# DIGITAL IMAGING FUNDAMENTALS

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# Contents

- This lecture will cover:
  - Elements of Visual Perception
  - Light and the electromagnetic spectrum
  - Image sensing and acquisition
  - Image representation
  - Image Sampling, quantisation and resolution

Most of the pictures are taken from, DIP book by Gonzales and Woods

# Elements of Visual Percention

- In this section we will
  - Develop basic understanding of human visual perception
  - Learn the mechanics and parameters related to how images are formed and perceived by humans
  - Know the physical limitations of human vision

# Structure of Human Eye

- There are three membranes of eye
  - The cornea and sclera outer cover
  - The choroid
  - The retina
- Retina
  - Innermost membrane
  - Two classes of light receptors found on retina
    - Cones
    - Rods

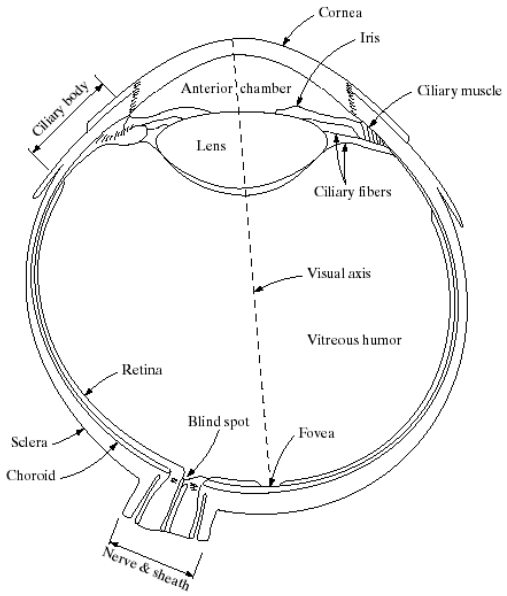
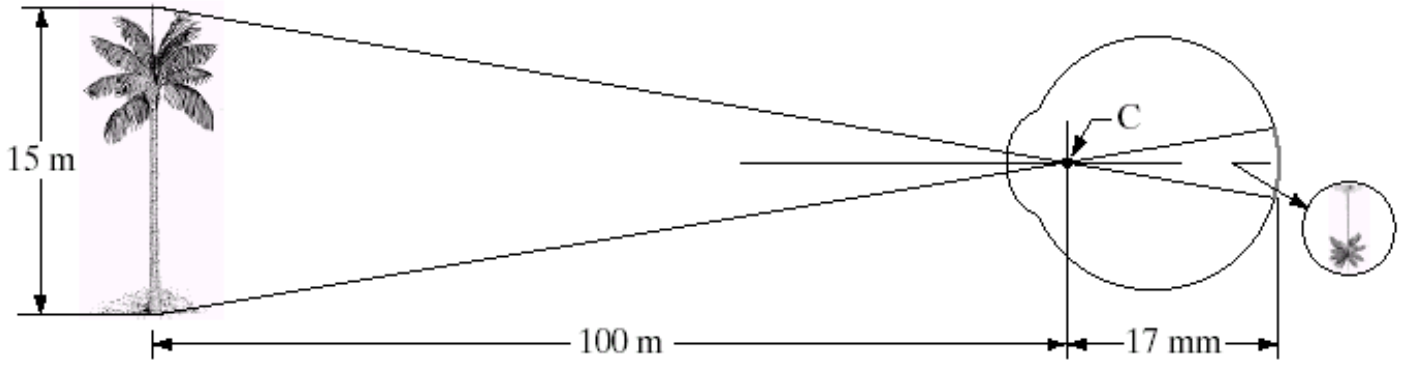



**FIGURE 2.1**
Simplified diagram of a cross section of the human eye.

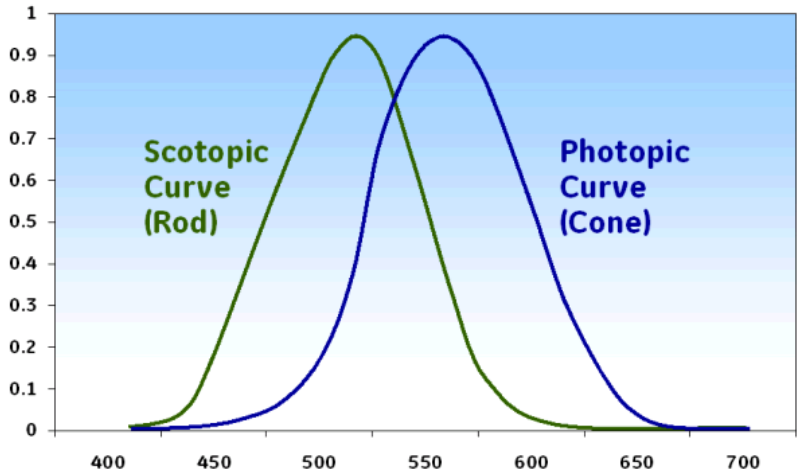
# Image Formation in the Eye

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



# Scotopic and Photopic Vision

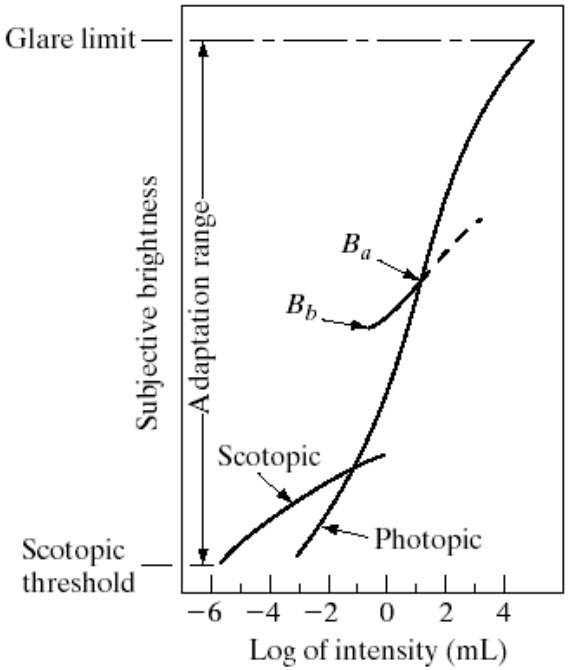
- Cones are far less in number than rods
- Cones are found at the fovea; Rods are found in areas surrounding fovea
- Rods are responsible for low-light vision
- Cones for bright-light vision
- In general, our vision is a mixture of both rod and cone response




