Digital Image Processing:

EYE PHYSIOLOGY

- A conceptual technique for the establishment of a model of the human visual system would be to perform a physiological analysis of the eye, the nerve paths to the brain, and those parts of the brain involved in visual perception.

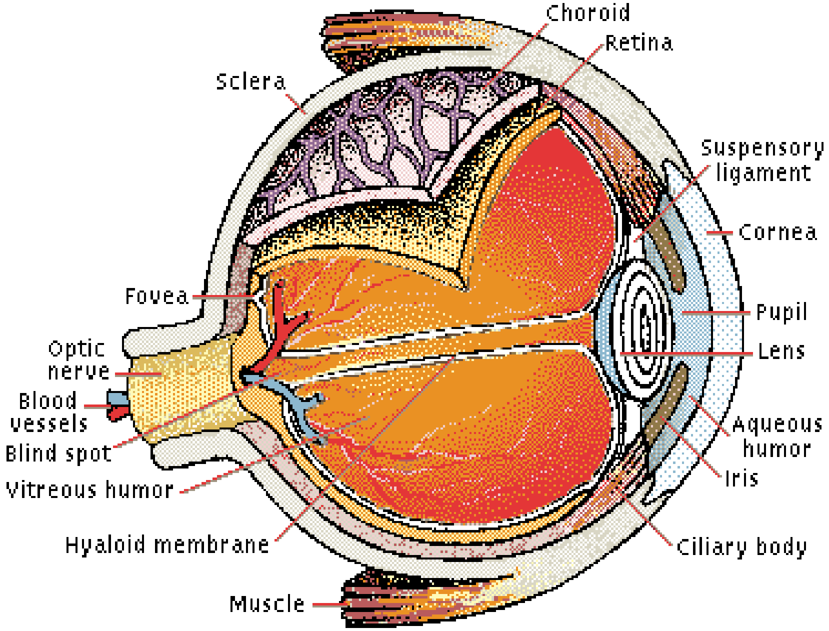


FIGURE 1: Eye cross section.

EYE PHYSIOLOGY

Figure 1 shows the horizontal cross section of a human eyeball. The front of the eye is covered by a transparent surface called the *cornea*. The remaining outer cover, called the *sclera*, is composed of a fibrous coat that surrounds the *choroid*, a layer containing blood capillaries. Inside the choroid is the *retina*, which is composed of two types of receptors: *rods* and *cones*. Nerves connecting to the retina leave the eyeball through the *optic nerve bundle*. Light entering the cornea is focused on the retina surface by a *lens* that changes shape under muscular control to perform proper focusing of near and distant objects. An *iris* acts as a diaphram to control the amount of light entering the eye.

EYE PHYSIOLOGY

- An eye contains about 6.5 million cones and 100 million rods distributed over the retina Figure 2 shows the distribution of rods and cones over a horizontal line on the retina. At a point near the optic nerve called the *fovea*, the density of cones is greatest.

This is the region of sharpest photopic vision. There are no rods or cones in the vicinity of the optic nerve, and hence the eye has a blind spot in this region.

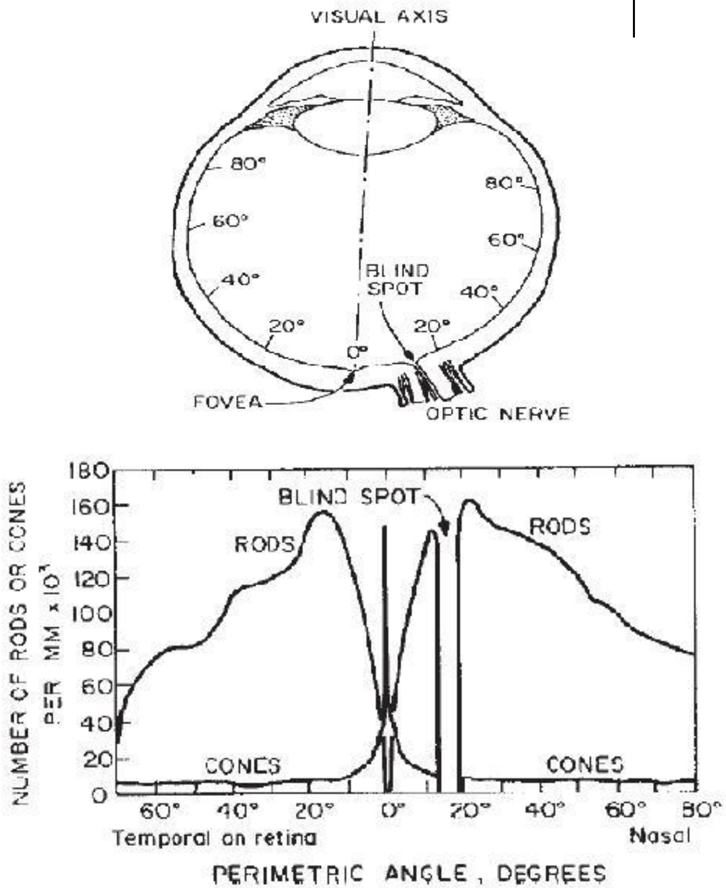


FIGURE 2. Distribution of rods and cones on the retina

Visual Perception: Human Eye

1. The ***lens*** contains 60-70% water, 6% of fat.

2. The ***iris*** diaphragm controls amount of light that enters the eye.
3. ***Light receptors*** in the ***retina***
   - About 6-7 millions ***cones*** for bright light vision called ***photopic***
     - Density of cones is about 150,000 elements/mm^2.
     - Cones involve in color vision.
     - Cones are concentrated in ***fovea*** about 1.5x1.5 mm^2.
   - About 75-150 millions ***rods*** for dim light vision called ***scotopic***
     - Rods are sensitive to low level of light and are not involved color vision.

4. ***Blind spot*** is the region of emergence of the optic nerve from the eye.

VISUAL PHENOMENA

The response of the eye to changes in the intensity of illumination is known to be nonlinear. Consider a patch of light of intensity surrounded by a background of intensity *I.* The just noticeable difference is to be determined as a function of *I*. Over a wide range of intensities, it is found that the ratio , called the *Weber fraction*, is nearly constant at a value of about 0.02.

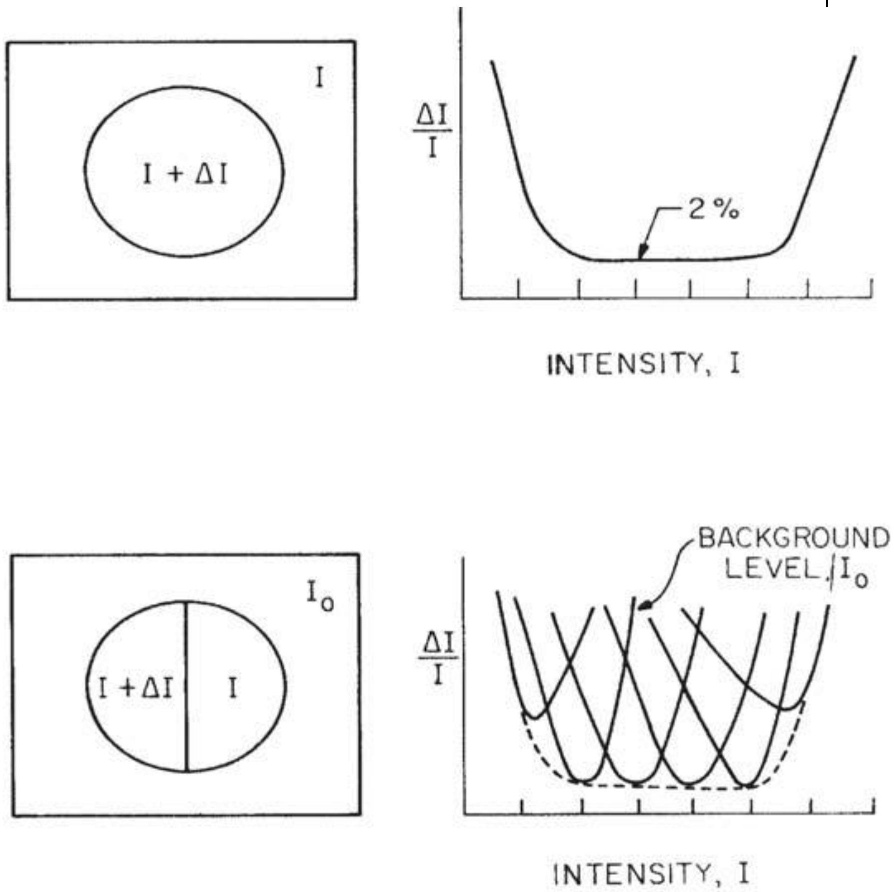


FIGURE: Contrast sensitivity measurements.

Modulation transfer function (MTF)

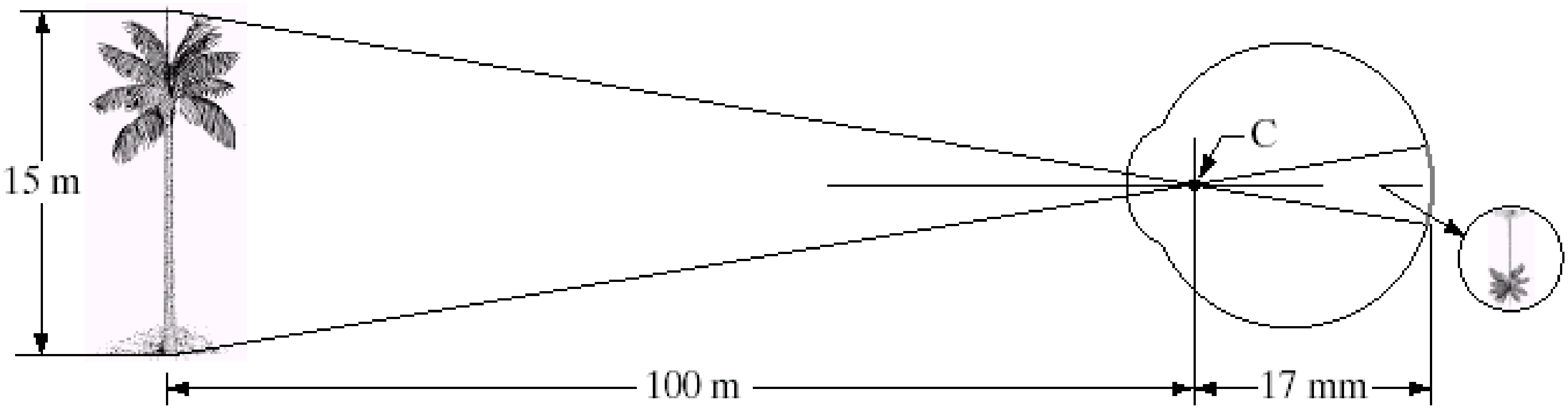
- The ratio of the magnitudes of the Fourier transforms of the input and output signals

$$\frac{|\mathcal{I}_O(\omega_x, \omega_y)|}{|\mathcal{I}_I(\omega_x, \omega_y)|} = |\mathcal{H}(\omega_x, \omega_y)|$$

