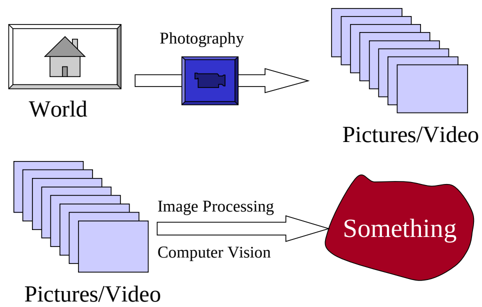
Image Processing (Computer Vision)

"Inverse Photography"



Stages in Computer Vision

- Physics: Image Formation (Light, Reflectance)
- Physics: Cameras: Optics (Lens), Sensors (CCD, CMOS)
- Image Processing: Coding (Transmission, Compression)
- Image Processing: Enhancement (Noise Cleaning, Colors)
- IP-CV: Feature Detection (Objects, Actions, Motion)
- Computer Vision: Scene recovery (3D, Reflectance)
- Computer Vision: Object Recognition
- Human and Machine Vision: Visual Perception
- Robotics: Control Action (autonomous driving)

Vision in Nature = Smart, Moving

- Only smart and moving organisms see!
  - Plants do not have eyes
- Visual recognition at early development
  - Babies recognize and track the mother very early
- Most of the brain is involved in vision processing

Application: Recognition

1984

2000

National Geographics: "Afghan Girl"

Panoramic Stereo Mosaics

(Last Exercise)

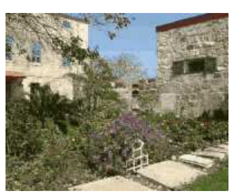


Image Processing: 2005/2006

Teacher: **Shmuel Peleg** <peleg@cs.huji.ac.il>
Assistant: **Yael Pritch** <yaelpri@cs.huji.ac.il>
Ozer Horaa: **Yael Shor** <yaelshor@cs.huji.ac.il>
Textbook:
Gonzalez & Woods, Digital Image Processing (2nd Ed.), Addison Wesley, 2002.
Jain, Pratt, Rosenfeld,….

Expected Work:
4 Written Exercises
4 individual computer exercises (MATLAB)
Grading:
Exam: 60-70%; Exercises: 30-40%

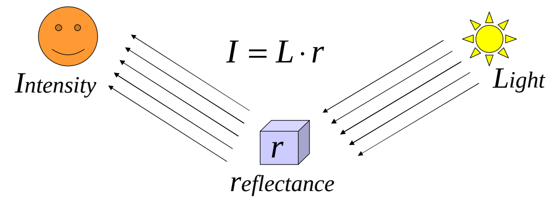
Relevant Computer Vision Courses

- Image Processing (Peleg)
- Computer Vision Seminar (Sundays 10-12)
- Computer Graphics (Sun 12-14, Wed 16-18, Lischinski)
- Introduction to Machine Learning (Mon 10-12, Tue 12-14, Shashua)

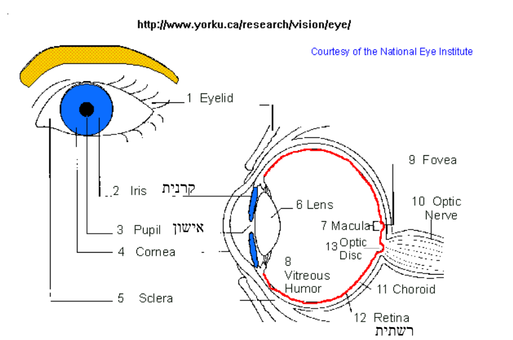
- Computer Vision (Werman)
- Image Sequence Analysis (Peleg)
- Issues in Computational & Biological Vision (Weinshall)
- Human Vision: A Computation Approach (Weiss)