Cone and Rod Sensitivity

# Brightness Adaption and Discrimination

- The range of light intensity levels to which the human visual system can adapt is enormous.
- However the total range of intensity levels it can discriminate simultaneously is rather small compared to the total adaption range



# Brightness Adaption and Discrimination

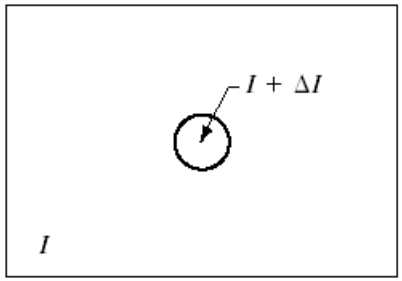
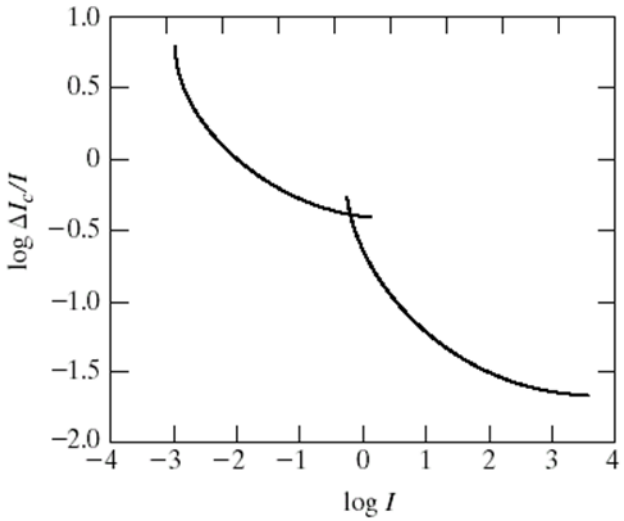


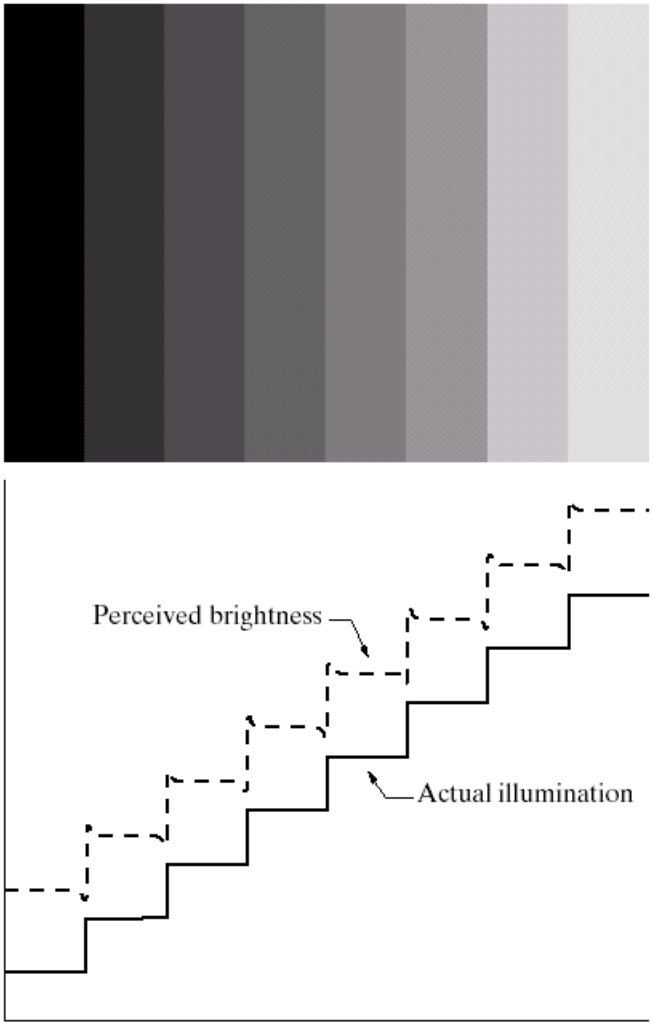

**FIGURE 2.5** Basic experimental setup used to characterize brightness discrimination.

**FIGURE 2.6** Typical Weber ratio as a function of intensity.




Discriminative ability is more at brighter light

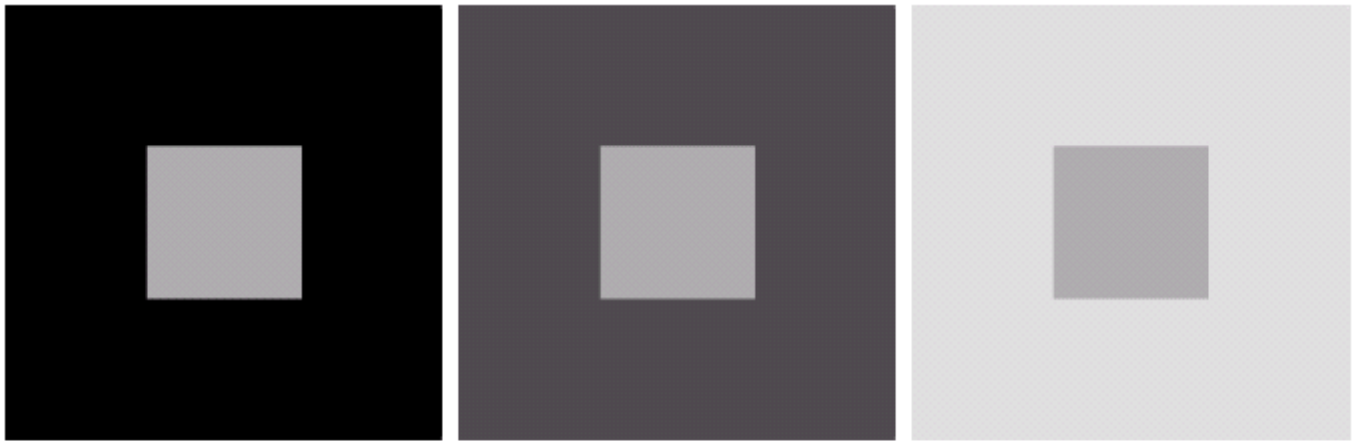
# Brightness Adaption and Discrimination




