Basic Concepts in Digital Image Processing

Image Processing → Image Analysis

Low level

Mid level

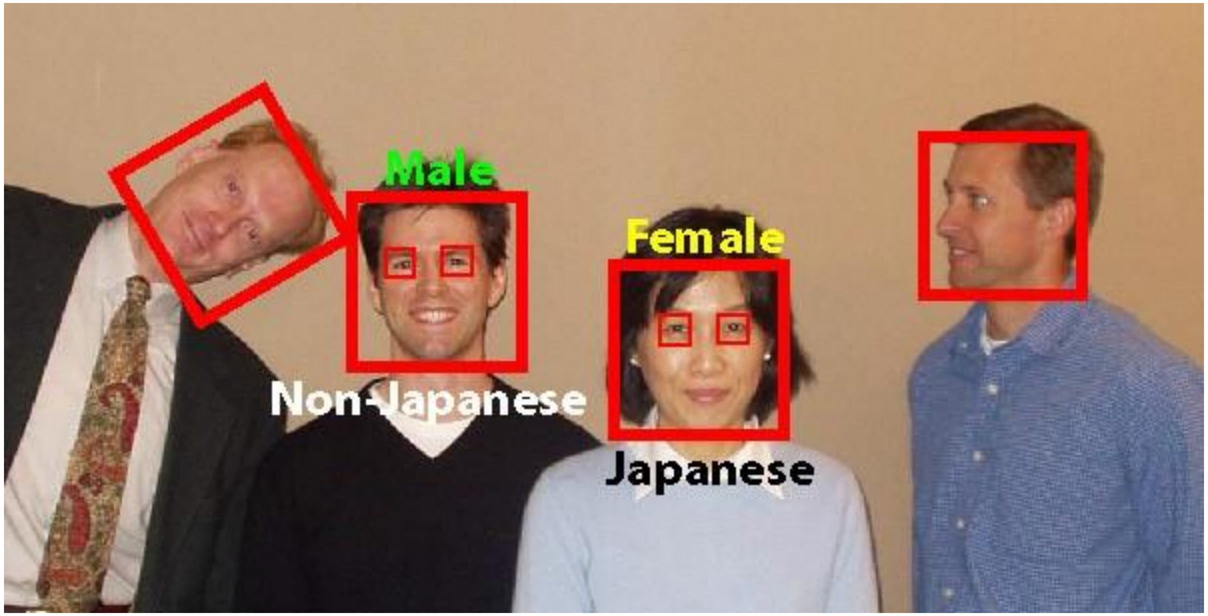
High level

- Image acquisition
- Image enhancement
- Image compression
- Image segmentation
- Object recognition
- Scene understanding
- Semantics

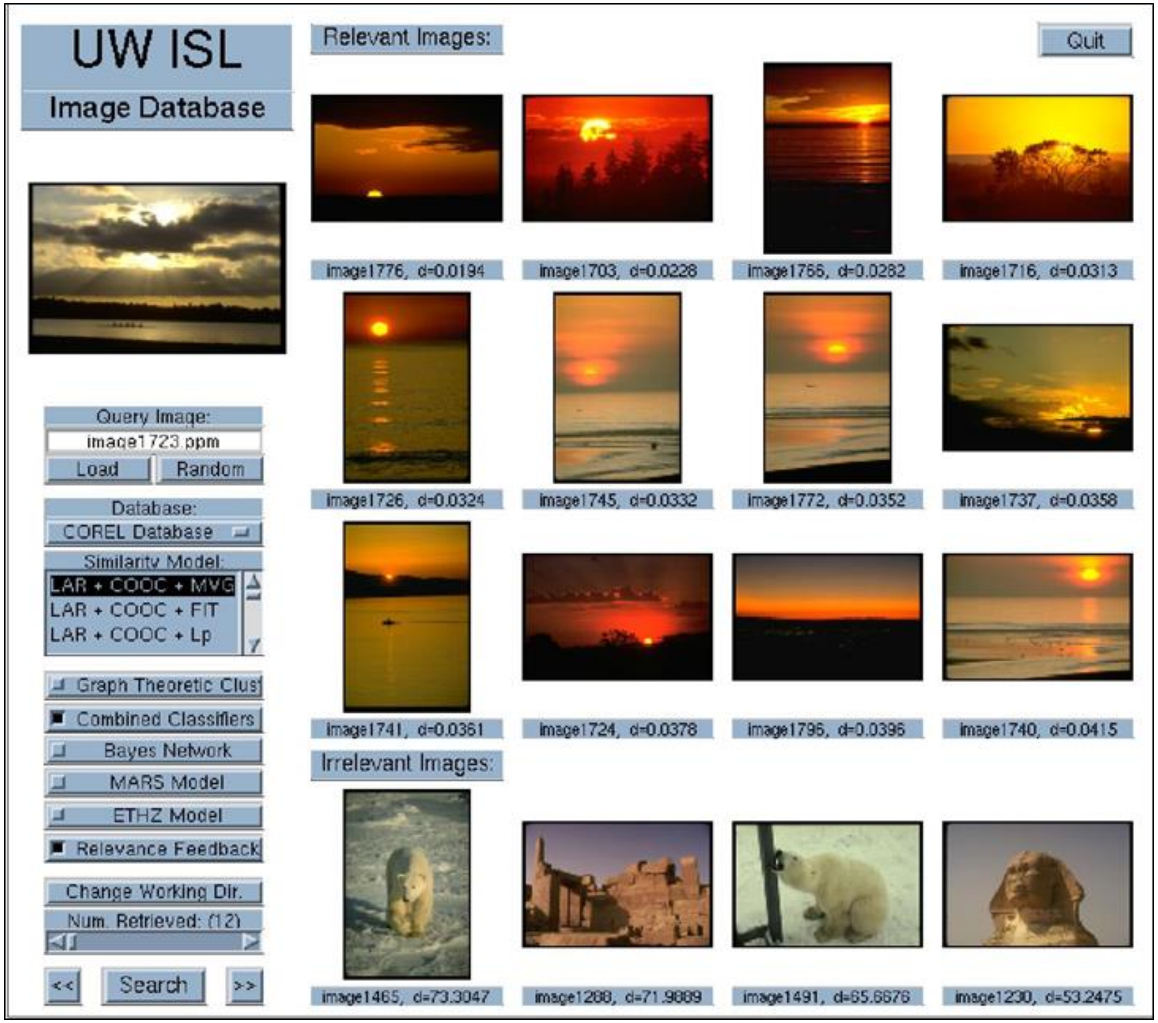
Image processing

Image analysis
(Computer vision,
Pattern recognition, etc.)

