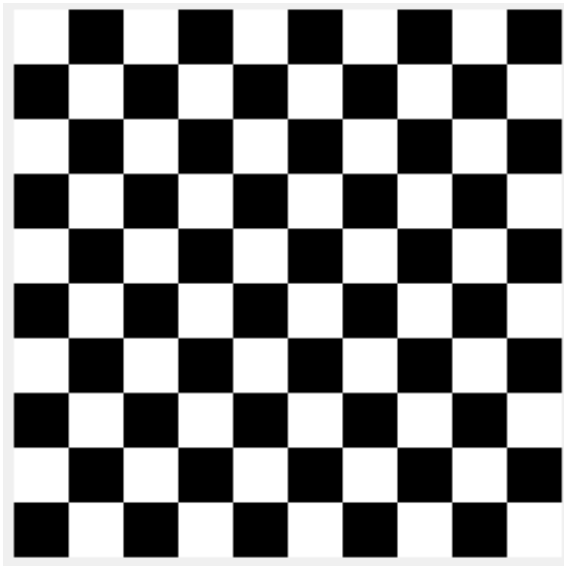
Is it enough?

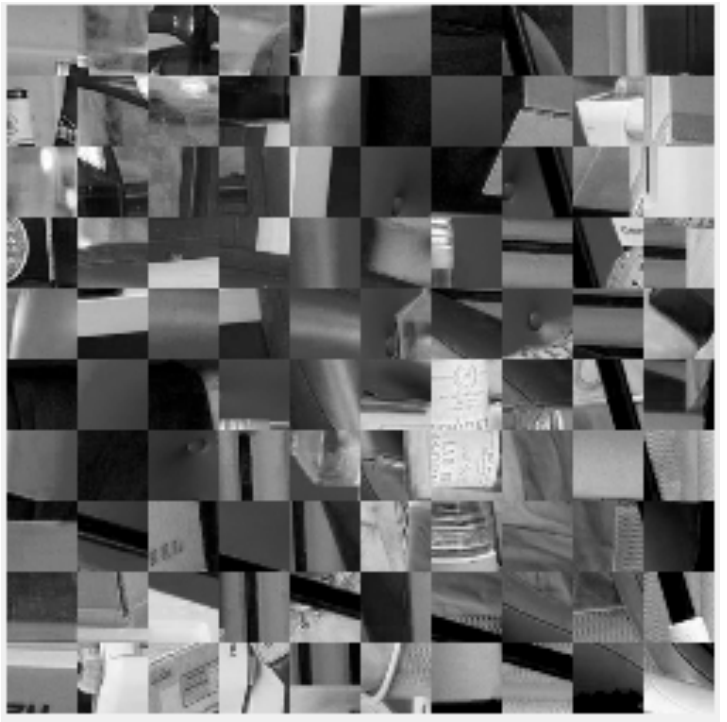


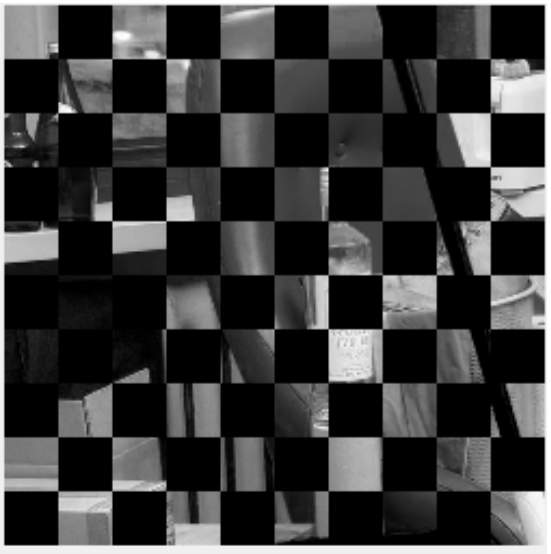


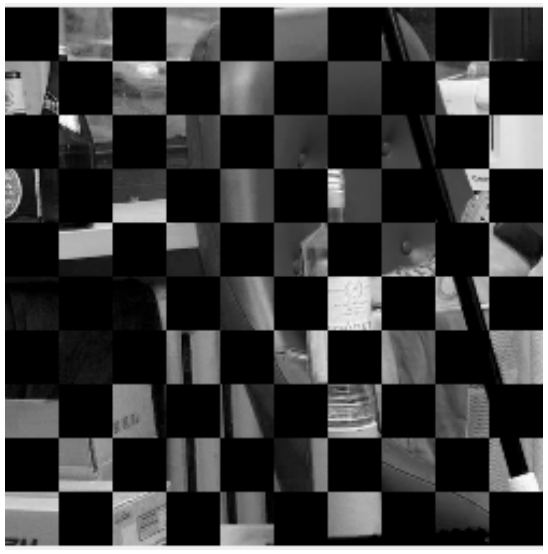

```
>> figure;histogram2(I1L(I1L~=0 & I1R~=0),I1R(I1L~=0 & I1R~=0),256,'DisplayStyle','tile')
>> colorbar
```

Is it enough?

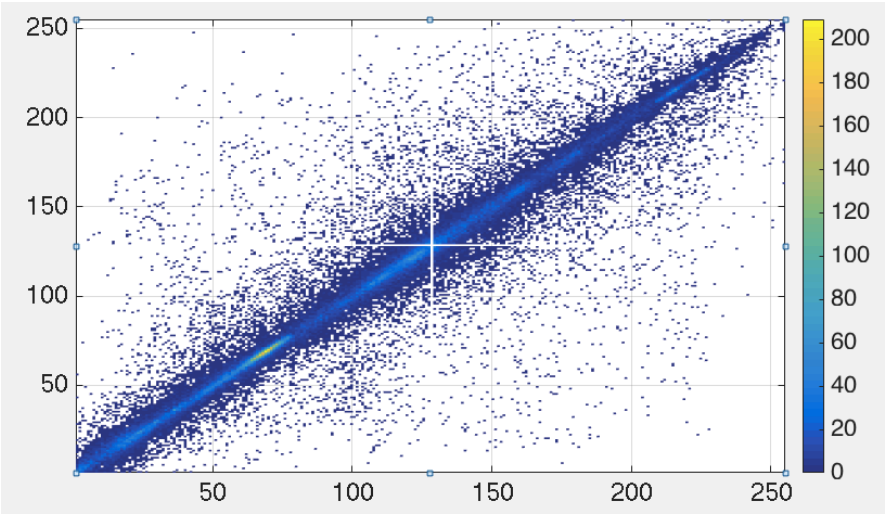


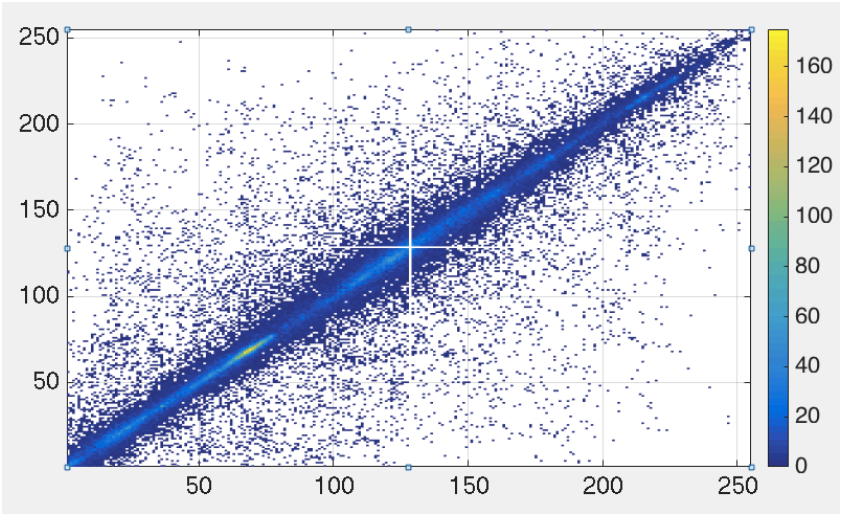






not yet there





Next Class

Sampling

Quantization

Histogram Processing