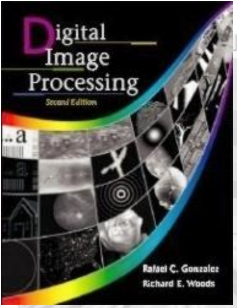


Chapter 2
Digital Image Fundamentals

Elements of Visual Perception

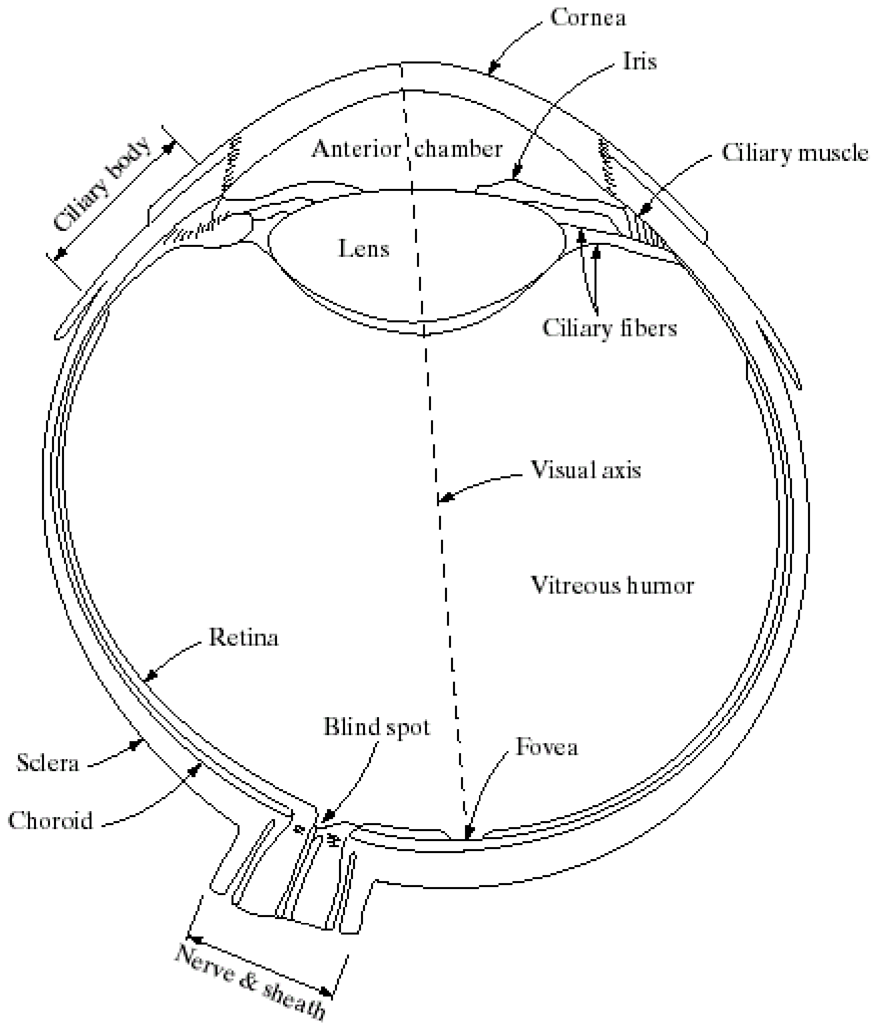


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

Cornea:
Sclera:
Choroid:
Retina:
Iris:
Lens:
Macula lutea:
Fovea
Blind spot:
Rod:
Cone:

Structure of the Human Eye

- Pattern vision is afforded by the distribution of discrete light receptors over the surface of the retina.
- There are two classes of receptors: cones and rods.
  - The number of cones in each eye: 6 to 7 millions
  - The number of rods in each eye: 75 to 150 millions
  - The cones is concentrated in the central portion of the retina (fovea).
  - The rods are distributed over the retinal surface.
- Photopic (bright-light) vision: vision with cones
  - color receptors, high resolution in the fovea, less sensitive to light
- Scotopic (dim-light) vision: vision with rods
  - color blind, much more sensitive to light (night vision), lower resolution

Structure of the Human Eye

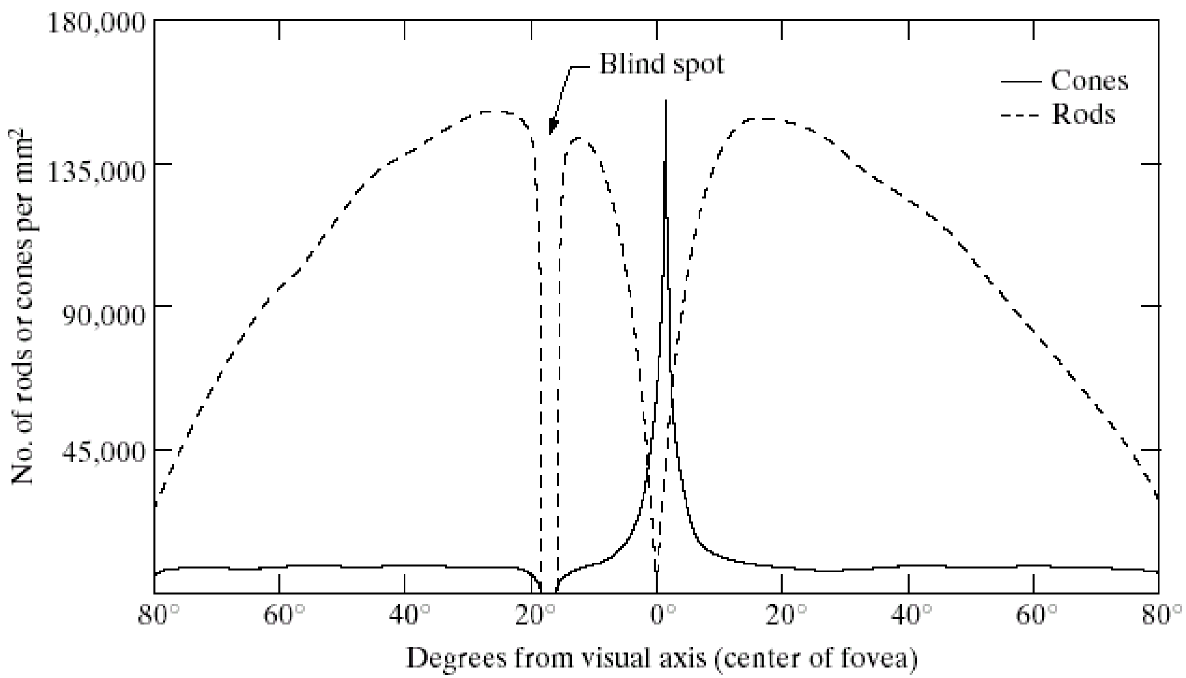
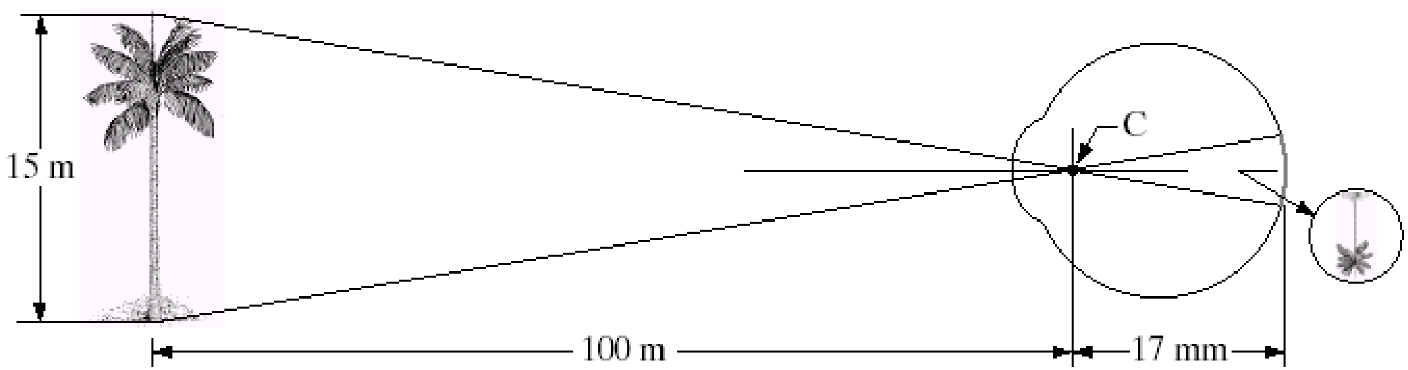


FIGURE 2.2 Distribution of rods and cones in the retina.

