Digital Image Processing

Contents

- Elements of visual perception
- Representing Digital Images
- Spatial and Intensity Resolution

Elements of visual perception

In the beginning…

we’ll have a look at the human eye

Fundamentals

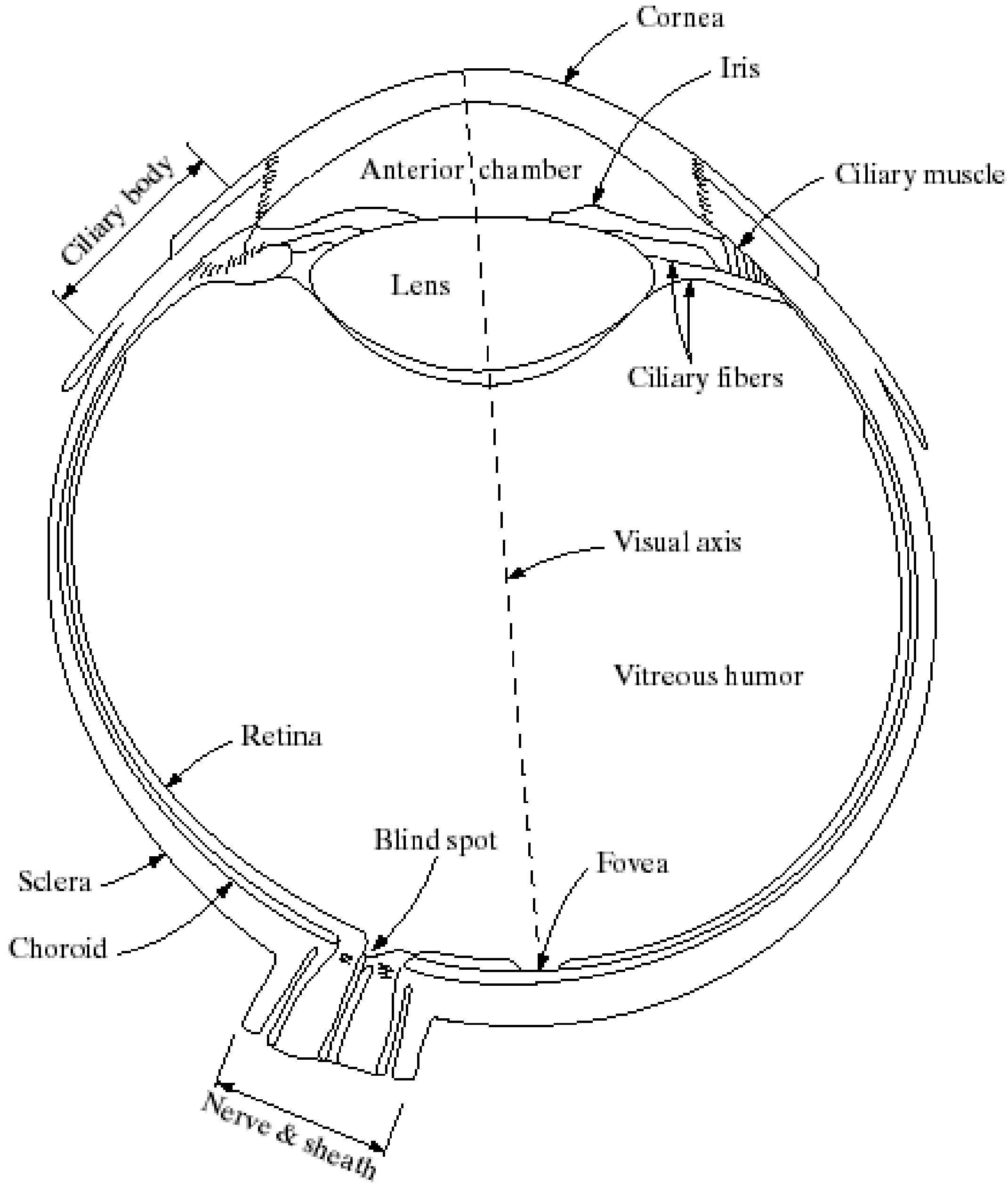


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

We are mostly interested in the retina:

It consists of cones and rods

Cones

color receptors

Each one is connected to its own nerve

About 7 million, primarily in the retina’s central portion for image details

Rods

Sensitive to illumination, not involved in color vision

About 130 million, all over the retina

General, overall view

Fundamentals

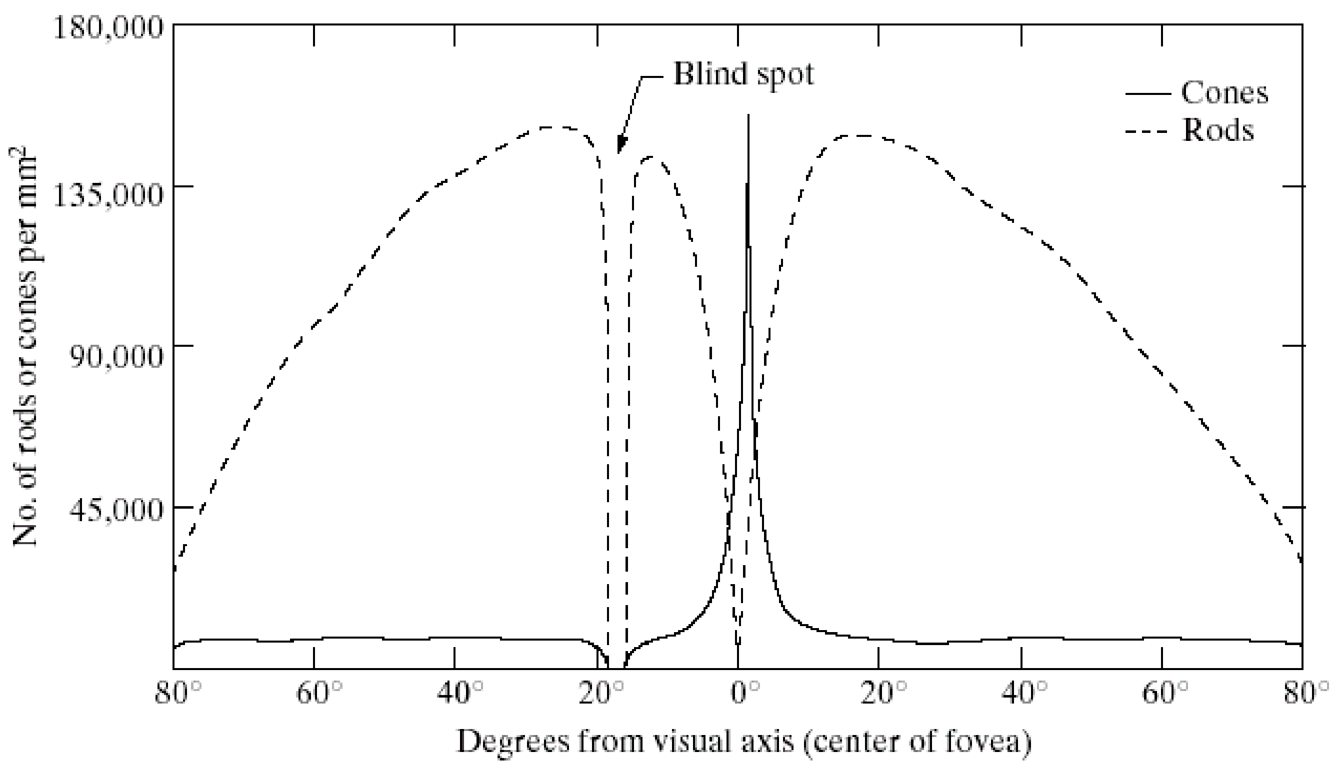


FIGURE 2.2 Distribution of rods and cones in the retina.

