数字图像基础
Digital Image Fundamentals

Contents

- Elements of Visual Perception(视觉感知基础)
- Image Sensing and Acquisition(图像的传感与获取)
- Image Sampling and Quantization(图像的数字化)
- Some Basic Relationships Between Pixels(像素空间关系)

Elements of Visual Perception

- **Human intuition and analysis play a central role in the choice of one technique versus another**
  - **This choice often is made based on subjective, visual judgments**
- **Developing a basic understanding of human visual perception**
  - **Most rudimentary aspects of human vision, in particular, the mechanics and parameters related to how images are formed in the eye, the physical limitations of human vision**

Structure of the Human Eye

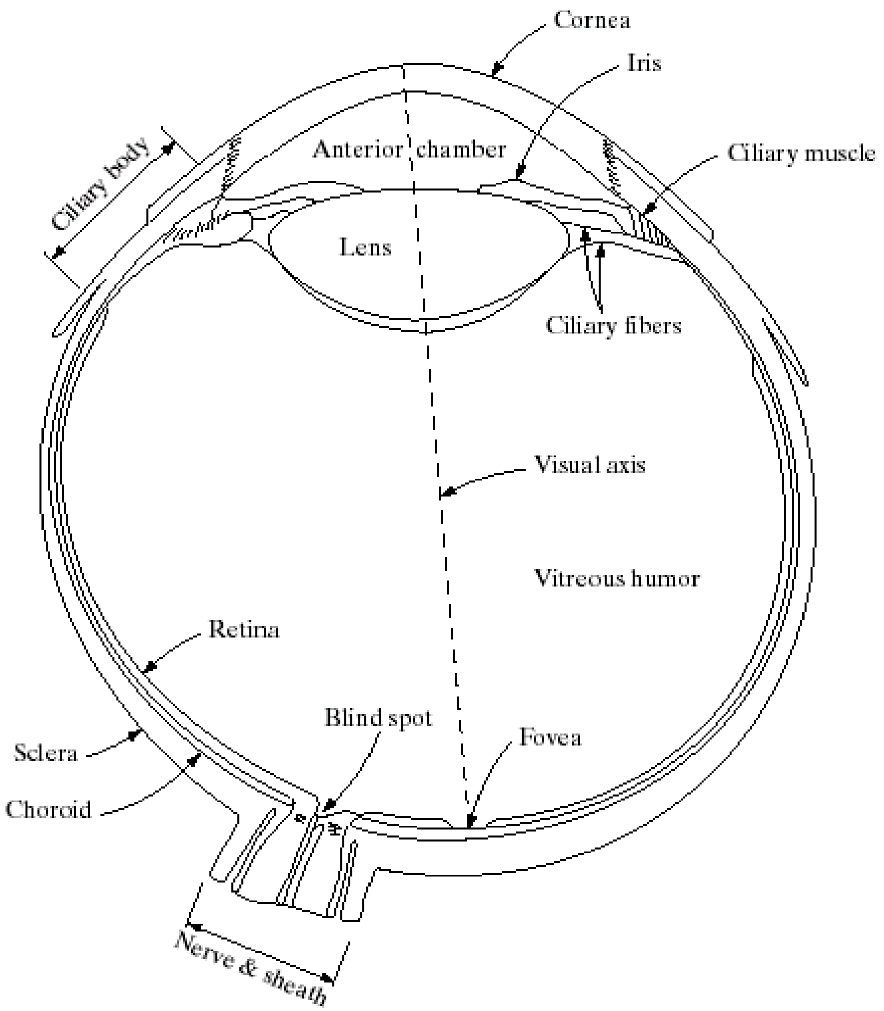


FIGURE 2.1
Simplified diagram of a cross section of the human eye.

Cornea: 角膜

Sclera: 巩膜

Choroid: 脉络膜

Retina: 视网膜

Lens: 晶状体

Fovea: 中央凹

Ciliary muscle: 睫状体

Structure of the Human Eye

- There are two classes of receptors distributed over the surface of the retina
  - *Cones*（锥状细胞）
    - 6~7 million in each eye, located primarily in the central portion of the retina, called the fovea
    - highly sensitive to color
    - Humans can resolve fine details with these cones largely because each one is connected to its own nerve end
    - cone vision is called photopic or bright-light vision（适亮视觉）

Structure of the Human Eye

- ***Rods*（柱状细胞）**
  - **75~150 million, distributed over the retina surface**
  - **give a general, overall picture of the field of view**
  - **they are not involved in color vision and are sensitive to low levels of illumination**
  - **for example, objects that appear brightly colored in daylight when seen by moonlight appear as colorless forms because only the rods are stimulated**
  - **this phenomenon is known as scotopic or dim-light vision（适暗视觉）**

Structure of the Human Eye

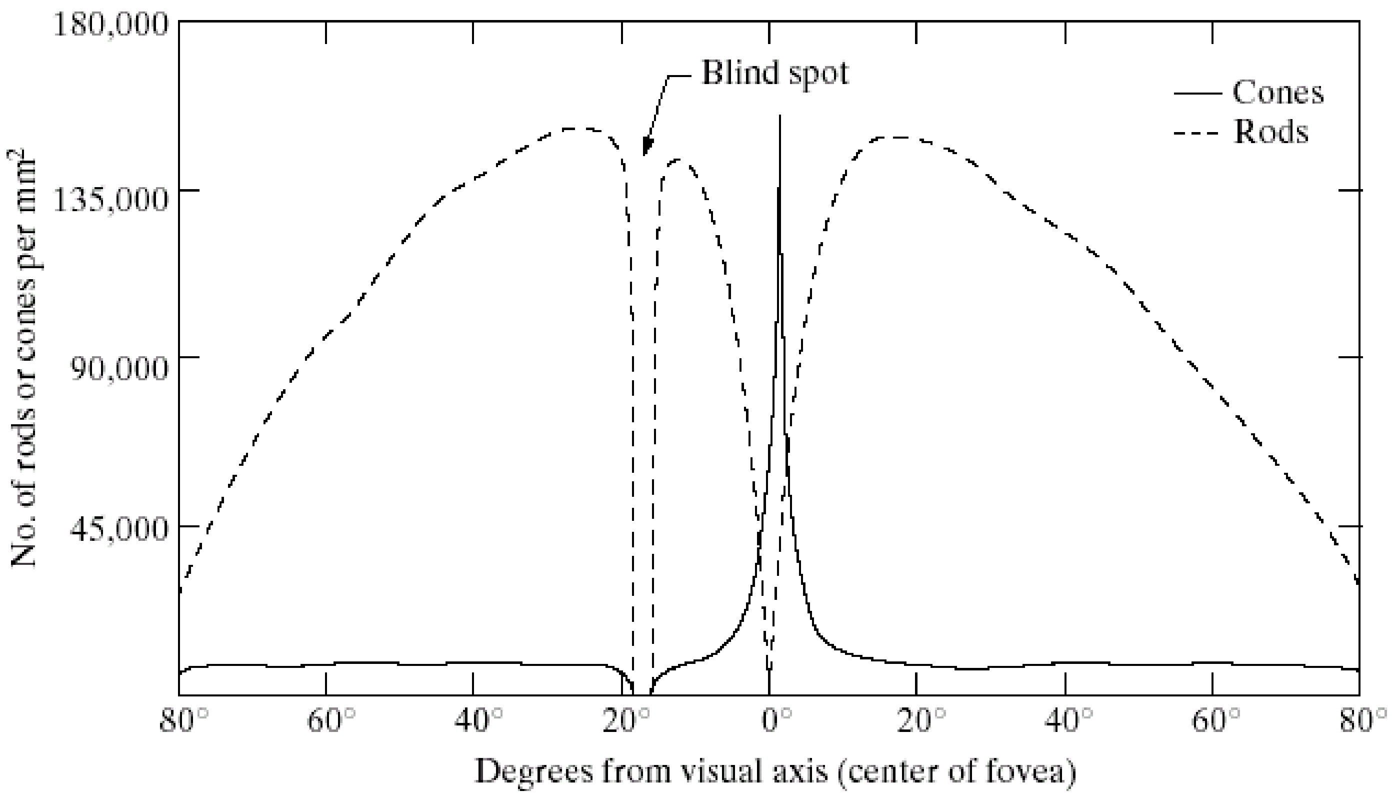
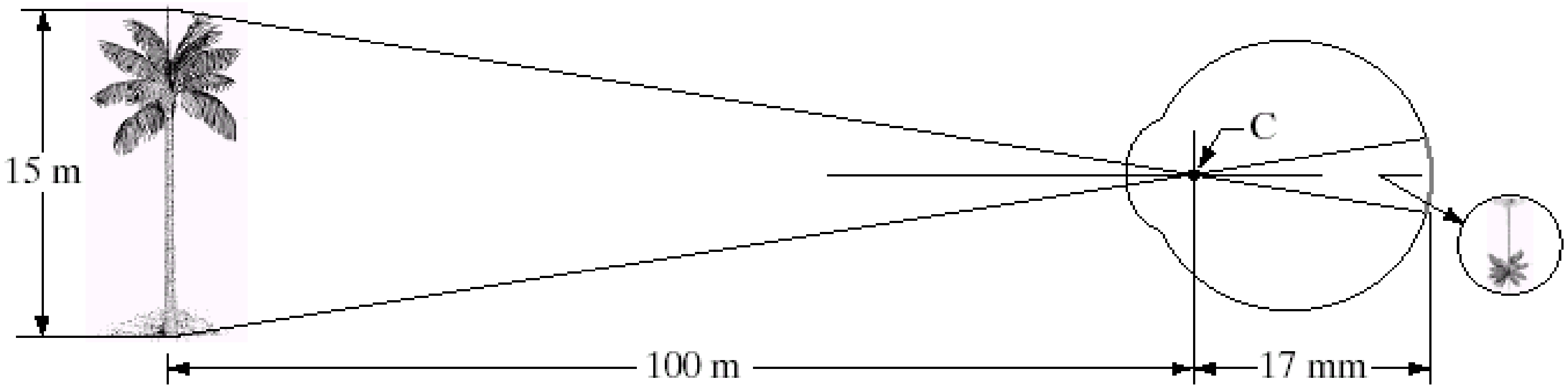


FIGURE 2.2 Distribution of rods and cones in the retina.