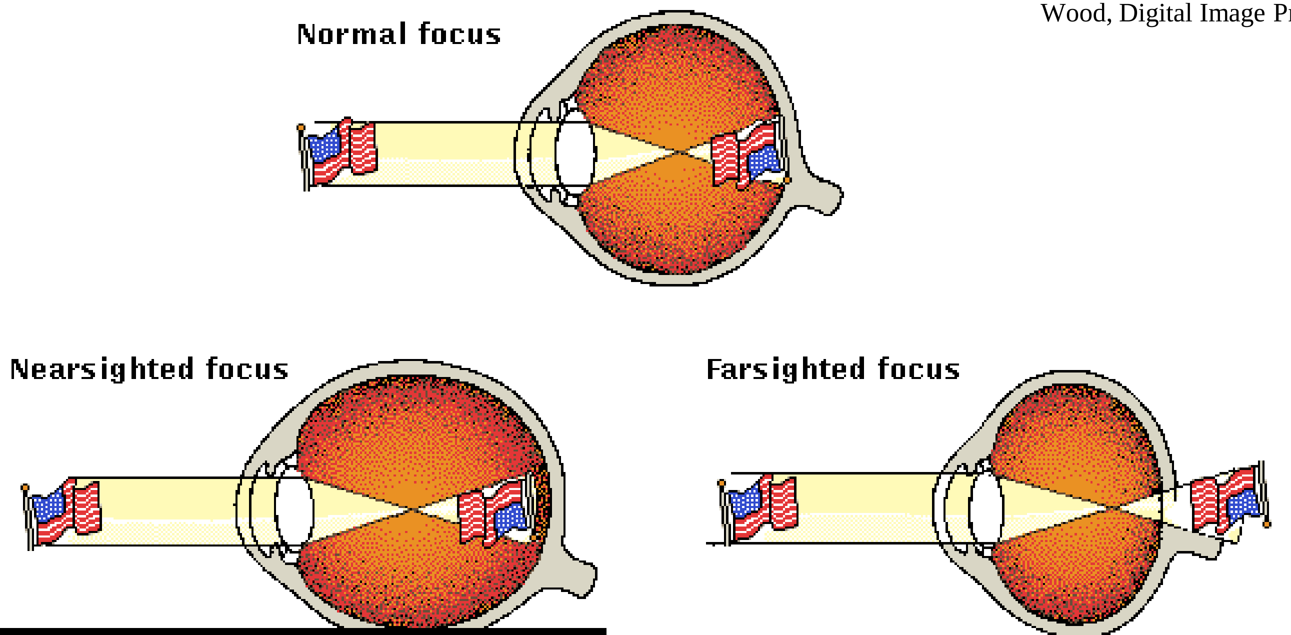
is called the *modulation transfer function* (MTF) of the optical system.

FIGURE: MTF measurements of the human visual system by modulated sine-wave grating.

Image Formation in the Human Eye

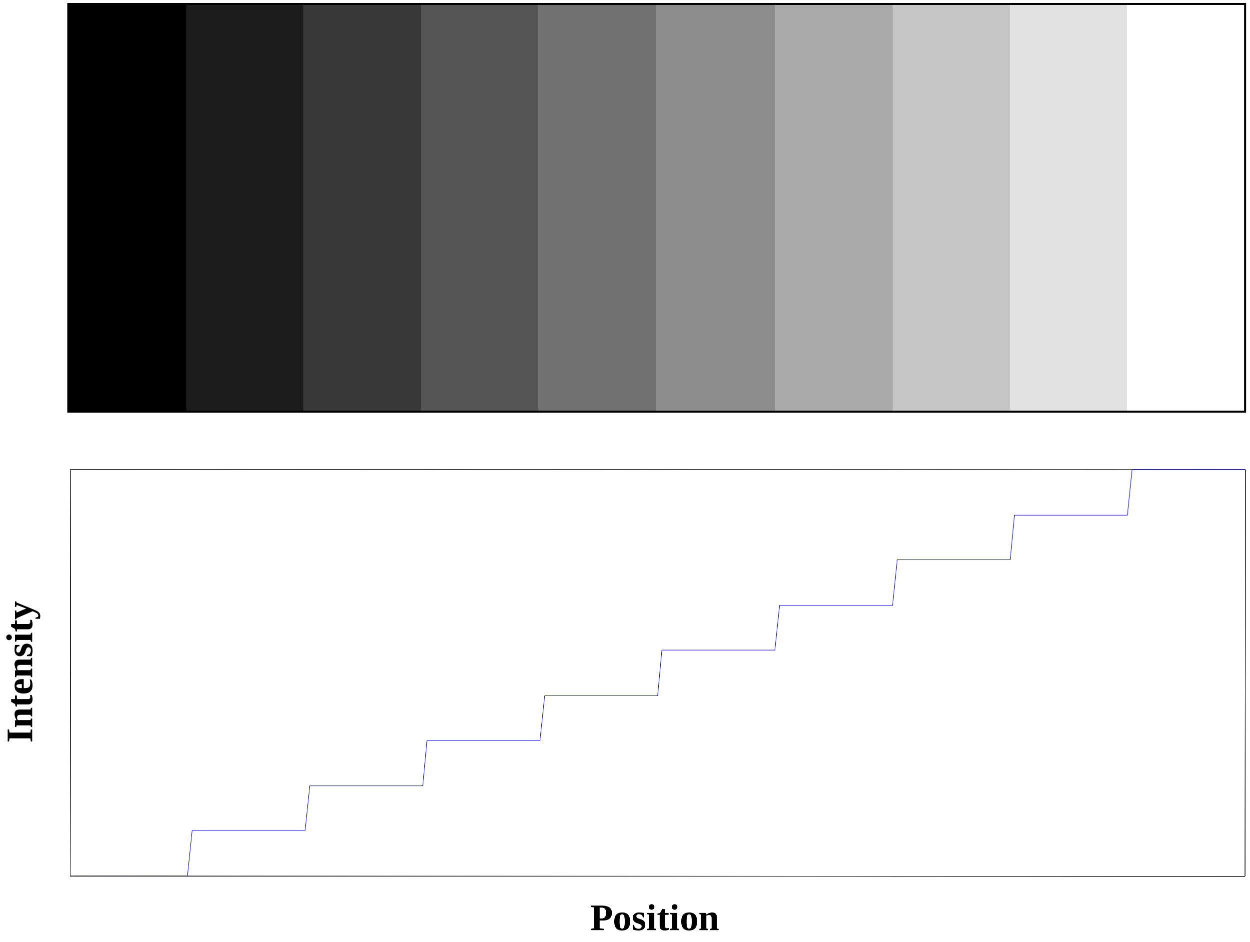


(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.



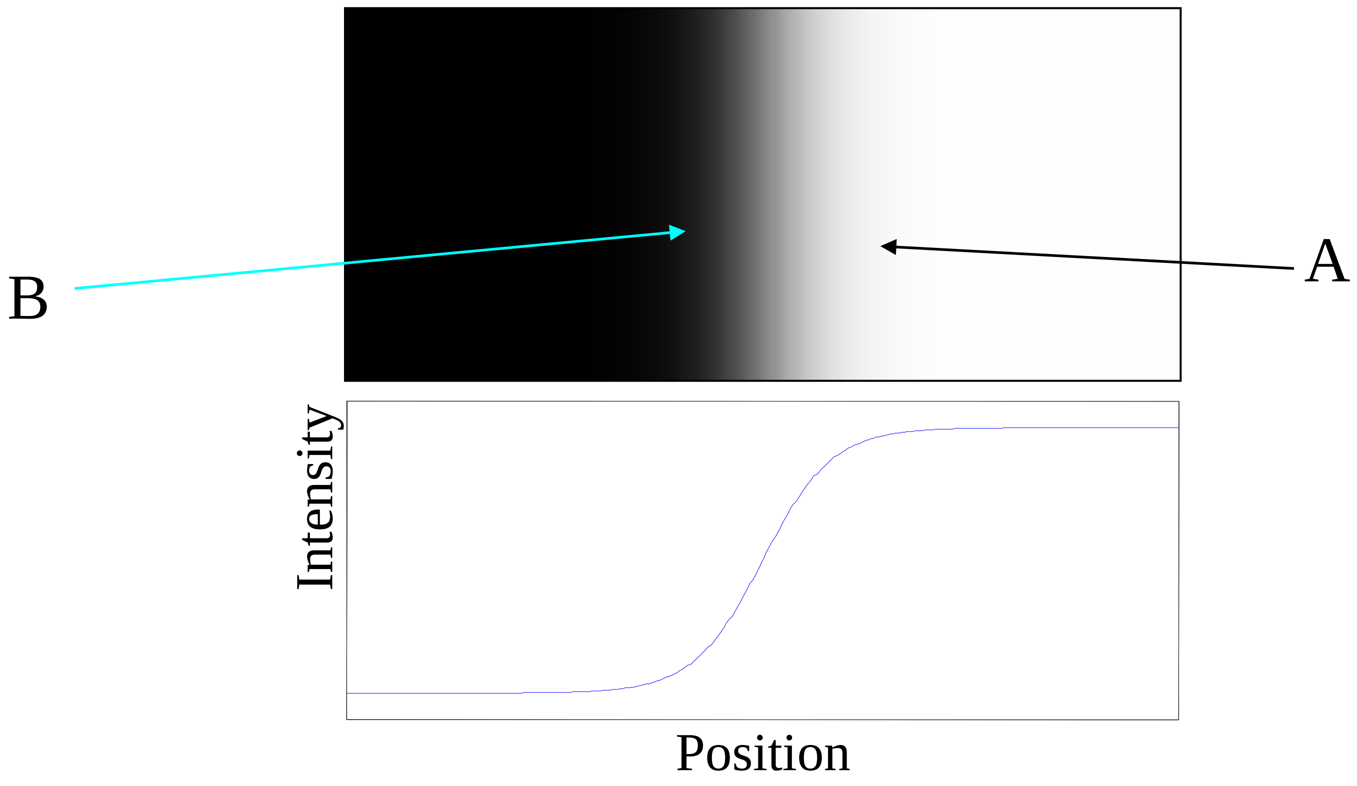
(Picture from Microsoft Encarta 2000)

Brightness Adaptation of Human Eye : Mach Band Effect



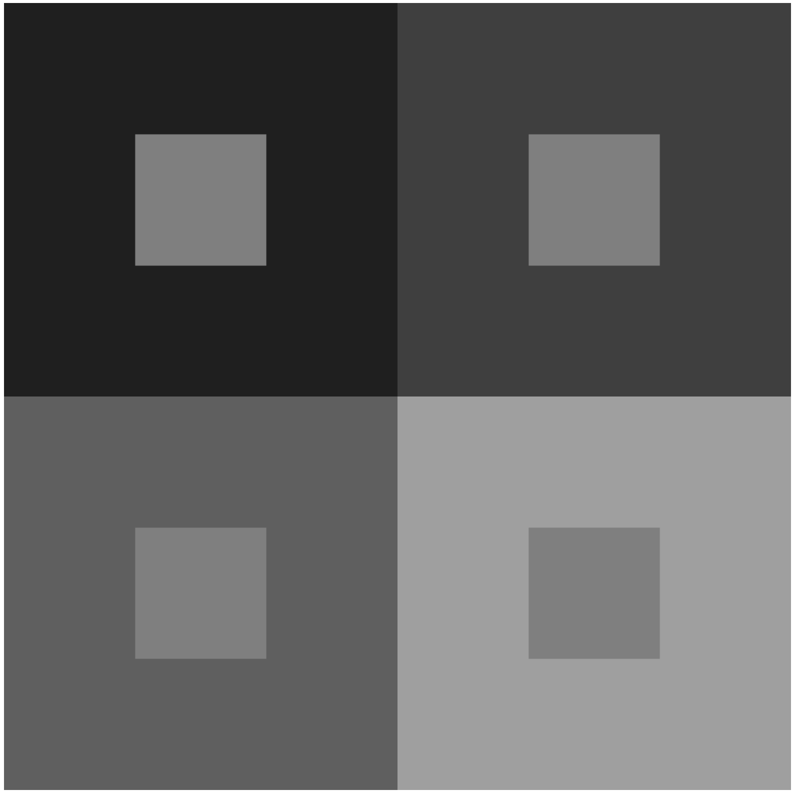
For middle steps human eyes can separate better than lower or higher steps

Mach Band Effect (Cont)



In area A, brightness perceived is darker while in area B is brighter. This phenomenon is called ***Mach Band Effect***.