Cone vision → Bright-Light vision (photopic)

Rod vision → Dim-light vision (scotopic)

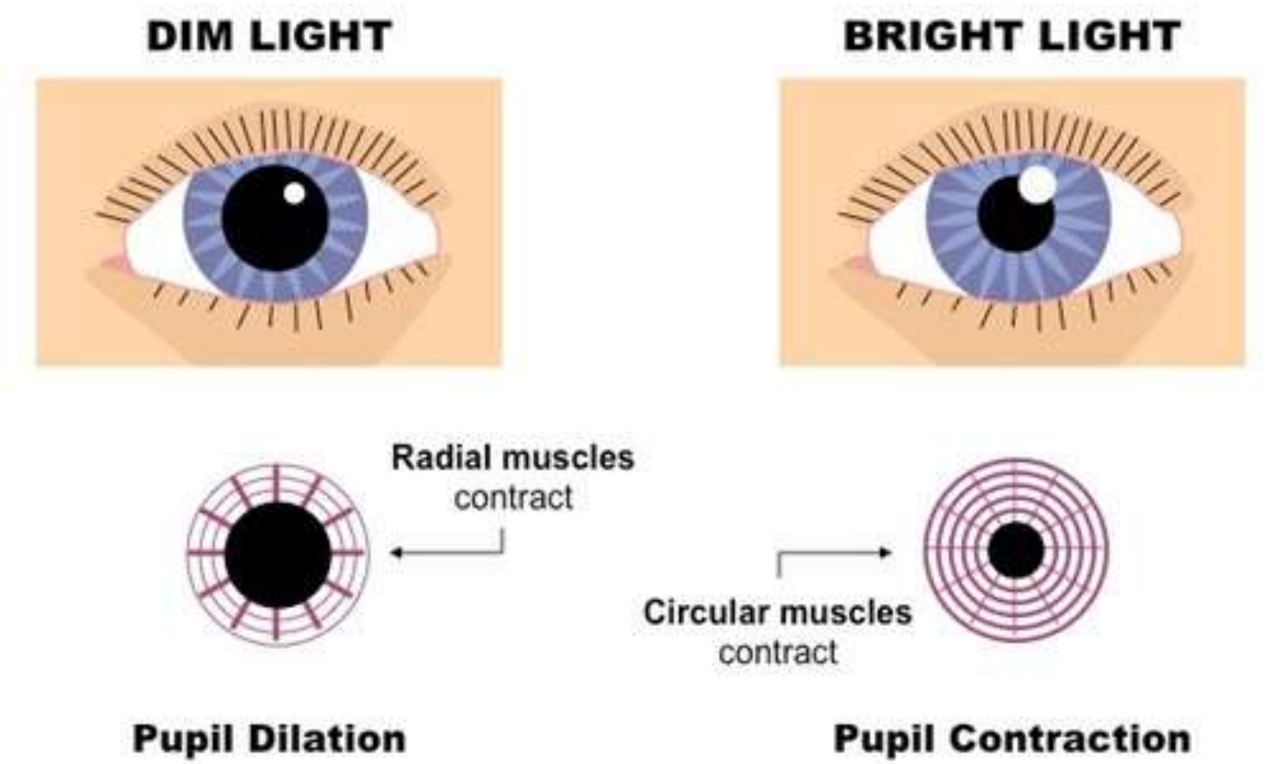


Image formation in the Eye

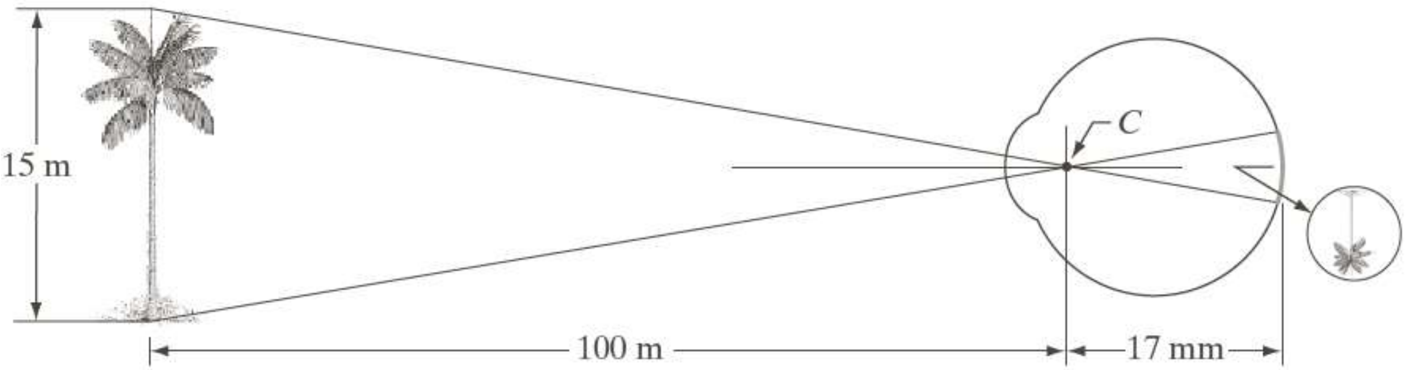


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point *C* is the optical center of the lens.

Human perception phenomena

Brightness Adaptation

Brightness Discrimination

Simultaneous Contrast

Optical Illusions

Brightness Adaptation

- Subjective brightness means intensity as preserved by the human visual system
- Brightness adaptation means the human visual system can operate only from scotopic to glare limit
  - It cannot operate over the range simultaneously. It accomplishes this large variation by changes in its overall intensity.