Image Formation in the Eye

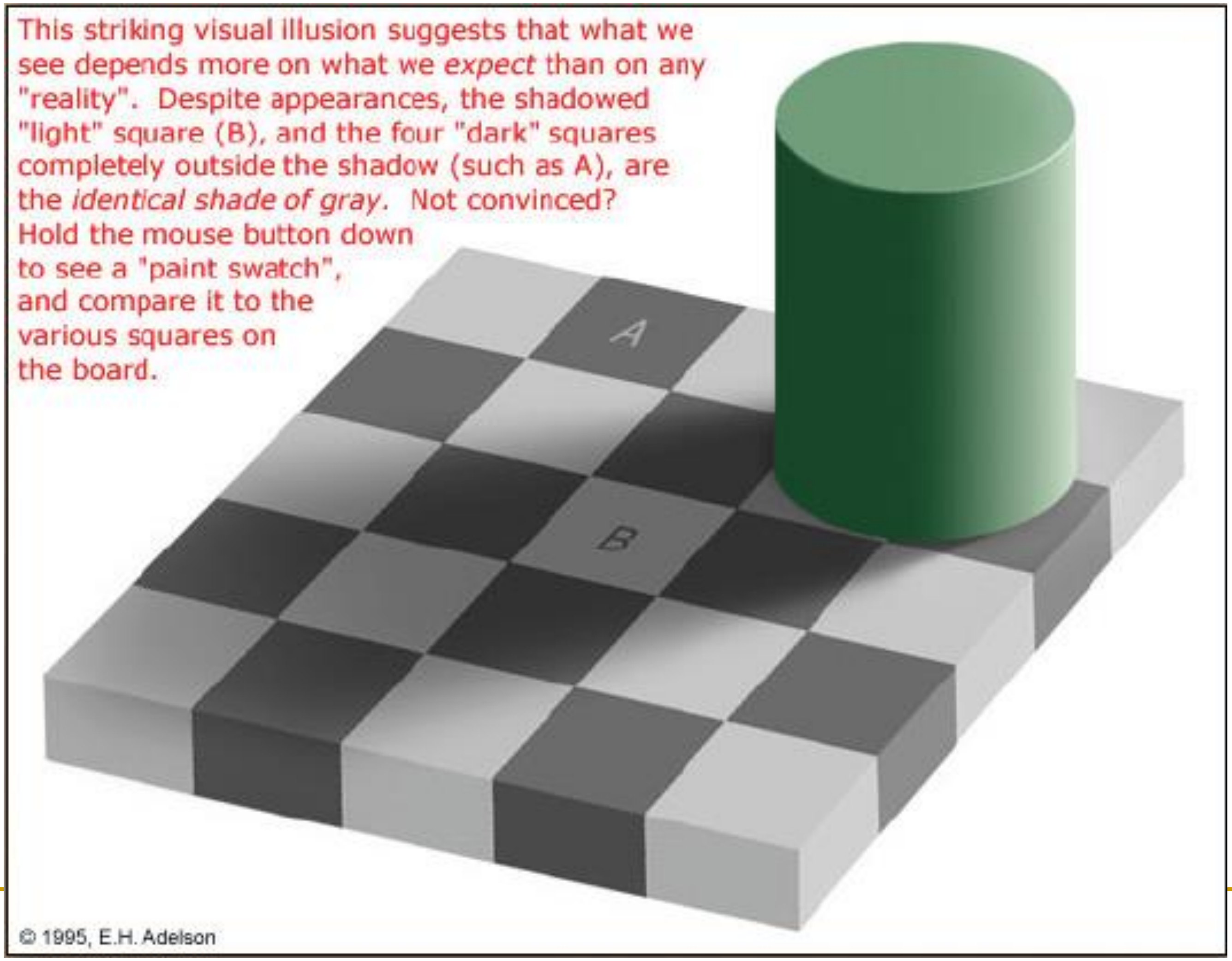
- **The distance between the center of the lens and the retina (called the *focal length*) varies from approximately 17 mm to about 14 mm, as the refractive power of the lens increases from its minimum to its maximum**

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



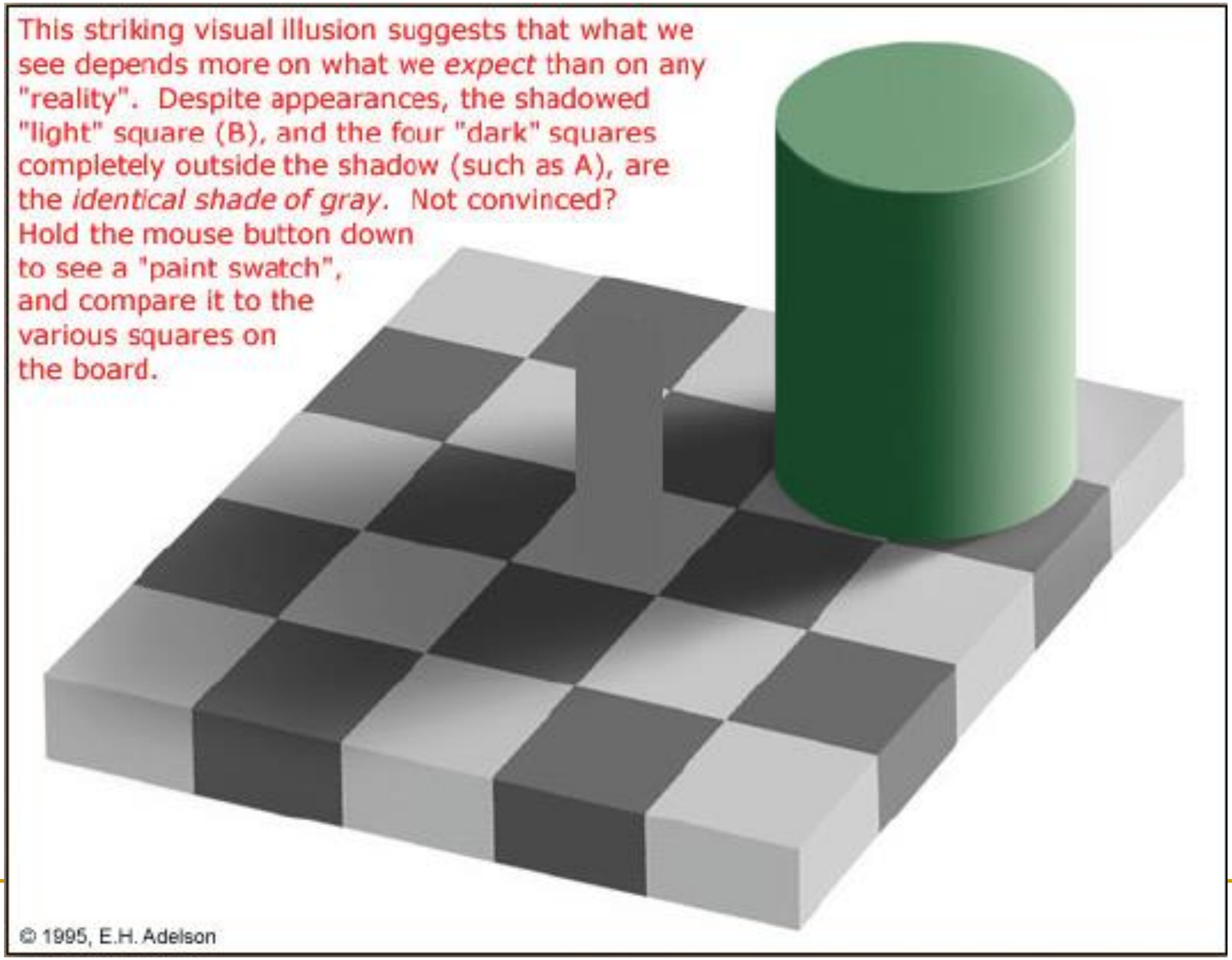
Brightness Adaptation and Discrimination