Brightness Adaptation of Human Eye : Simultaneous Contrast



Simultaneous contrast. All small squares have exactly the same intensity but they appear progressively darker as background becomes lighter.

Simultaneous Contrast

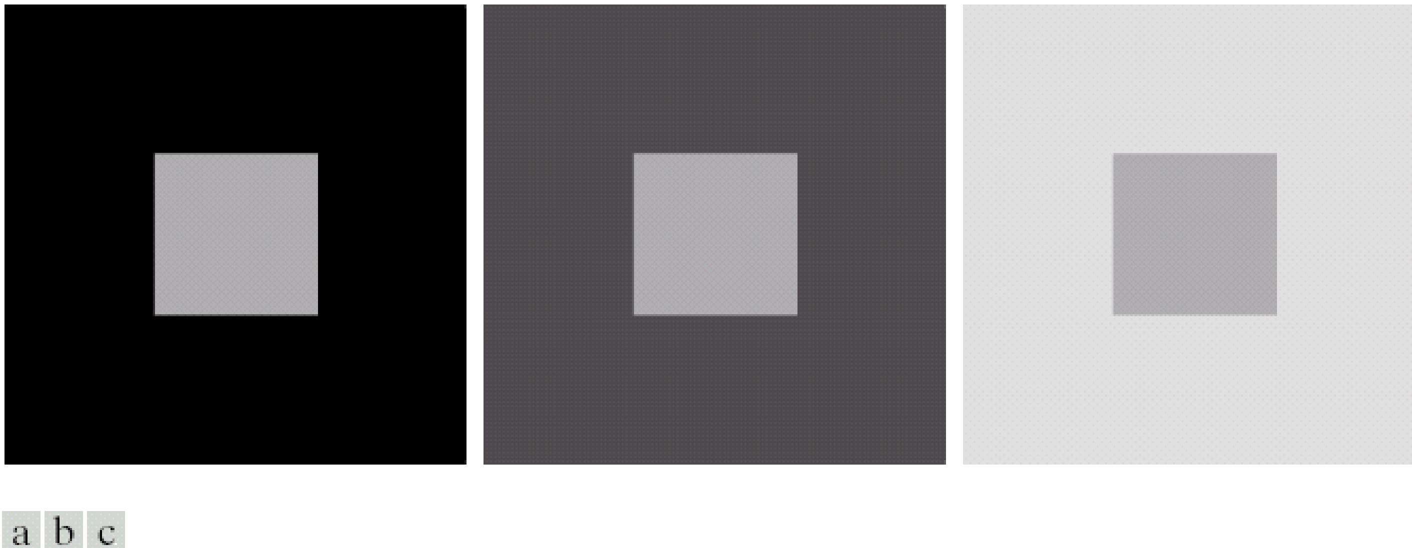


FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Visible Spectrum

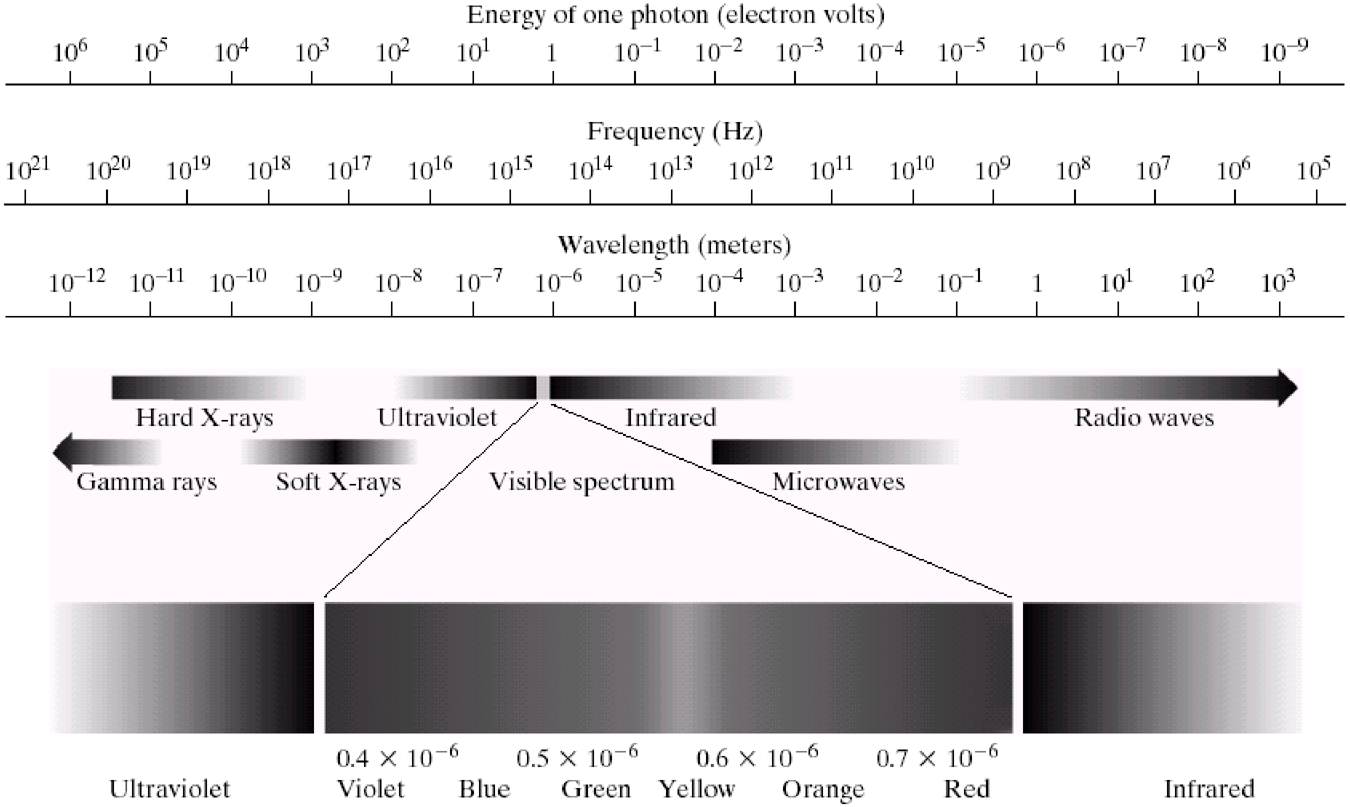
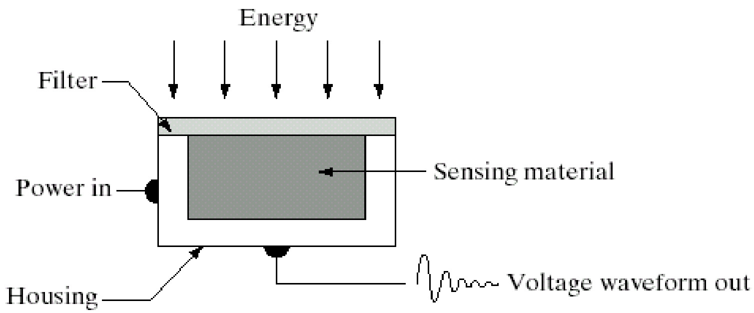


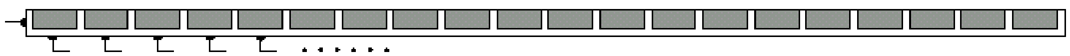
FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

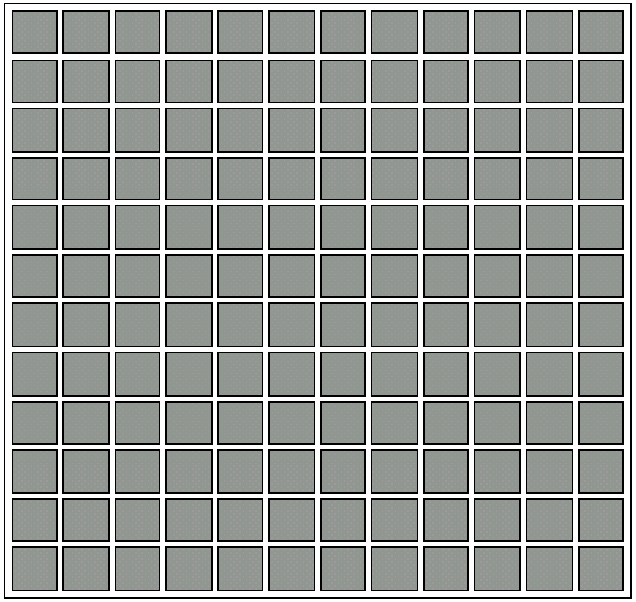
Image Sensors



Single sensor



Line sensor



Array sensor

Image sensor typically use in digital camera

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Fundamentals of Digital Images

- **An image**: **a multidimensional function of spatial coordinates**.
- **Spatial coordinate**: (x,y) for 2D case such as photograph,
  (x,y,z) for 3D case such as CT scan images
  (x,y,t) for movies
- The function f may represent intensity (for monochrome images) or color (for color images) or other associated values.

Digital Images

Digital image: an image that has been discretized both in Spatial coordinates and associated value.

- Consist of 2 sets:(1) a point set and (2) a value set

- Can be represented in the form

  $I = \{(x,a(x)): x \in X, a(x) \in F\}$

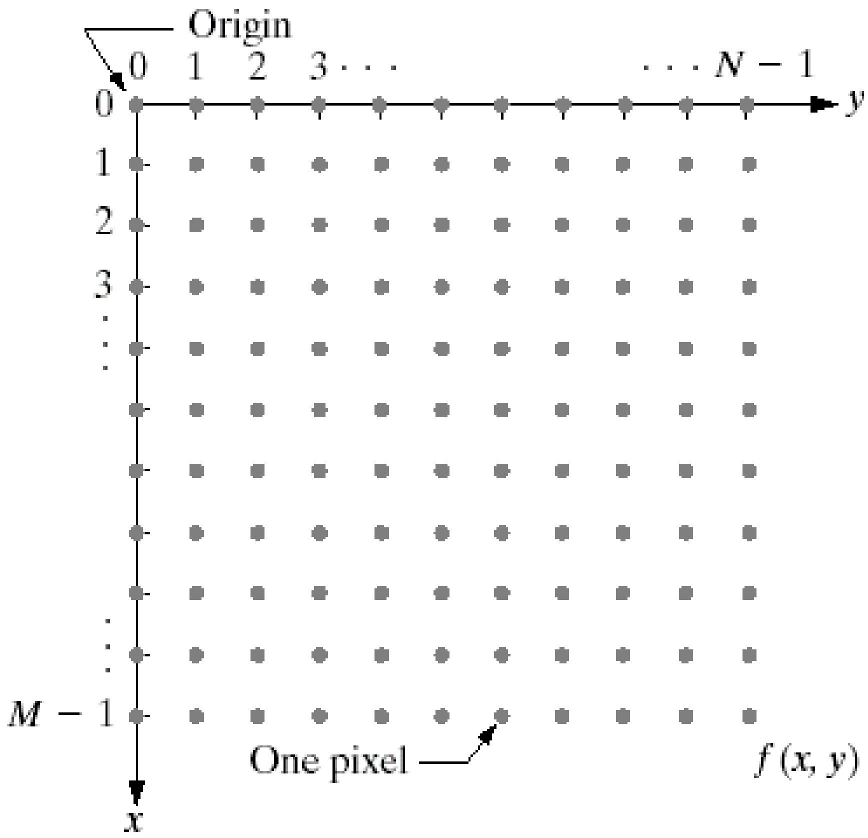
  where X and F are a point set and value set, respectively.