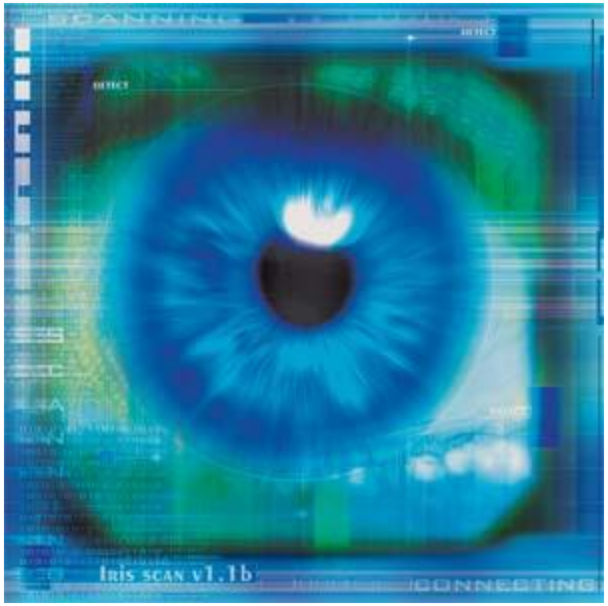
Object Detection / Recognition

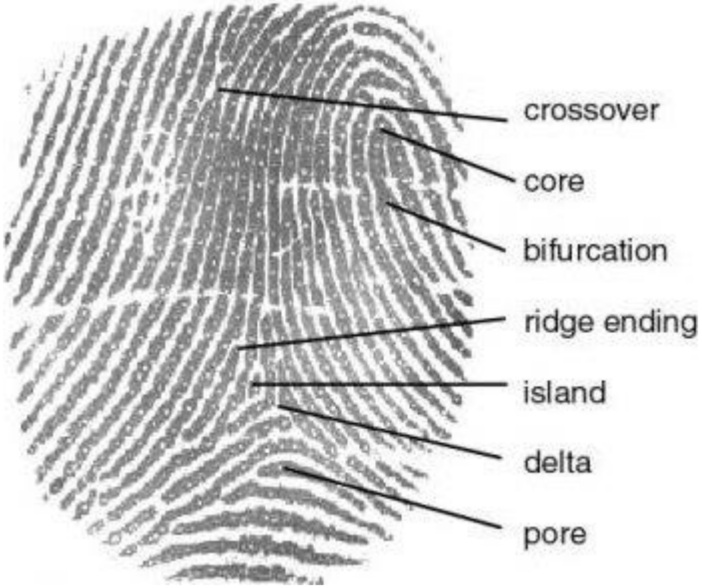


Content-Based Image Retrieval

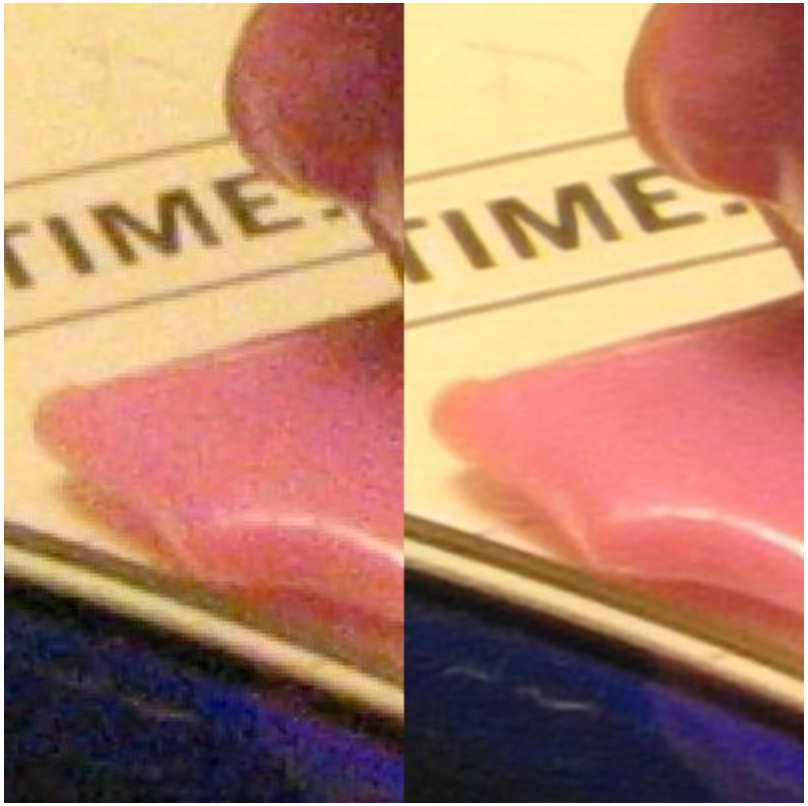


Biometrics


IRIS SCAN v1.1b
CONNECTING


crossover
core
bifurcation
ridge ending
island
delta
pore

Super-Resolution



Applications of Digital Image Processing

Digital camera

Photoshop

Human computer interaction

Medical imaging for diagnosis and treatment

Surveillance

Automatic driving

…

Fast-growing market!

Now,

Introducing some basic concepts in digital image processing

- **Human vision system**
- **Basics of image acquisition**

Reading: Chapter 2.

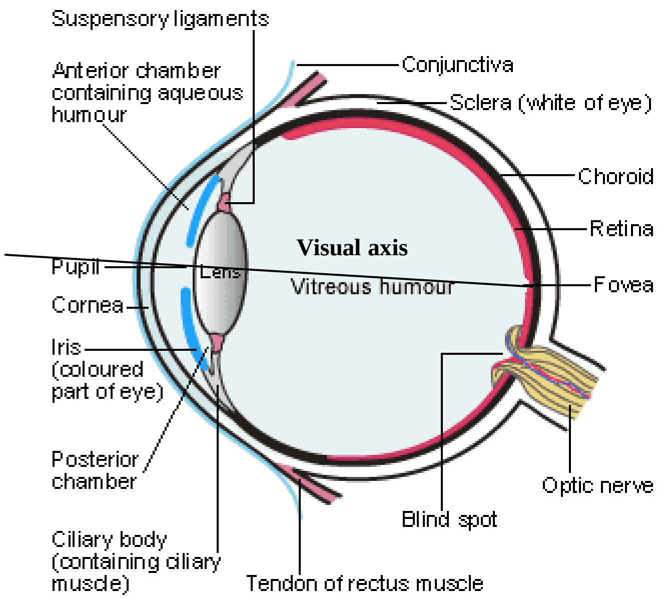
Elements of Human Visual Perception

Human visual perception plays a key role in selecting a technique

Lens and Cornea: focusing on the objects

Two receptors in the retina:

- Cones and rods
- Cones located in fovea and are highly sensitive to color
- Rods give a general overall picture of view, are insensitive to color and are sensitive to low level of illumination



http://www.mydr.com.au/eye-health/eye-anatomy

Distribution of Rods and Cones in the Retina

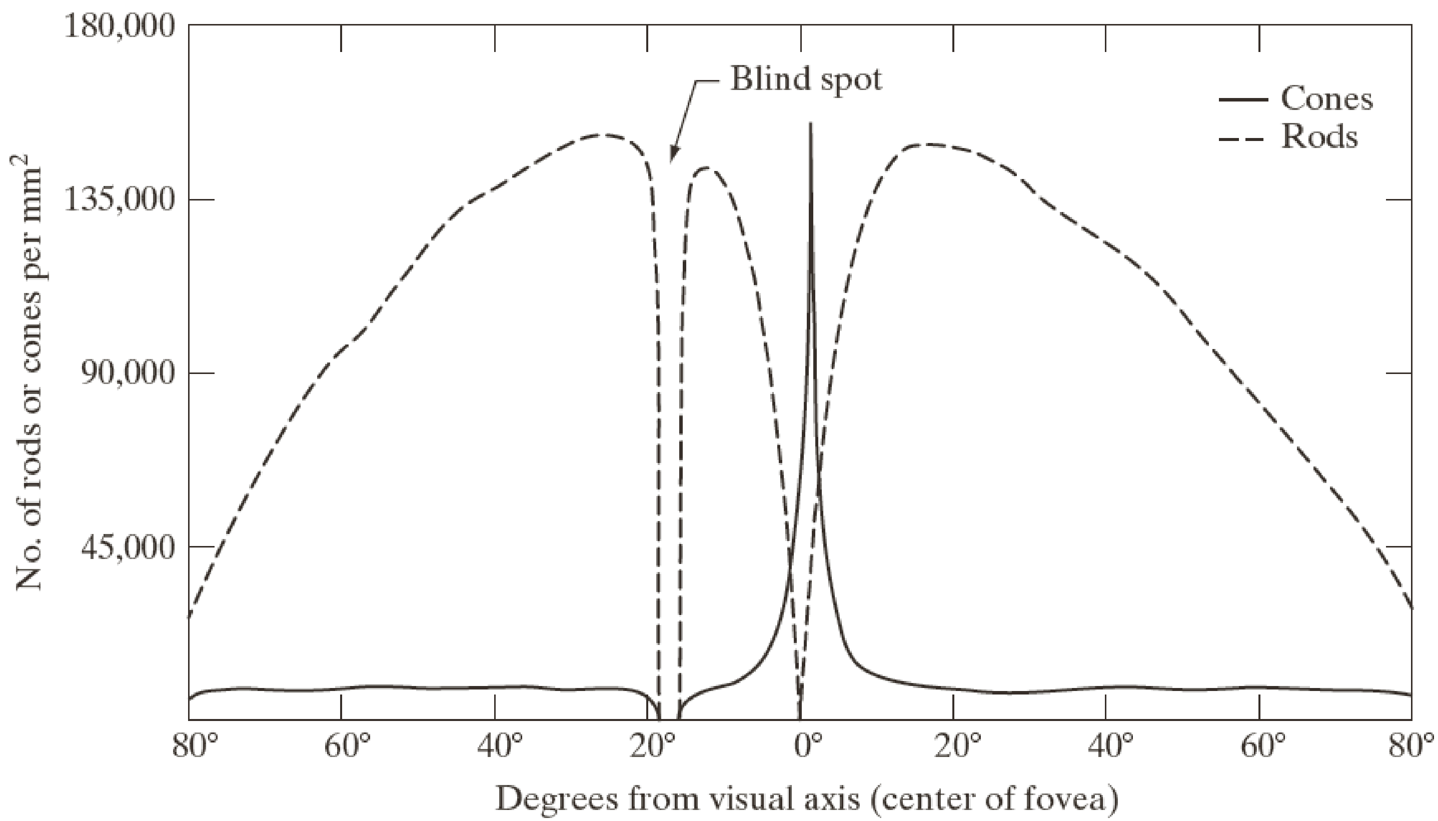


FIGURE 2.2 Distribution of rods and cones in the retina.

Brightness Adaptation: Subjective Brightness

Scotopic:

- **Vision under low illumination**
- **rod cells are dominant**

Photopic:

- **Vision under good illumination**
- **cone cells are dominant**

The total range of distinct intensity levels the eye can discriminate *simultaneously* is rather small

Brightness adaptation level

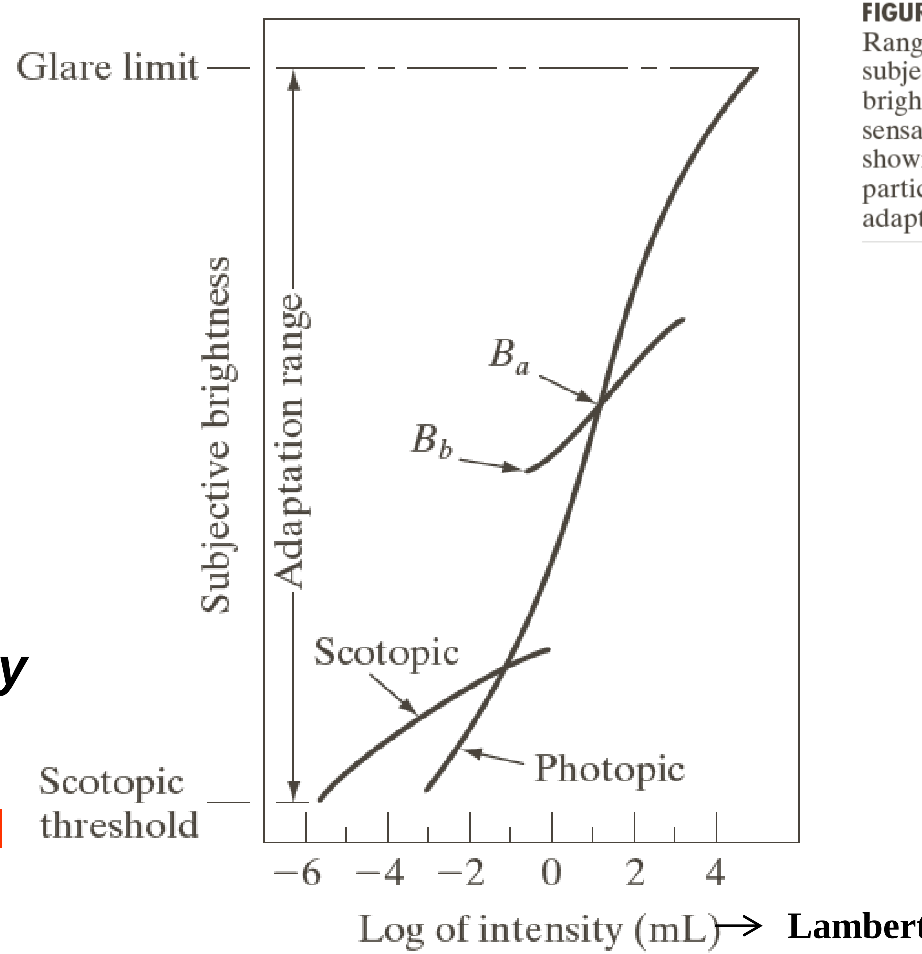


FIGURE 2.4 Range of subjective brightness sensations showing a particular adaptation level.