Image Formation

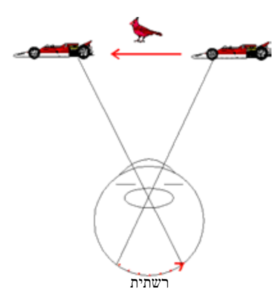
- Light is emitted by light source
- Light is reflected from objects
- Reflected light is sensed by eye or by camera



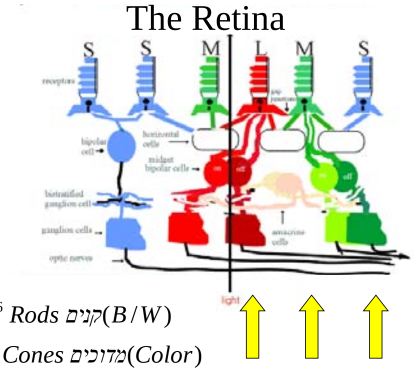
The Human Eye (2.1)



World to Retina Projection



The Retina

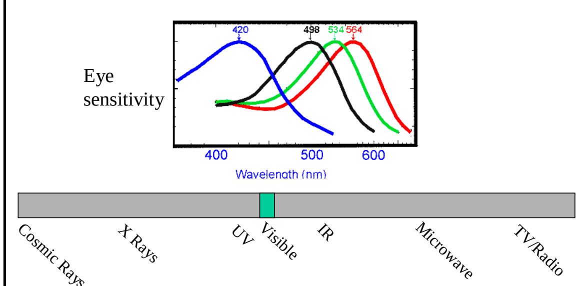


$120 \bullet 10^6$ *Rods* קנים *(B/W)*

$7 \bullet 10^6$ *Cones* מדוכים *(Color)*

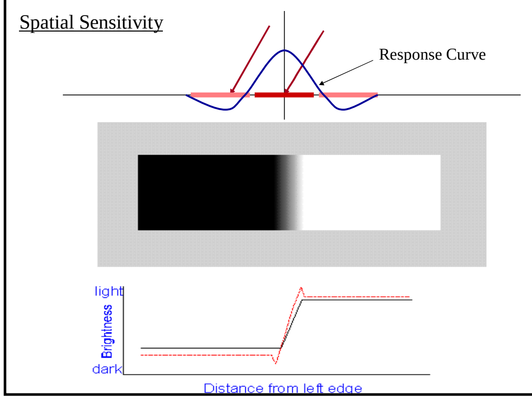
$\approx 10^4$ *Nerves*

Colors - Electromagnetic Radiation

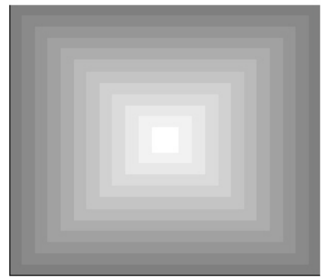


- Visible Light Range: 350-780 nm
- Maximum Sun Energy: 450 nm
- Best Atmospheric Transmittance: Visible Range

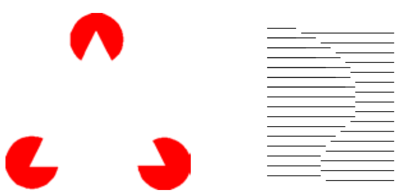
Mach Bands (1)



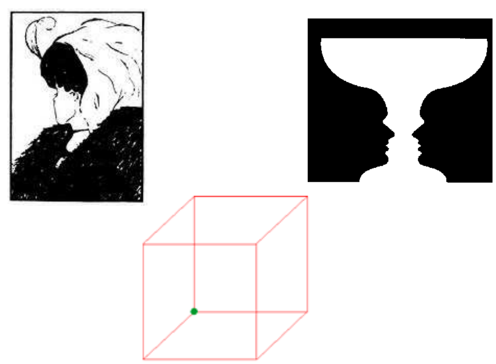
Mach Bands (2)



Visual Illusions



Dual Interpretations



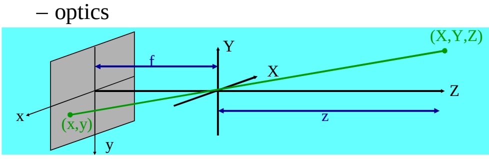
What is That?