- An element of the image, $(x,a(x))$ is called a ***pixel*** where

  - x is called the pixel location and

  - $a(x)$ is the pixel value at the location x

Conventional Coordinate for Image Representation

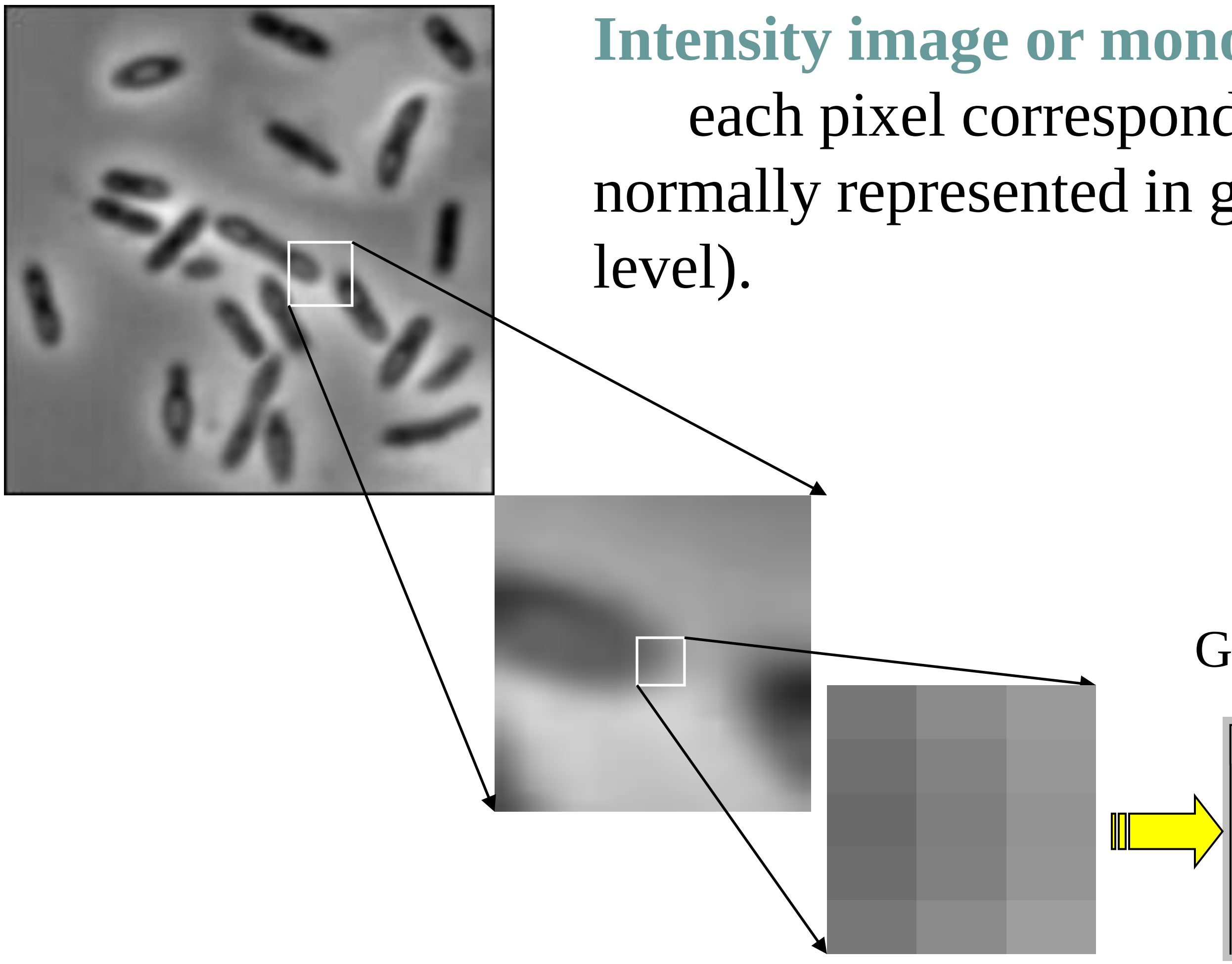


(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Digital Image Types : Intensity Image

Intensity image or monochrome image

each pixel corresponds to light intensity normally represented in gray scale (gray level).



Gray scale values

10	10	16	28
9	6	26	37
15	25	13	22
32	15	87	39

Digital Image Types : RGB Image

Color image or RGB image: each pixel contains a vector representing red, green and blue components.

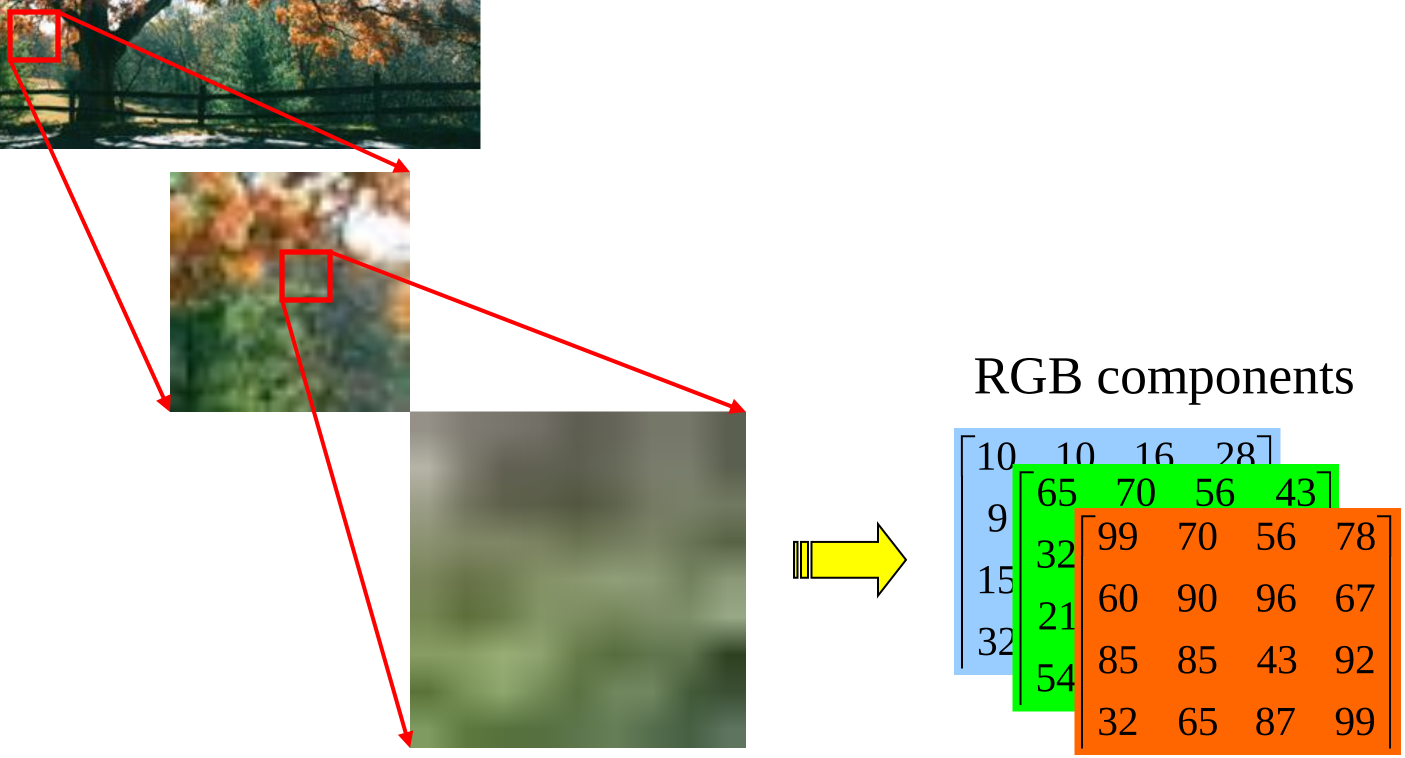


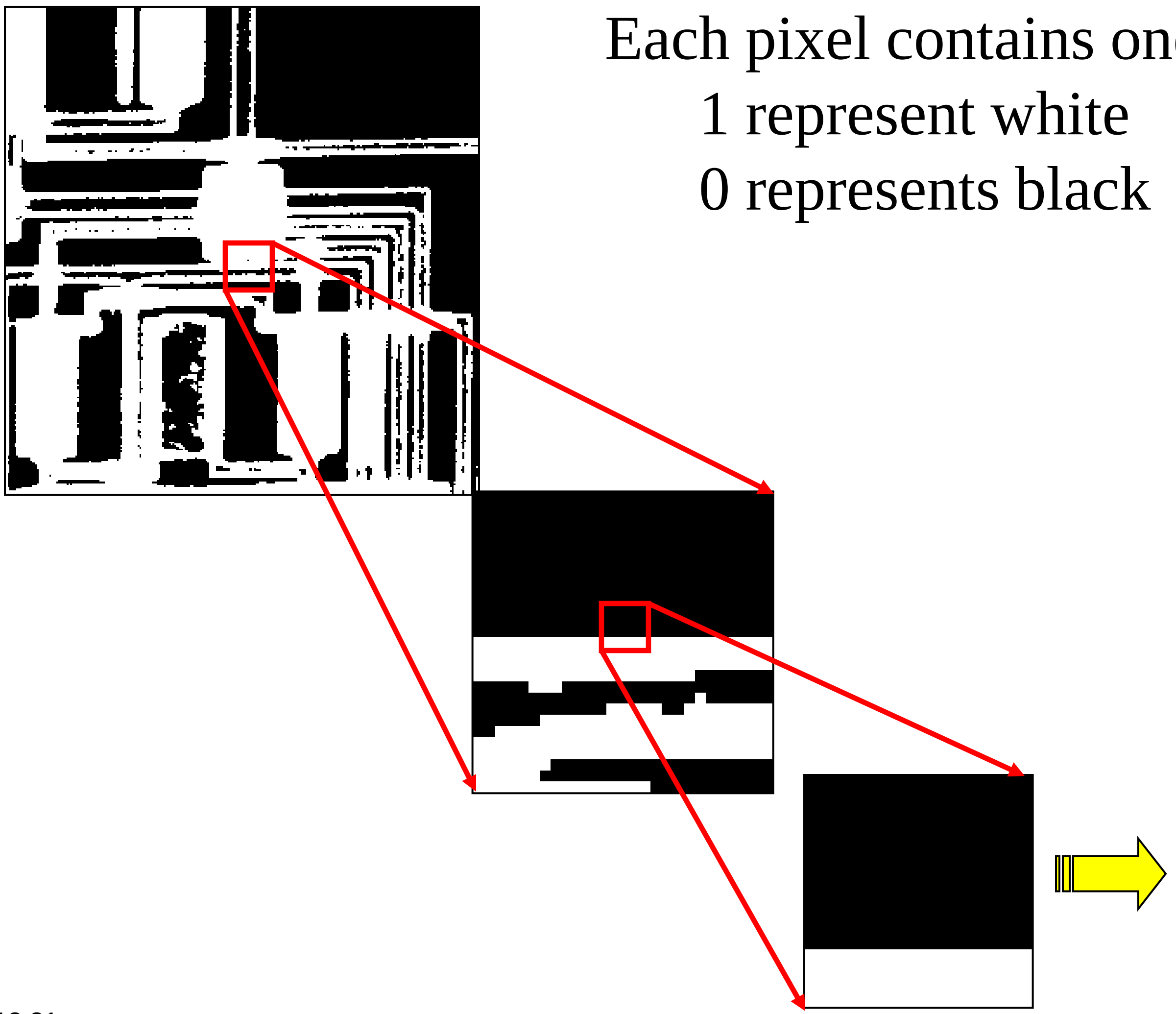
Image Types : Binary Image

Binary image or black and white image

Each pixel contains one bit :