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 Adaption and Discrimination



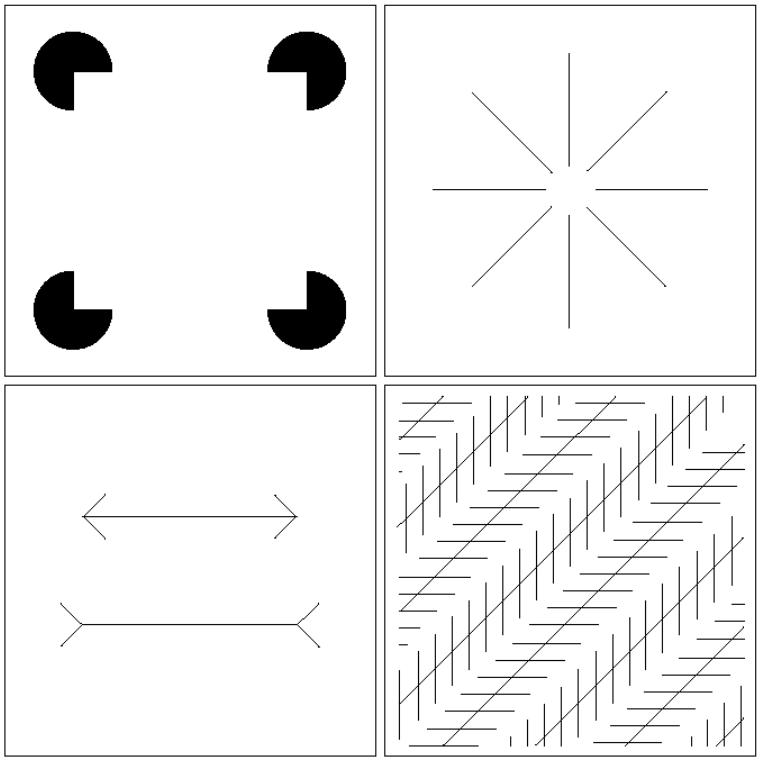
a b c

**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 Adaption and Discrimination

Optical illusion:

A human perception phenomenon in which the eye fills in non-existing information or wrongly perceived geometrical properties.



# Light and Electromagnetic Spectrum

- The range of colors we perceive in visible light represents a very small portion of the electromagnetic spectrum.

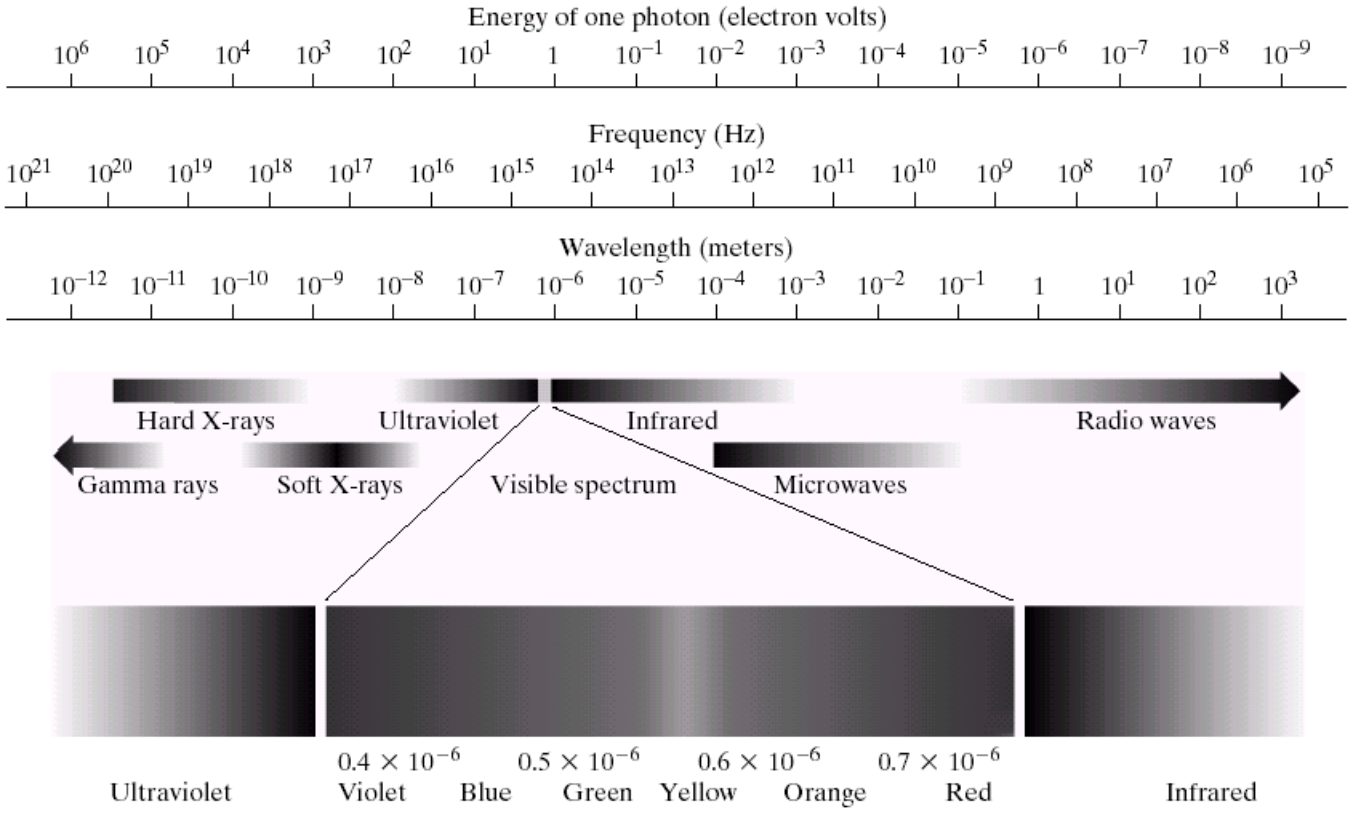
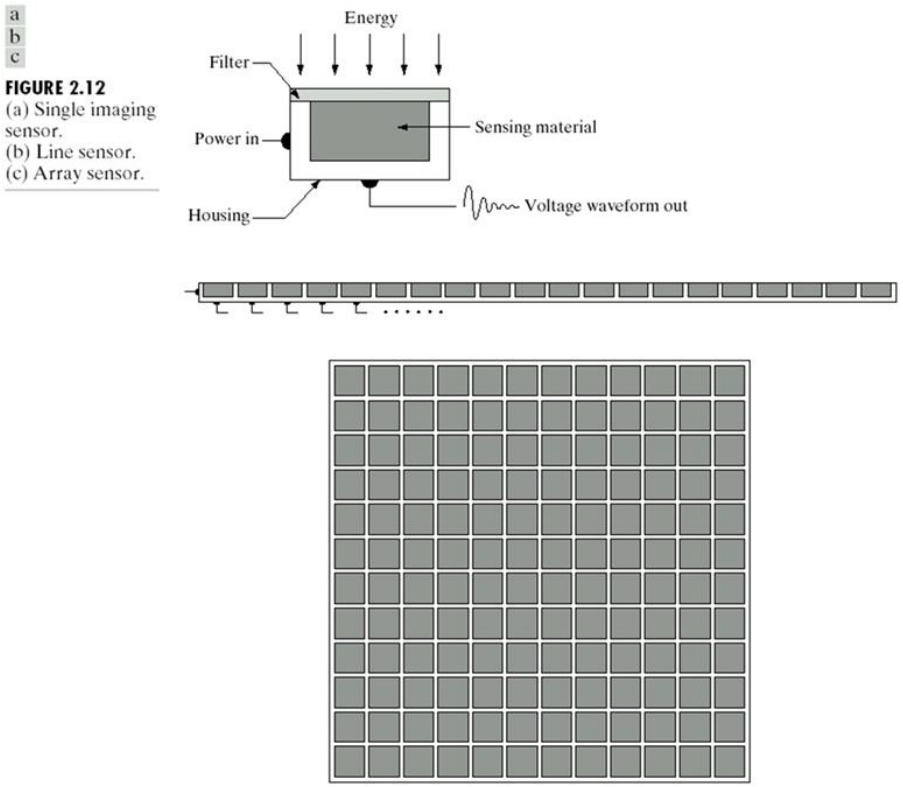