Brightness Discrimination

Weber Ratio/Fraction

$$\frac{\Delta I_c}{I}$$

$I + \Delta I_c$:

Short-duration flash

Small ratio: good brightness discrimination

Large ratio: poor brightness discrimination

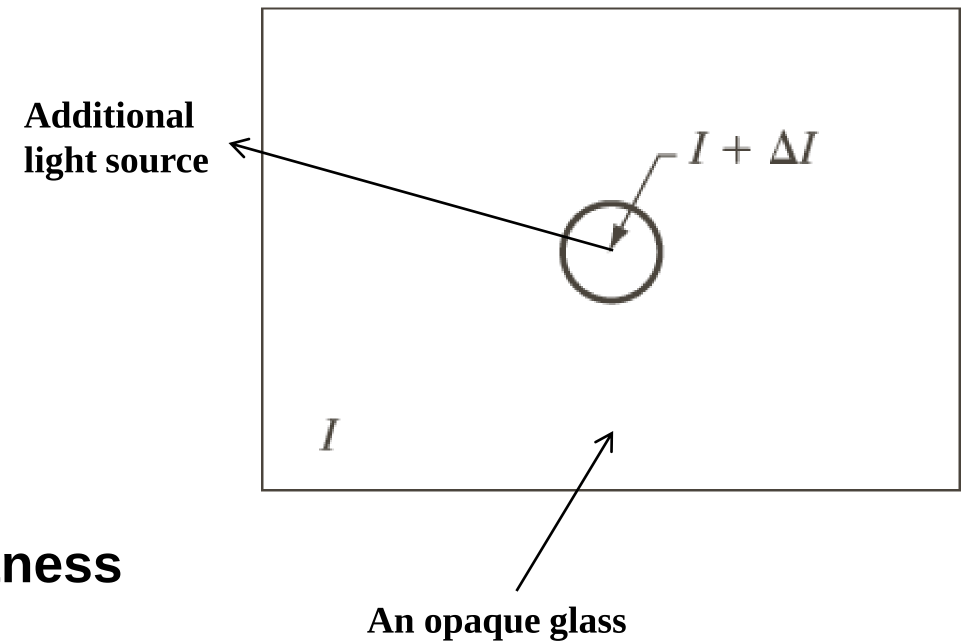


FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

Brightness Discrimination at Different Intensity Levels

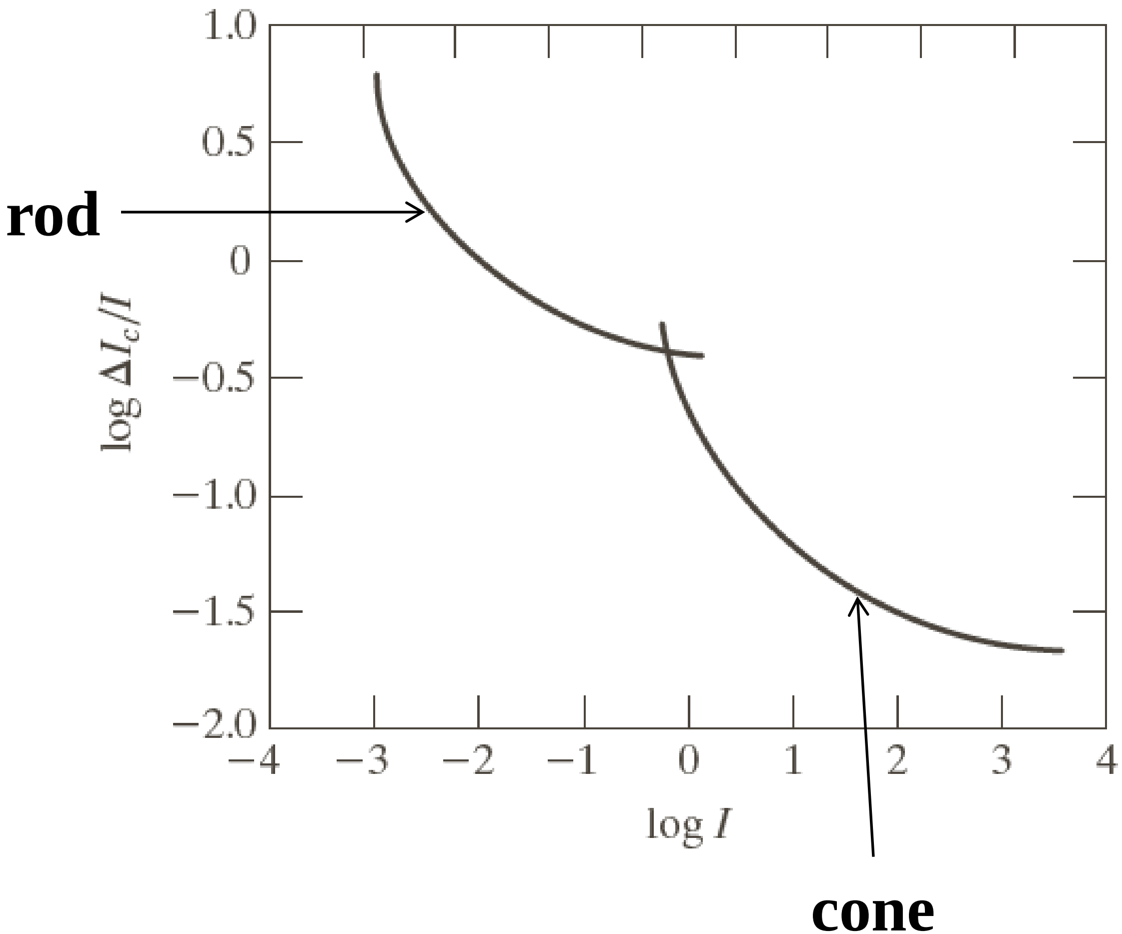
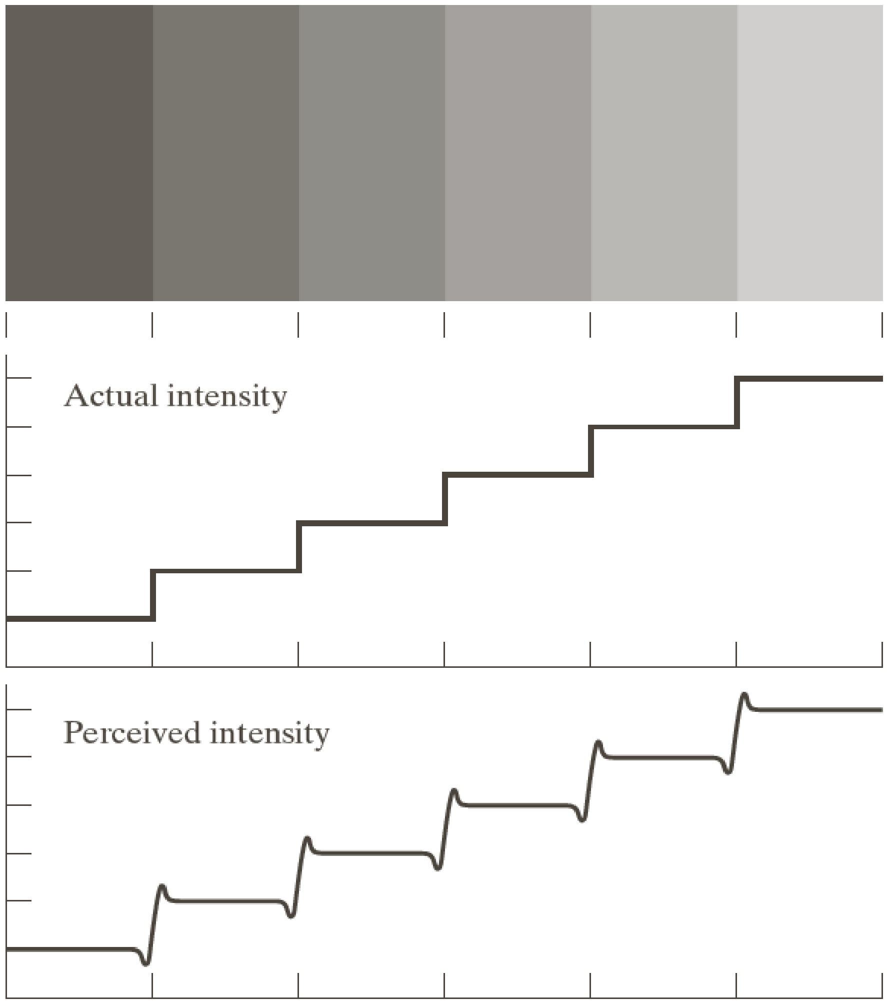


FIGURE 2.6 Typical Weber ratio as a function of intensity.