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.



- Focal length of the eye: 17 to 14 mm
- Let h be the height in mm of that object in the retinal image, then

$$15/100 = h / 17 \; , \; h = 2.55\text{mm}$$

- The retinal image is reflected primarily in the area of the fovea.

Brightness Adaptation and Discrimination

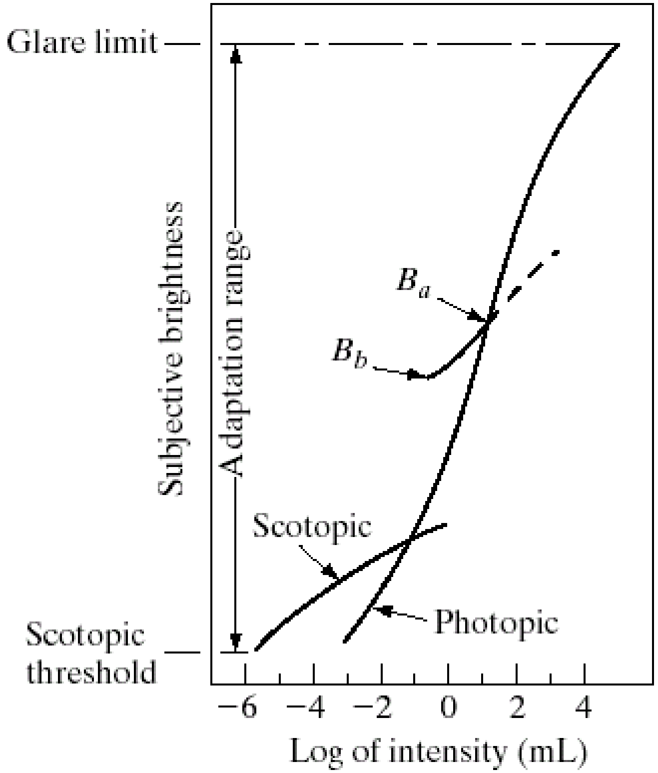
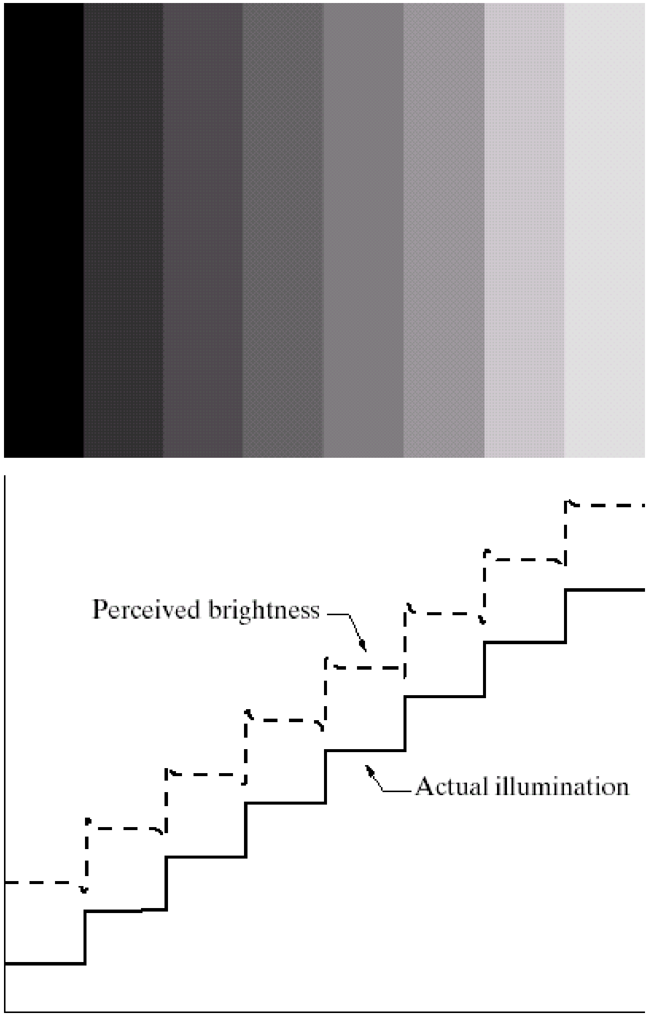


FIGURE 2.4 Range of subjective brightness sensations showing a particular adaptation level.

- The range of brightness that the eye can adapt to is enormous, roughly around 10^{10} to 1.
- Photopic vision alone has a range of around 10^6 to 1.
- Brightness adaptation: example " B_a "
- mL: millilambert

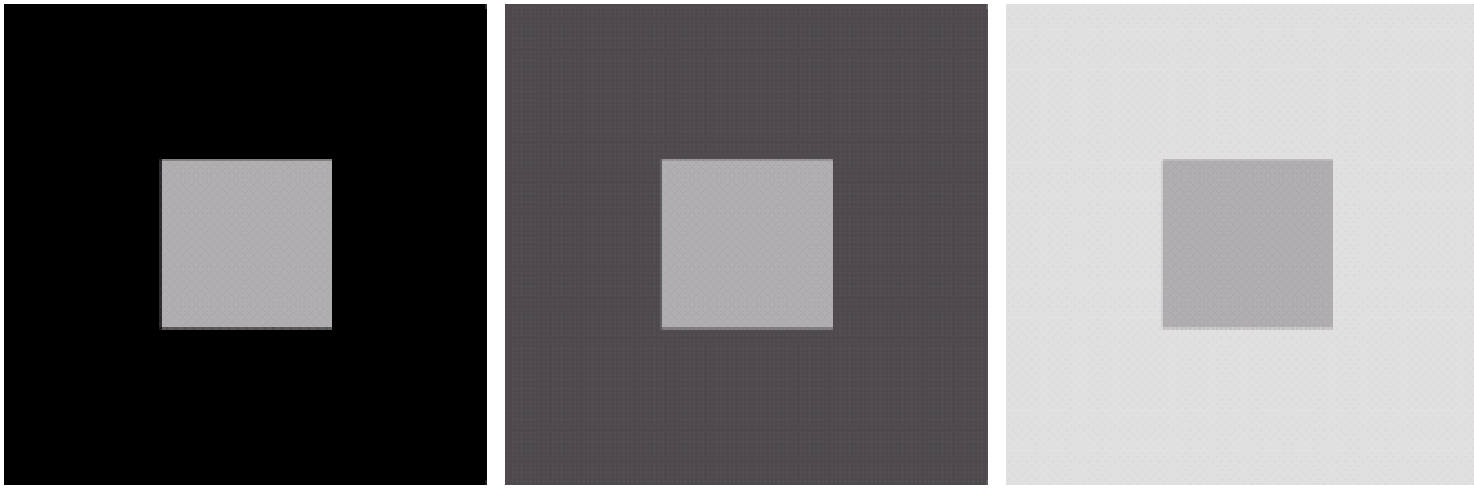
Brightness Adaptation and Discrimination
Example: Mach bands



a
b

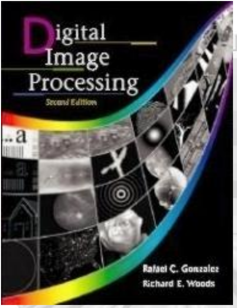
FIGURE 2.7 (a) An example showing that perceived brightness is not a simple function of intensity. The relative vertical positions between the two profiles in (b) have no special significance; they were chosen for clarity.