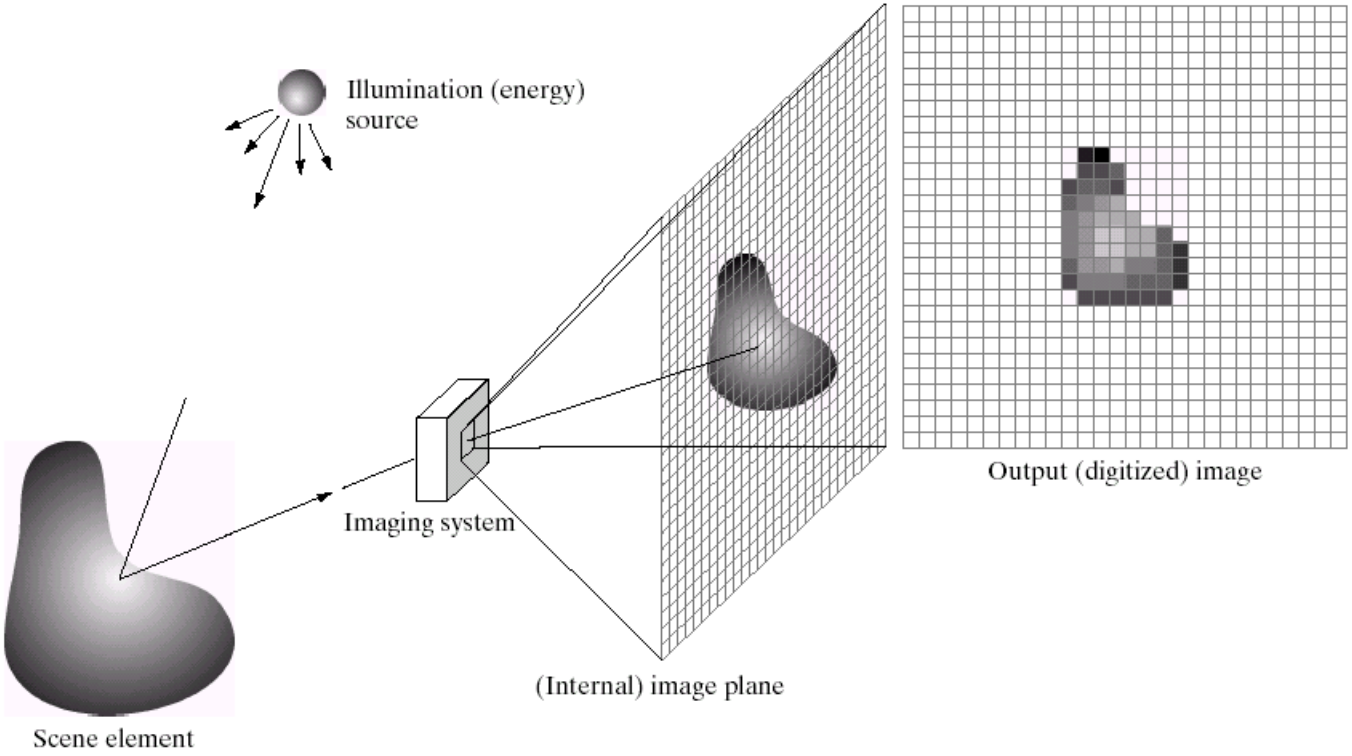

**FIGURE 2.10** The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

# Image Sensing and Acquisition

- Images are generated by the combination of an "illumination" source and the reflection of energy from that source by the elements of the "scene" being imaged



# Image Sensing and Acquisition




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.