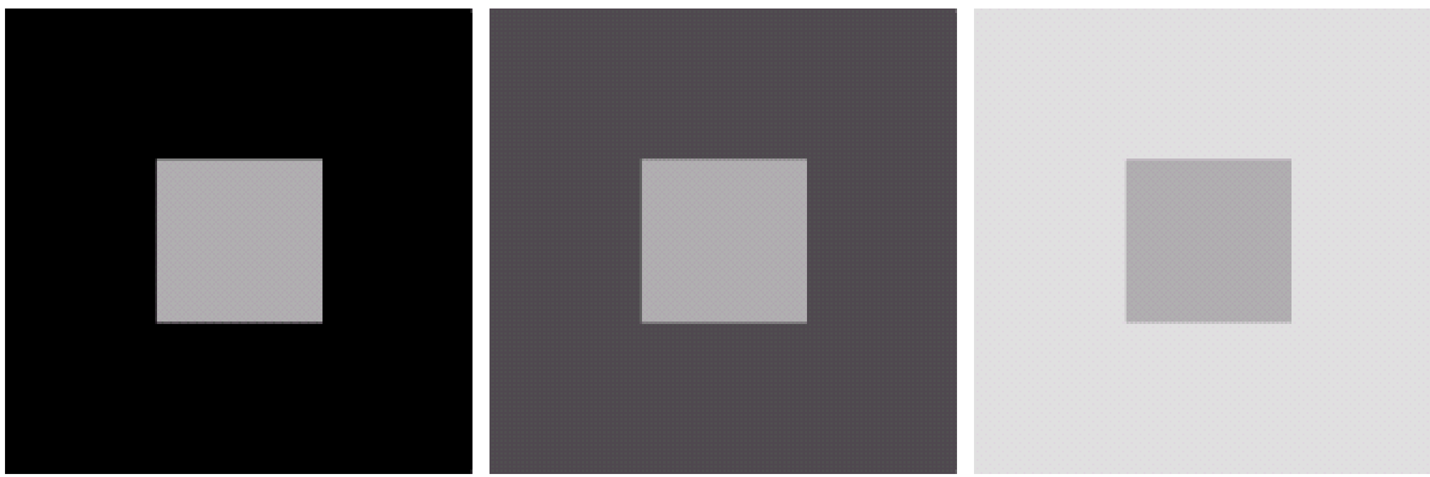
Perceived Intensity is Not a Simple Function of the Actual Intensity (1)



a
b
c

FIGURE 2.7 Illustration of the Mach band effect. Perceived intensity is not a simple function of actual intensity.

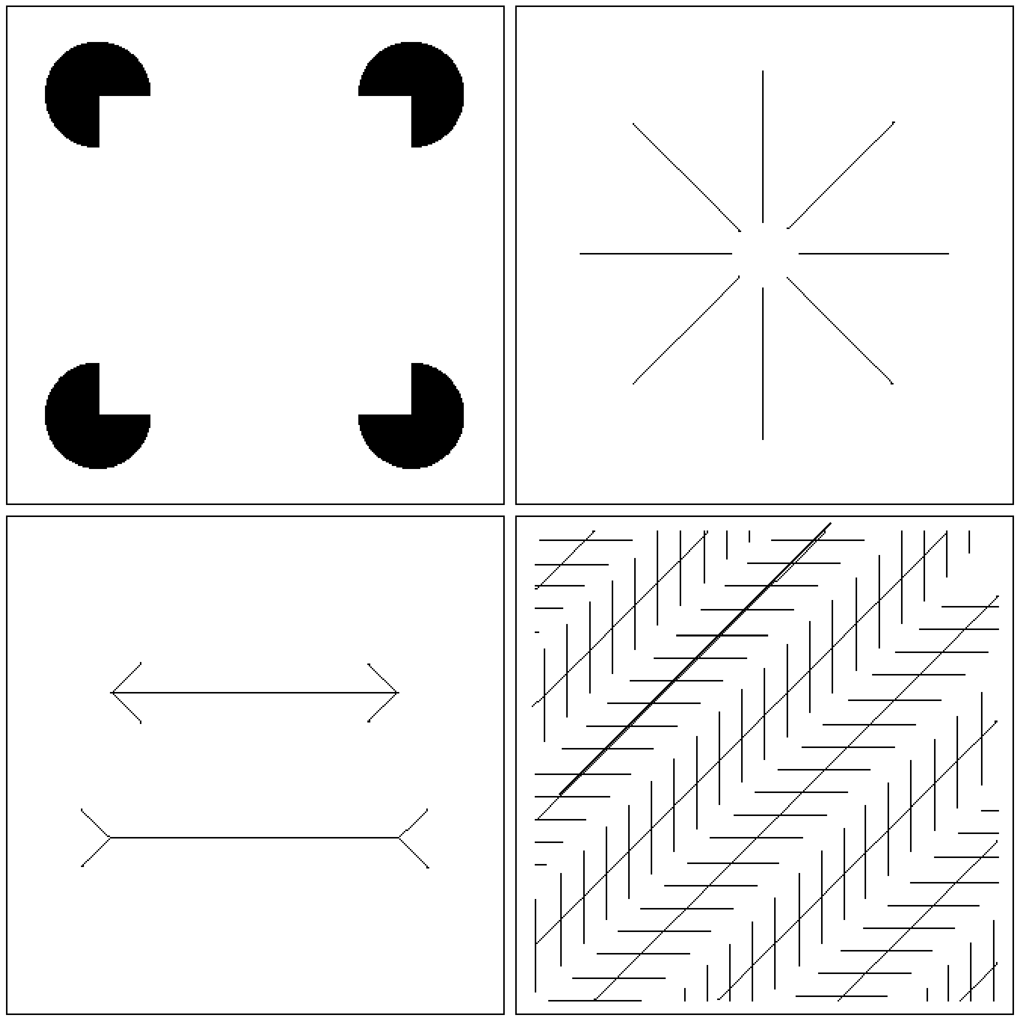
Perceived Intensity is Not a Simple Function of the Actual Intensity – Simultaneous Contrast



a b c

FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

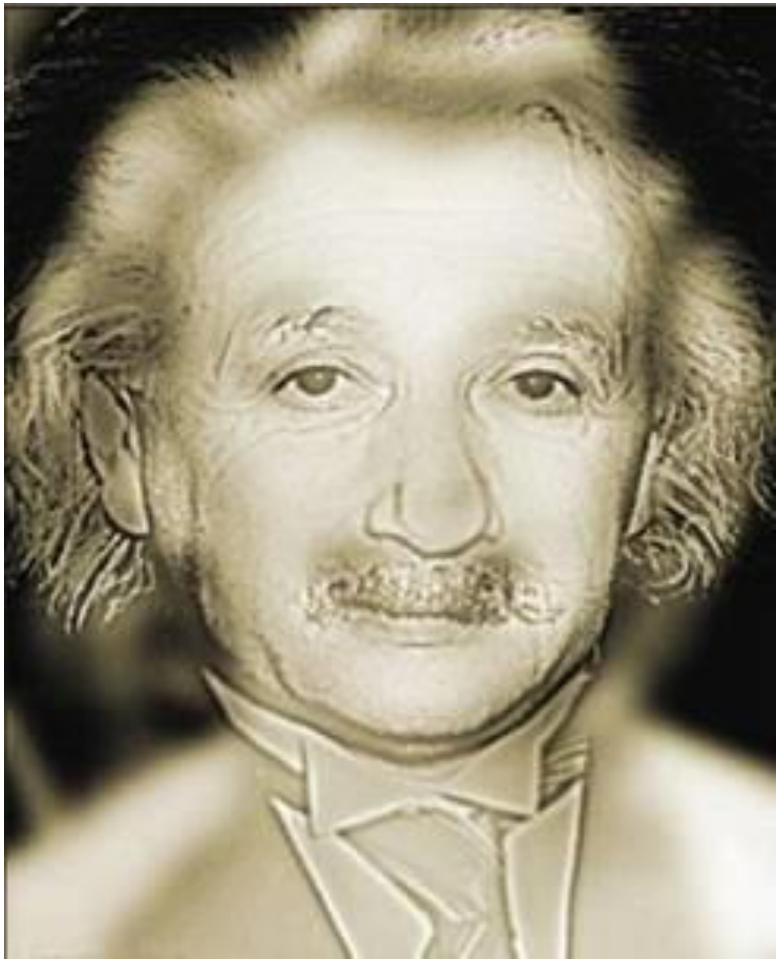
Optical Illusions: Complexity of Human Vision



a b
c d

FIGURE 2.9 Some well-known optical illusions.

More Optical Illusions



http://www.123opticalillusions.com/

http://brainden.com/optical-illusions.htm

Object Perception

How do we perceive separate features, objects, scenes, etc. in the environment?

- **Perception of a scene involves multiple levels of perceptual analysis.**

Scenes

Objects

Groups of Features

Features

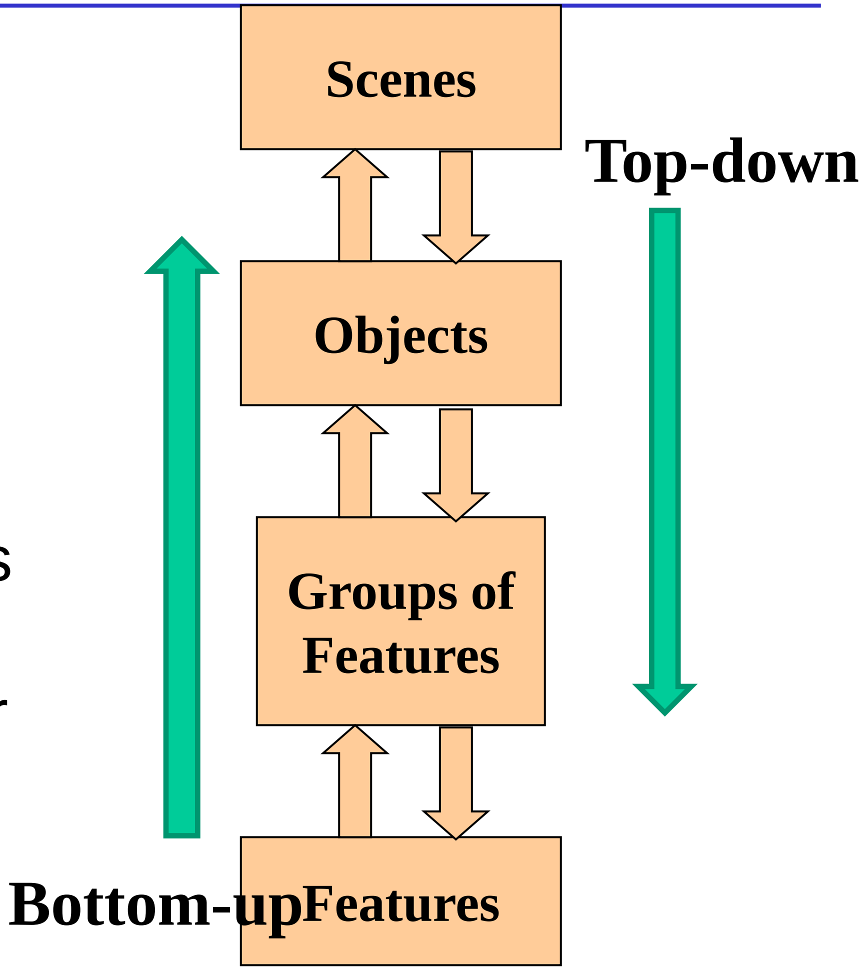
What Do We Do With All Of This Visual Information??