Brightness Adaptation and Discrimination
Example: Simultaneous Contrast



a b c

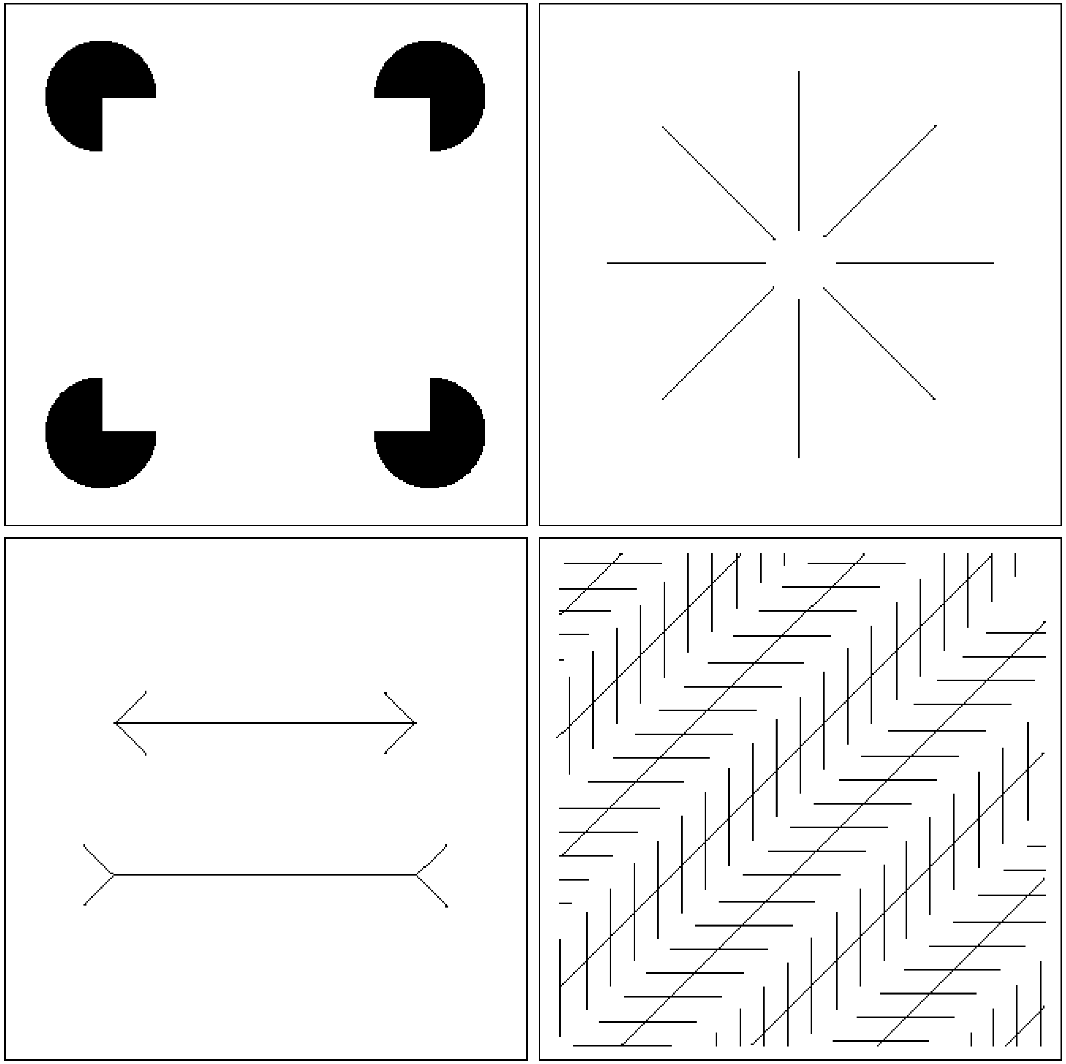
FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

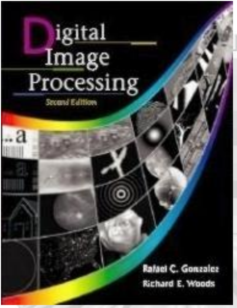


Brightness Adaptation and Discrimination Examples for Human Perception Phenomena

a b
c d

FIGURE 2.9 Some well-known optical illusions.





Light and the Electromagnetic Spectrum

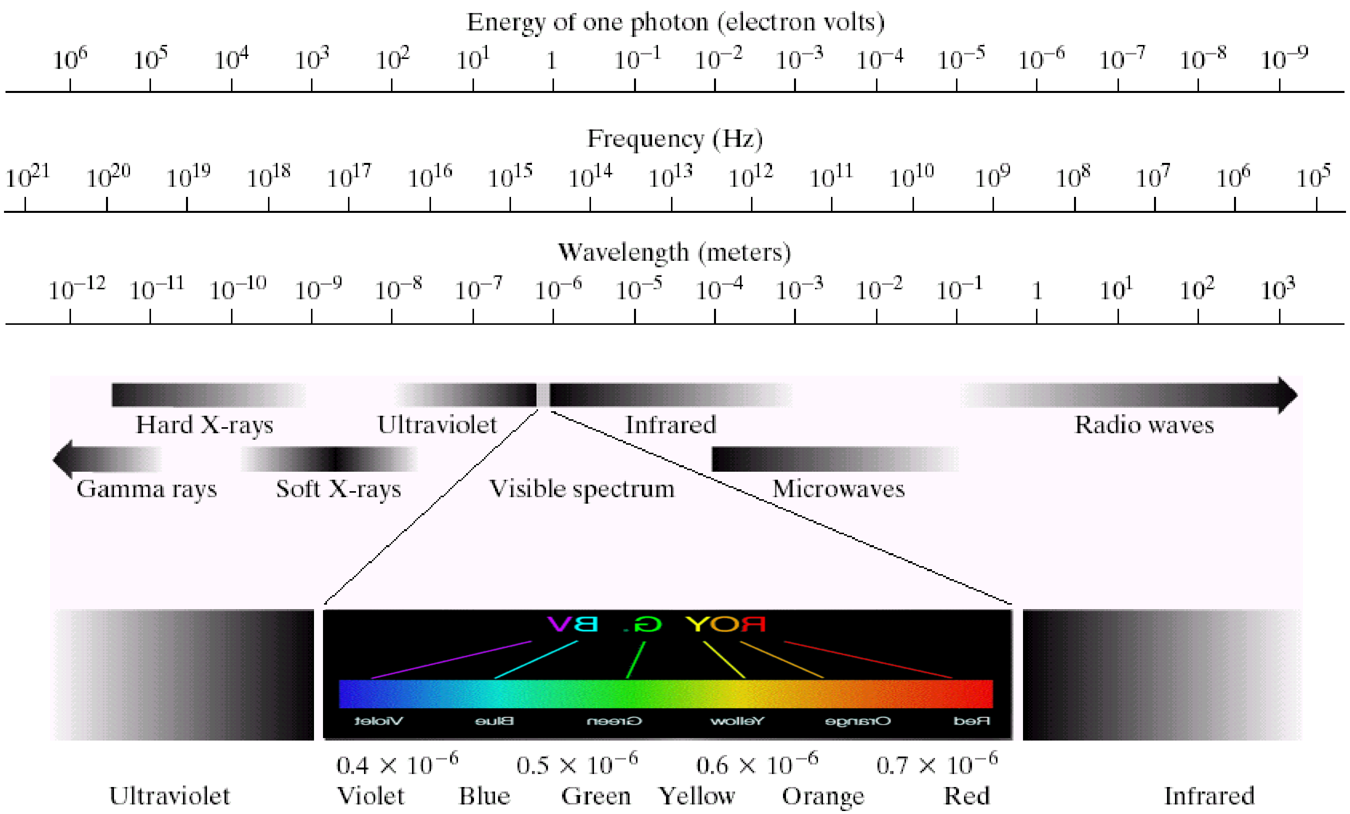


FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

Light and the Electromagnetic Spectrum

- Three basic quantities described the quality of a chromatic light source:
  - Radiance: the total amount energy that flow from the light source (can be measured)
  - Luminance: the amount of energy an observer perceives from a light source (can be measured)
  - Brightness: a subjective descriptor of light perception; perceived quantity of light emitted (cannot be measured)