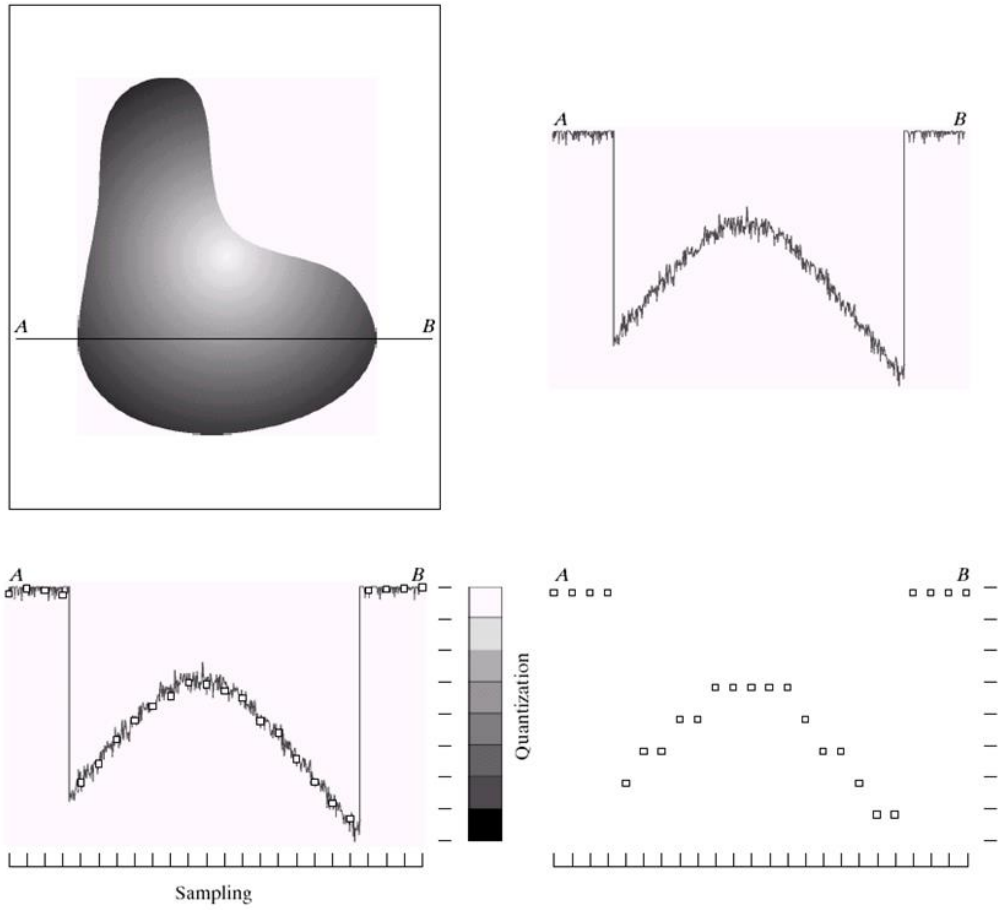
# A Simple Image Model

- The term image refers to a two-dimensional light-intensity function, denoted by $f(x, y)$
  - The value of $f$ at the spatial coordinate $(x, y)$ gives the intensity of the image at that point
- Here $0 < f(x, y) < \infty$
- The basic nature of $f(x, y)$are characterized by following two components
  - Illumination *i*(*x*, *y*) : the amount of source light incident on the scene being viewed
  - Reflectance *r*(*x*, *y*) : the amount of light reflected by the objects in scene
- $f(x, y) = i(x, y)r(x, y)$

# Image Sampling and Quantization

- An image is continuous with respect to the x- and y-coordinates, and also in amplitude (light-intensity).
- To convert it to a digital form, we have to sample the function in both coordinates and also in amplitude.
- Digitizing the coordinate values is called **sampling.**
- Digitizing the amplitude values is called **quantization.**