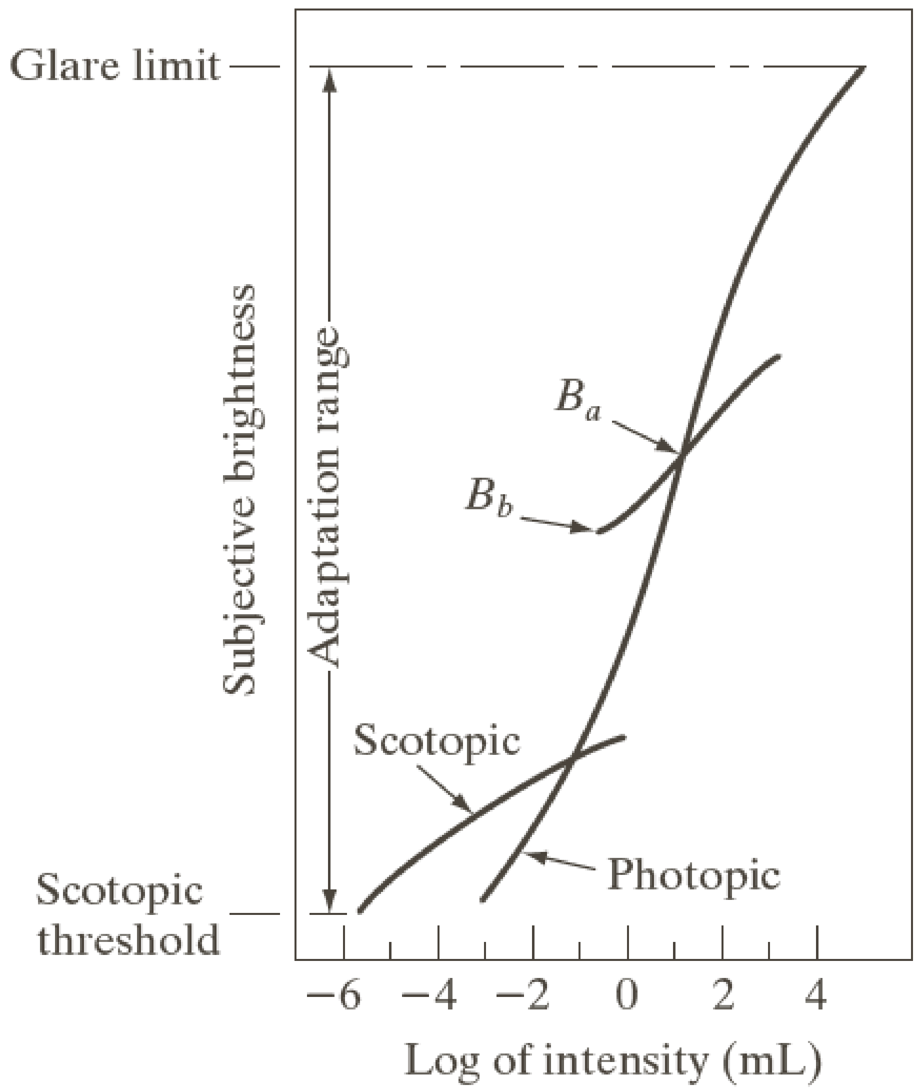


FIGURE 2.4 Range of subjective brightness sensations showing a particular adaptation level.

Brightness Discrimination

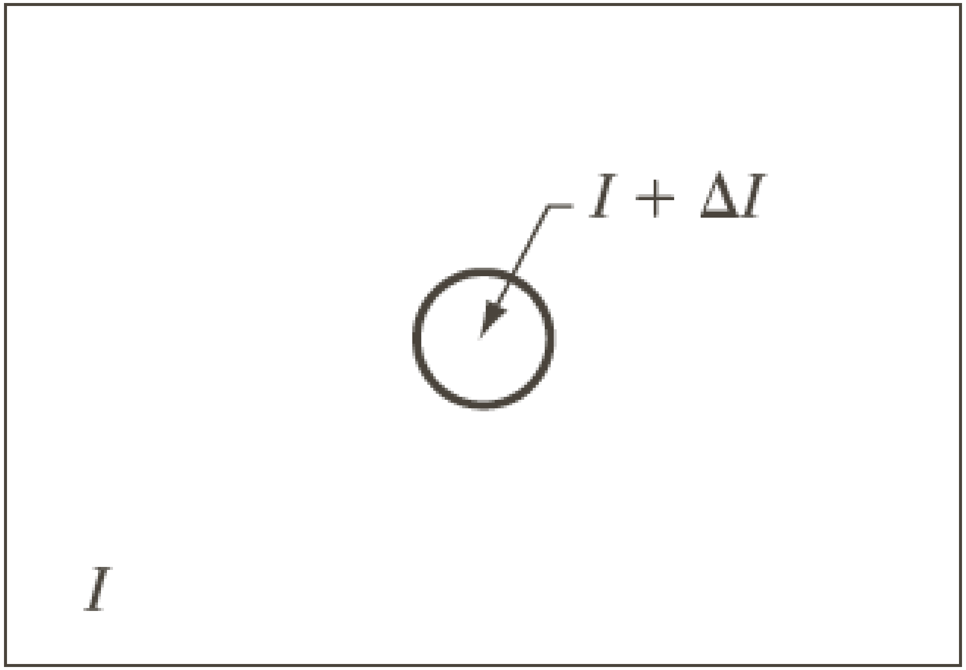
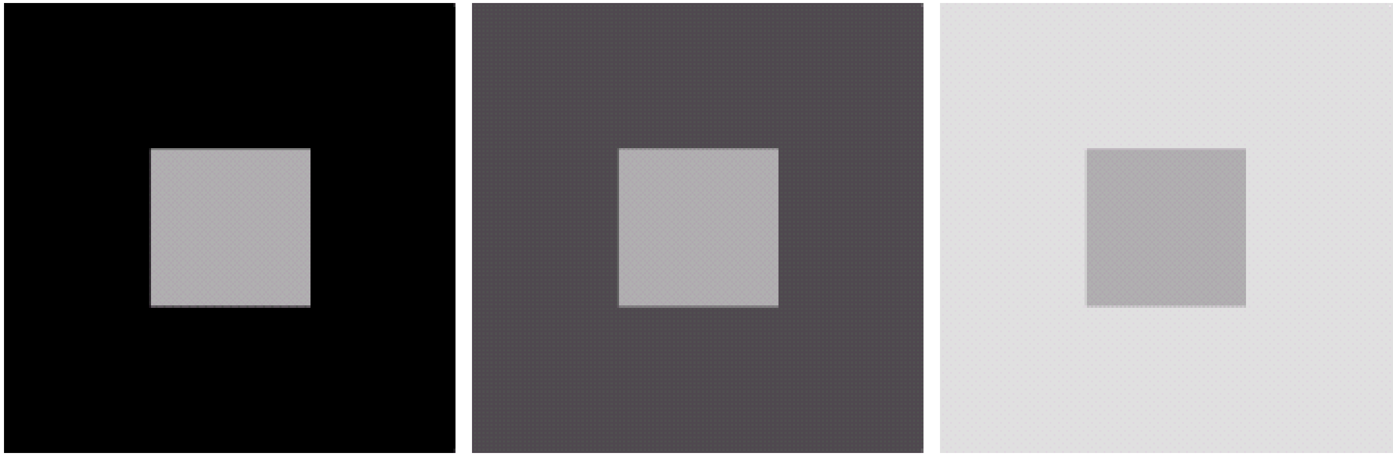


FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

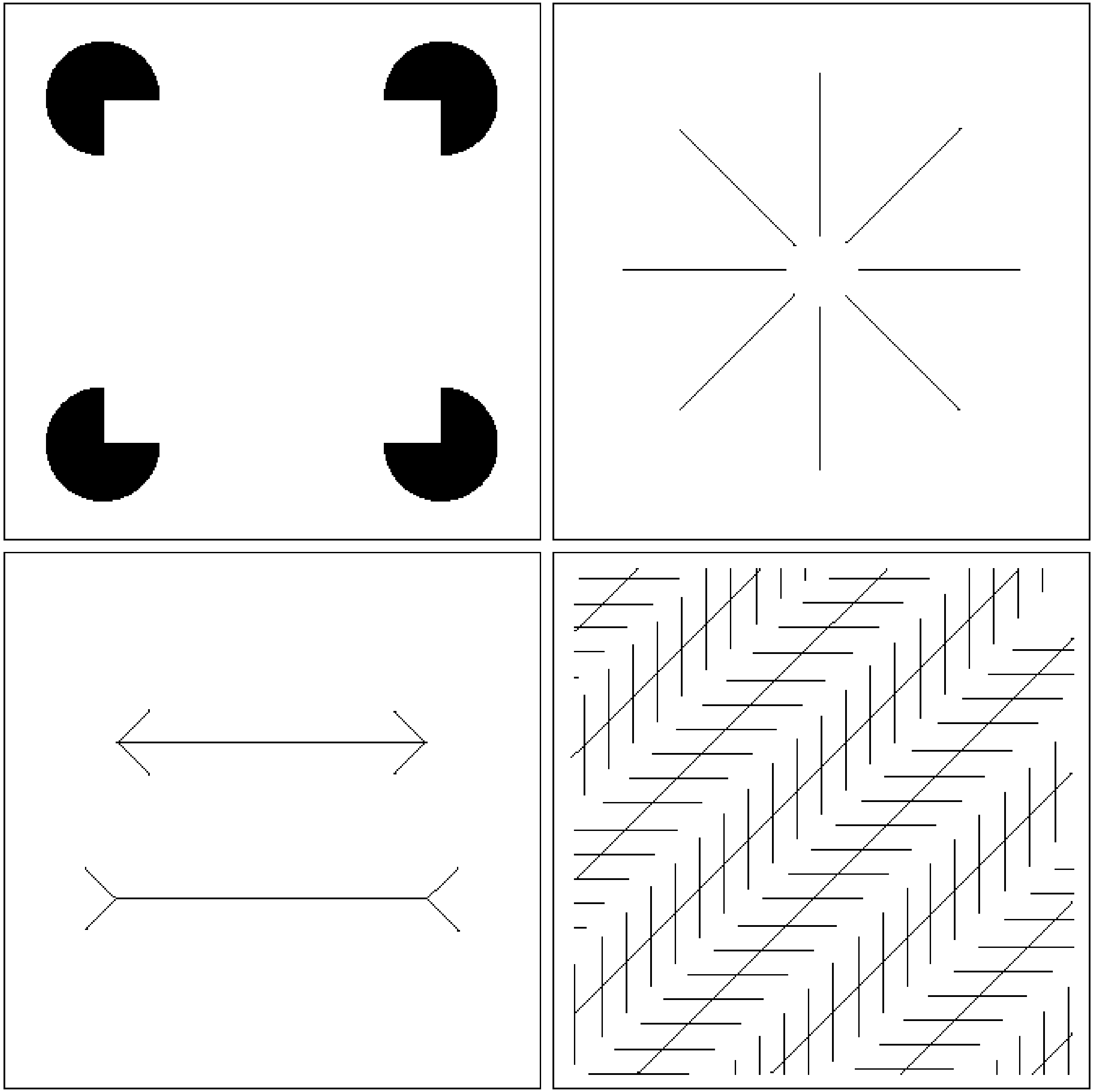
Simultaneous contrast



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



a b
c d

FIGURE 2.9 Some well-known optical illusions.

optical illusions:

Digital Image Processing does NOT (primarily) deal with cognitive aspects of the perceived image !

Fundamentals

The human eye is sensible to electromagnetic waves in the ‘visible spectrum’ :

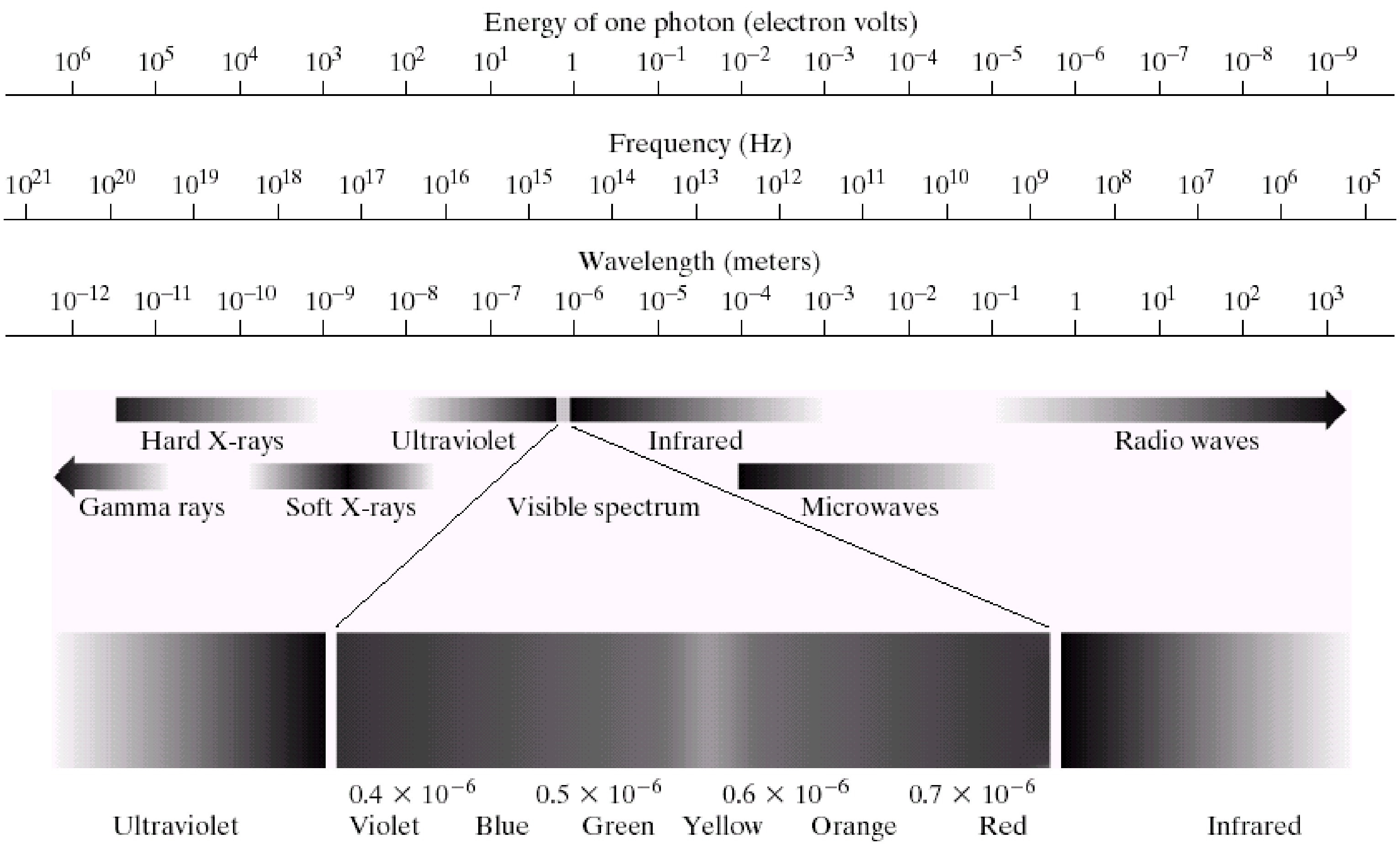
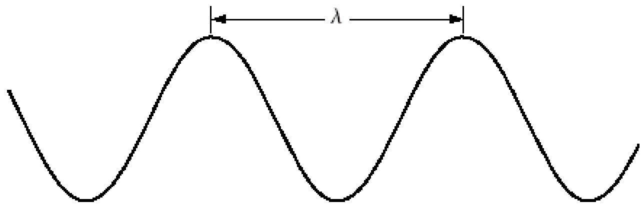


FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

The human eye is sensible to electromagnetic waves in the 'visible spectrum' , which is around a wavelength of

0.000001 m = 0.001 mm

FIGURE 2.11
Graphical representation of one wavelength.



The human eye

Is able to perceive electromagnetic waves in a certain spectrum

Is able to distinguish between wavelengths in this spectrum (colors)

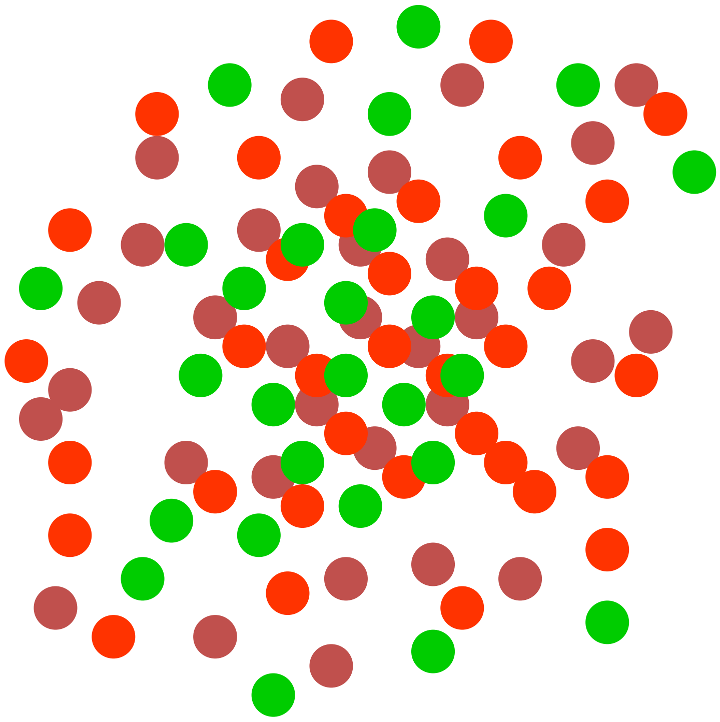
Has a higher density of receptors in the center

- Maps our 3D reality to a 2 dimensional image !