Light and the Electromagnetic Spectrum

- Relationship between frequency (ν) and wavelength (λ)

  $\lambda = \dfrac{c}{\nu}$, where c is the speed of light

- Energy of a photon

  $E = h\nu$, where h is Planck's constant

FIGURE 2.11 Graphical representation of one wavelength.

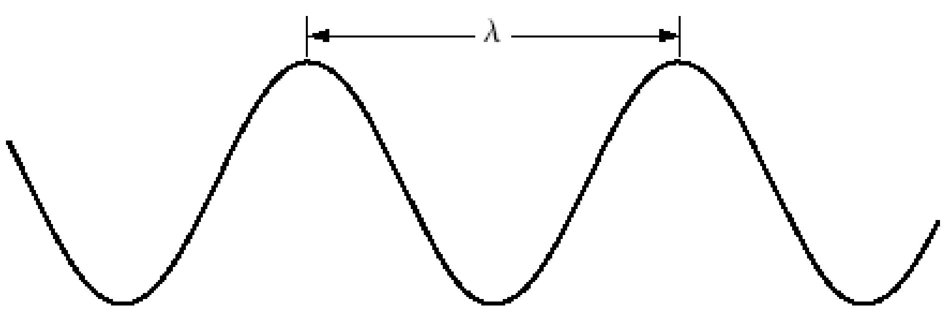
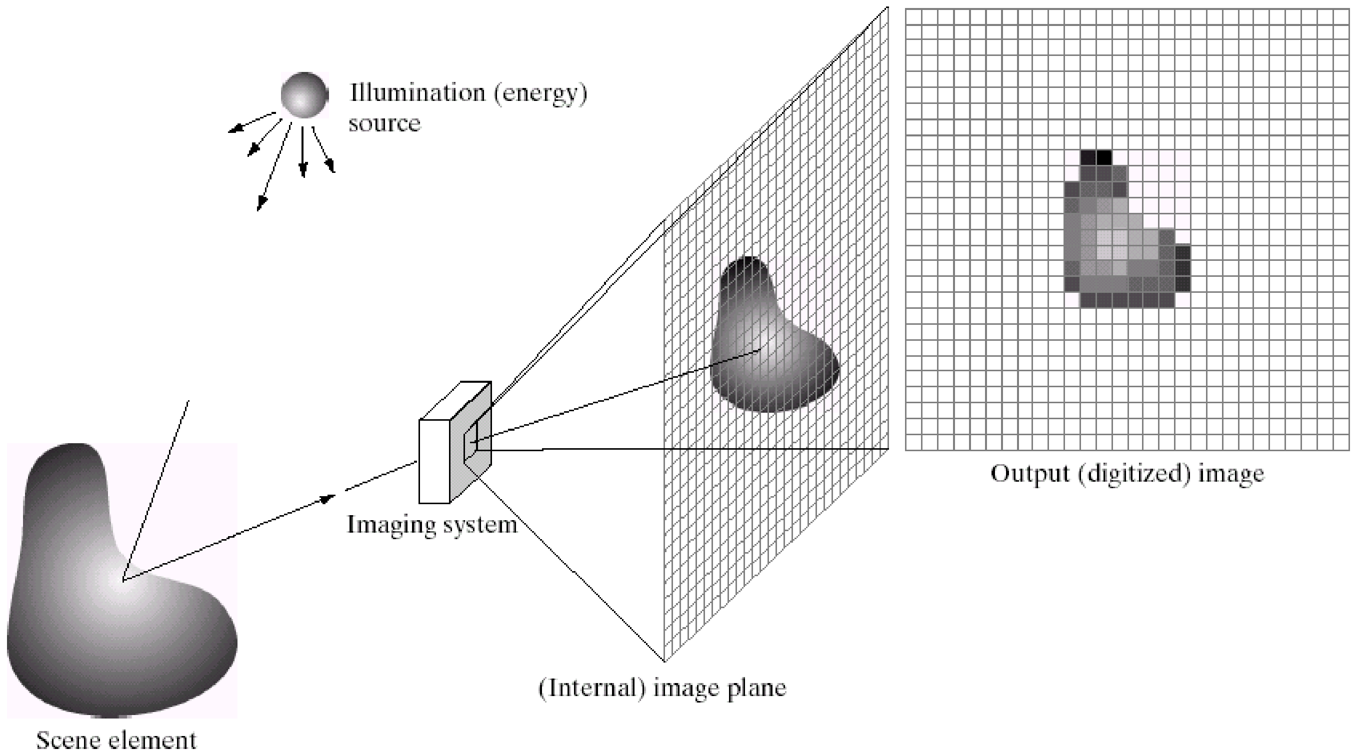


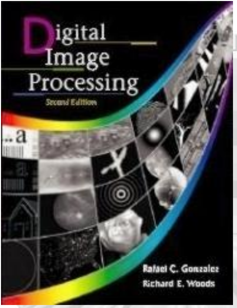
Image Sensing and Acquisition

- Nowadays most visible and near IR electromagnetic imaging is done with 2-dimensional charged-coupled devices (CCDs).



a b c d e

FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.



A Simple Image Formation Model

- Binary images: images having only two possible brightness levels (black and white)
- Gray scale images : “black and white” images
- Color images: can be described mathematically as three gray scale images