Image Digitization (2.3)

- Transforming the 3D world into 2D image
  - Perspective Projection (Optics)
- Sampling the Image Plane
  - Finite number of **Pixels**
- Quantizing the color/gray-level
  - Finite number of colors

Perspective Projection (2.5.2)

- Transforming the 3D world into 2D image
  - Continuous Perspective Projection
  - optics



$$x = \frac{f}{Z} X$$

$$y = \frac{f}{Z} Y$$

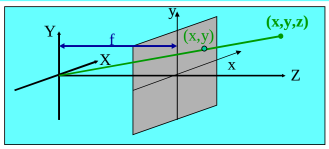


Image Sampling

- Sampling the Image Plane
  - Finite number of **Pixels**

Original   Reduce by 4   Reduce by 16   Reduce by 32

Color/Grey-level Quantization

- Quantizing the color/gray-level
  - Finite number of colors

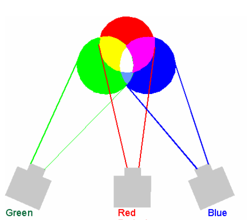
256 Levels   16 Levels   4 Levels   2 Levels

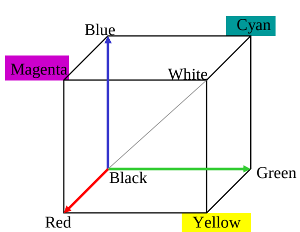
Digital Pictures

- A Matrix of numbers (B/W)
- A Matrix of triplets (RGB Color, etc.)

1	2	3	4	5	6	7	8	9	10	9	8	7	6	5
2	4	5	6	7	8	9	10	11	12	11	10	9	8	7
3	5	6	7	8	9	10	11	12	13	12	11	10	9	8
4	6	7	8	9	10	11	12	13	14	13	12	11	10	9
5	7	8	9	10	11	12	13	14	15	14	13	12	11	10
6	8	9	10	11	12	13	14	15	16	15	14	13	12	11
7	9	10	11	12	13	14	15	16	17	16	15	14	13	12
8	10	11	12	13	14	15	16	17	18	17	16	15	14	13
9	11	12	13	14	15	16	17	18	19	18	17	16	15	14
10	12	13	14	15	16	17	18	19	20	19	18	17	16	15
9	11	12	13	14	15	16	17	18	19	18	17	16	15	14
8	10	11	12	13	14	15	16	17	18	17	16	15	14	13
7	9	10	11	12	13	14	15	16	17	16	15	14	13	12
6	8	9	10	11	12	13	14	15	16	15	14	13	12	11
5	7	8	9	10	11	12	13	14	15	14	13	12	11	10
4	6	7	8	9	10	11	12	13	14	13	12	11	10	9
3	5	6	7	8	9	10	11	12	13	12	11	10	9	8
2	4	5	6	7	8	9	10	11	12	11	10	9	8	7
1	3	4	5	6	7	8	9	10	11	10	9	8	7	6

Color Spaces (4.6)

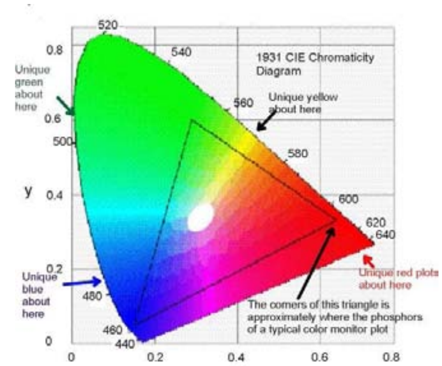




Y - Luminance

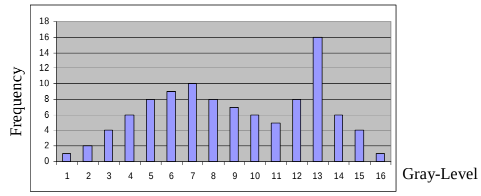
$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