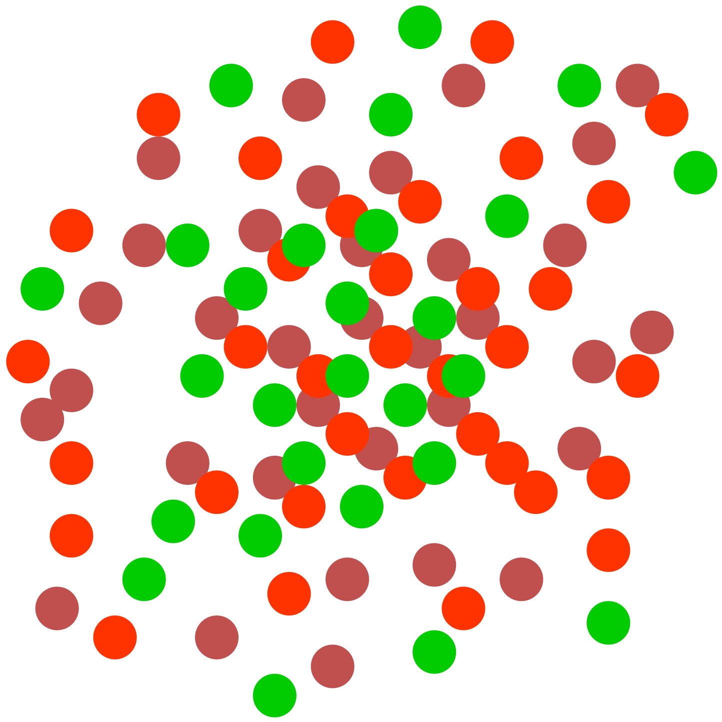
…or more precise:

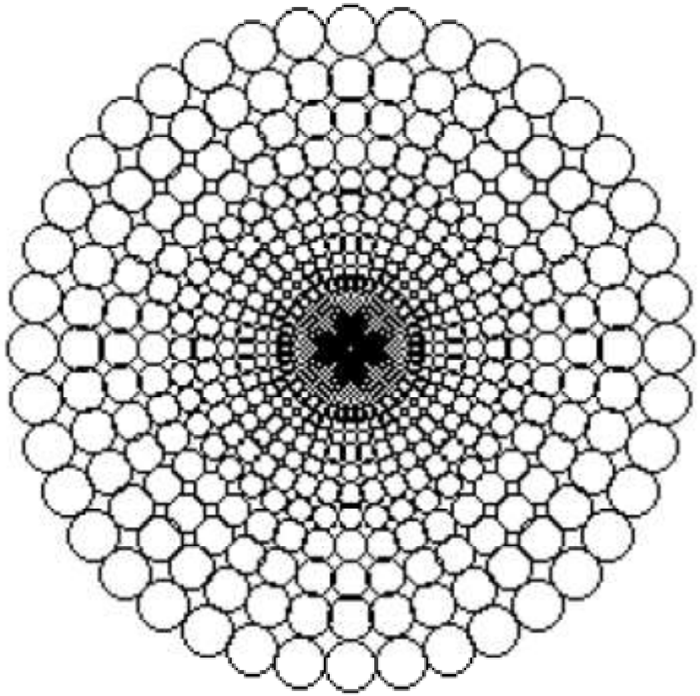
maps our continuous reality to a (spatially) DISCRETE 2D image

What is an image ?