- Let $f(x,y)$ be an image function, then

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

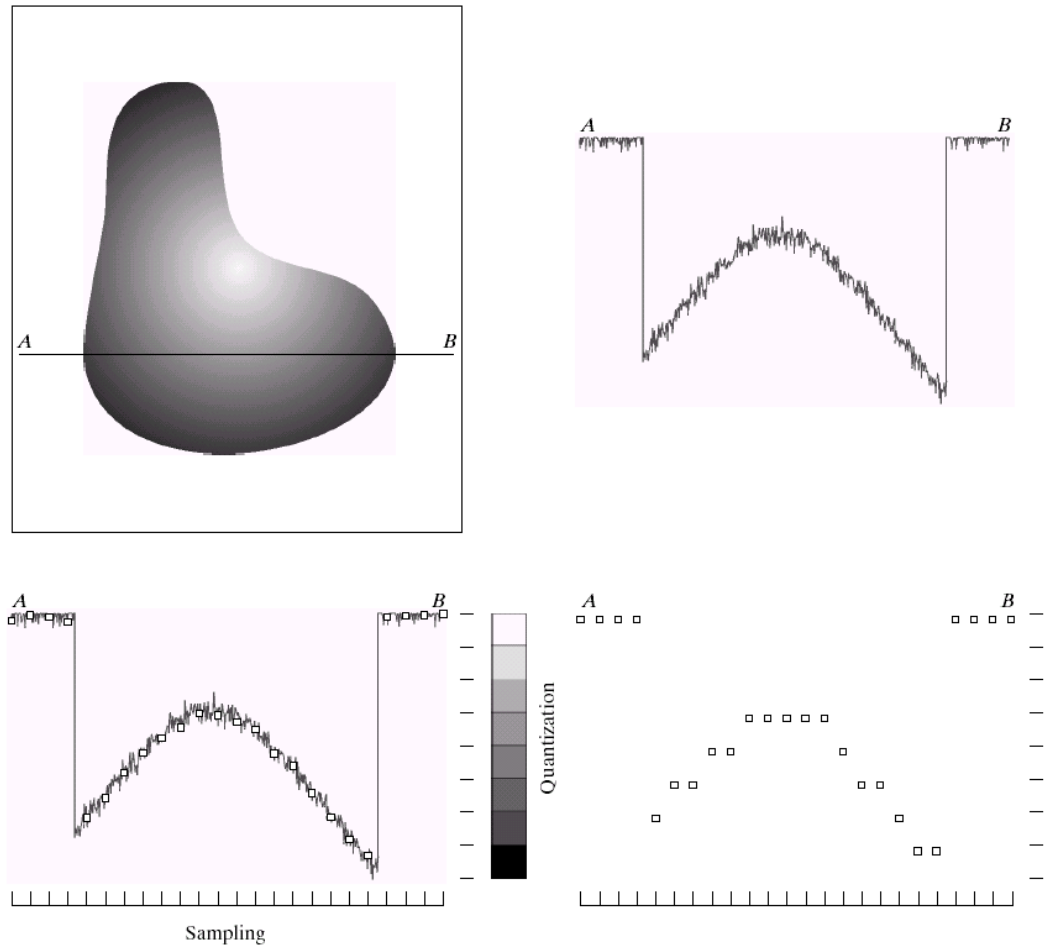
  where $i(x,y)$: the illumination function

  $r(x,y)$: the reflection function

  Note: $0 < i(x,y) < \infty$ and $0 < r(x,y) < 1$.

- For digital images the minimum gray level is usually 0, but the maximum depends on number of quantization levels used to digitize an image. The most common is 256 levels, so that the maximum level is 255.

Image Sampling and Quantization

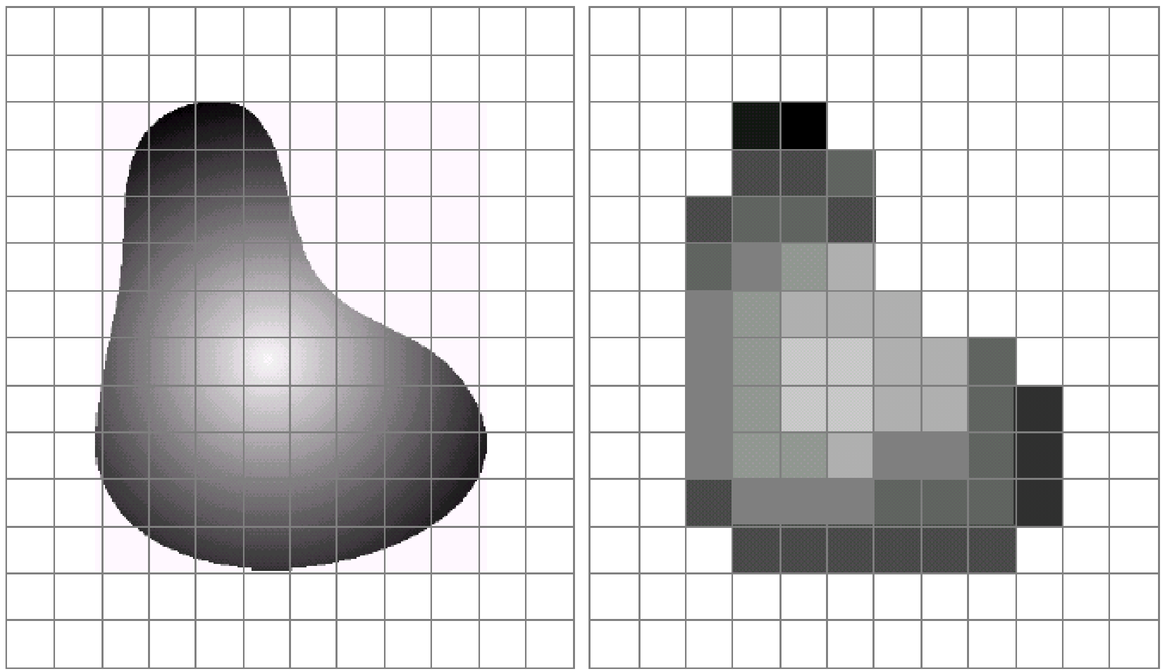


a b
c d

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.

Image Sampling and Quantization

- Sampling: digitizing the 2-dimensional spatial coordinate values
- Quantization: digitizing the amplitude values (brightness level)