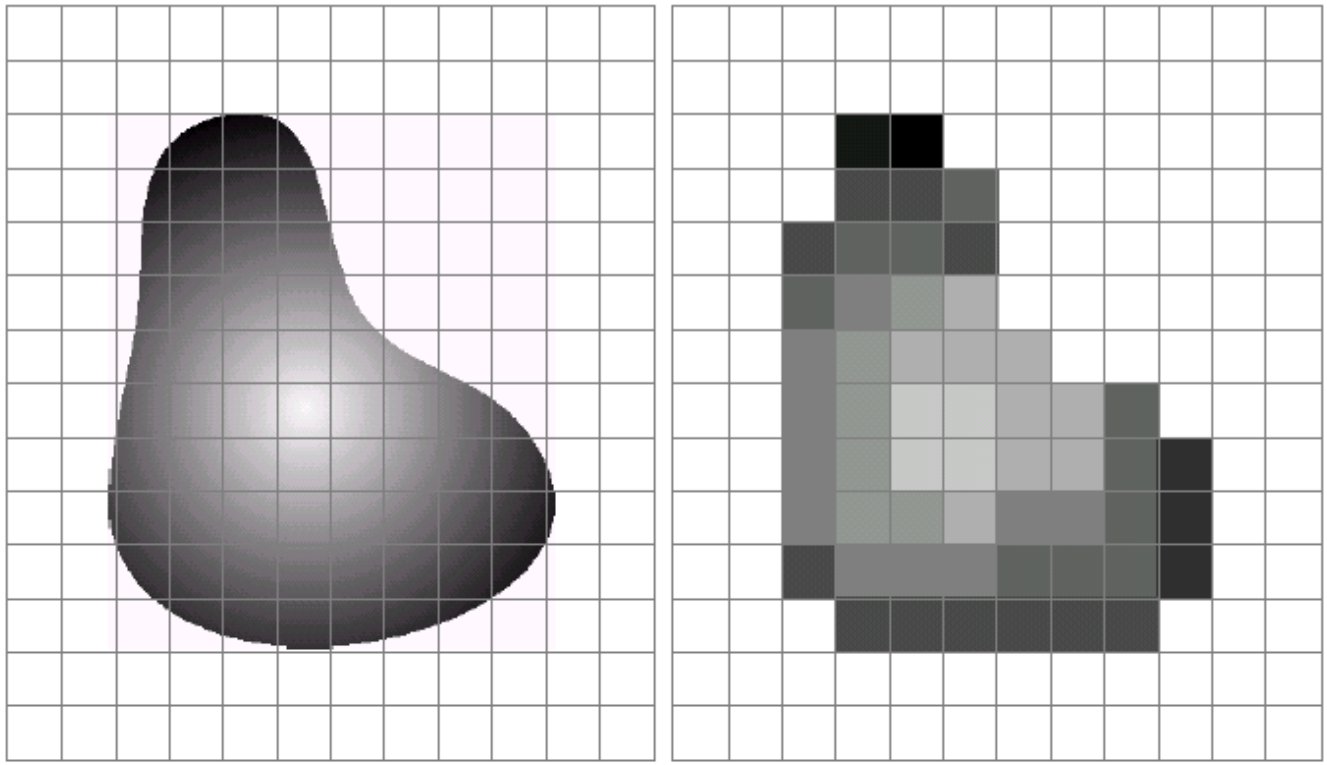
# Image Sampling and Quantization




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

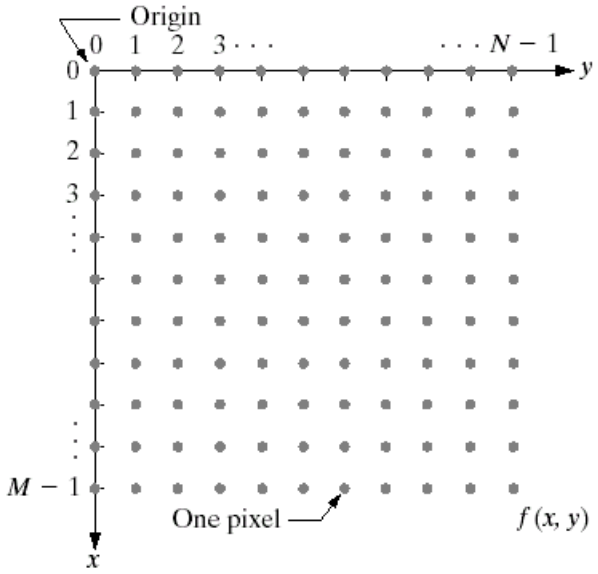


a b

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

# Representing Digital Images

- A digital image is composed of *M* rows and *N* columns of pixels each storing a value
- Pixel values are most often grey levels in the range 0-255
- Images can easily be represented as matrices where each element of this matrix is called picture element or pixel.



# Representing Digital Images

- The digitization of an image requires the decisions regarding the values of M, N and $L$
  - There are no restriction on M and N other than they must be positive integer
  - The number of intensity typically $L = 2^k$

  Where the discrete levels are equally spaced and they are integer in the interval $[0, L-1]$

# 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 |

# Representing Digital Images

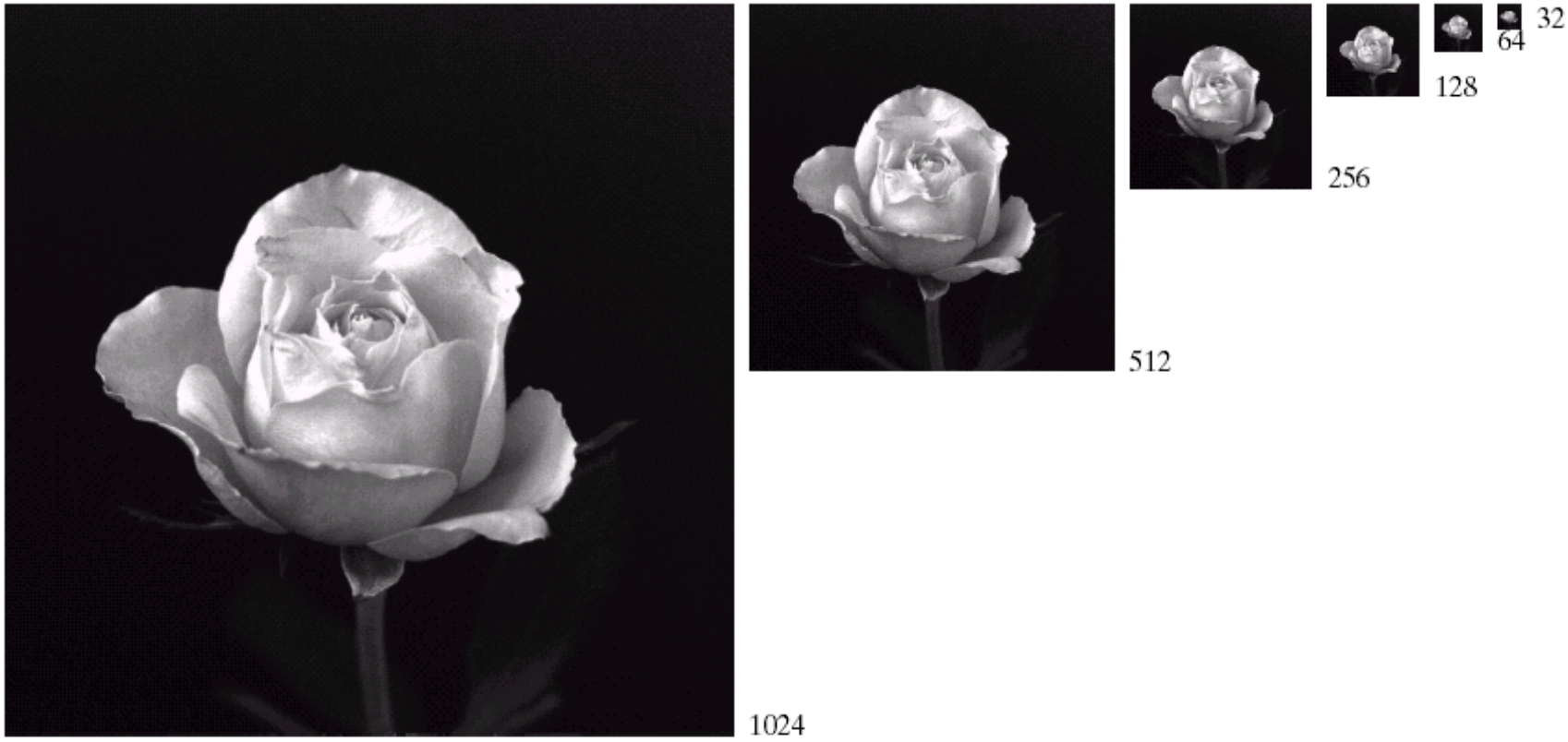
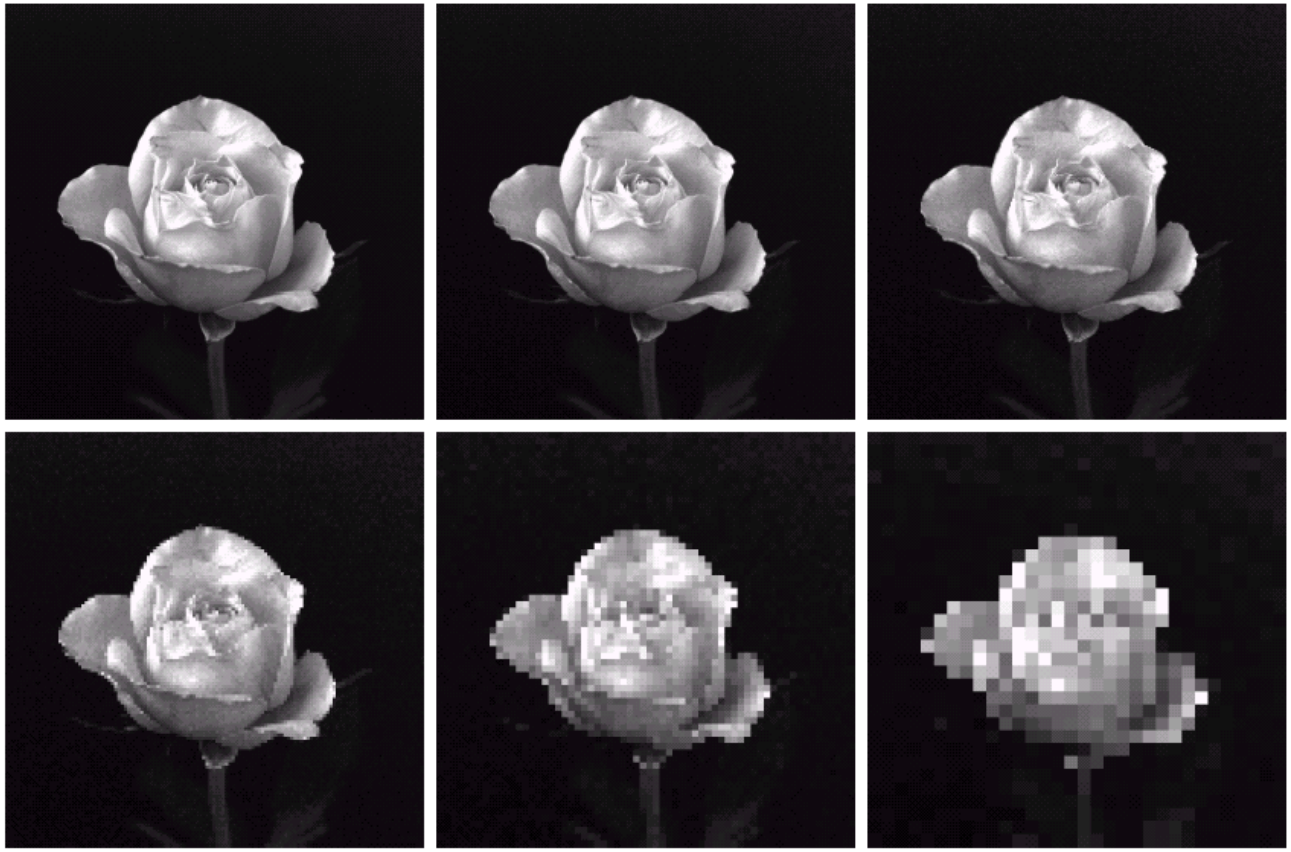