1 represent white

0 represents black



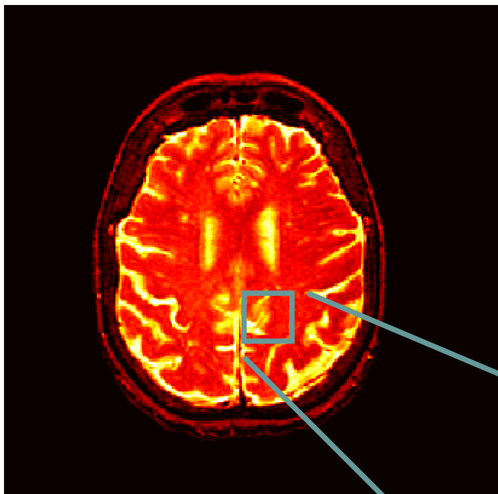
Binary data

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

Image Types : Index Image

Index image

Each pixel contains index number pointing to a color in a color table



$$\begin{bmatrix} 1 & 4 & 9 \\ 6 & 4 & 7 \\ 6 & 5 & 2 \end{bmatrix}$$

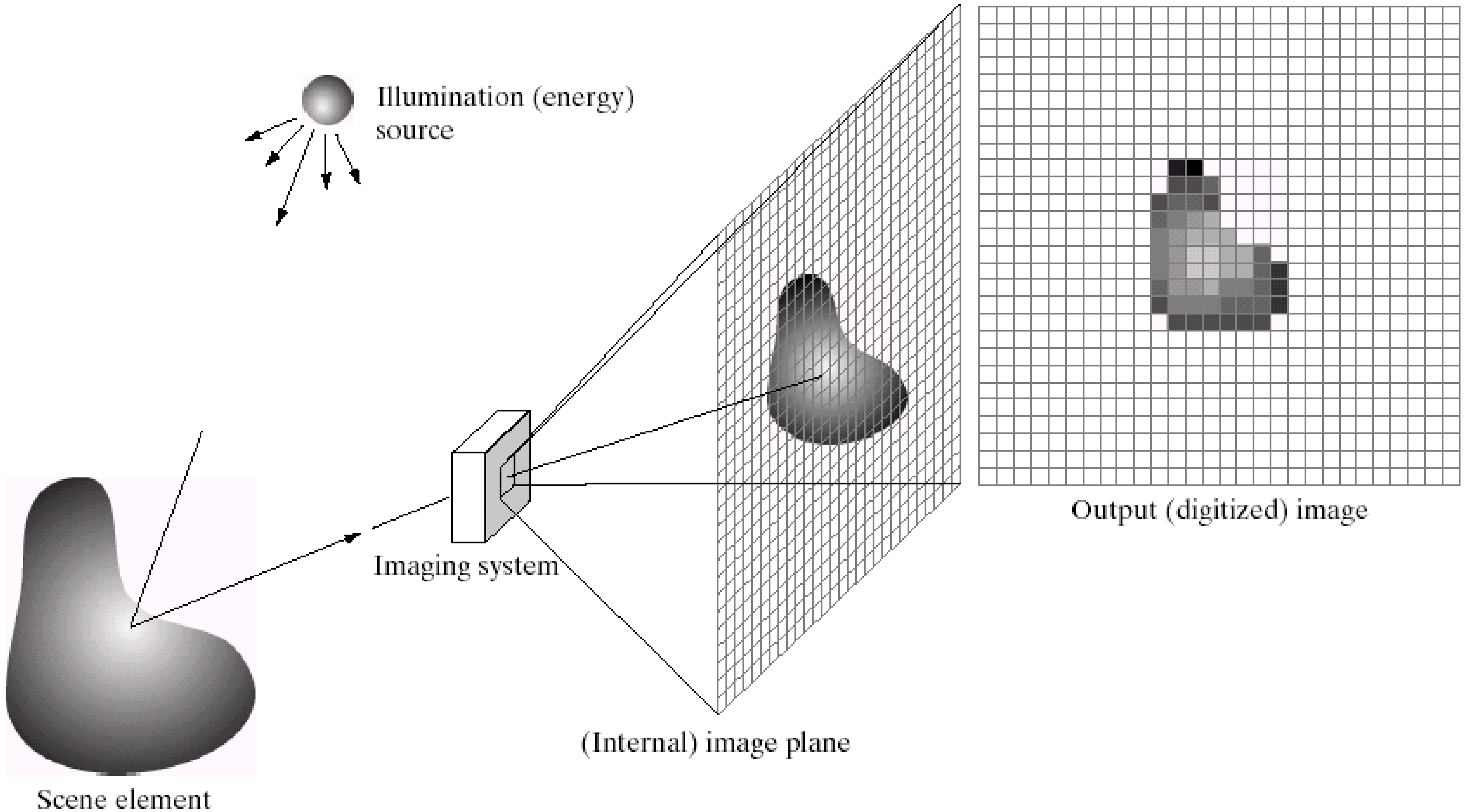
Index value

Color Table

Index No.	Red component	Green component	Blue component
1	0.1	0.5	0.3
2	1.0	0.0	0.0
3	0.0	1.0	0.0
4	0.5	0.5	0.5
5	0.2	0.8	0.9
…	…	…	…

This type image use in CT scan

Digital Image Acquisition Process



(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Generating a Digital Image

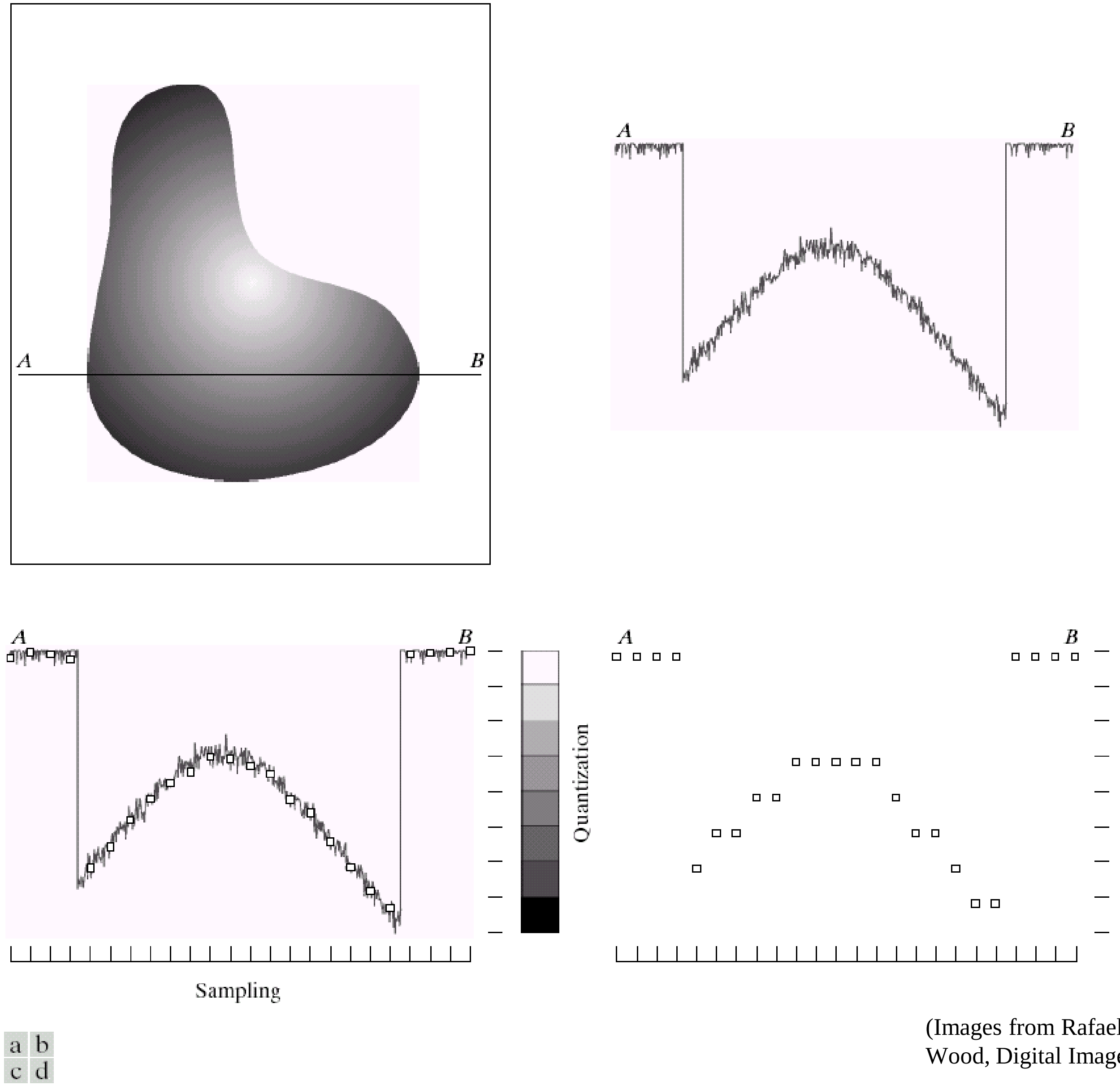
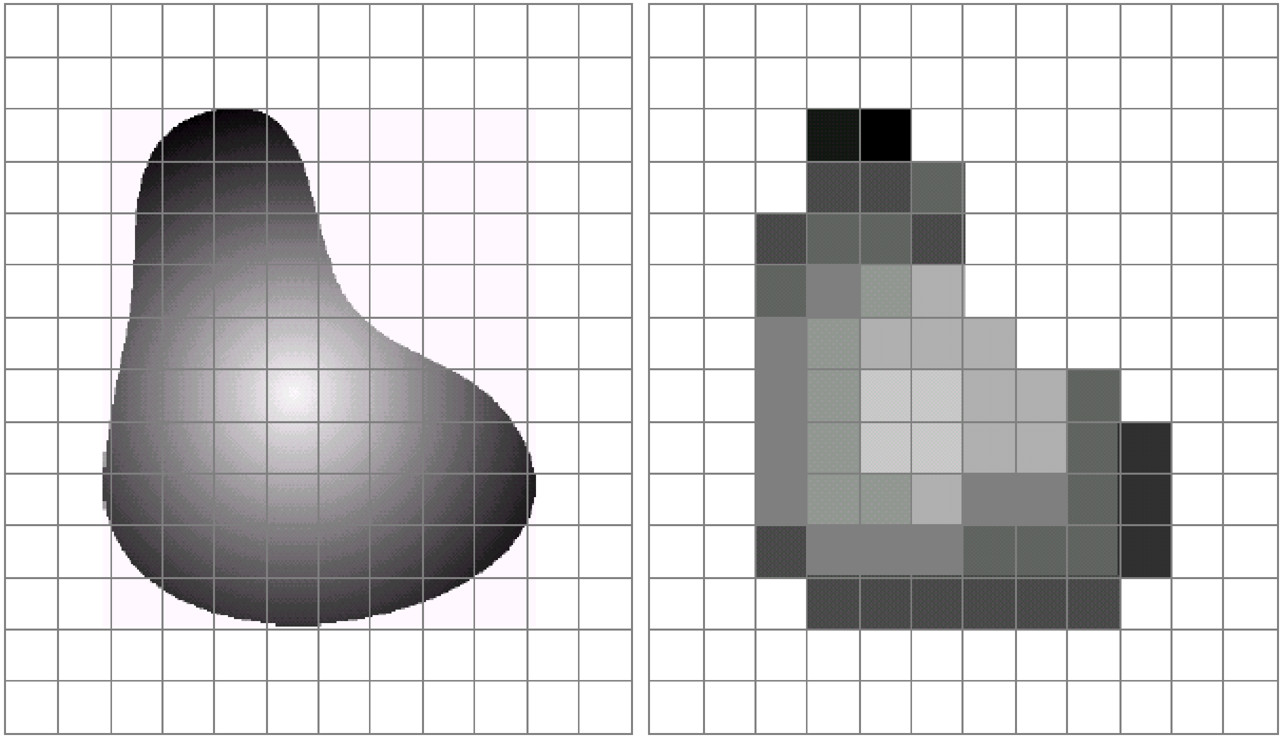