a b

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

Representing Digital Images

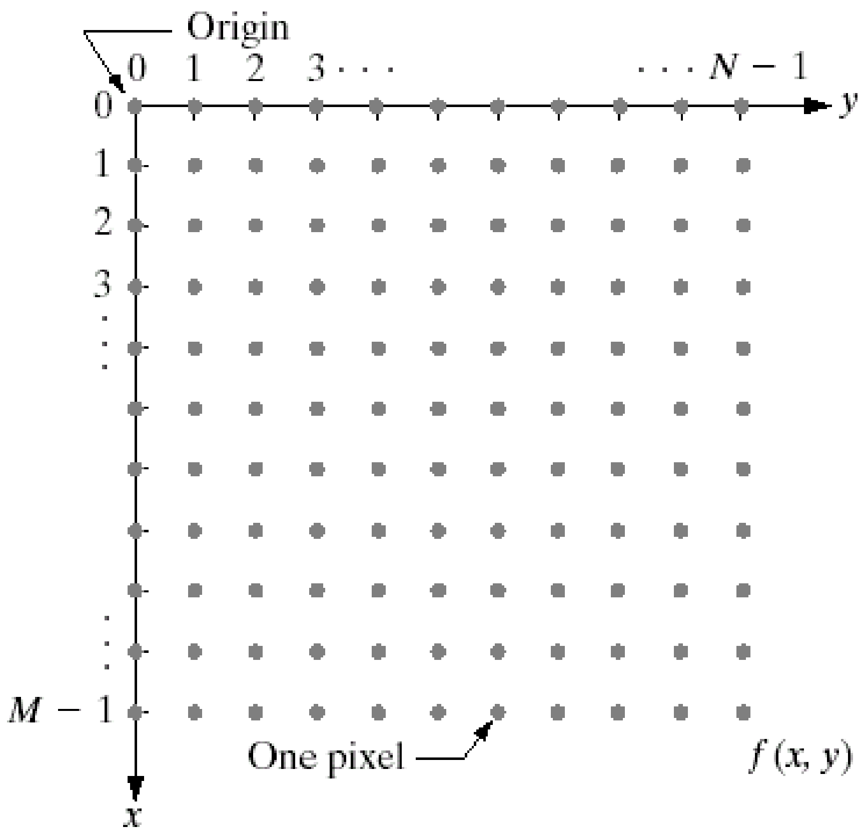
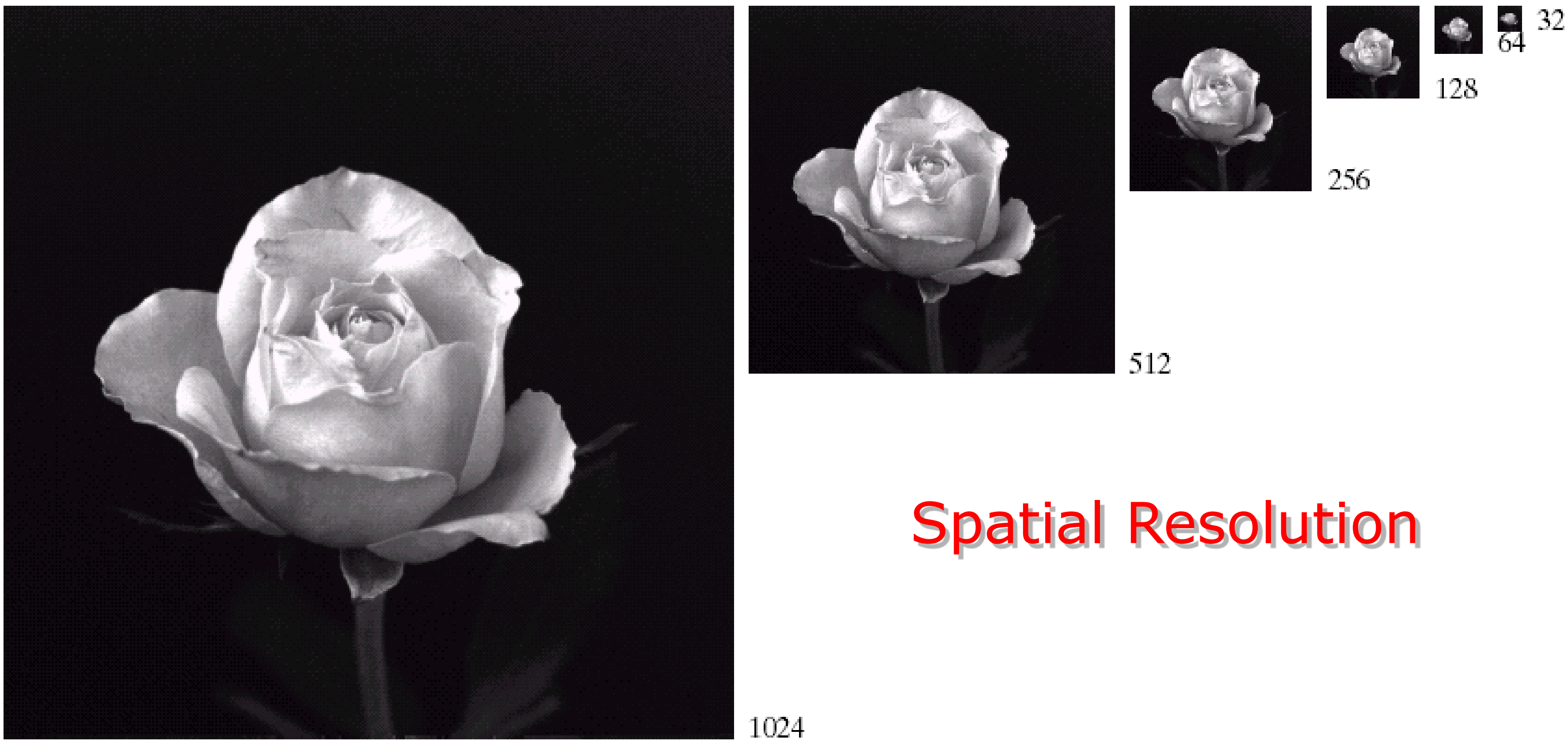


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

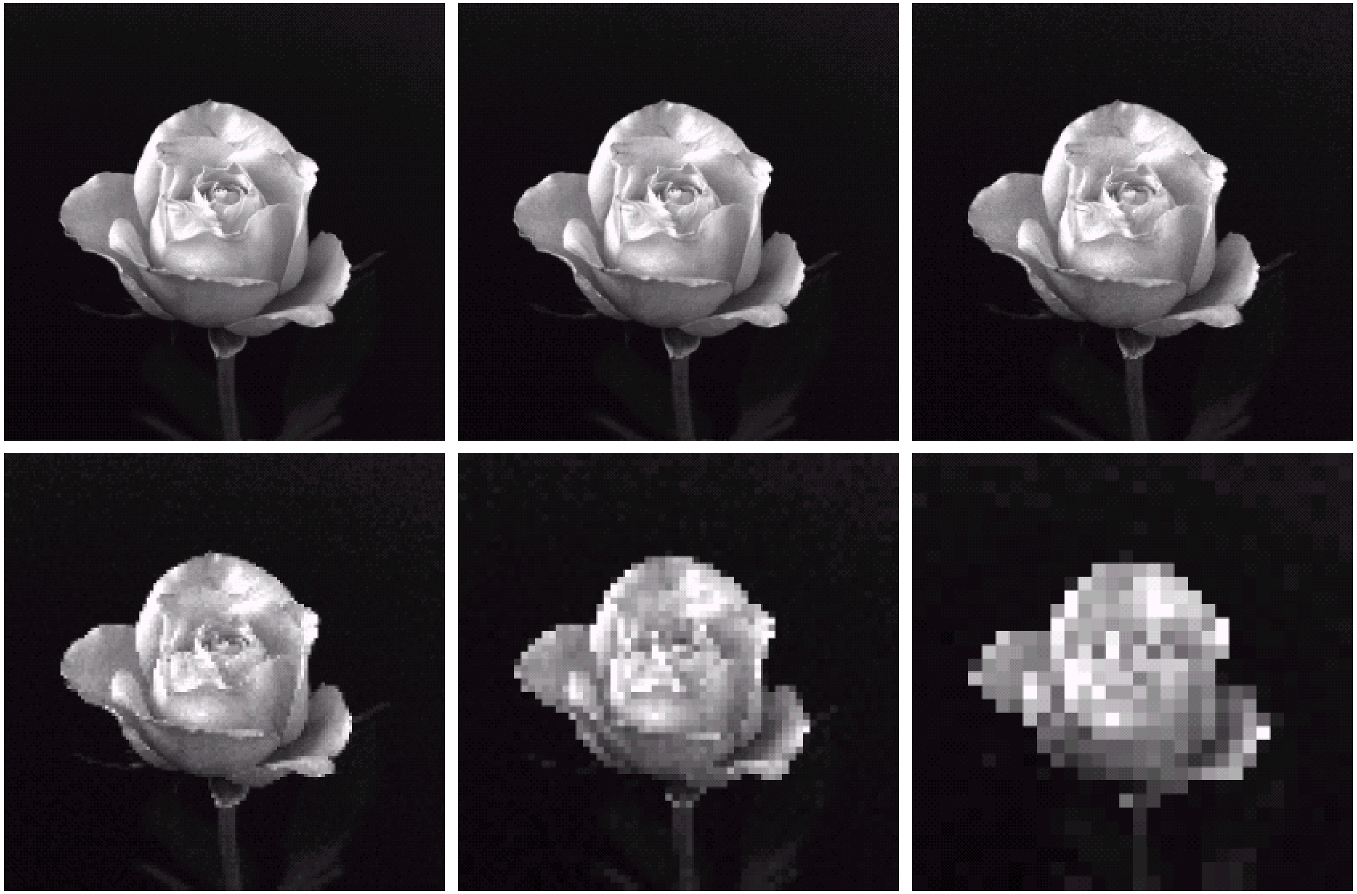
Spatial and Gray-Level Resolution



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.