**FIGURE 2.19** A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

# Representing Digital Images



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.

# Spatial and Intensity Resolution

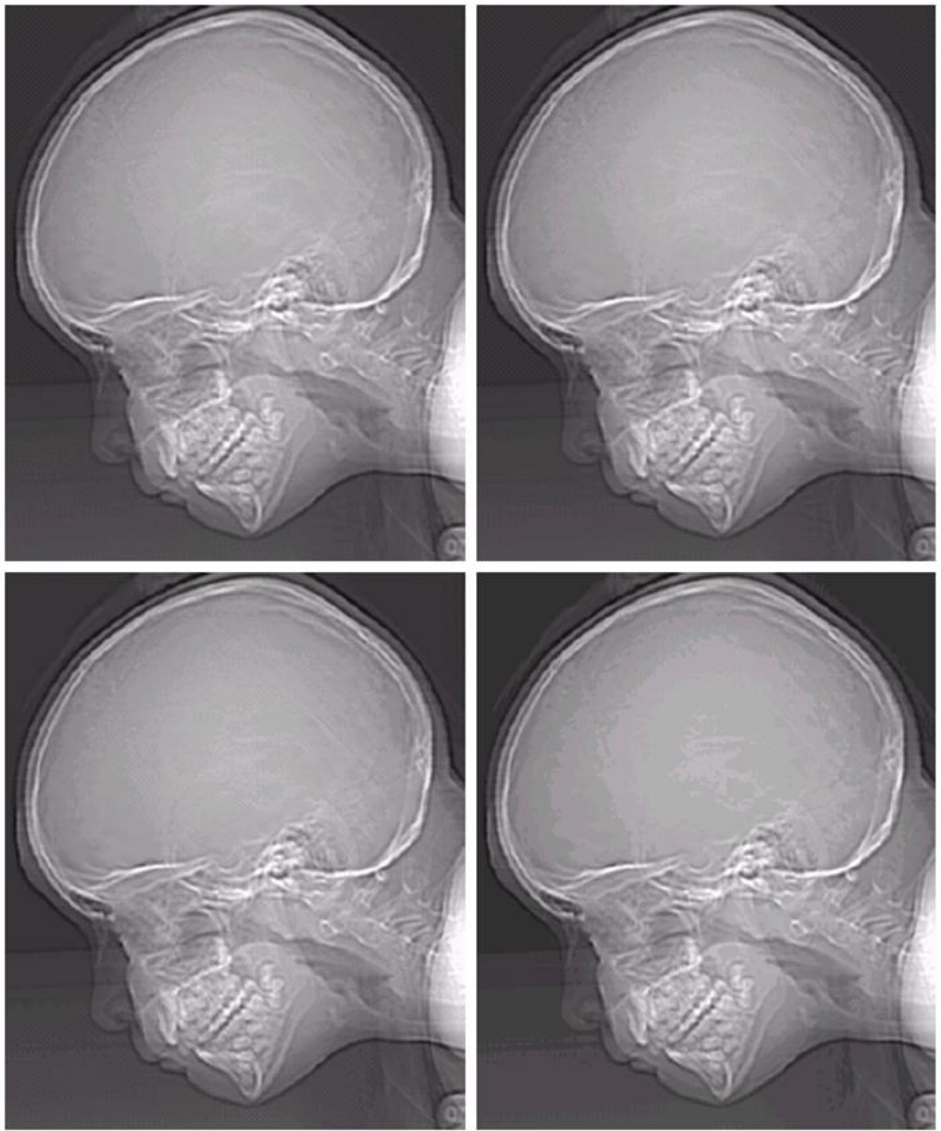
- Spatial Resolution:
  - a measure of the smallest discernible detail in an image.
- Intensity Resolution:
  - A measure of smallest discernible change is intensity level.