- **Perception**



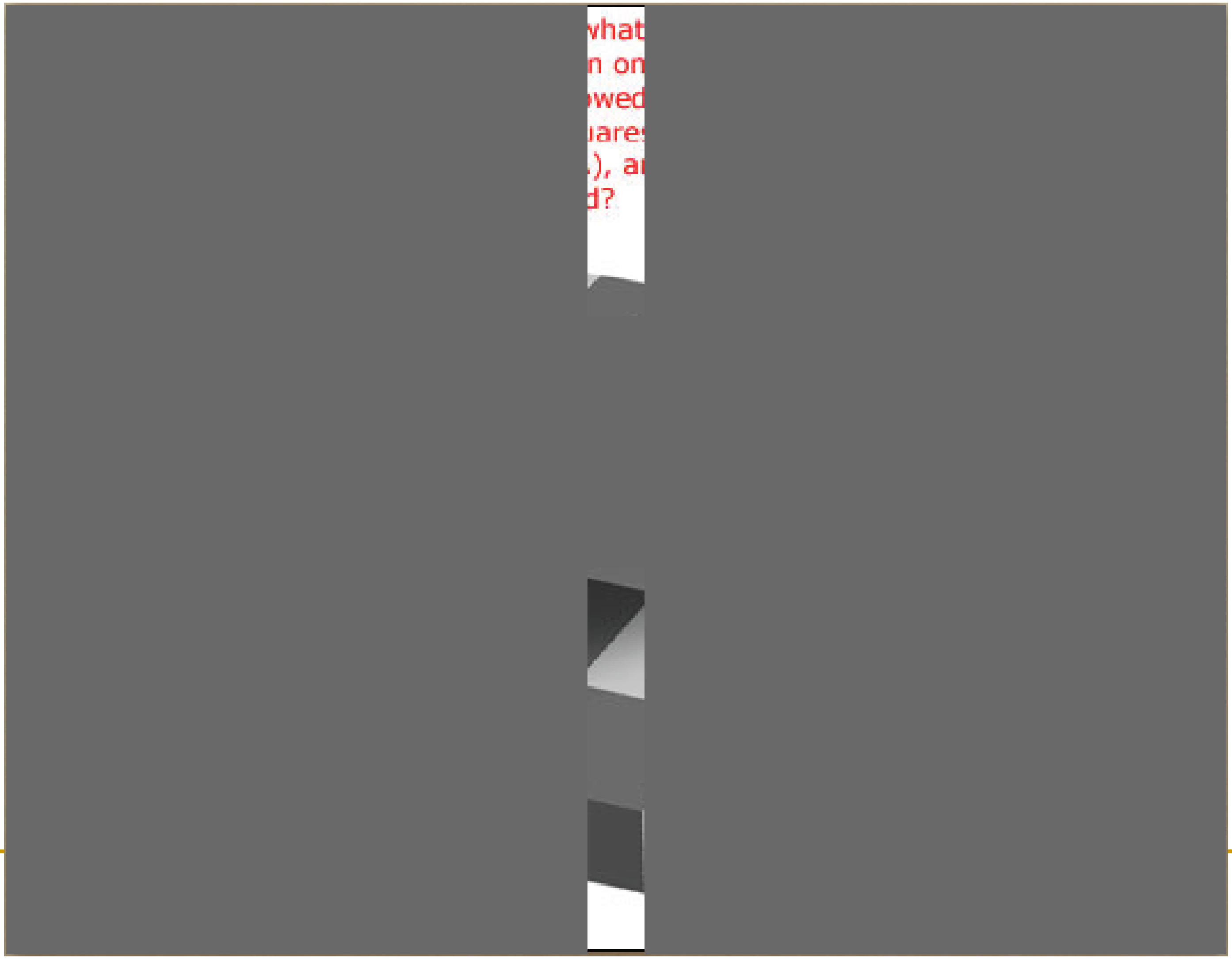
Brightness Adaptation and Discrimination

- Perception

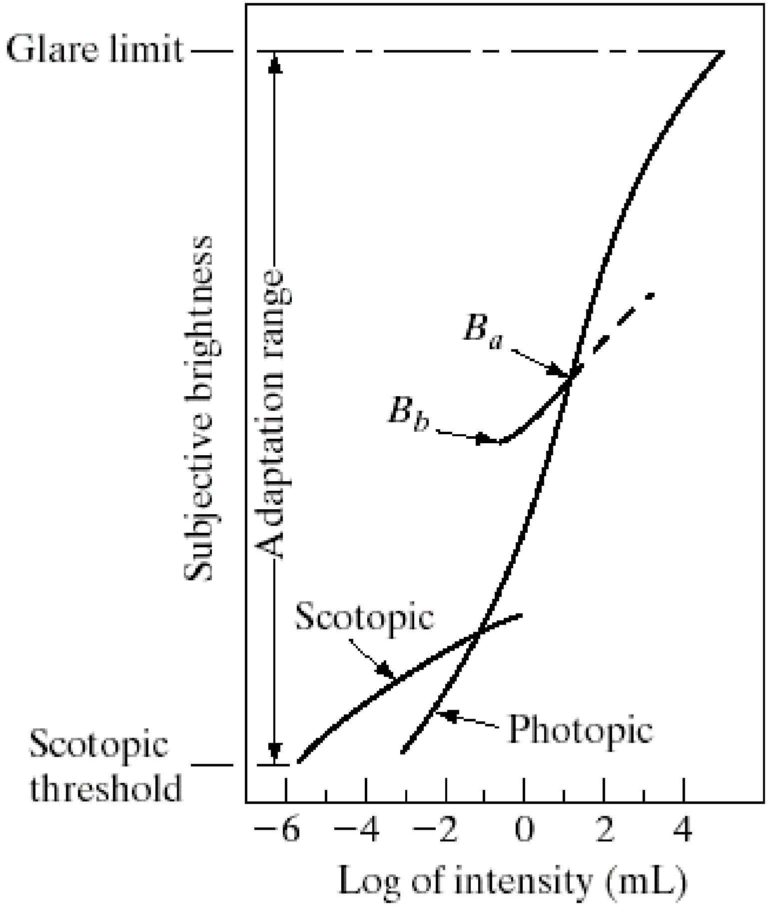


Brightness Adaptation and Discrimination

- Perception



Brightness Adaptation and Discrimination



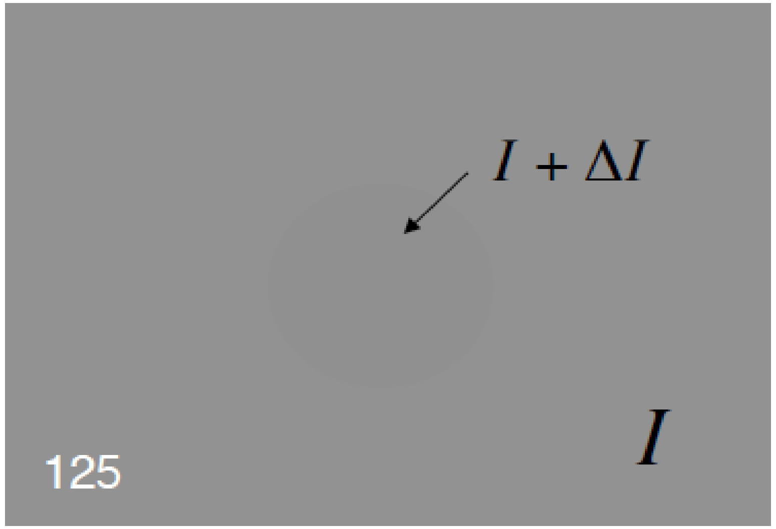
The range of light intensity levels to which the human visual system can adapt is enormous (on the order of 10^{10}), from the scotopic threshold to the glare limit

The total range of distinct intensity levels it can discriminate simultaneously is rather small when compared with the total adaptation range

subjective brightness **is a logarithmic function of the light intensity incident on the eye**

Brightness Adaptation and Discrimination

- **Having a subject look at a flat, uniformly illuminated area which is illuminated from behind by light source whose intensity *I*, add an increment, *ΔI*, to this field, in the form of a short-duration flash that appears as a circle in the center**
- **If *ΔI* is not bright enough, the subject says "no" indicating no perceivable change. As *ΔI* gets stronger, the subject says "yes" indicating a perceived change**



Can you see the circle?

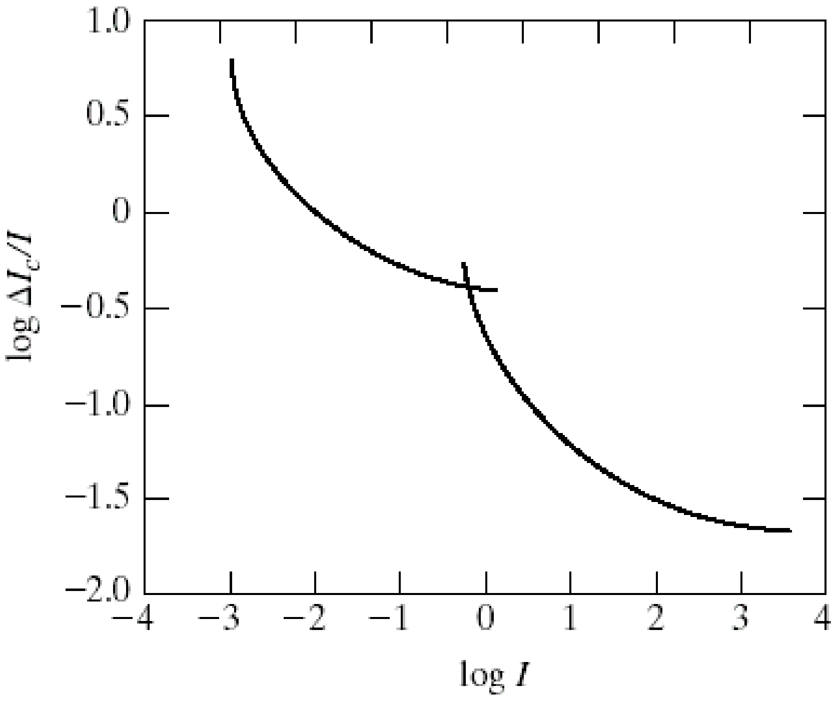
Source: Bernd Girod

Brightness Adaptation and Discrimination

- ***Weber ratio*:** **the quantity $\Delta I_c / I$, where ΔI_c is the increment of illumination discriminable 50% of the time with background illumination I**