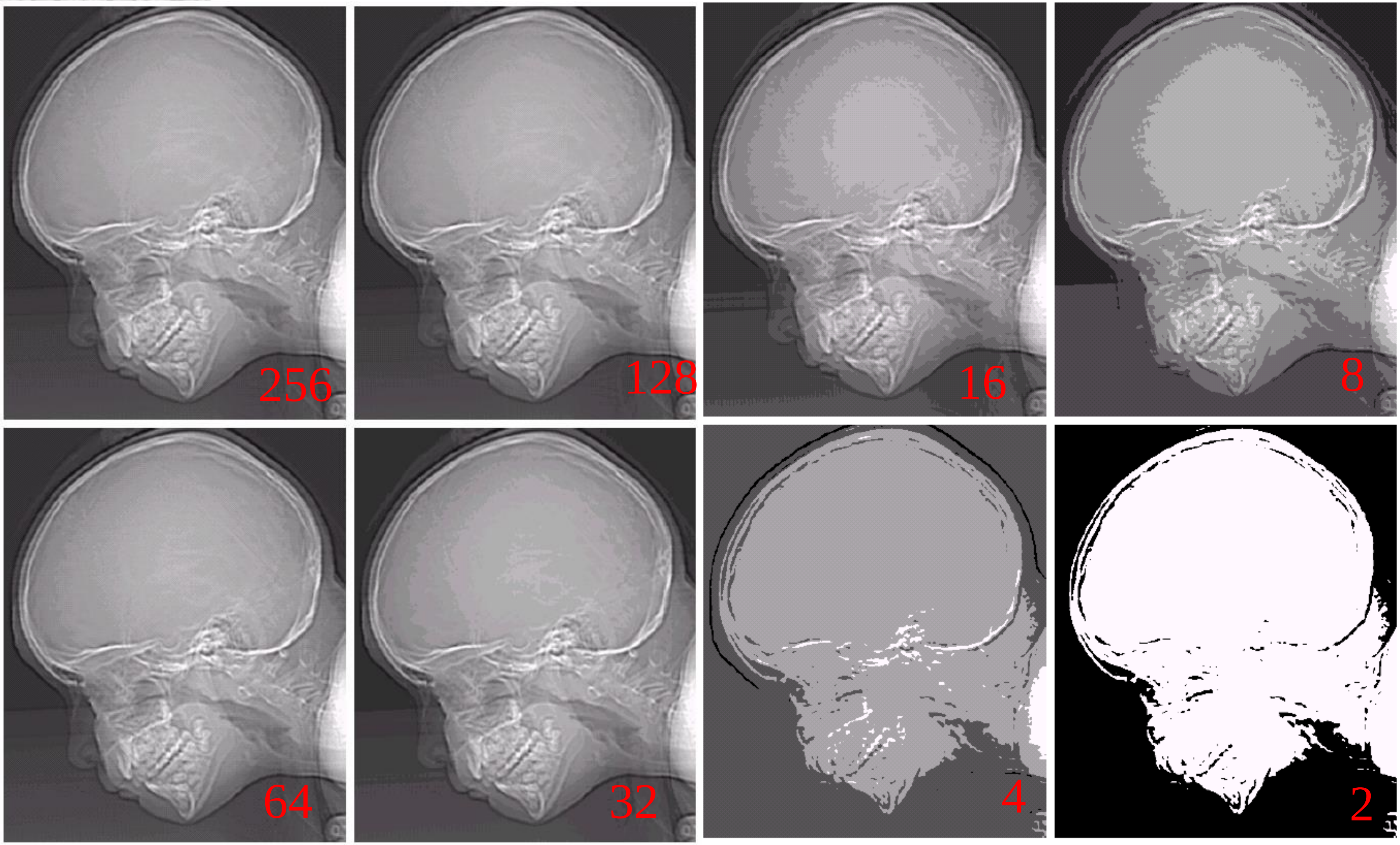
Spatial Resolution by Re-sampling



a b c
d e f

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.

Gray-Level Resolution

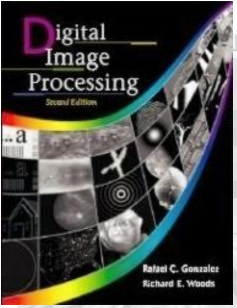


How to Decide Spatial and Gray-Level Resolution?

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.)

- Figure 2.22 (a): The woman's face; Image with low level of detail.
- Figure 2.22 (b): The cameraman; Image with medium level of detail.
- Figure 2.22 (c): The crowd picture; Image with a relatively large amount of detail.



Aliasing and Moiré Pattern

- All signals (functions) can be shown to be made up of a linear combination sinusoidal signals (sines and cosines) of different frequencies. (Chapter 4)
- For physical reasons, there is a highest frequency component in all real world signals.
- Theoretically,
  - if a signal is sampled at more than twice its highest frequency component, then it can be reconstructed exactly from its samples.
  - But, if it is sampled at less than that frequency (called undersampling), then aliasing (失真) will result.
  - This causes frequencies to appear in the sampled signal that were not in the original signal.
  - The Moiré pattern shown in Figure 2.24 is an example. The vertical low frequency pattern is a new frequency not in the original patterns.

Aliasing and Moiré Pattern
The effect of aliased frequencies

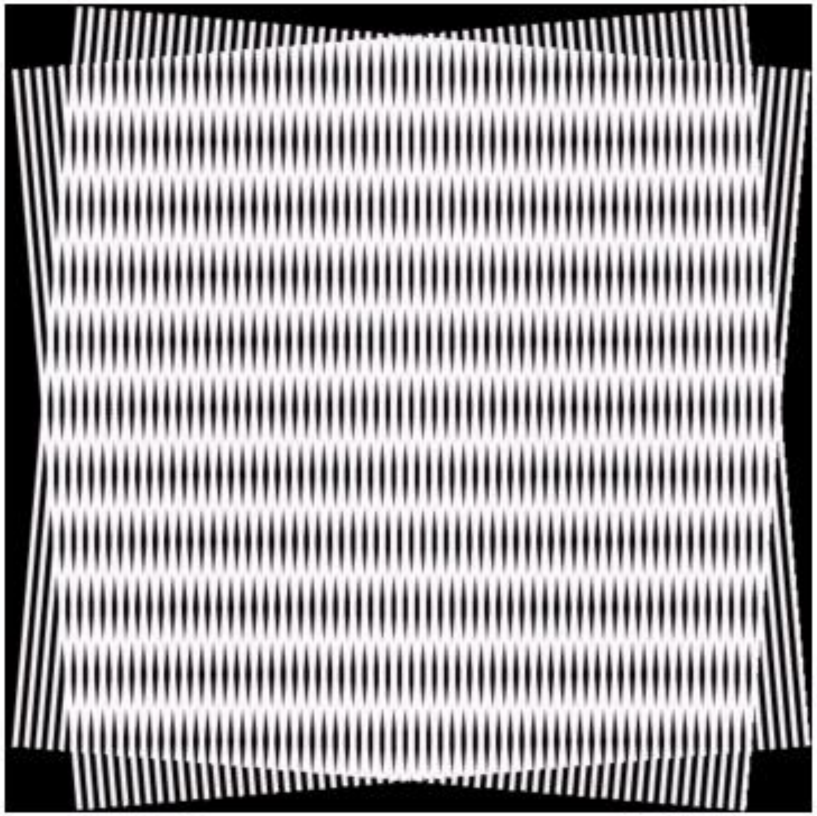


FIGURE 2.24 Illustration of the Moiré pattern effect.