"Bottom up processing"

- Data-driven
- Sensation reaches brain, and then brain makes sense of it

"Top down processing"

- Cognitive functions informs our sensation
- E.g., walking to refrigerator in middle of night



Now,

Introducing some basic concepts in digital image processing

- **Human vision system. Why we need to study human eye?**
- **Basics of image acquisition**
  - Geometry – size, location, …
  - Appearance – color, intensity

Image Formation in the Eye

Image is upside down in the retina/imaging plane!

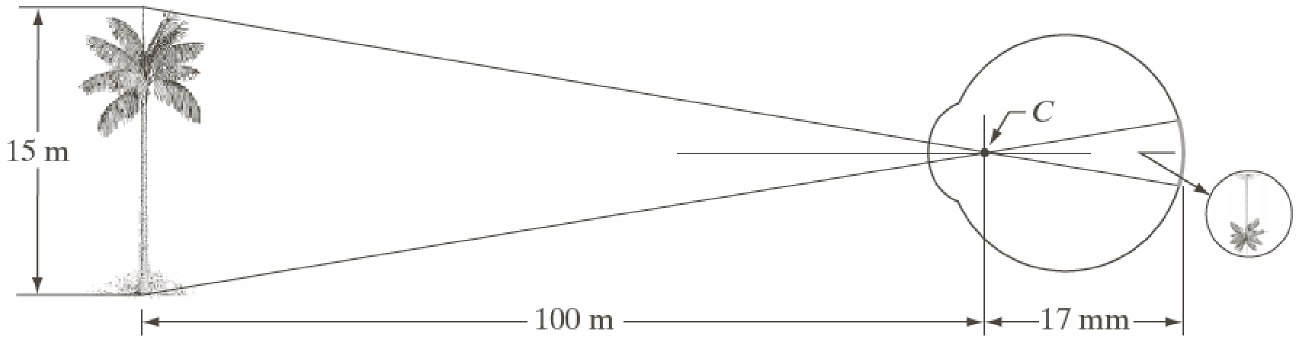
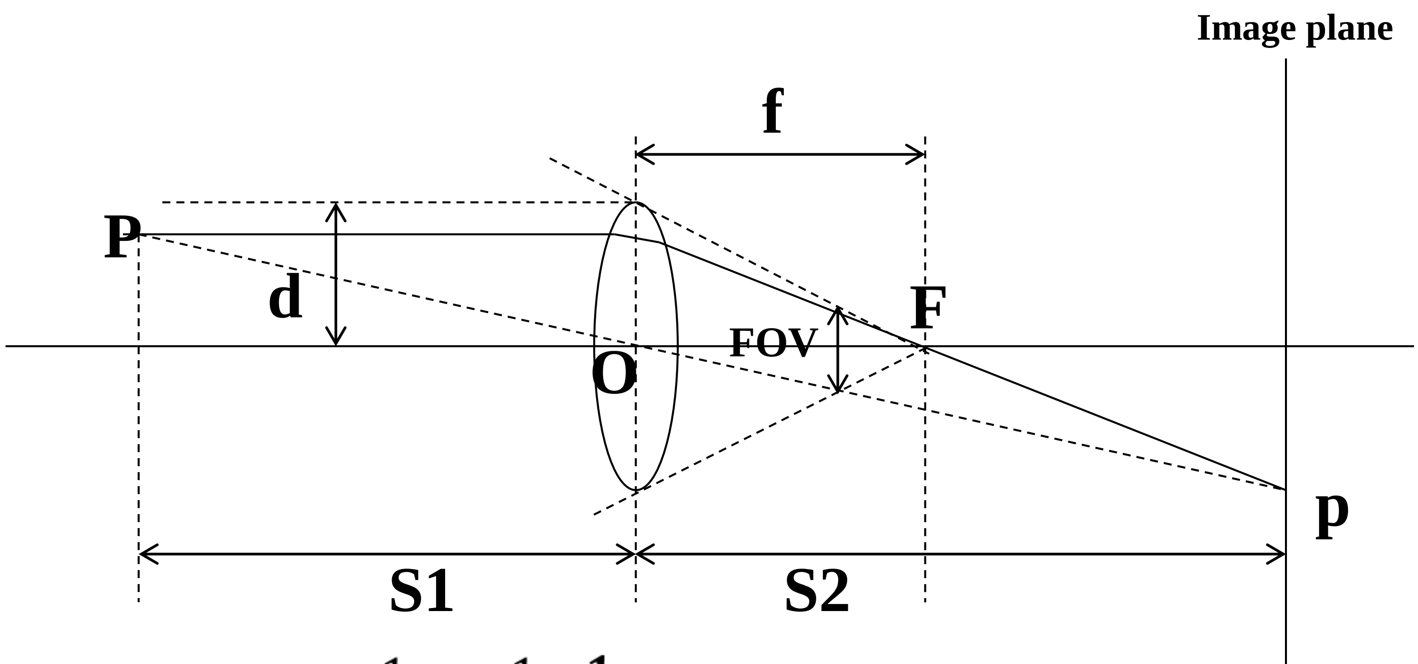


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point *C* is the optical center of the lens.

Adjust focus length

- **Camera**
- **Human eye**

Lens Parameters



Thin lens theory: $\frac{1}{S1} + \frac{1}{S2} = \frac{\mathbf{1}}{\boldsymbol{f}}$

Field of View: $\omega = 2arctan\frac{d}{f}$

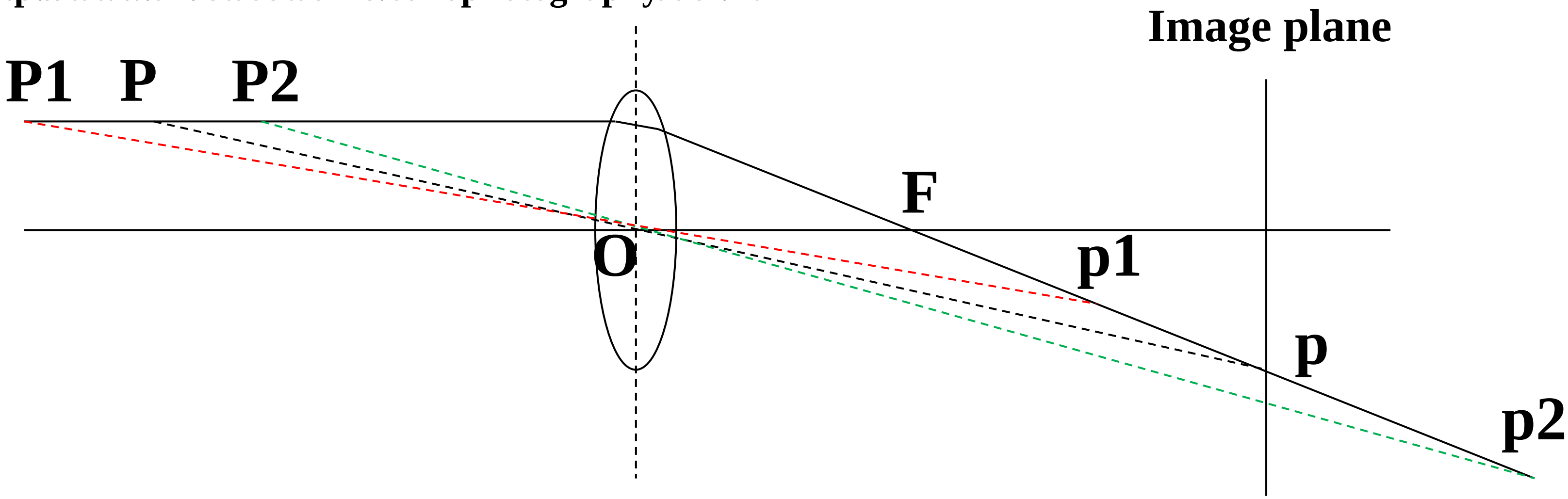
FOV

- **Increasing the distance from the object to the lens will reduce the size of image**
- **Large focus length will give a small FOV**