This curve shows that:
brightness discrimination is poor at low levels of illumination, and it improves significantly as background illumination increased

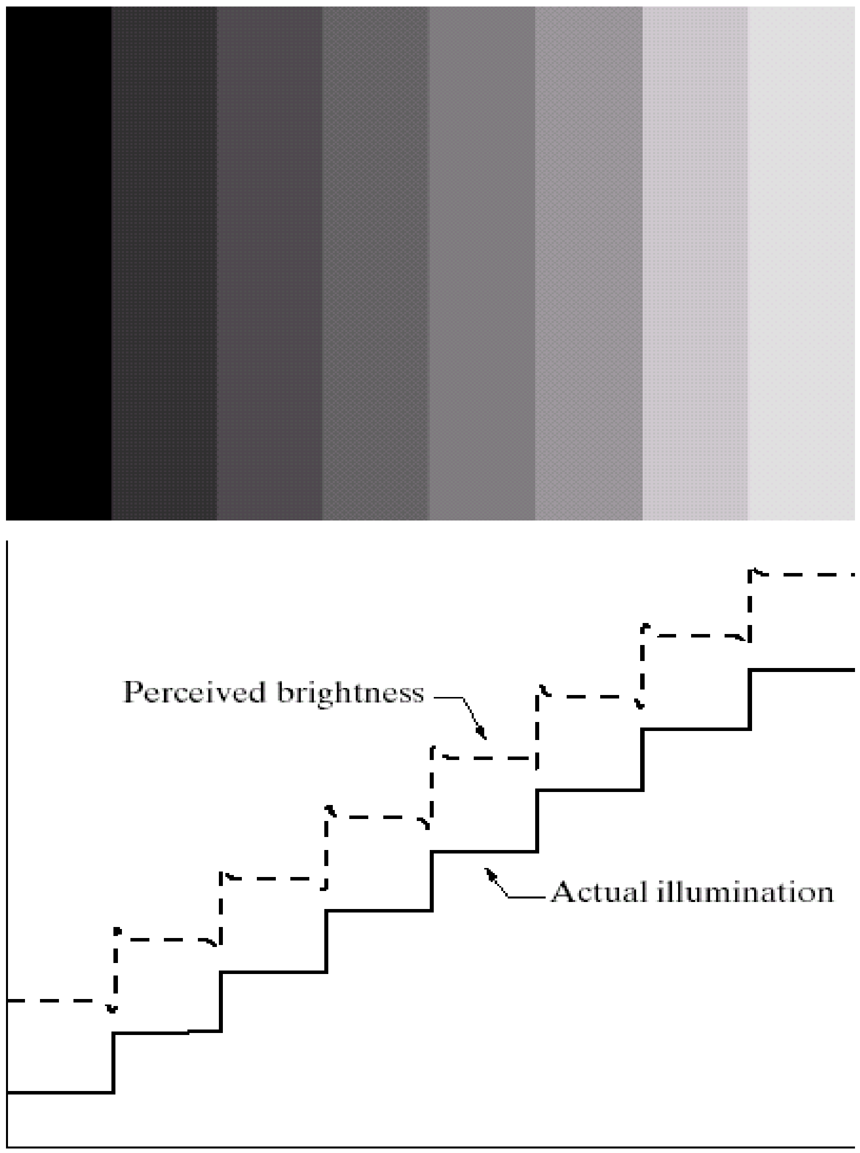
Two branches: rods and cones



Brightness Adaptation and Discrimination

- **Two phenomena clearly demonstrate that perceived brightness is not a simple function of intensity**
  - **Mach bands (Ernst Mach, 1865)**
  - **Simultaneous contrast**

Brightness Adaptation 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 Adaptation and Discrimination

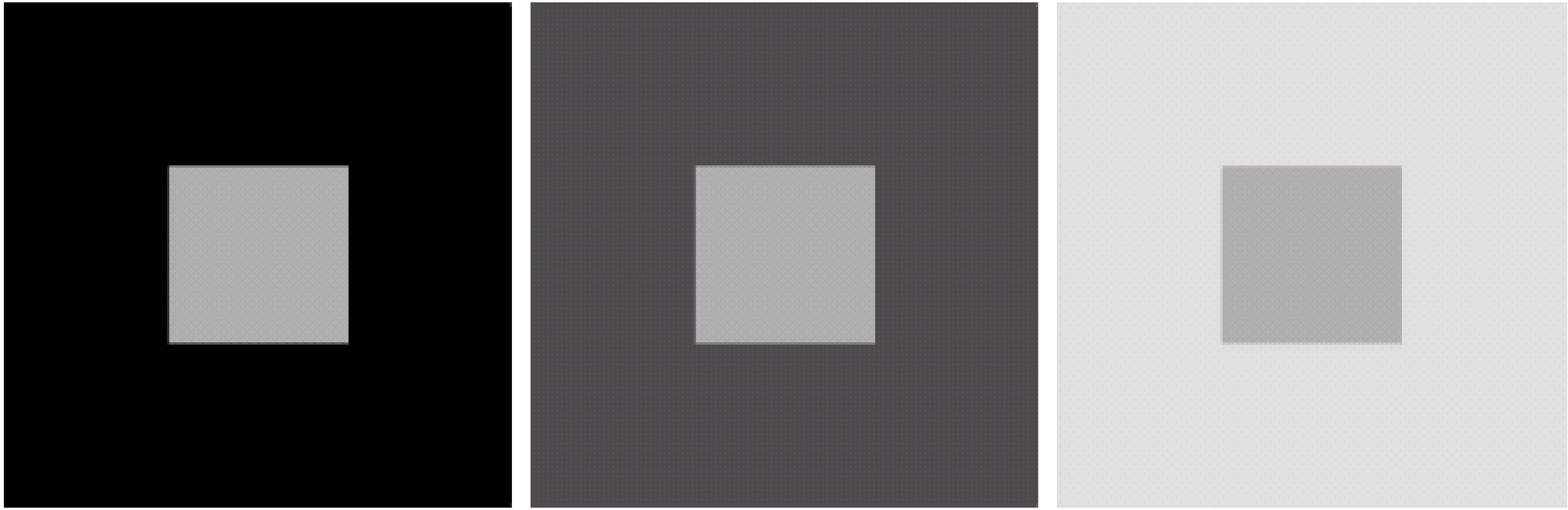


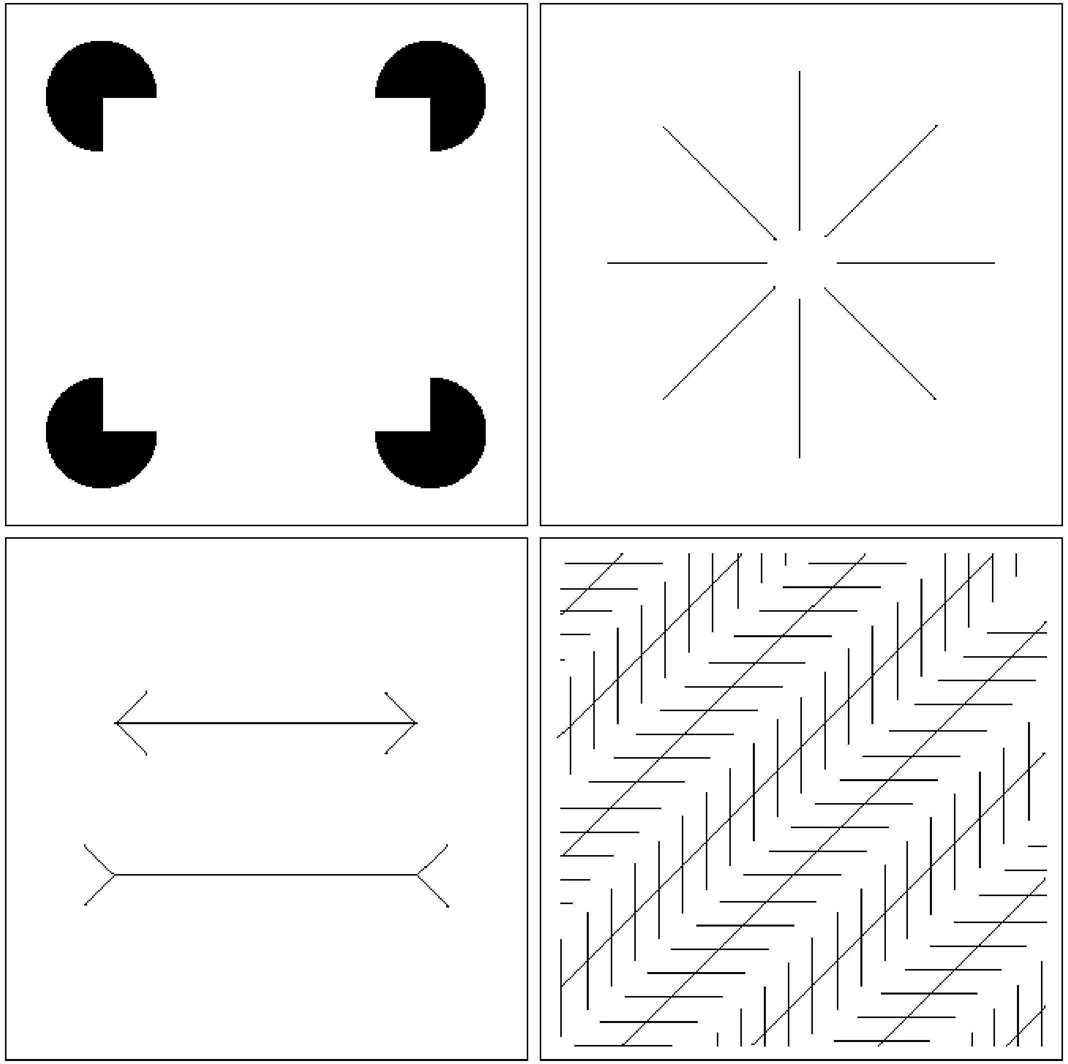
FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