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Image Sampling and Quantization



a b

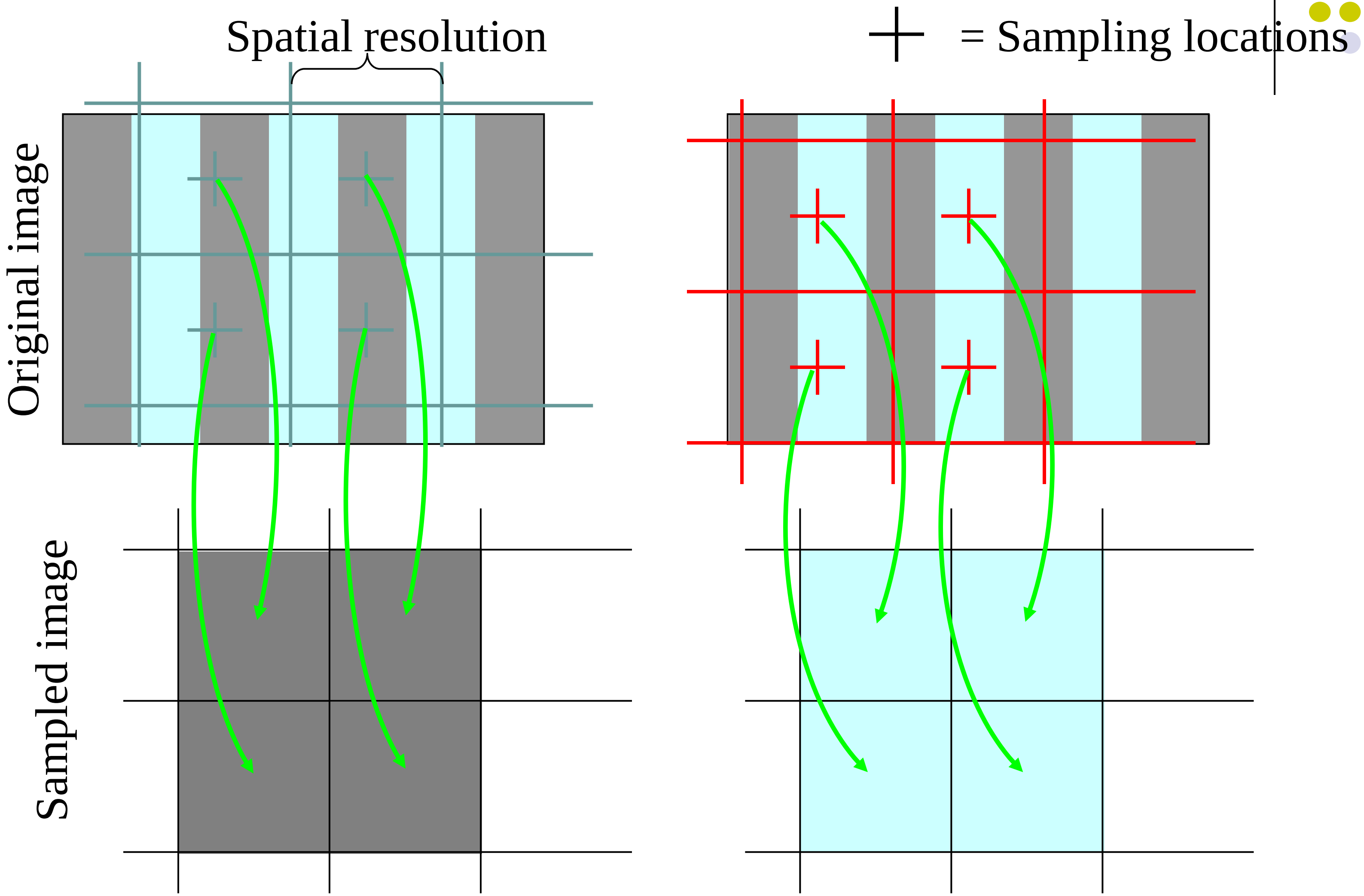
FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

Image sampling: discretize an image in the spatial domain

Spatial resolution / image resolution: pixel size or number of pixels

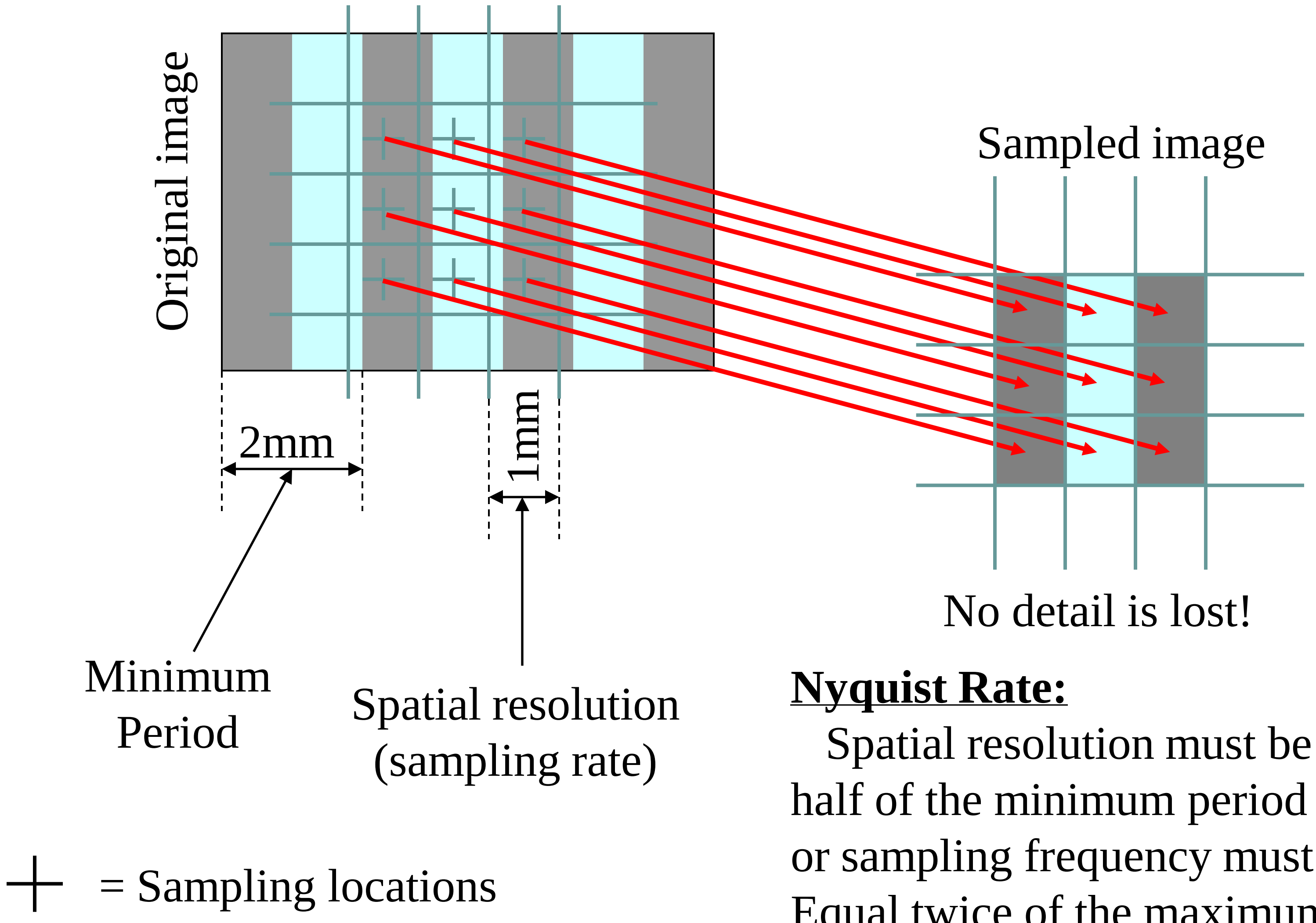
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

How to choose the spatial resolution



Under sampling, we lost some image details!

How to choose the spatial resolution : Nyquist Rate



Nyquist Rate:

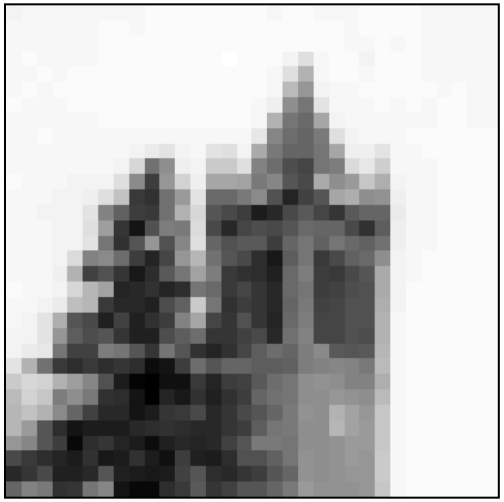
Spatial resolution must be less or equal half of the minimum period of the image or sampling frequency must be greater or Equal twice of the maximum frequency.