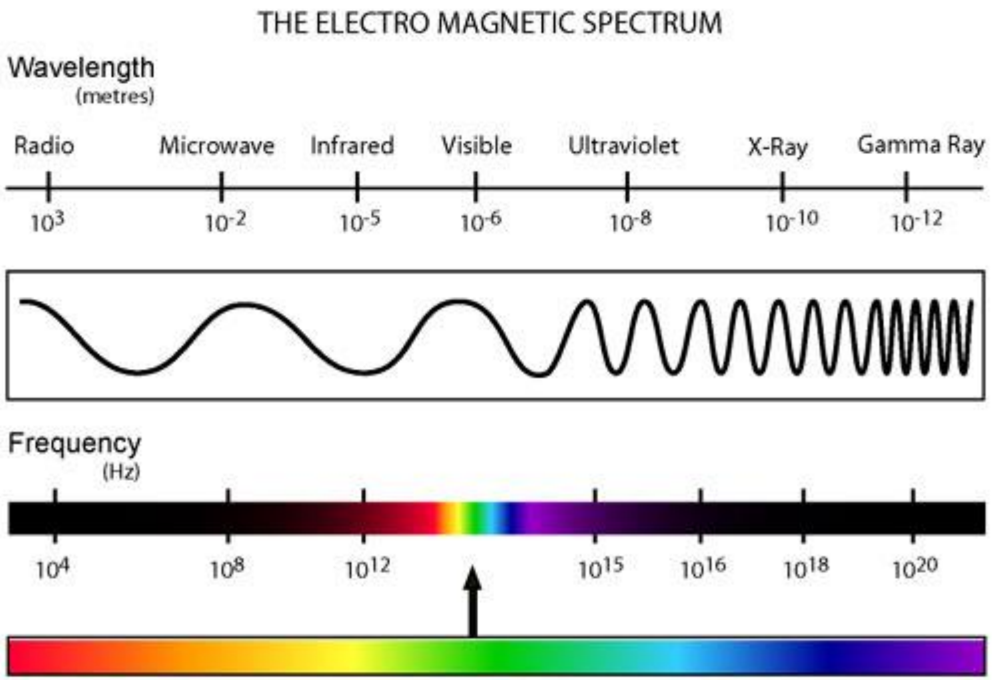
Depth of Field & Out of Focus

http://www.azuswebworks.com/photography/dof.html

- DOF is inversely proportional to the focus length
- DOF is proportional to S1



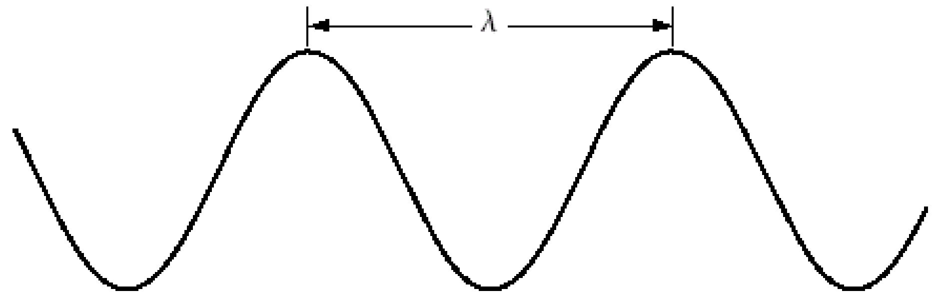
Light and EM Spectrum



http://www.kollewin.com/blog/electromagnetic-spectrum/

Relation Among Wavelength, Frequency and Energy

FIGURE 2.11
Graphical representation of one wavelength.



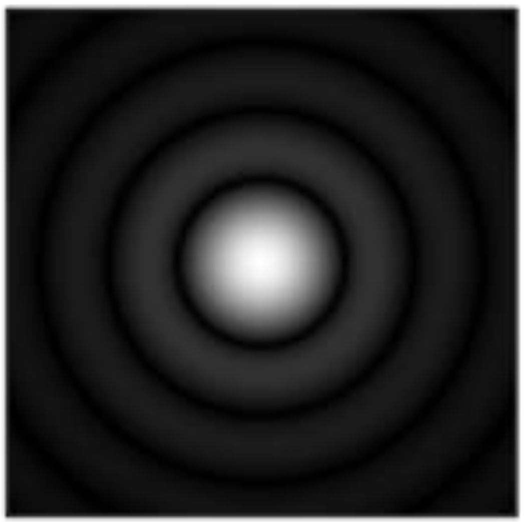
wavelength (λ), frequency (v), and energy (E)

$$\lambda = \frac{c}{v}, \quad c = 2.998\times10^{8}\, m/s \text{ is the speed of light}$$

$$E = hv, \;\; h \text{ is the Planck's constant}, 6.626068\times10^{-34}\ \mathrm{m}^2\ \mathrm{kg}\ /\ \mathrm{s}$$

Light and EM Spectrum

What size of the object you can "see"? Diffraction-limit.



http://en.wikipedia.org/wiki/Airy_disc

Airy disk: the size is proportional to wavelength and f-number (focal length/lens dimension)

$$\sim \lambda \frac{f}{d}$$

Image Sensing and Acquisition

Illumination energy → digital images

Incoming energy is transformed into a voltage

Digitizing the response

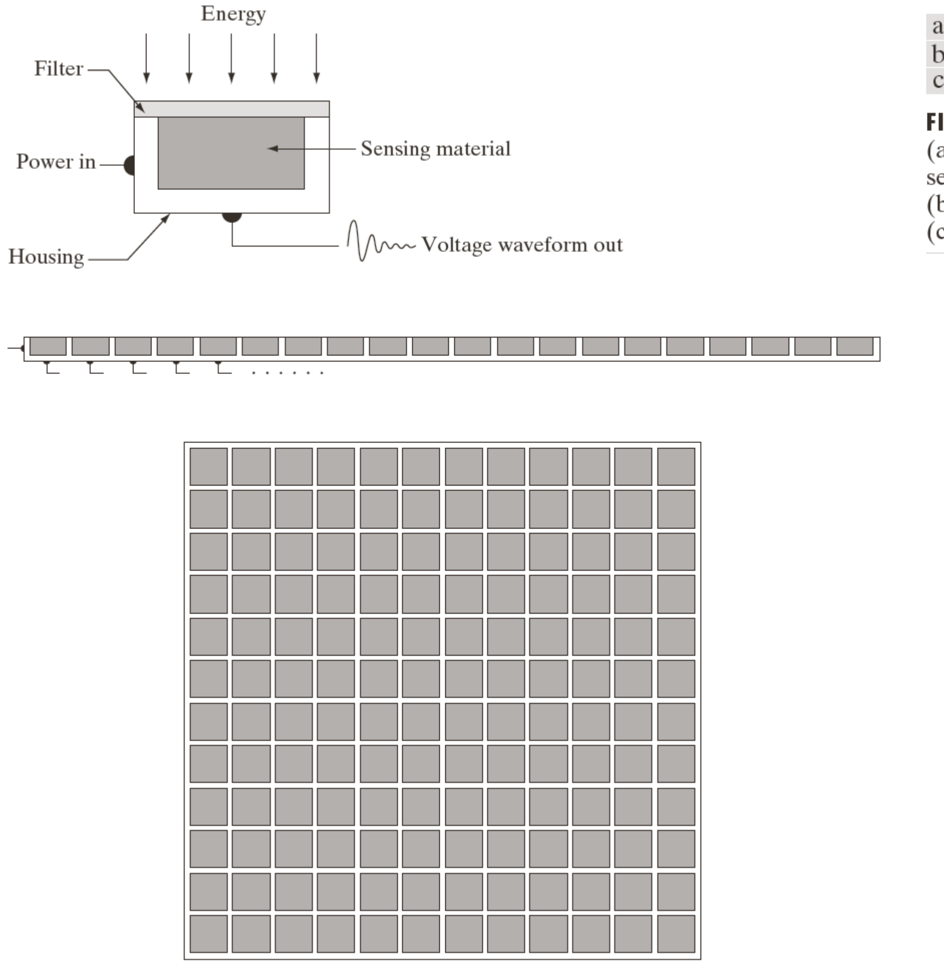
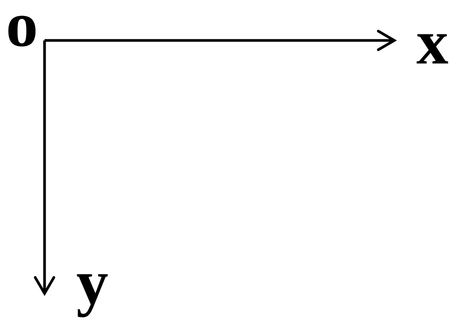


FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

A (2D) Image

An image = a 2D function *f*(*x*,*y*) where

- *x* and *y* are spatial coordinates
- *f*(*x*,*y*) is the intensity or gray level



An digital image:

- *x*, *y*, and *f*(*x*,*y*) are all finite
- For example $x \in \{1, 2, \ldots, M\}$, $y \in \{1, 2, \ldots, N\}$

$$f(x, y) \in \{0, 1, 2, \ldots, 255\}$$

Digital image processing → processing digital images by means of a digital computer

Each element (*x*,*y*) in a digital image is called a pixel (picture element)

A Simple Image Formation Model

$$f(x, y) = i(x, y) \cdot r(x, y)$$

$0 < f(x,y) < \infty$: **Image (positive and finite)**

Source: $0 < i(x,y) < \infty$: **Illumination component**

Object: $0 < r(x,y) < 1$: **Reflectance/transmission component**

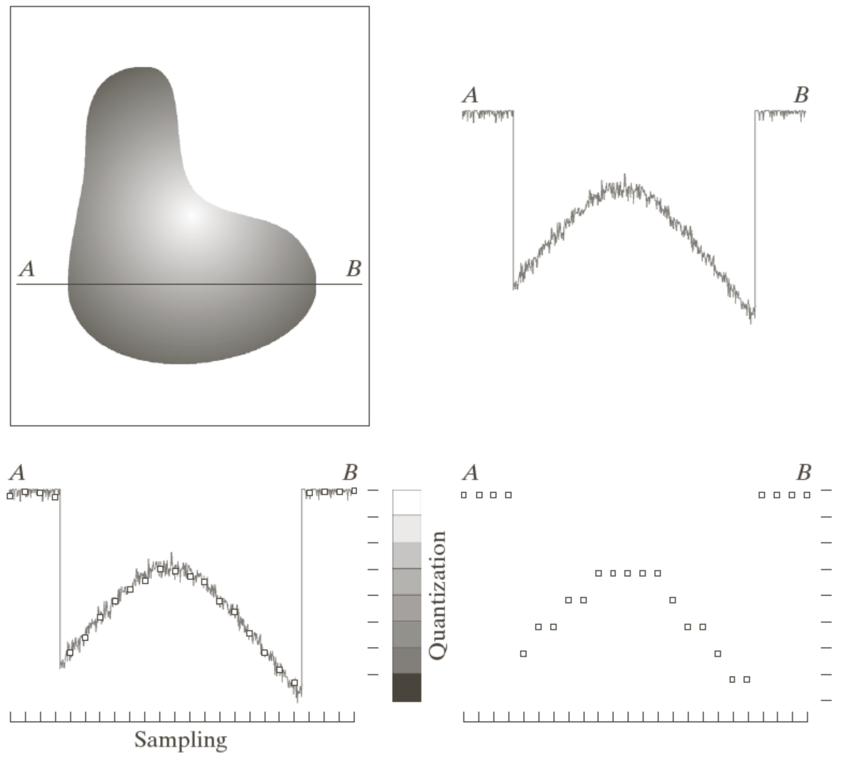
$L_{\min} < f(x,y) < L_{\max}$ **in practice**