CIE Chromaticity Diagram (1931)



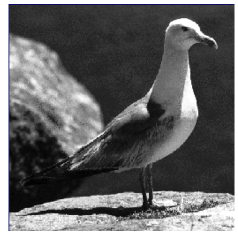
The Histogram

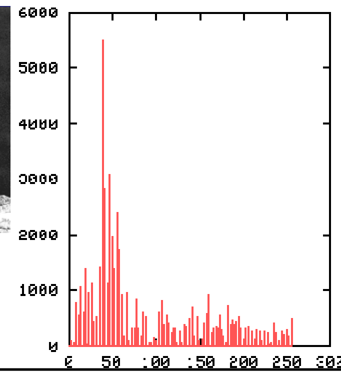
- Frequency counting of gray levels



- In continuous intensities:
  a continuous probability distribution *p(g)*

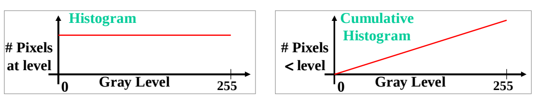
Histogram - Example





Histogram Equalization

- Equal usage of all gray levels

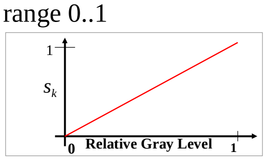


- Normalizing to range 0..1

N Pixels, Range *0 .. K-1*

n_i = # pixels at *i*

$$s_k = \frac{1}{N}\sum_{i=1}^{k} n_i$$



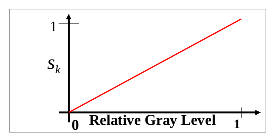
$r_k = \frac{k}{K}$

Histogram Equalization

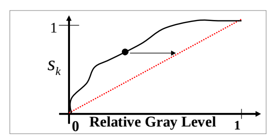
N Pixels, Range *0 .. K-1*

n_i = # pixels at *i*

$$s_k = \frac{1}{N}\sum_{i=1}^{k} n_i$$



$r_k = \frac{k}{K}$



$r_k = \frac{k}{K}$

Histogram Equalization (cont.)

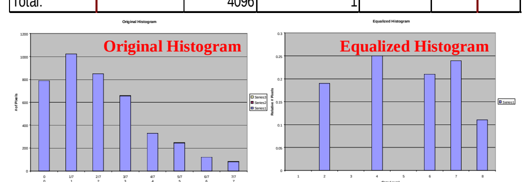
N Pixels, Range *0 .. K-1* n_i = # pixels at *i*

Normalized Cumulative Occurrence: $s_j = \frac{1}{N}\sum_{i=1}^{j} n_i$

- For every original level j:
  Change its gray level to $s_j \cdot (K-1)$
- Stretch gray levels back to [*0.. K-1*]

Equalization Example

Grey Level (*k*)	Normalized (*r*)	# Pixels (*n*)	Normalized (*n/N*)	Cumulative	Approx	Result
0	0	790	0.19	0.19	1/7	1
1	1/7	1023	0.25	0.44	3/7	3
2	2/7	850	0.21	0.65	5/7	5
3	3/7	656	0.16	0.81	6/7	6
4	4/7	329	0.08	0.89	6/7	6
5	5/7	245	0.06	0.95	1	7
6	6/7	122	0.03	0.98	1	7
7	7/7	81	0.02	1.00	1	7
Total:		4096	1			



Examples for Equalization

Adaptive Histogram Equalization

- Different regions in a single image
  - Example: Coin on white paper
- Poor result for Histogram Equalization
  - Do the coins and paper separately
  - How to segment?
- Compute histogram in local regions around each pixel