Zooming and Shrinking Digital Images

- Zooming: increasing the number of pixels in an image so that the image appears larger
  - Nearest neighbor interpolation
    - For example: pixel replication--to repeat rows and columns of an image
  - Bilinear interpolation
    - Smoother
  - Higher order interpolation
- Image shrinking: subsampling

Zooming and Shrinking Digital Images

Nearest neighbor
Interpolation
(Pixel replication)

Bilinear
interpolation

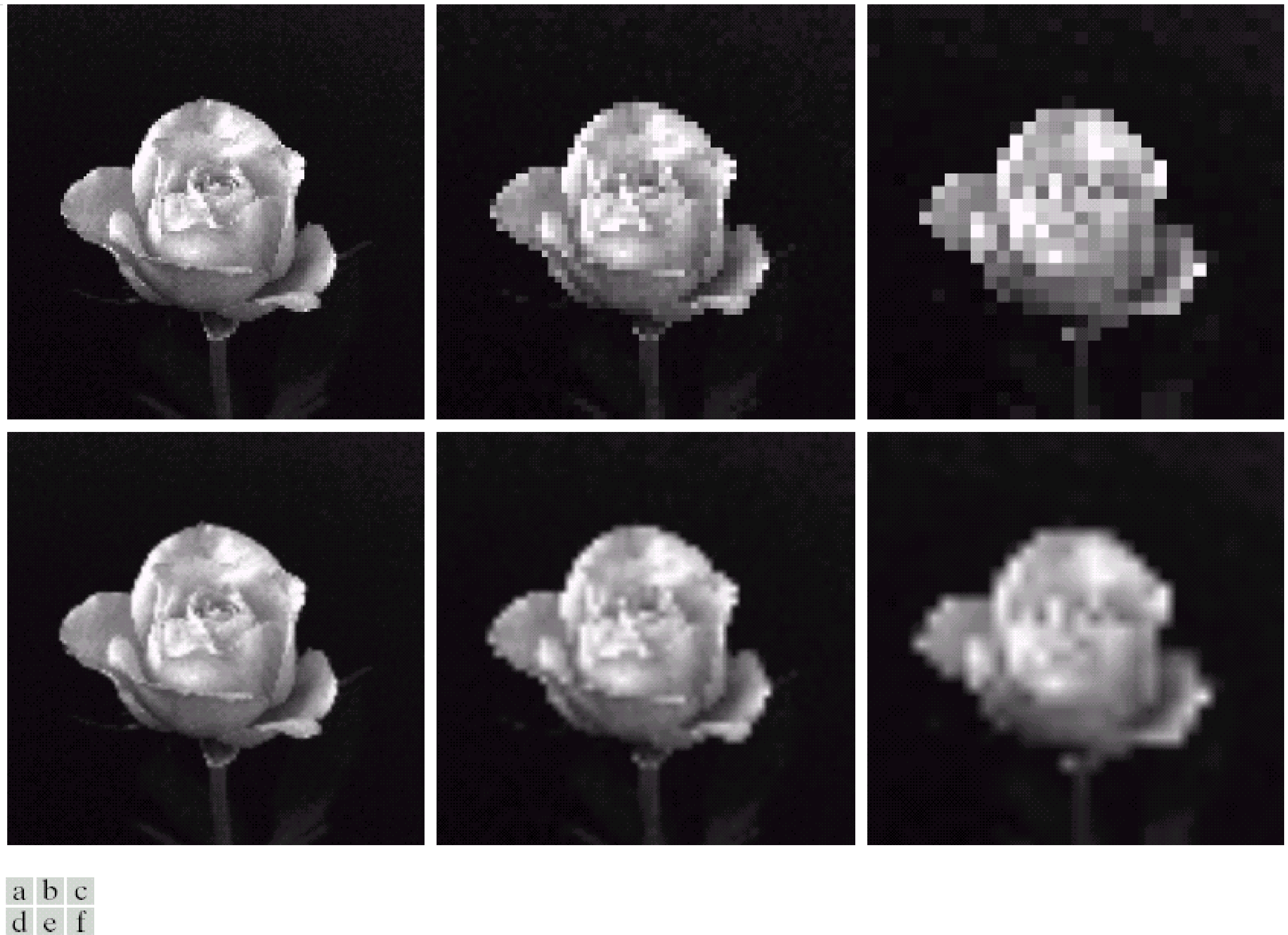


FIGURE 2.25 Top row: images zoomed from 128 × 128, 64 × 64, and 32 × 32 pixels to 1024 × 1024 pixels, using nearest neighbor gray-level interpolation. Bottom row: same sequence, but using bilinear interpolation.

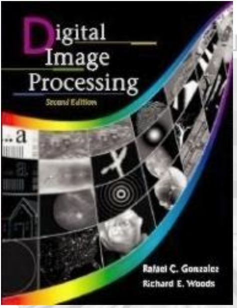
Some Basic Relationships Between Pixels

- Neighbors of a pixel
  - There are three kinds of neighbors of a pixel:
    - $N_4(p)$ 4-neighbors: the set of horizontal and vertical neighbors
    - $N_D(p)$ diagonal neighbors: the set of 4 diagonal neighbors
    - $N_8(p)$ 8-neighbors: union of 4-neighbors and diagonal neighbors

	O	
O	X	O
	O	

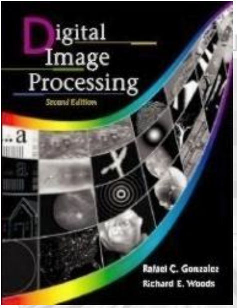
O		O
	X	
O		O

O	O	O
O	X	O
O	O	O



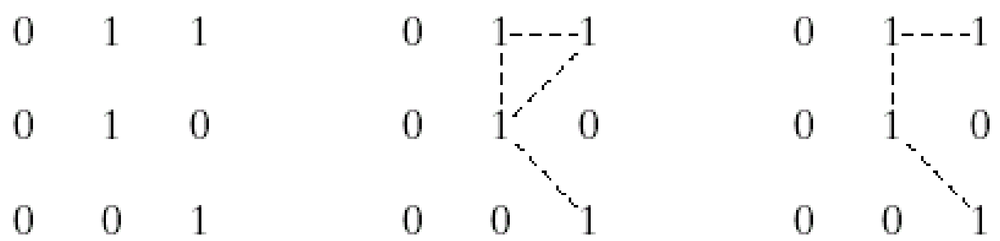
Some Basic Relationships Between Pixels

- Adjacency:
  - Two pixels that are neighbors and have the same grey-level (or some other specified similarity criterion) are adjacent
  - Pixels can be 4-adjacent, diagonally adjacent, 8-adjacent, or m-adjacent.
- *m*-adjacency (mixed adjacency):
  - Two pixels *p* and *q* of the same value (or specified similarity) are *m*-adjacent if either
    - (i) *q* and *p* are 4-adjacent, or
    - (ii) *p* and *q* are diagonally adjacent and do not have any common 4-adjacent neighbors.
    - They cannot be both (i) and (ii).



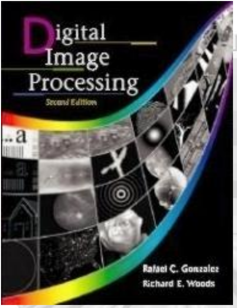
Some Basic Relationships Between Pixels

- An example of adjacency:



a b c

FIGURE 2.26 (a) Arrangement of pixels; (b) pixels that are 8-adjacent (shown dashed) to the center pixel; (c) *m*-adjacency.



Some Basic Relationships Between Pixels

- Path:
  - The length of the path
  - Closed path
- Connectivity in a subset *S* of an image
  - Two pixels are connected if there is a path between them that lies completely within *S*.
- Connected component of *S*:
  - The set of all pixels in *S* that are connected to a given pixel in *S*.
- Region of an image
- Boundary, border or contour of a region
- Edge: a path of one or more pixels that separate two regions of significantly different gray levels.

Some Basic Relationships Between Pixels

- Distance measures
  - Distance function: a function of two points, *p* and *q*, in space that satisfies three criteria

$$(a)\ D(p,q) \geq 0$$

$$(b)\ D(p,q) = D(q,p), \text{ and}$$

$$(c)\ D(p,z) \leq D(p,q) + D(q,z)$$

  - The Euclidean distance $D_e(p, q)$

$$D_e(p,q) = \sqrt{(x-s)^2 + (y-t)^2}$$

  - The city-block (Manhattan) distance $D_4(p, q)$

$$D_4(p,q) = |x-s| + |y-t|$$

  - The chessboard distance $D_8(p, q)$

$$D_8(p,q) = \max(|x-s|, |y-t|)$$