where $L_{\min} = i_{\min} r_{\min}$ **and** $L_{\max} = i_{\max} r_{\max}$

i(x,y): **Sunlight: 10,000 lm/m^2 (cloudy), 90,000lm/m^2 clear day**
Office: 1000 lm/m^2

r(x,y): **Black velvet 0.01; white pall 0.8; 0.93 snow**

Image Sampling and Quantization



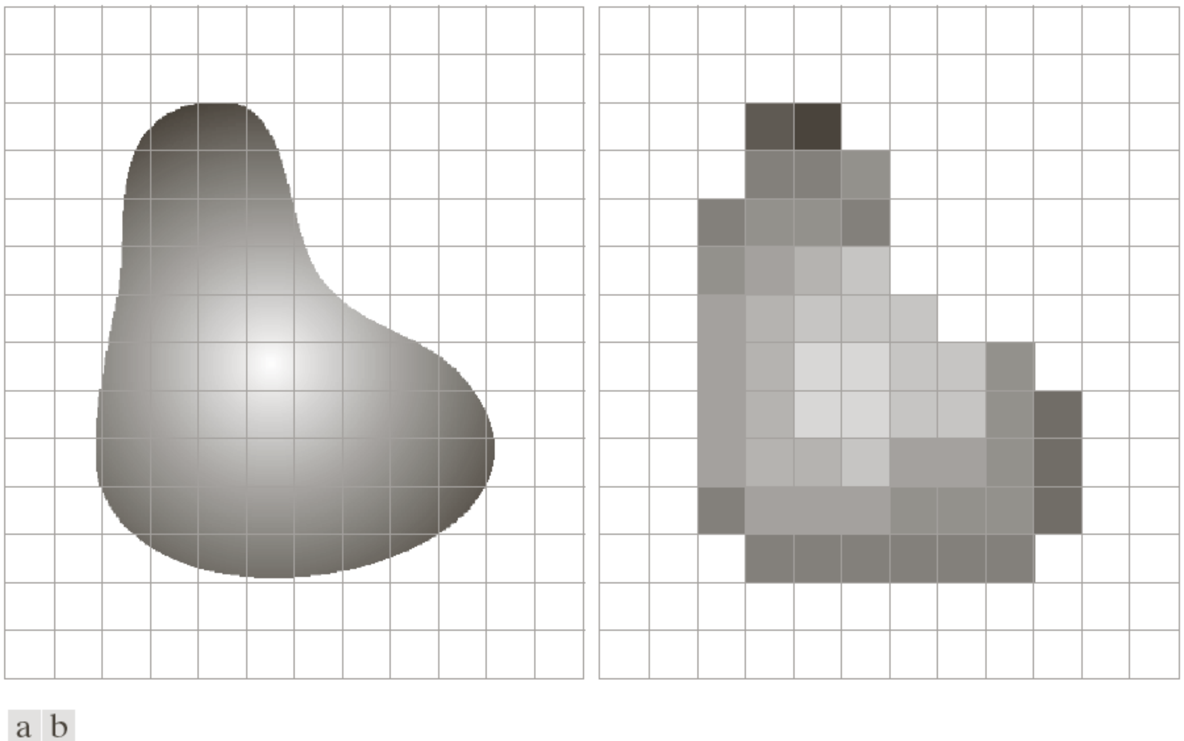
a b
c d

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.

Sampling: Digitizing the coordinate values (usually determined by sensors)

Quantization: Digitizing the amplitude values

Image Sampling and Quantization in a Sensor Array



CCD array

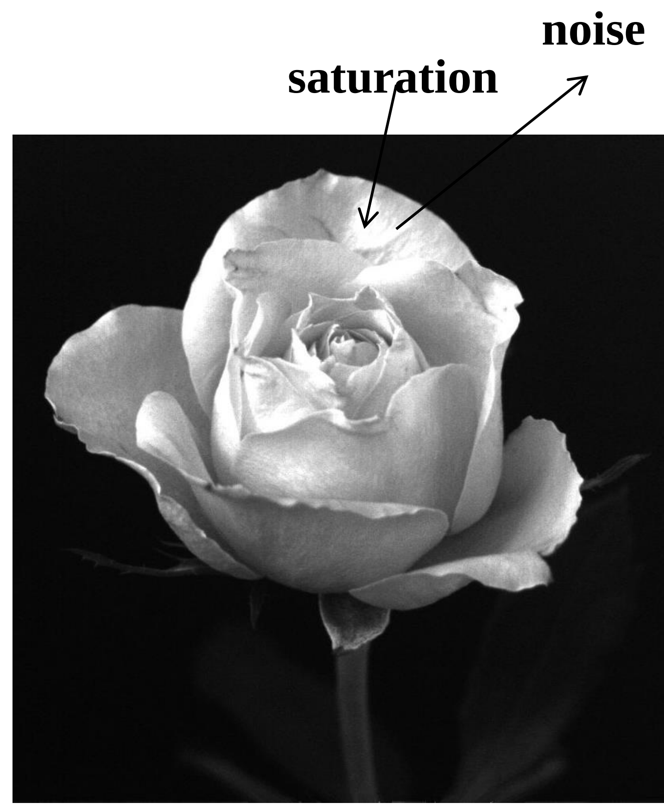
FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Dynamic Range

$L_{\min} < f(x,y) < L_{\max}$ **in practice**

where $L_{\min} = i_{\min} r_{\min}$ **and** $L_{\max} = i_{\max} r_{\max}$

$0 \leq f(x,y) \leq L-1$ **and** $L = 2^k$



Dynamic range/contrast ratio:

the ratio of the maximum detectable intensity level (saturation) to the minimum detectable intensity level (noise)

$$\frac{I_{max}}{I_{min}}$$

Representing Digital Images

(a)*: f*(*x*,*y*), *x*=0, 1, …, *M*-1, *y*=0,1, …, *N*-1

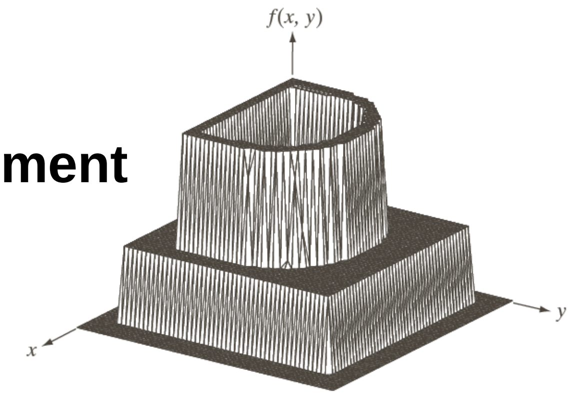
***x*, *y*: spatial coordinates → spatial domain**

(b): suitable for visualization

(c): processing and algorithm development

***x*: extend downward (rows)**

***y*: extend to the right (columns)**



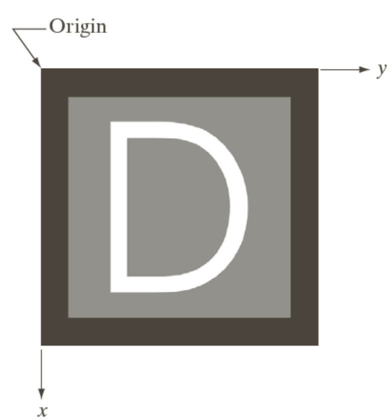
Number of bits storing the image

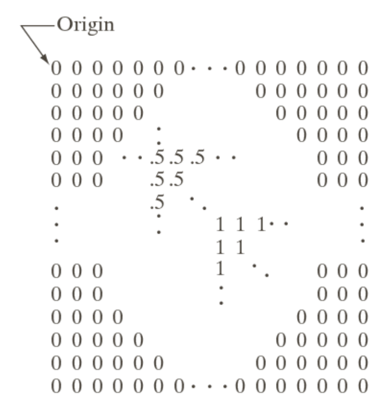
↑

$$b = M \times N \times k$$

a
b c

FIGURE 2.18
(a) Image plotted as a surface.
(b) Image displayed as a visual intensity array.
(c) Image shown as a 2-D numerical array (0, .5, and 1 represent black, gray, and white, respectively).





Store an Image

TABLE 2.1
Number of storage bits for various values of N and k.

N/k	1 (L = 2)	2 (L = 4)	3 (L = 8)	4 (L = 16)	5 (L = 32)	6 (L = 64)	7 (L = 128)	8 (L = 256)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

Spatial Resolution

Spatial resolution: smallest discernible details

- # of line pairs per unit distance
- # of dots (pixels) per unit distance
  - Printing and publishing
  - In US, dots per inch (dpi)

Newspaper $\longrightarrow$ magazines $\longrightarrow$ book

Large image size itself does not mean high spatial resolution!