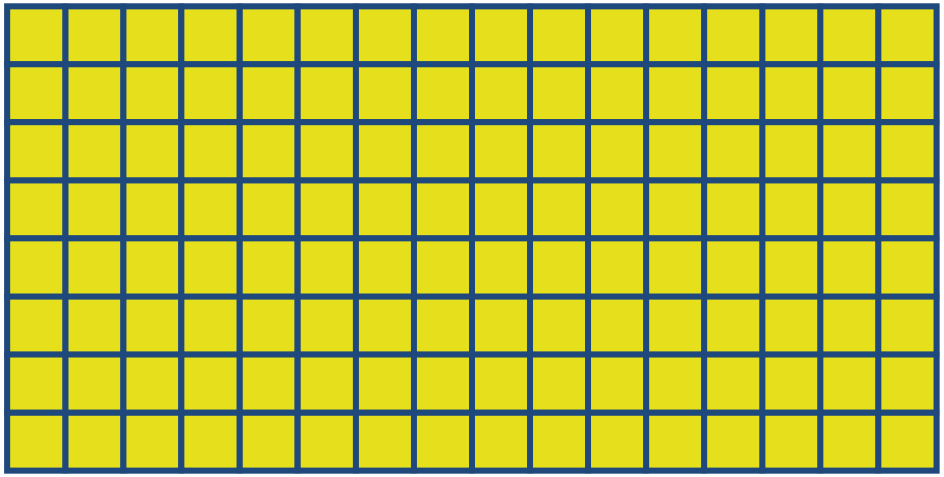


The retinal model is mathematically hard to handle



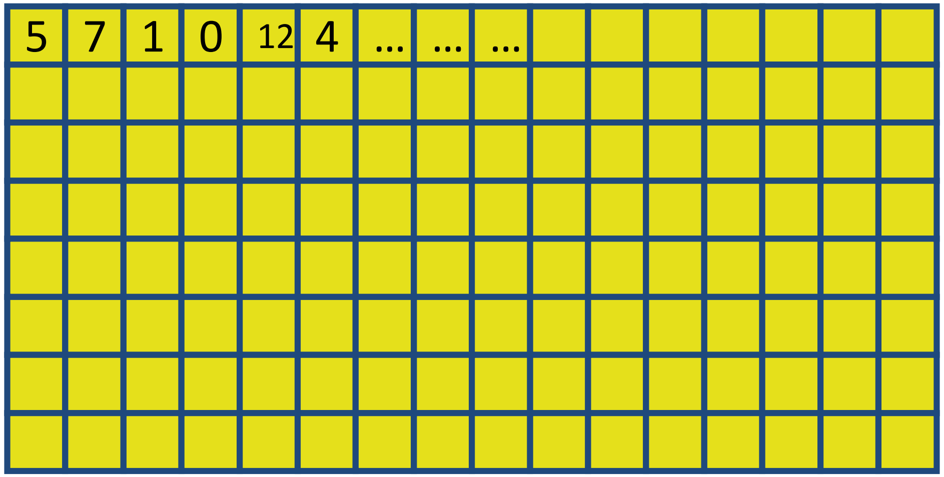


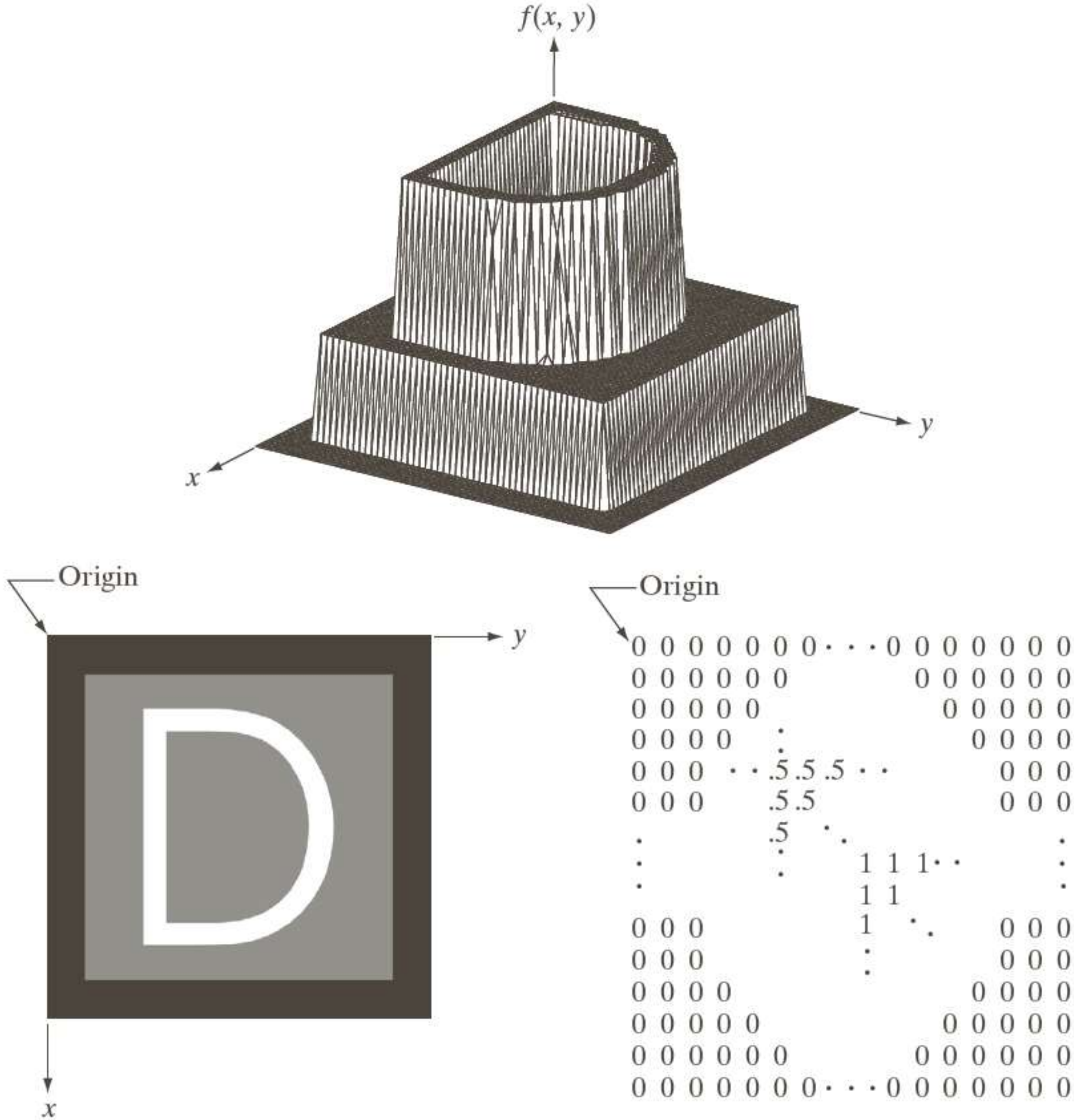
Easier: 2D array of cells, modelling the cones/rods



The *position* of each cell defines the position of the receptor

The *numerical value* of the cell represents the illumination received by the receptor





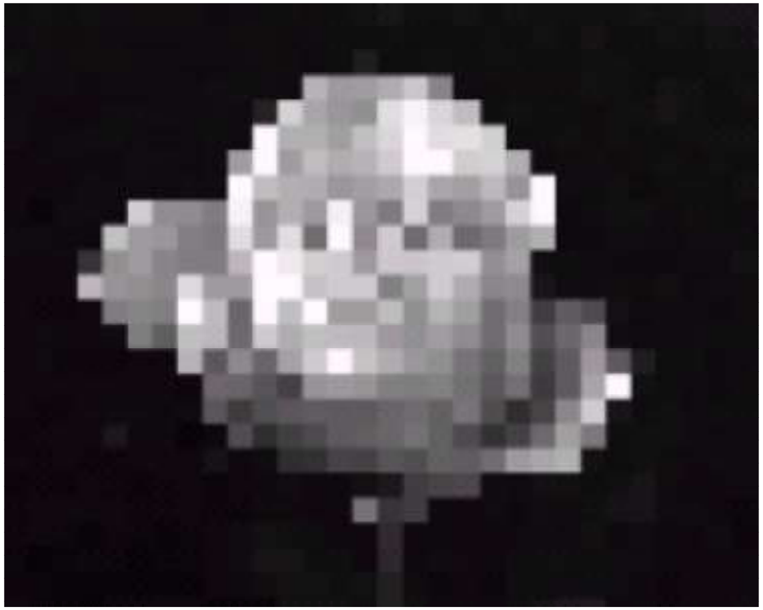
a
b c

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).

With this model, we can create GRAYVALUE images

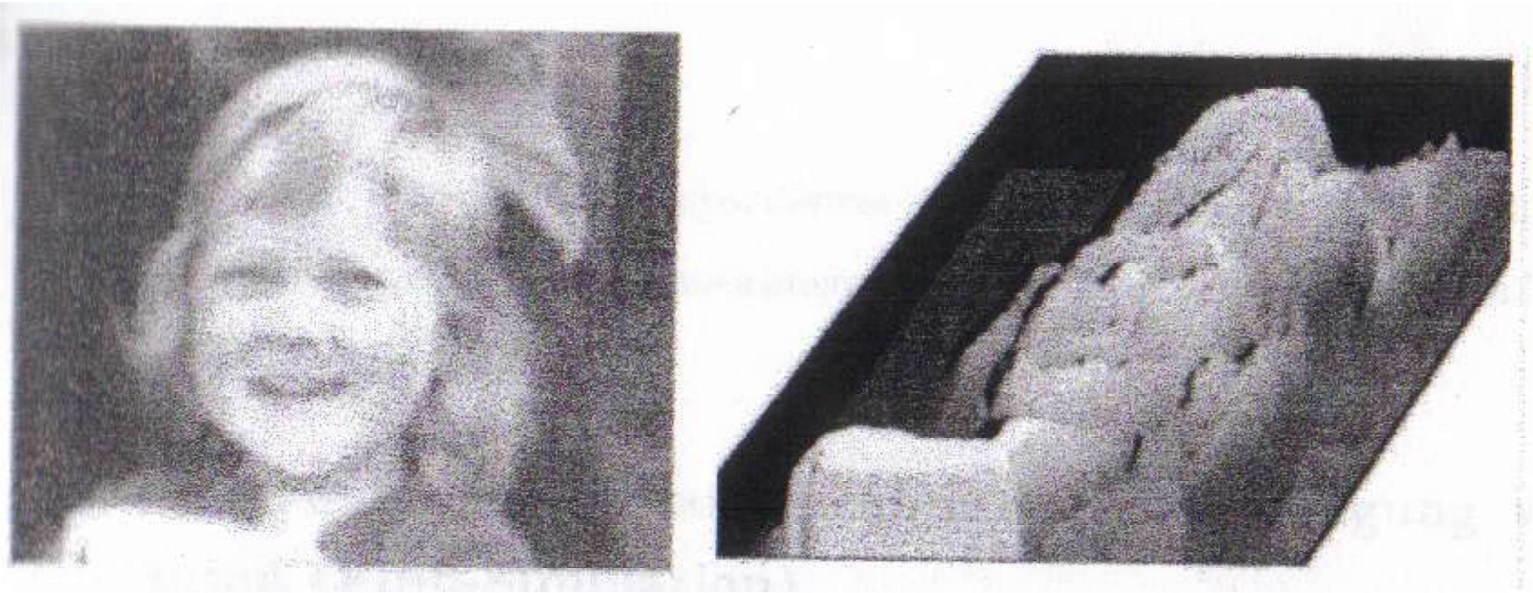
Value = 0: BLACK (no illumination / energy)

Value = 255: White (max. illumination / energy)



A 2D grayvalue - image is a 2D -> 1D function,

$$v = f(x,y)$$



As we have a function, we can apply operators to this function, e.g.

$$H(f(x,y)) = f(x,y) / 2$$

Operator

Image (= function !)