Optical Illusions

Other examples of human perception phenomena

Optical illusions:

the eye fills in nonexisting information or wrongly perceives geometrical properties of objects



Optical Illusions

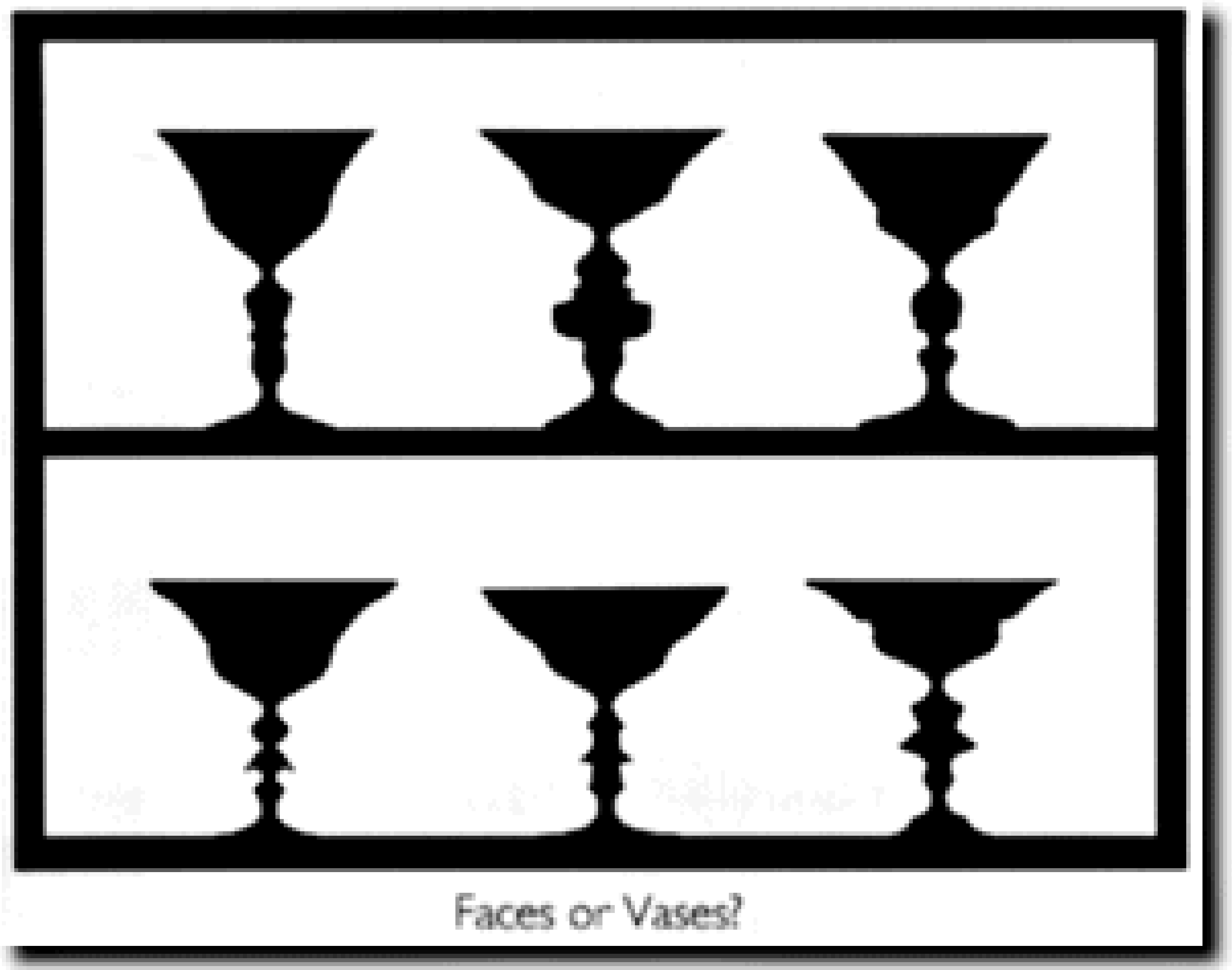


Image Sensing and Acquisition

- **Images are generated by the combination of**
  - **"illumination" source**
  - **reflection (absorption) of energy from that source by the elements of the "scene" being imaged**

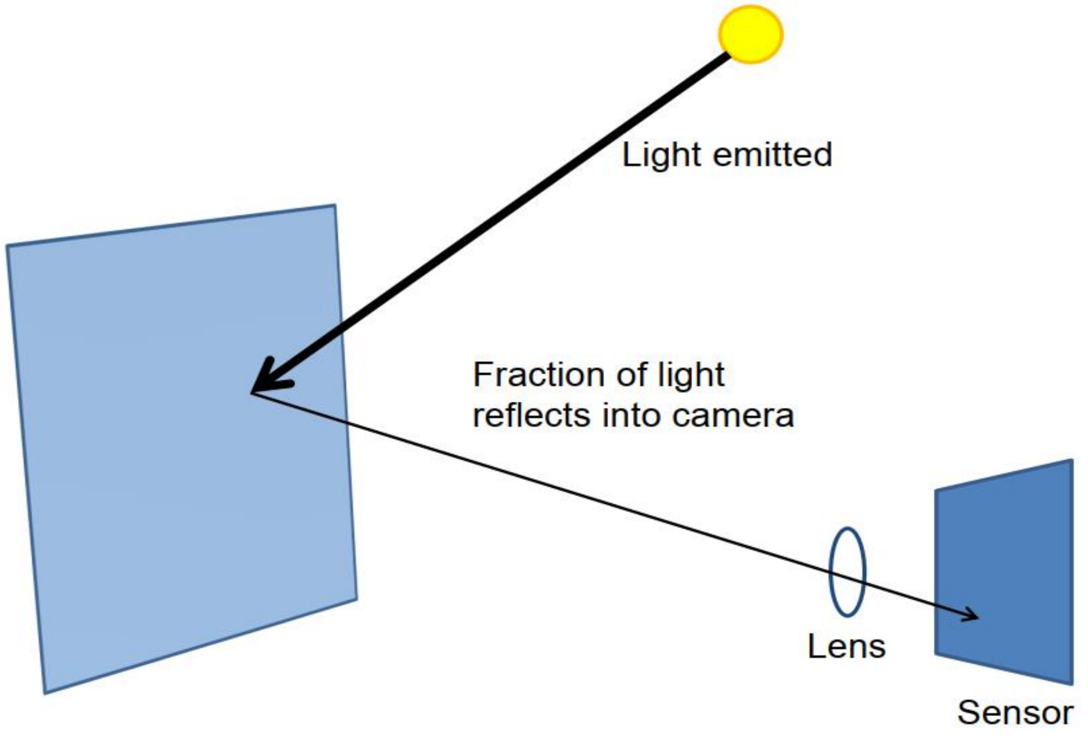


Image Sensing and Acquisition

- **A simple Image Formation Model**
  - ***f*(*x*, *y*) may be characterized by two components**

$$\boxed{f(x, y) = i(x, y) r(x, y)}$$

  - **illumination: *i*(*x*, *y*)**

$$\boxed{0 < i(x, y) < \infty}$$

  - **reflectance (transmissivity): *r*(*x*, *y*)**

$$\boxed{0 < r(x, y) < 1}$$

Image Sensing and Acquisition

- **The output of most sensors is continuous, to create a digital image, we need to convert the continuous sensed data into digital form.**

- **Image digitalization involves two processes:**
  - **Sampling:** **digitizing the coordinate values**
  - **Quantization:** **digitizing the amplitude values**