# 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



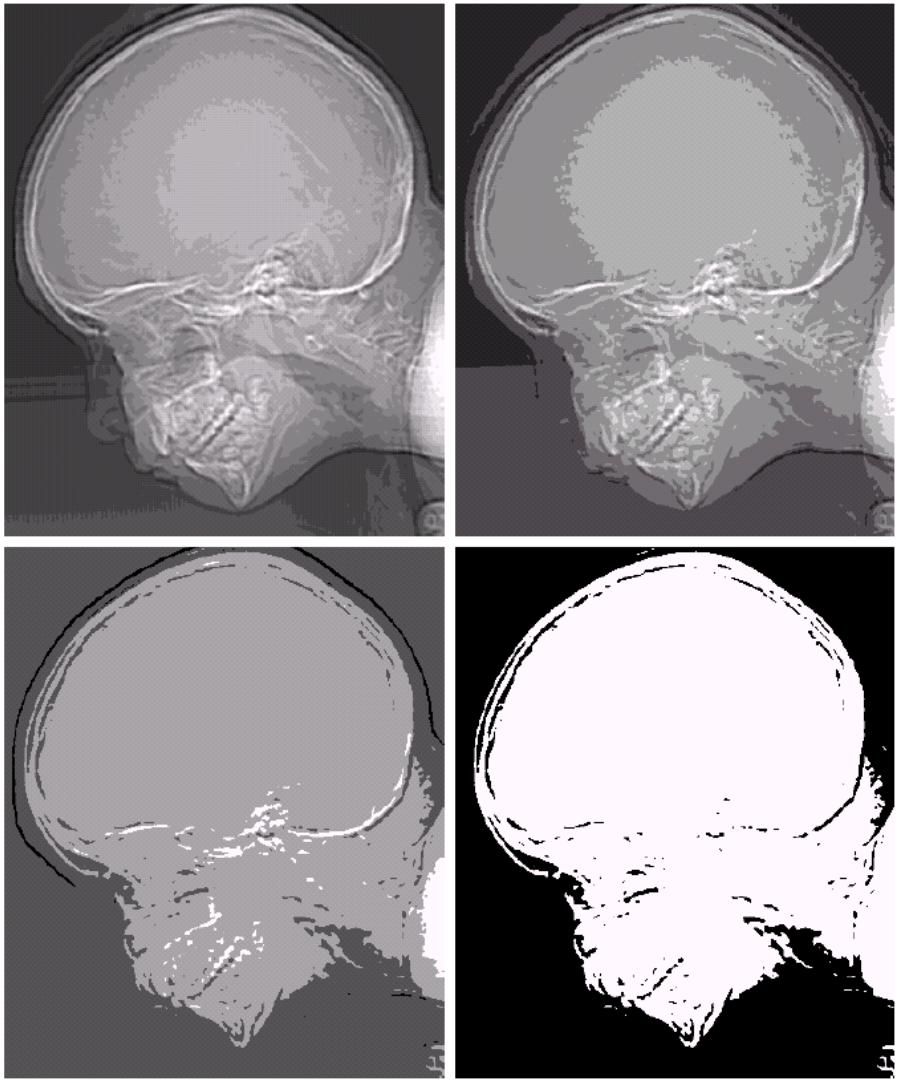
a b
c d

**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

e f
g h

**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.)



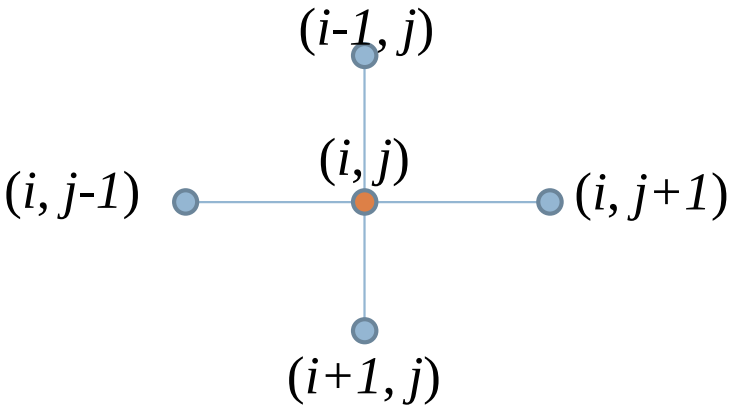
# Spatial and Intensity Resolution

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.)

# Basic Relationship Between Pixels

- Neighborhood of a Pixel $(i, j)$
  - 4 neighbors
    - (i-1,j), $(i+1,j)$, $(i,j-1)$, $(i,j+1)$




  - 8 neighbors
    - (i-1,j), $(i+1,j)$, $(i,j-1)$, $(i,j+1)$, (i-1,j-1), $(i+1,j-1)$, $(i-1,j+1)$, $(i+1,j+1)$

# Basic Relationship Between Pixels

- Adjacency
  - 4 adjacency: when pixels $p$ and $q$ are 4 neighbors
  - 8 adjacency: when pixels $p$ and $q$ are 8 neighbors
- Distance measures between two pixels p and q
  - Euclidean distance: $\mathrm{sqrt}((i-k)^2+(j-l)^2)$
  - City block distance: $|i-k|+|j-l|$
  - Chessboard distance: $\max(|i-k|,|j-l|)$

# Operations on Images

- An image is a matrix
- Practically any **activity** on an image matrix that produces another image is called an **operation** on the image
- Examples:
  - Filters
  - Point operations
  - Geometric transformations
  - …