$H(f(x,y)) = f(x,y) / 2$

6	8	2	0
12	200	20	10

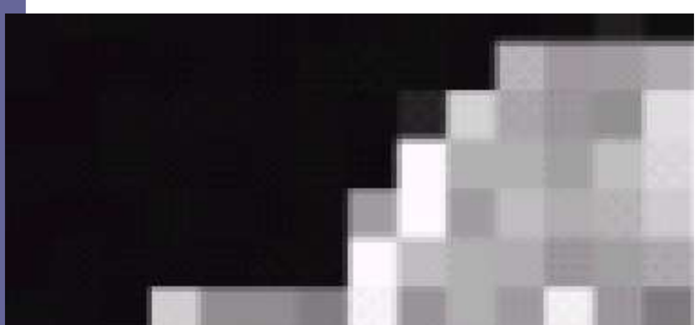
$\longrightarrow$

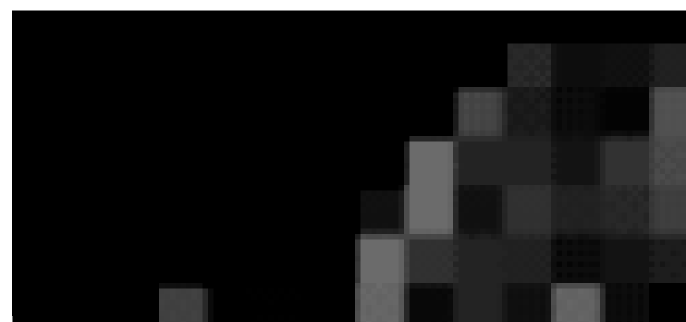
3	4	1	0
6	100	10	5

Remember: the value of the cells is the illumination (or brightness)

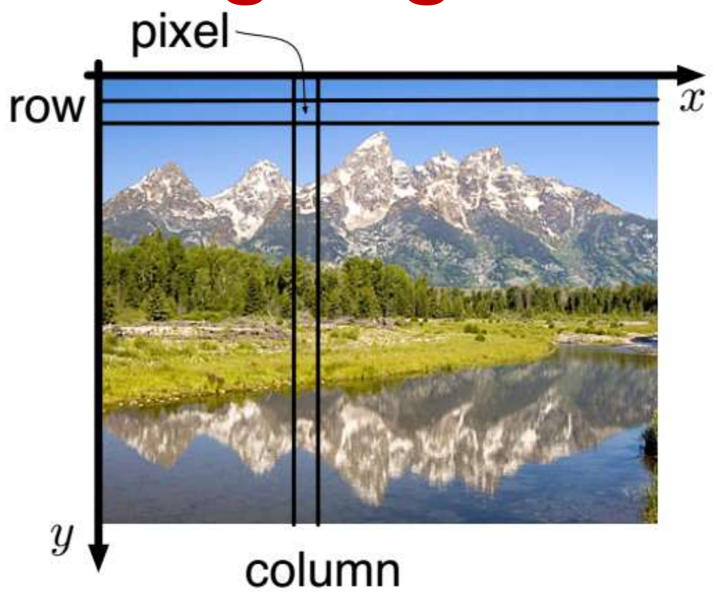
6	8	2	0
12	200	20	10

3	4	1	0
6	100	10	5





Representing Digital Images



- Two-dimensional function *f(x,y)* or matrix
- *x, y, f(x,y)* are discrete and finite
- Image size = *maxx* x *maxy* -- e.g. 640x480
- Pixel intensity value *f(x,y)* ∈ [0, 255]

Representing Digital Images

- The representation of an M×N numerical array as

$$f(x,y)=\begin{bmatrix} f(0,0) & f(0,1) & \dots & f(0,N-1) \\ f(1,0) & f(1,1) & \dots & f(1,N-1) \\ \dots & \dots & \dots & \dots \\ f(M-1,0) & f(M-1,1) & \dots & f(M-1,N-1) \end{bmatrix}$$

Representing Digital Images

- The representation of an M×N numerical array as

$$A = \begin{bmatrix} a_{0,0} & a_{0,1} & \cdots & a_{0,N-1} \\ a_{1,0} & a_{1,1} & \cdots & a_{1,N-1} \\ \cdots & \cdots & \cdots & \cdots \\ a_{M-1,0} & a_{M-1,1} & \cdots & a_{M-1,N-1} \end{bmatrix}$$

Representing Digital Images

- The representation of an M×N numerical array in MATLAB

$$f(x,y)=\begin{bmatrix} f(1,1) & f(1,2) & \cdots & f(1,N) \\ f(2,1) & f(2,2) & \cdots & f(2,N) \\ \cdots & \cdots & \cdots & \cdots \\ f(M,1) & f(M,2) & \cdots & f(M,N) \end{bmatrix}$$

Representing Digital Images

- Discrete intensity interval [0, L-1], $L=2^k$
- The number b of bits required to store a $M \times N$ digitized image

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

Representing Digital Images

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 and Intensity Resolution

- Spatial resolution
  — A measure of the smallest discernible detail in an image
  — stated with *line pairs per unit distance, dots (pixels) per unit distance, dots per inch (dpi)*

- Intensity resolution
  — The smallest discernible change in intensity level
  — stated with *8 bits, 12 bits, 16 bits, etc.*

Standard
DVD

Blue-ray
DVD

Spatial and Intensity Resolution

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.