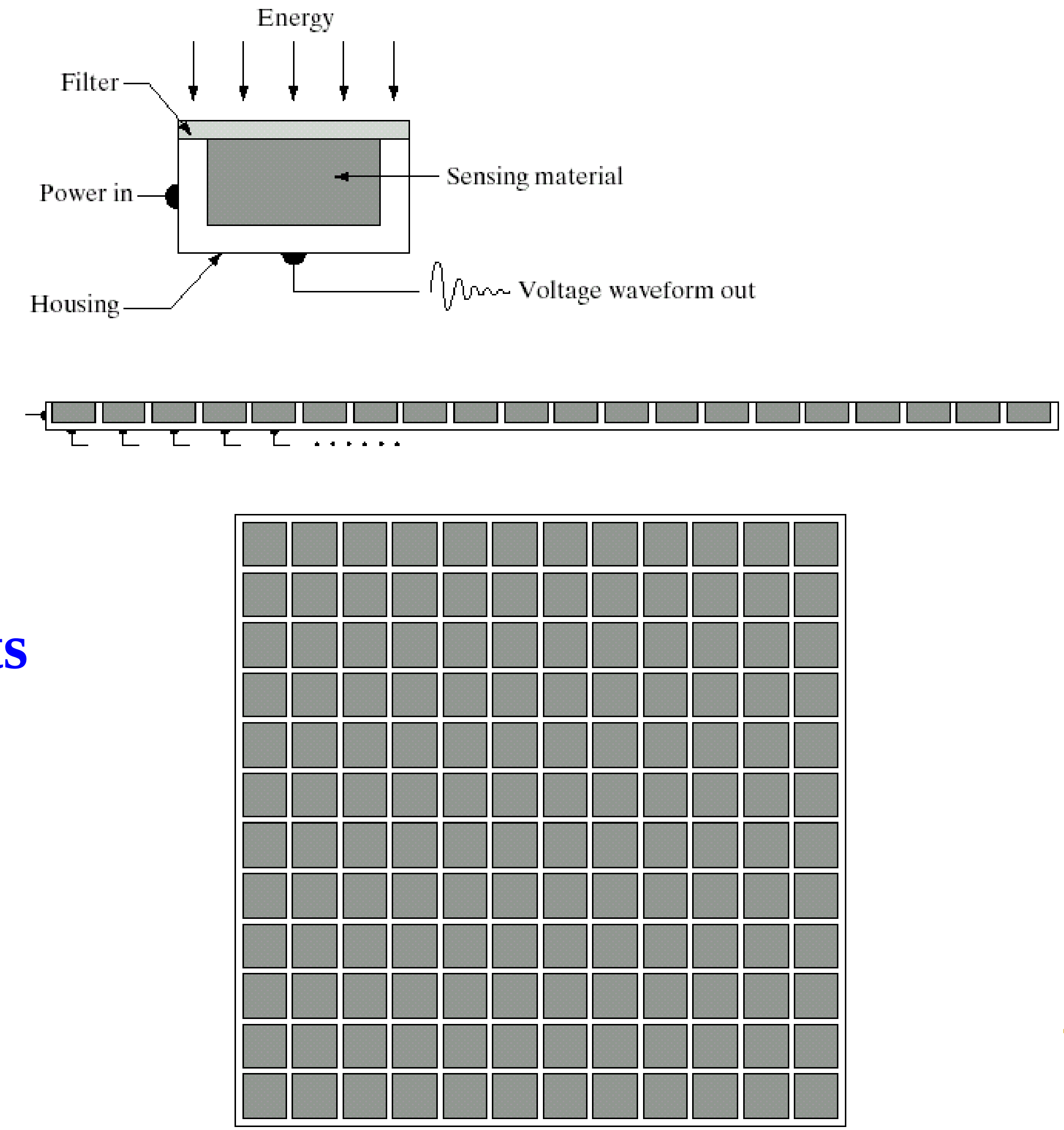
Image Sensing and Acquisition

- **In practice, the method of sampling is determined by the sensor arrangement**
  - **Single sensor: sampling is accomplished by selecting the number of individual mechanical increments at which we activate the sensor to collect data**
  - **Sensing strip: the number of sensors in the strip establishes the sampling limitations in one image direction**
  - **Sensing array: the number of sensors in the array establishes the limits of sampling in both directions**

Image Sensing and Acquisition

a
b
c

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



Three principal sensor arrangements used to transform illumination energy into digital images

Image Sensing and Acquisition

- **Image Acquisition Using a Single Sensor**

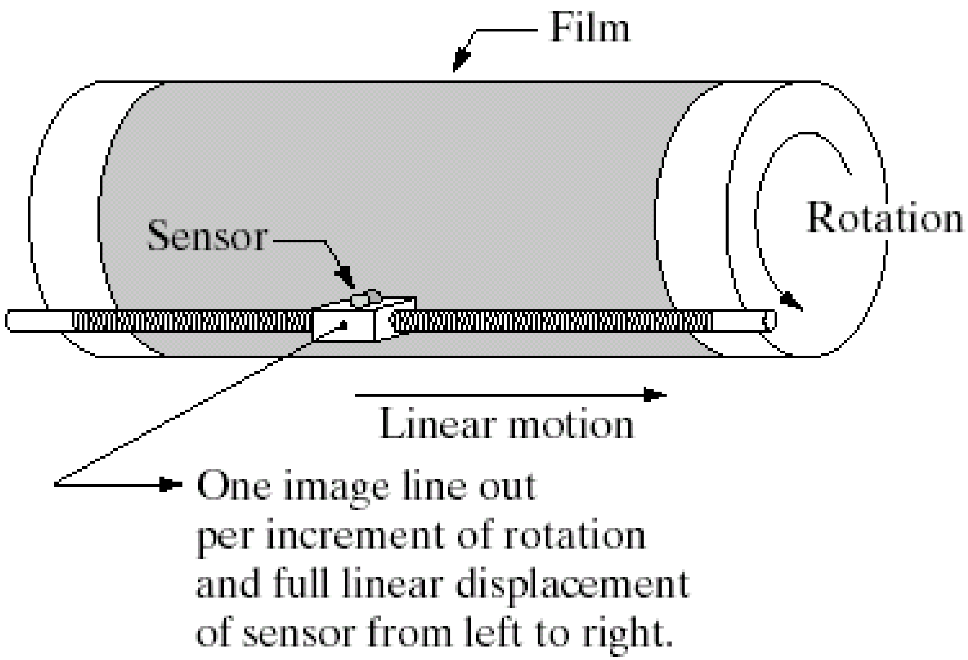
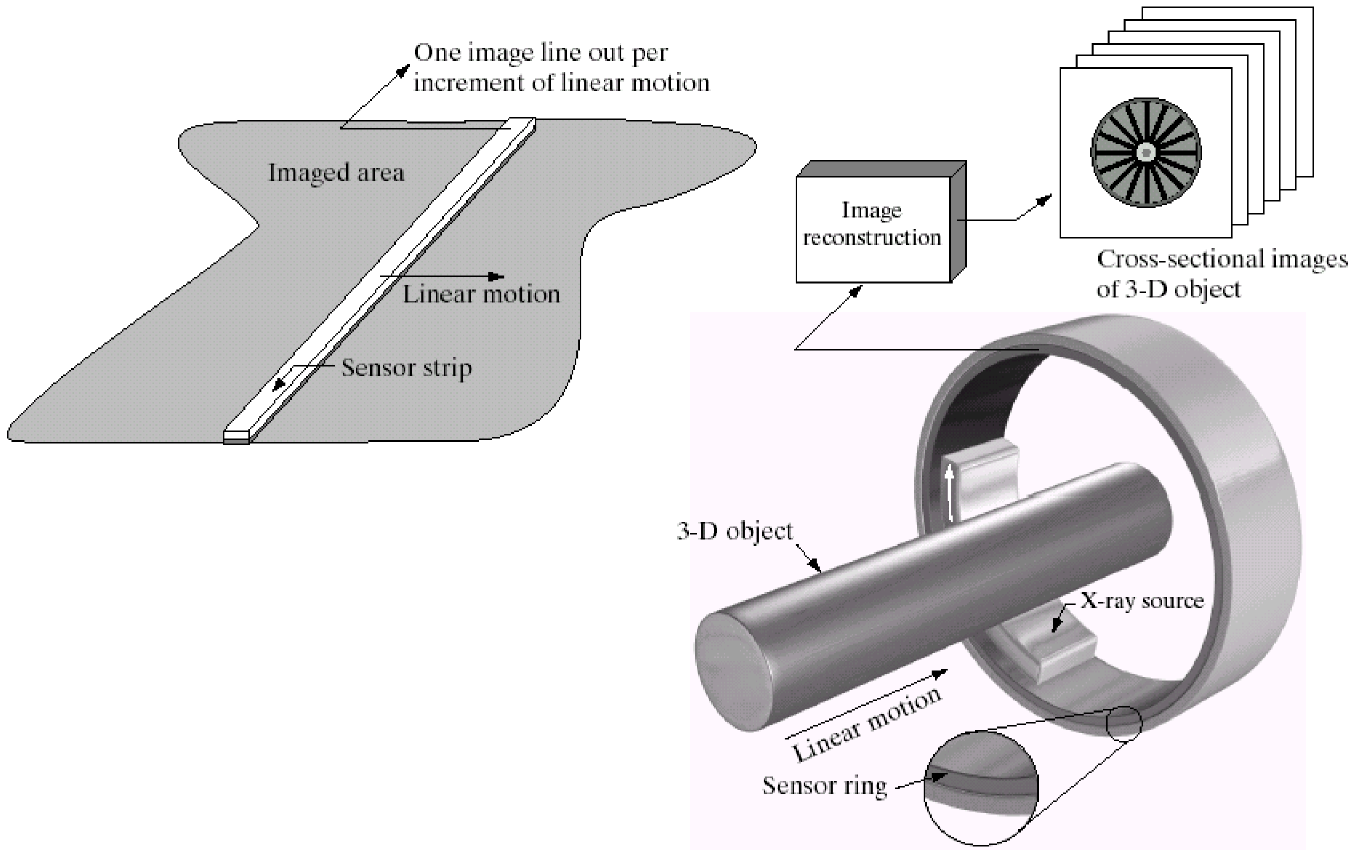


FIGURE 2.13 Combining a single sensor with motion to generate a 2-D image.