Effect of Spatial Resolution

256x256 pixels

128x128 pixels

64x64 pixels



32x32 pixels

Effect of Spatial Resolution

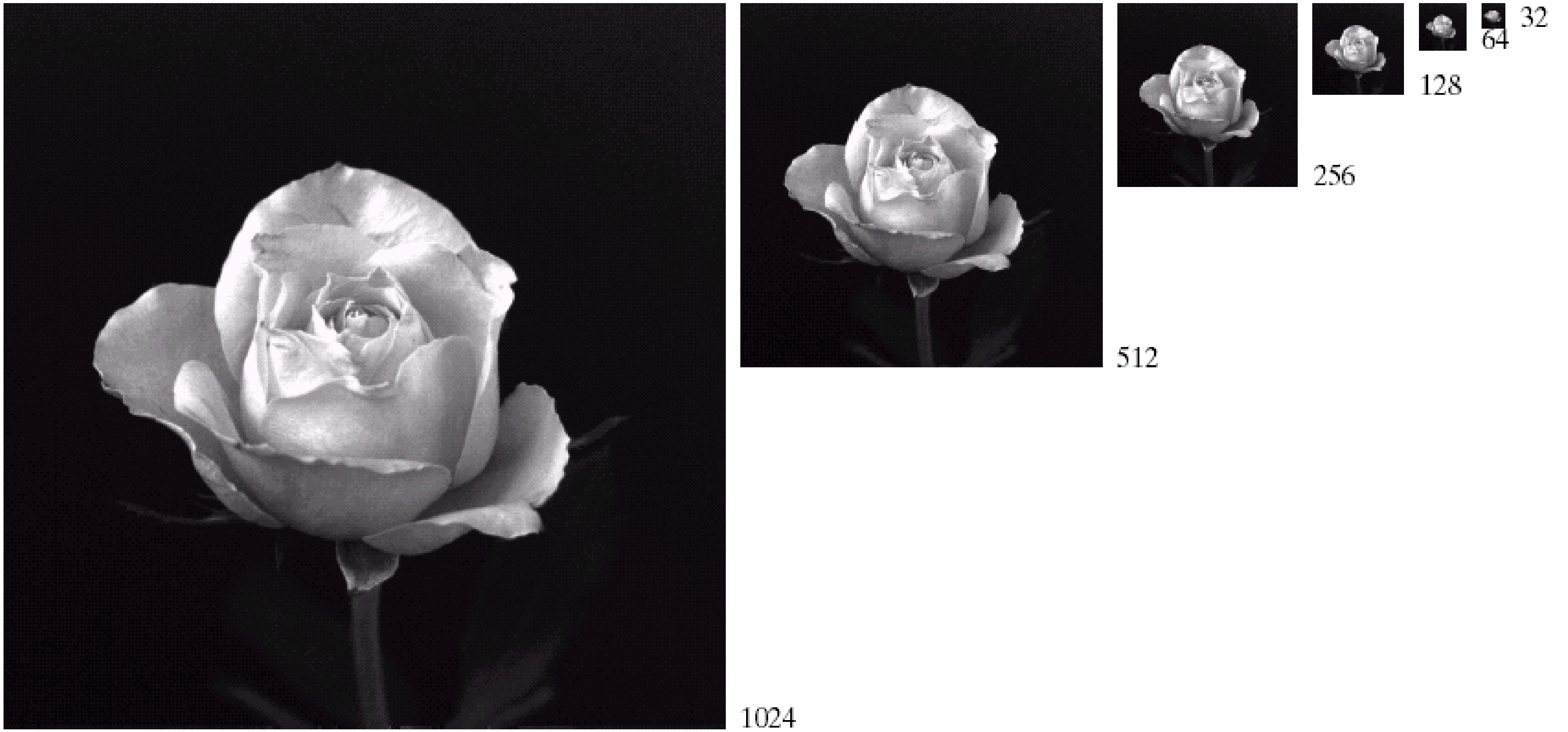
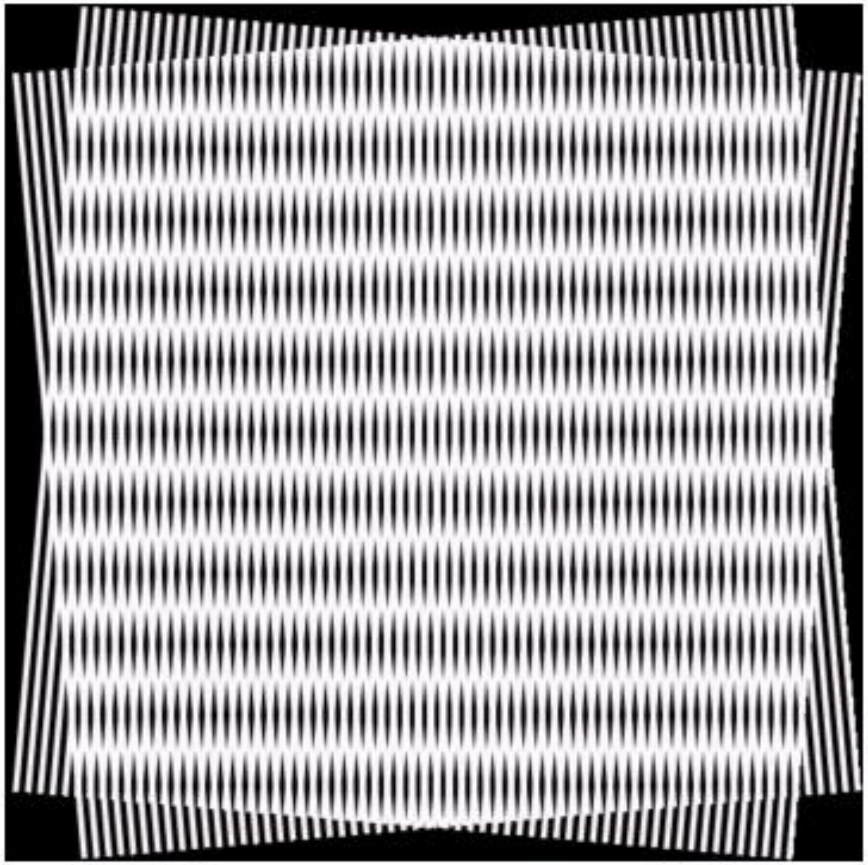


FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

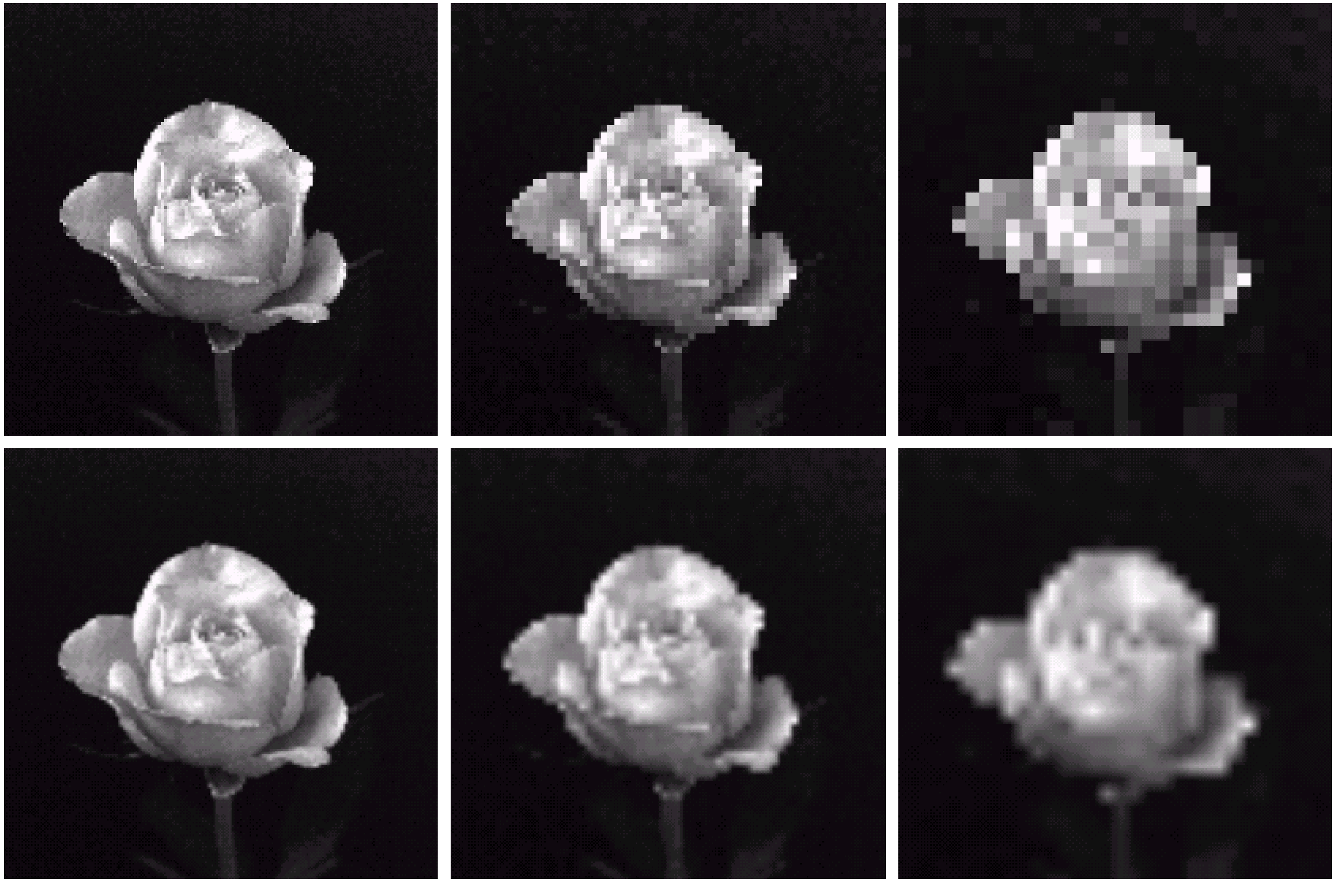
Moire Pattern Effect : Special Case of Sampling



Moire patterns occur when frequencies of two superimposed periodic patterns are close to each other.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Can we increase spatial resolution by interpolation ?



a b c
d e f

FIGURE 2.25 Top row: images zoomed from 128 × 128, 64 × 64, and 32 × 32 pixels to 1024 × 1024 pixels, using nearest neighbor gray-level interpolation. Bottom row: same sequence, but using bilinear interpolation.

Down sampling is an irreversible process.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Effect of Spatial Resolution

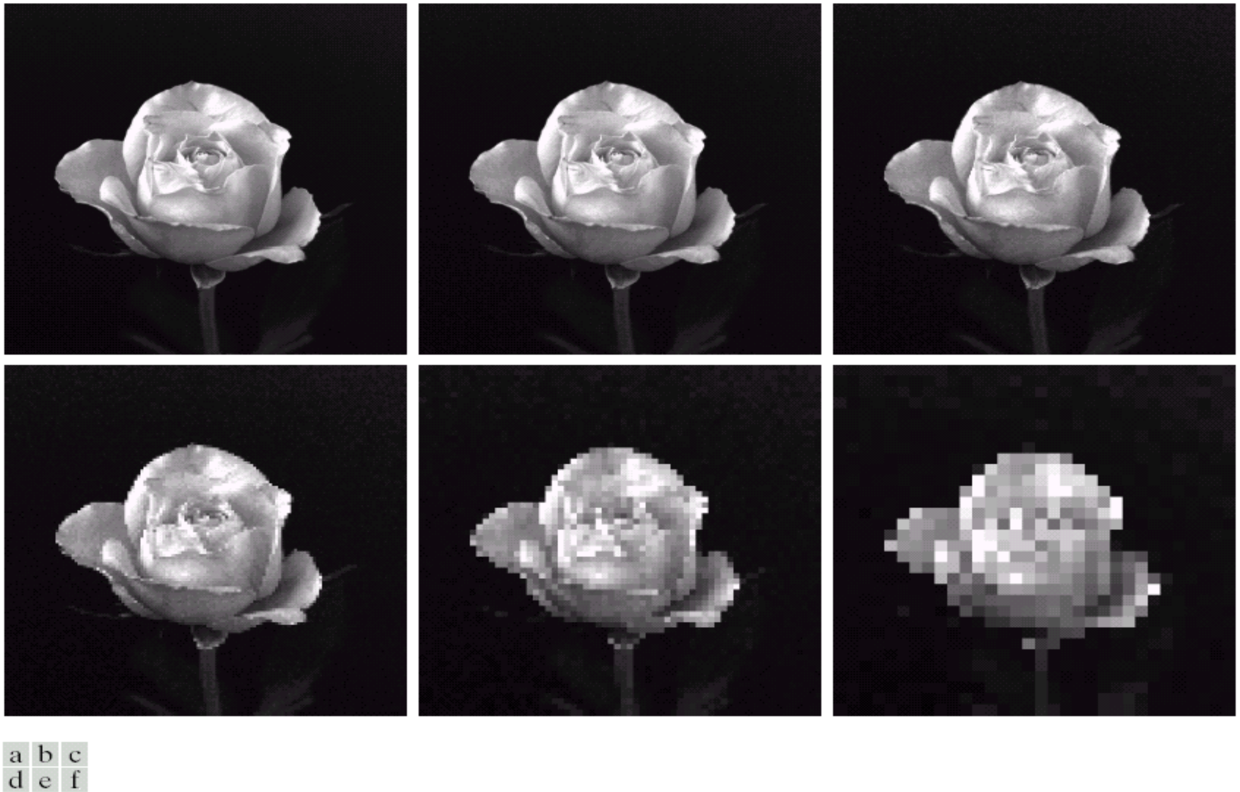


FIGURE 2.20 (a) 1024 × 1024, 8-bit image. (b) 512 × 512 image resampled into 1024 × 1024 pixels by row and column duplication. (c) through (f) 256 × 256, 128 × 128, 64 × 64, and 32 × 32 images resampled into 1024 × 1024 pixels.