Spatial and Intensity Resolution

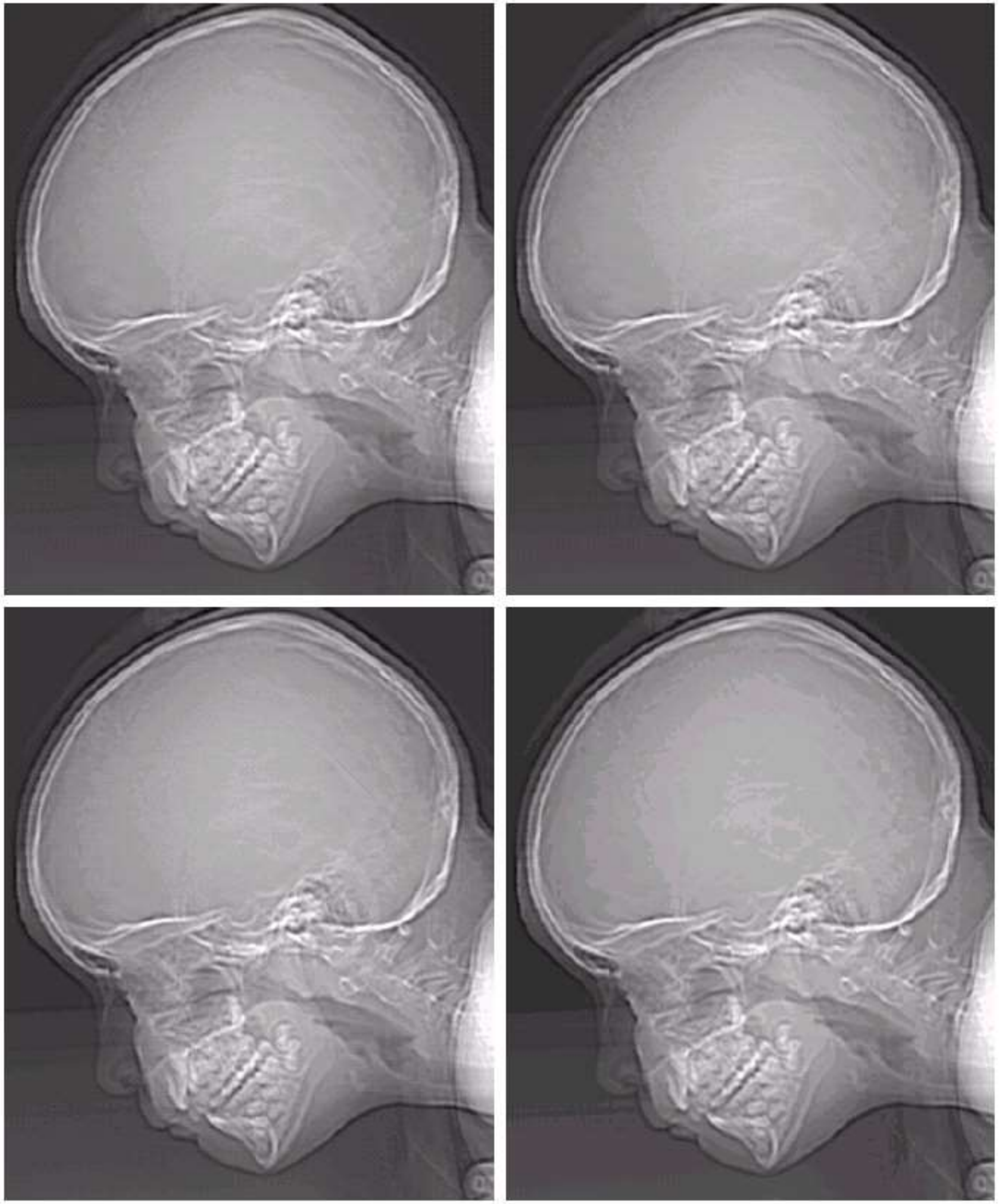


FIGURE 2.21 (a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.

Spatial and Intensity Resolution

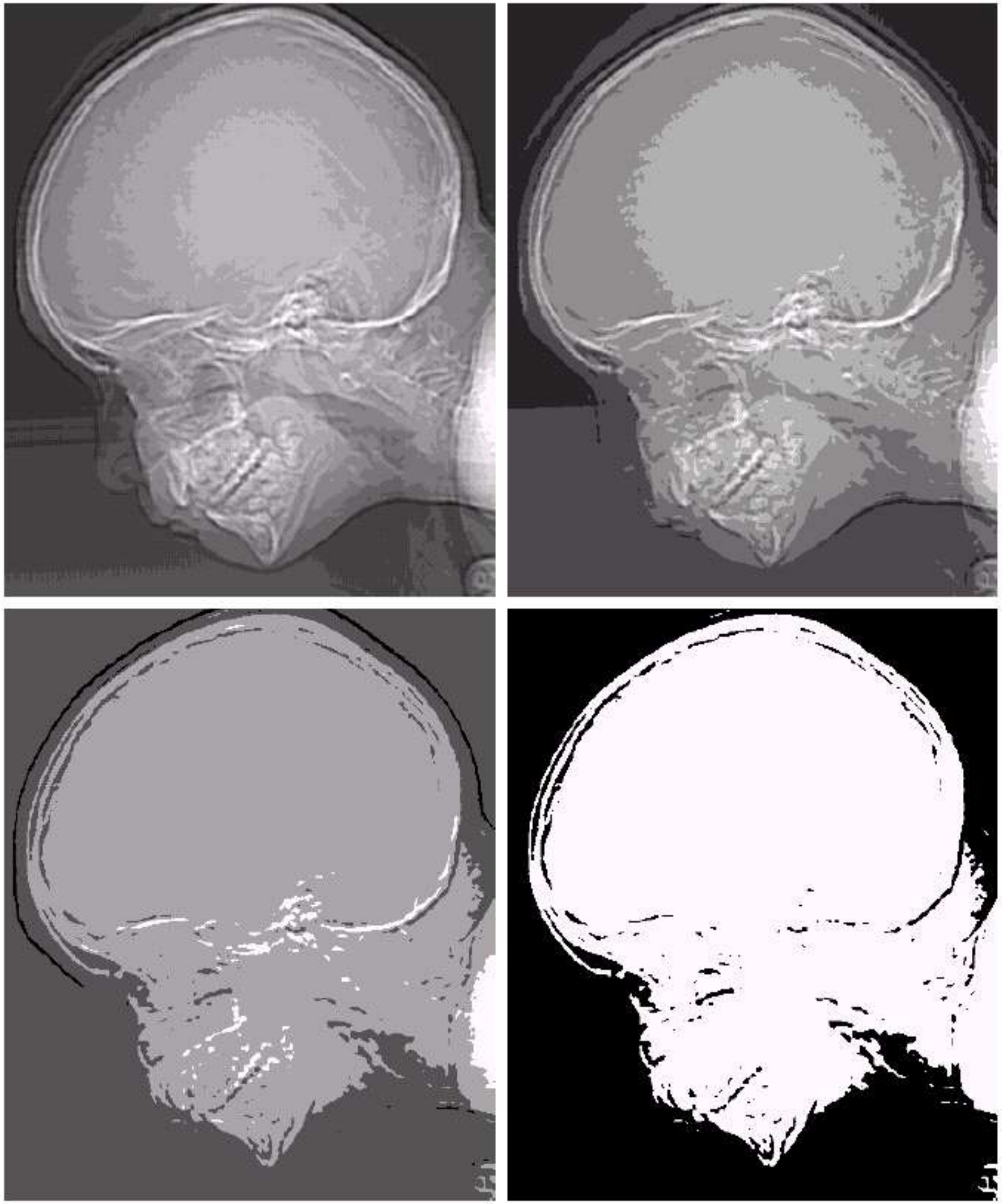


FIGURE 2.21 *(Continued)* (e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)

Homework 2

- How many bytes are required to store the following images of 512x512 dimension (size)
  - Monochrome image
  - 4-bit grayscale image
  - 8-bit grayscale image
  - 16-bit grayscale image
  - 8-bit color image
  - 24-bit color image

MATLAB Image Processing Toolbox

- **Basic MATLAB Commands**
  - img = imread('name')
  - size(img)
  - imshow(img)
  - imwrite(img, 'name')
  - im2double(img)
  - rgb2gray(img),
  - im2bw(img)
  - img1 = img(1:3:end-4,1:4:end-2)
  - zeros(m,n), ones(m,n)
  - rand(m,n), randn(m,n)
  - min(min(I1)), max(max(I2))

MATLAB Image Processing Toolbox

- **Basic MATLAB Commands**

```
figure;
subplot(2,2,1);
 imshow(I1);
 title('Fig. 1 caption');
subplot(2,2,2);
 imshow(I2);
 title('Fig. 2 caption');
subplot(2,2,3);
 imshow(I3);
title('Fig. 3 caption');
Scaled = uint8( 255.0 * ( I1 - min(min(I1)) ) ...
   /(max(max(I1))-min(min(I1))));
subplot(2,2,4);
imshow(Scaled);
title('Fig. 4 caption');
```