Image Sensing and Acquisition

- **Image Acquisition Using Sensor Strips**



a b

FIGURE 2.14 (a) Image acquisition using a linear sensor strip. (b) Image acquisition using a circular sensor strip.

Image Sensing and Acquisition

- **Image Acquisition Using Sensor Arrays**

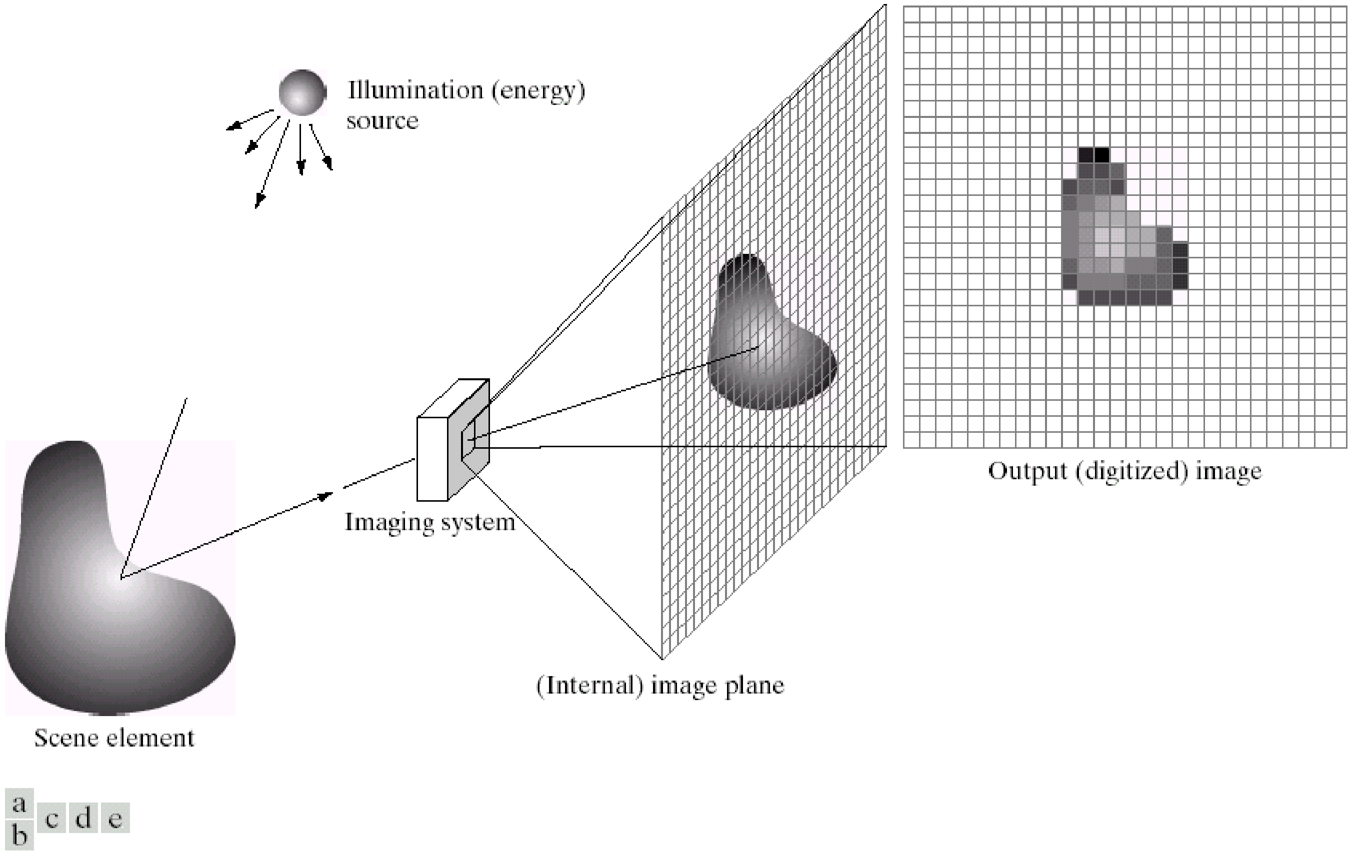


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Image Sampling and Quantization

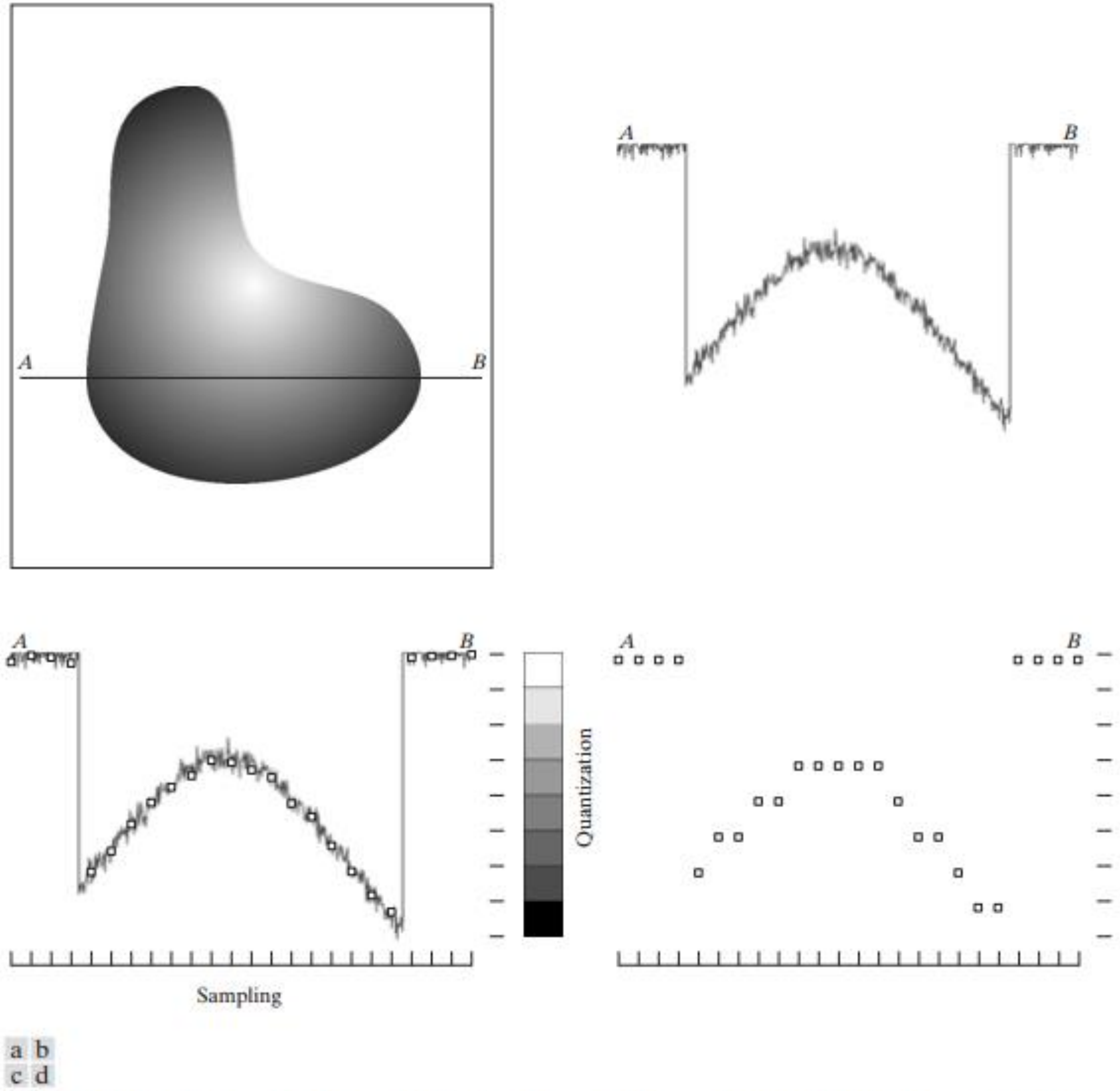
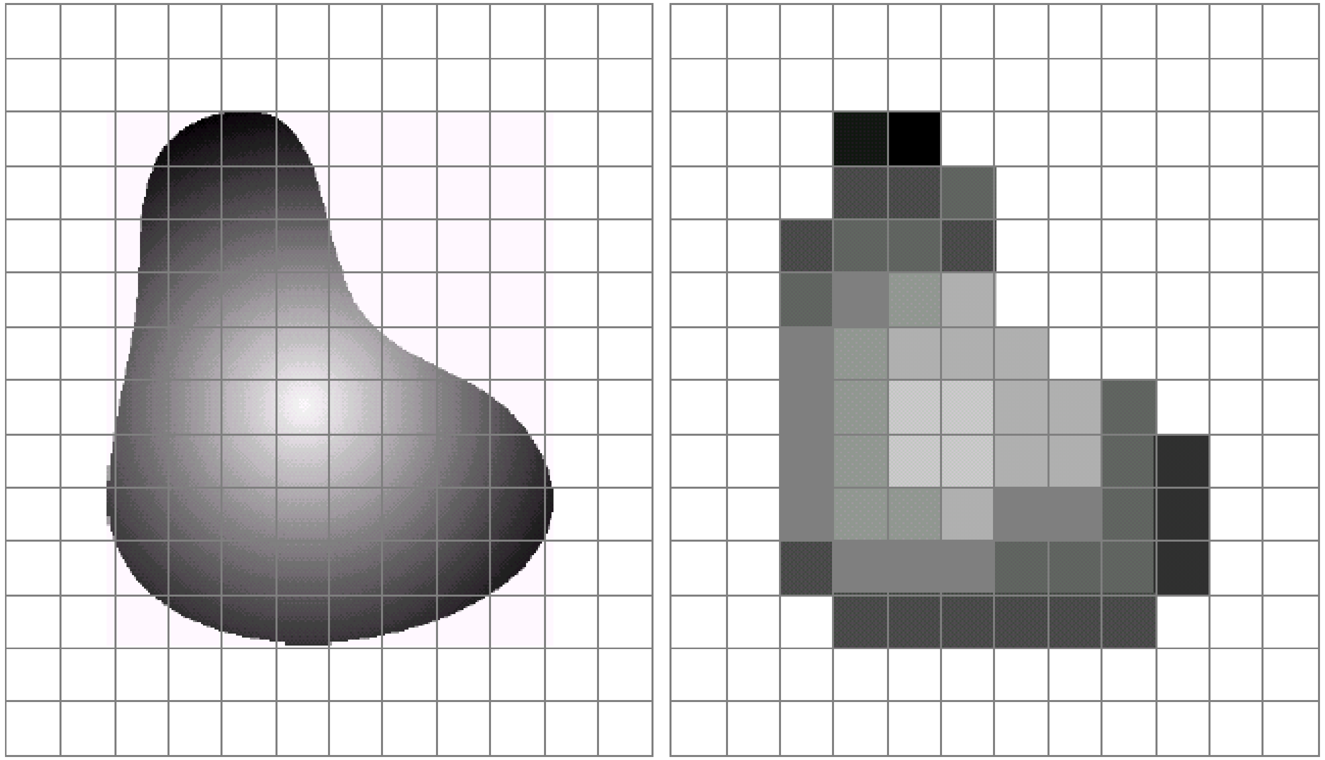