Figure 2.20(a) shows a 1024x1024, 256-level digital image of a rose. Figures 2.9(b)-(f) show the results of reducing the spatial resolution form N=1024 to N=512,256,128,64 and 32, respectively.

Image Quantization

Image quantization:

discretize continuous pixel values into discrete numbers

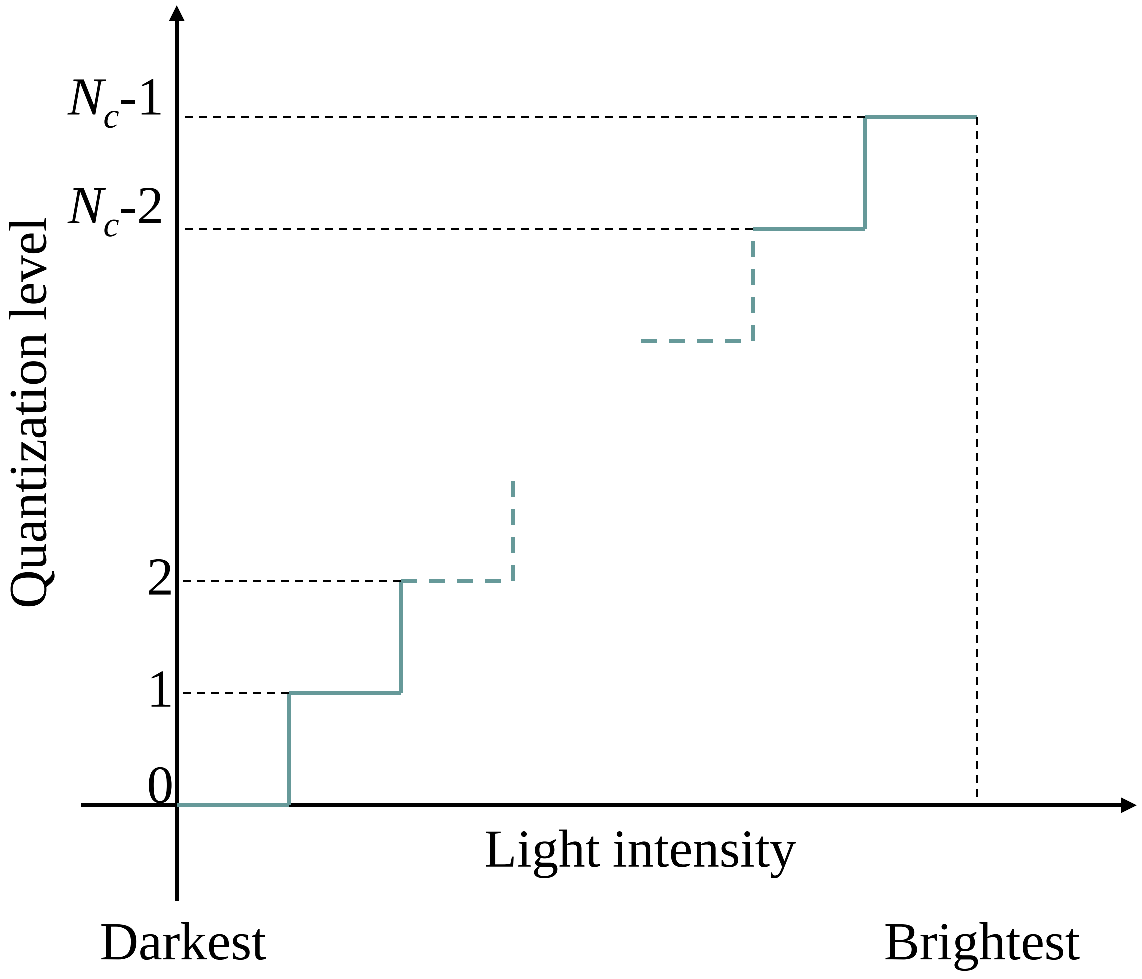
Color resolution/ color depth/ levels:

- No. of colors or gray levels or
- No. of bits representing each pixel value
- No. of colors or gray levels N_c is given by

$$N_c = 2^b$$

where b = no. of bits

Quantization function



Effect of Quantization Levels

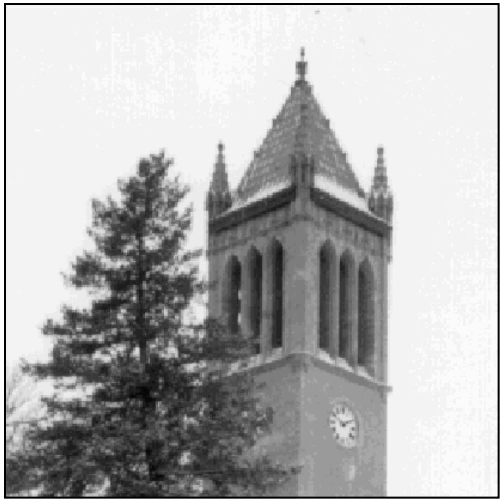
256 levels

128 levels

64 levels

32 levels

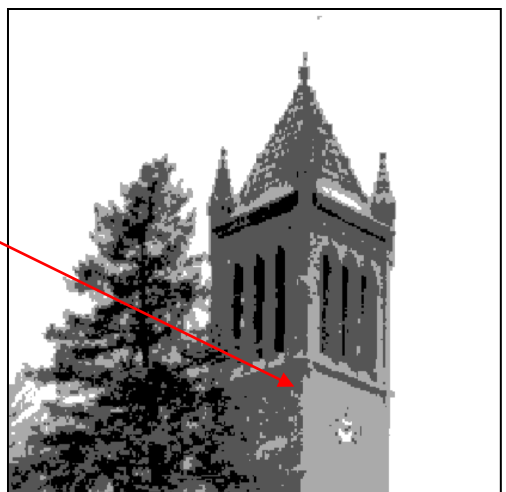
Effect of Quantization Levels (cont.)



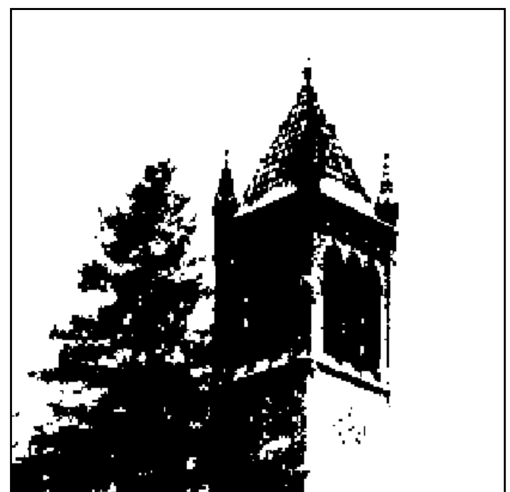
16 levels

8 levels

In this image, it is easy to see false contour.



4 levels



2 levels

How to select the suitable size and pixel depth of images

The word “suitable” is subjective: depending on “subject”.

Low detail image

Lena image

Medium detail image

Cameraman image

High detail image

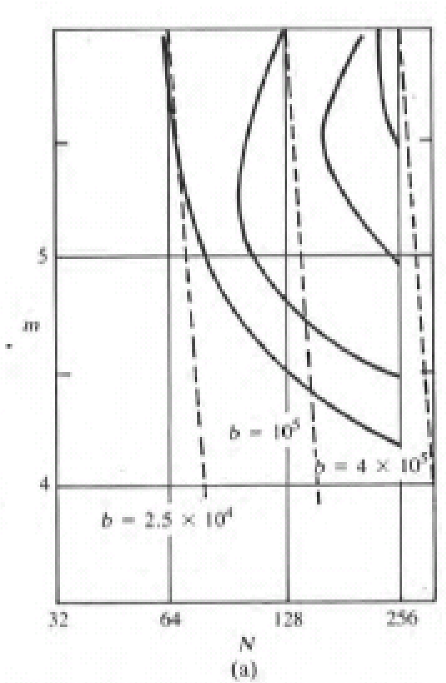
Crowded image

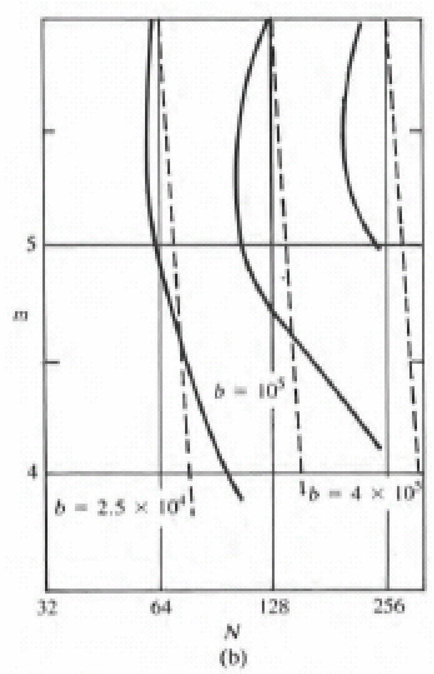
To satisfy human mind

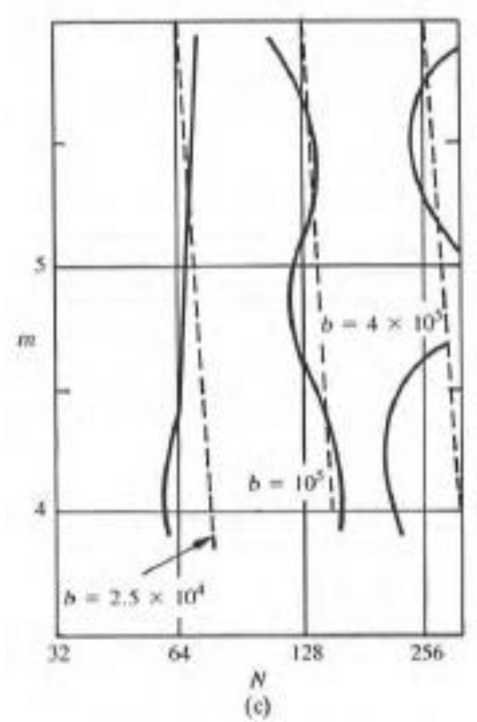
1. For images of the same size, the low detail image may need more pixel depth.
2. As an image detail increases, fewer gray levels may be needed.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Isopreference curves







(a) Face

(b) Cameraman

(c) Crowd

Human vision: Spatial Frequency vs Contrast