$\longrightarrow$ **Scene/object size in the image**

1280*960

http://www.shimanodealer.com/fishing_reports.htm

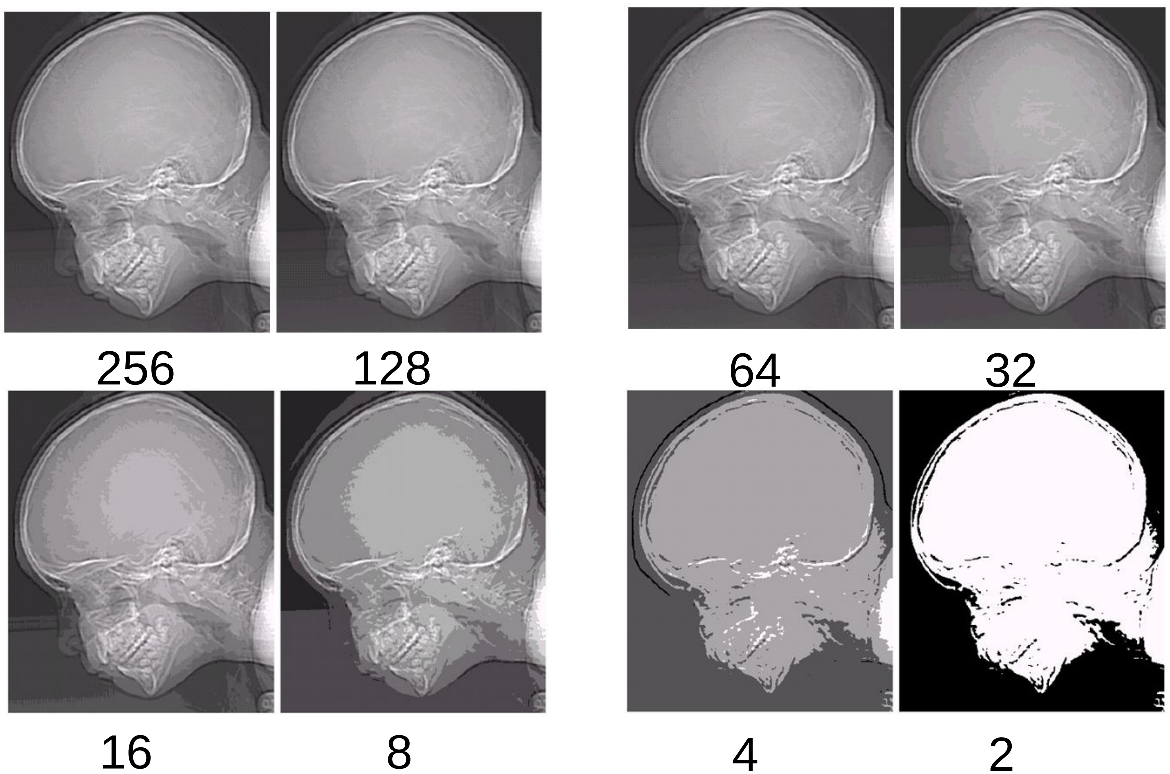
a b
c d

FIGURE 2.20 Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.

Intensity Resolution

Intensity resolution

- Smallest discernible change in intensity levels
- Using the number of levels of intensities
- False contouring (banding) when *k* is small - undersampling



Isopreference Curves

a b c

FIGURE 2.22 (a) Image with a low level of detail. (b) Image with a medium level of detail. (c) Image with a relatively large amount of detail. (Image (b) courtesy of the Massachusetts Institute of Technology.)

Vary the spatial and intensity sampling simultaneously:

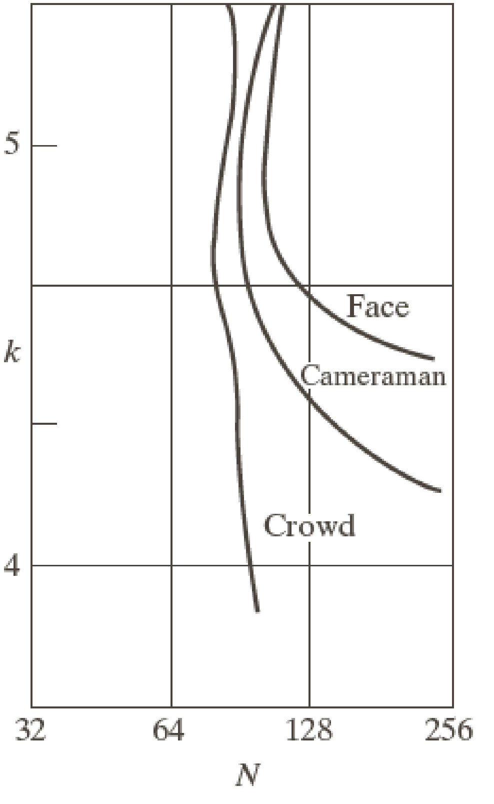


FIGURE 2.23 Typical isopreference curves for the three types of images in Fig. 2.22.

Basic Set and Logical Operations

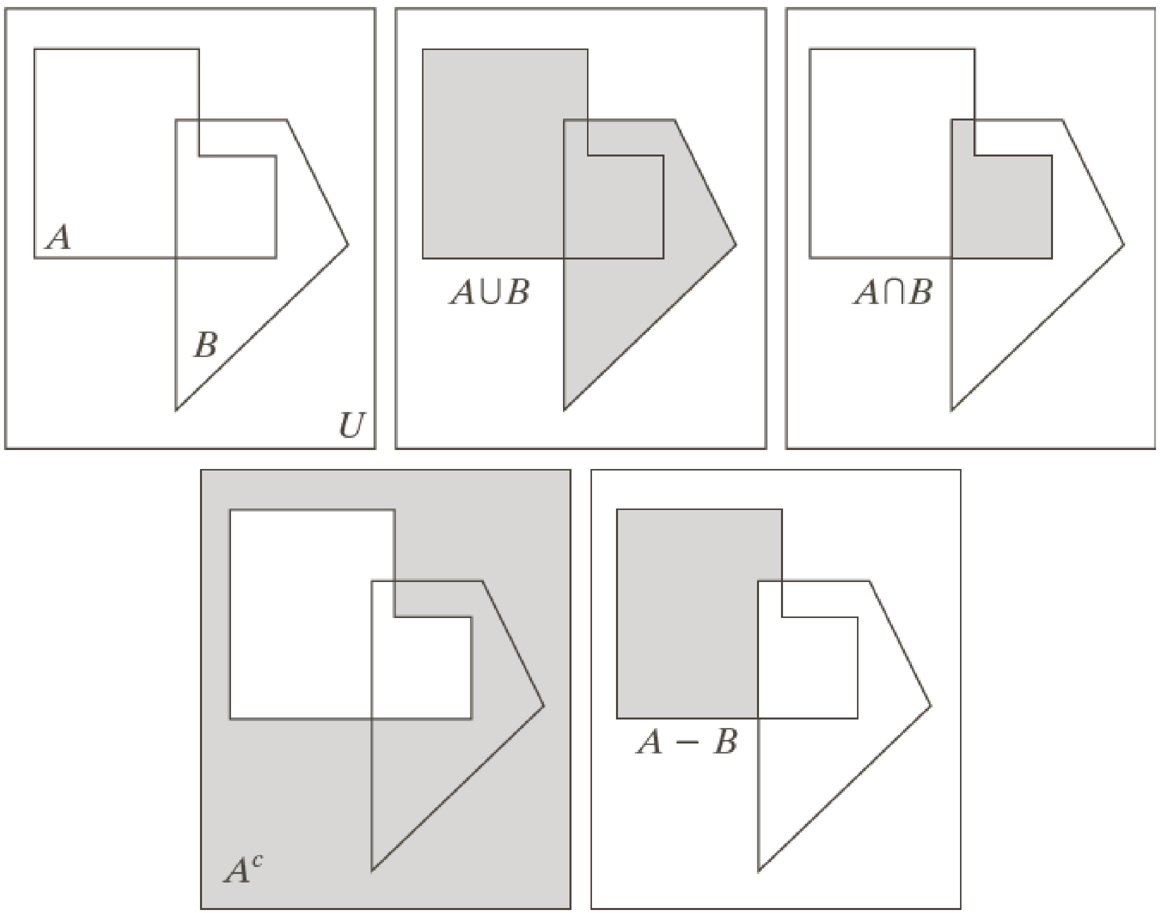
- A is a set: A={.}   e.g. A={1,…,255} or $A = \{w|w = 1, \dots, 255\}$

$A = \emptyset$ for empty set

- a is an element of A$(a \in A)$ or a isn't an element of A$(a \notin A)$
- A is a *subset* of B if every element in A also is in B $(A \sqsubseteq B)$
- C is the *union* of two sets A and B $(C = A \cup B)$
- C is the *intersection* of A and B $(C = A \cap B)$
- Disjoint or mutual exclusive sets $(A \cap B = \emptyset)$
- *Set universe* is the set of all elements in an application
- *Set difference* $(A - B = \{w|w \in A, w \notin B\})$

Set Operations Based on Coordinates

A region in an image is represented by a set of coordinates within the region



a b c
d e

FIGURE 2.31 (a) Two sets of coordinates, A and B, in 2-D space. (b) The union of A and B. (c) The intersection of A and B. (d) The complement of A. (e) The difference between A and B. In (b)–(e) the shaded areas represent the member of the set operation indicated.

Some Basic Relationships between Pixels

Neighbors of a pixel

$N_4(\mathbf{p})$

	(x-1,y)	
(x,y-1)	(x,y)	(x,y+1)
	(x+1,y)	

$N_D(\mathbf{p})$

(x-1,y-1)		(x-1,y+1)
	(x,y)	
(x-1,y+1)		(x+1,y+1)

$N_8(\mathbf{p})$

(x-1,y-1)	(x-1,y)	(x-1,y+1)
(x,y-1)	(x,y)	(x,y+1)
(x-1,y+1)	(x+1,y)	(x+1,y+1)

Adjacency

Adjacency is the relationship between two pixels *p* and *q*

***V* is a set of intensity values used to define adjacency**

- **Binary image: V={1} or V={0}**
- **Gray level image:** $\boldsymbol{V \sqsubseteq \{0, 1, \ldots, 255\}}$

$\boldsymbol{f(p) \in V}$ and $\boldsymbol{f(q) \in V} \Rightarrow$ **Intensity constraints**

Three types of adjacency:

4-adjacency

p

$$\begin{matrix} 0 & 1 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{matrix}$$

$\boldsymbol{q \in N_4(p)}$

8-adjacency

$$\begin{matrix} 0 & 1 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{matrix}$$

$\boldsymbol{q \in N_8(p)}$

m-adjacency

$$\begin{matrix} 0 & 1 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{matrix}$$

$\boldsymbol{q \in N_D(p)}$ **and** $N_4(q) \cap N_4(p) = \emptyset$

$or\ q \in N_4(p)$