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Image Sampling and Quantization



a b

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

Image Sampling and Quantization

- **Representing Digital Images**

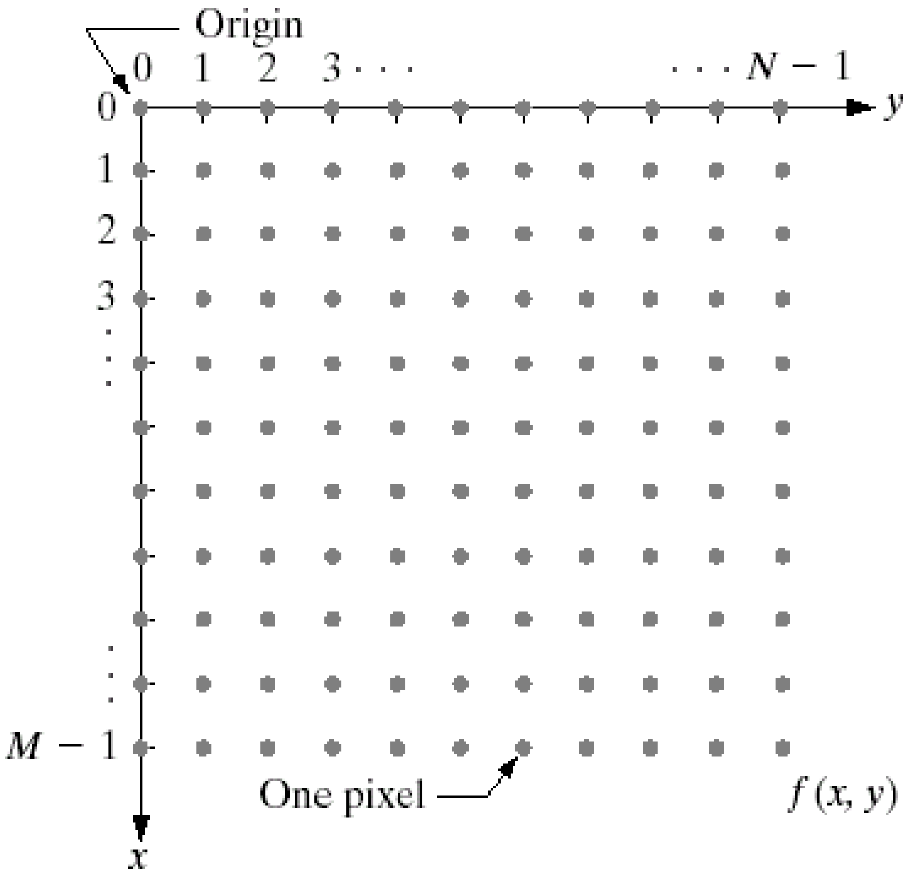


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

Image Sampling and Quantization

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

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

Image Sampling and Quantization

- **The number of gray levels:** $L = 2^k$
- **The number, *b*, of bits required to store a digitized image is:**

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

- **When M=N, this equation becomes**

$$b = N^2 \times k$$

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

Image Sampling and Quantization

- **Spatial resolution**
  - **The smallest discernible detail in an image**
  - **For a digital image:** $M \times N$

- **Gray-level resolution (pixel depth)**
  - **The smallest discernible change in gray level**
  - **For a digital image:** L

Image Sampling and Quantization

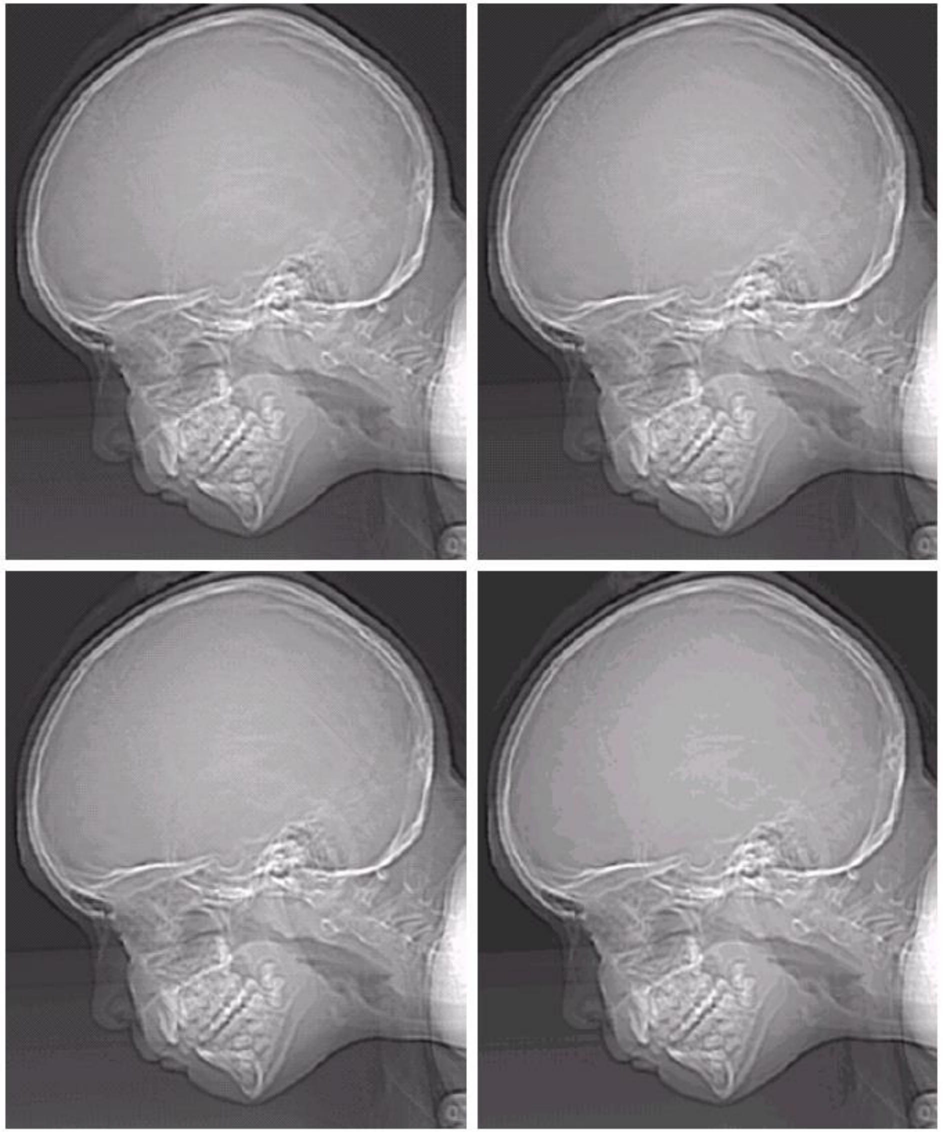
FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

Image Sampling and Quantization

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.

Image Sampling and Quantization



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.

Image Sampling and Quantization

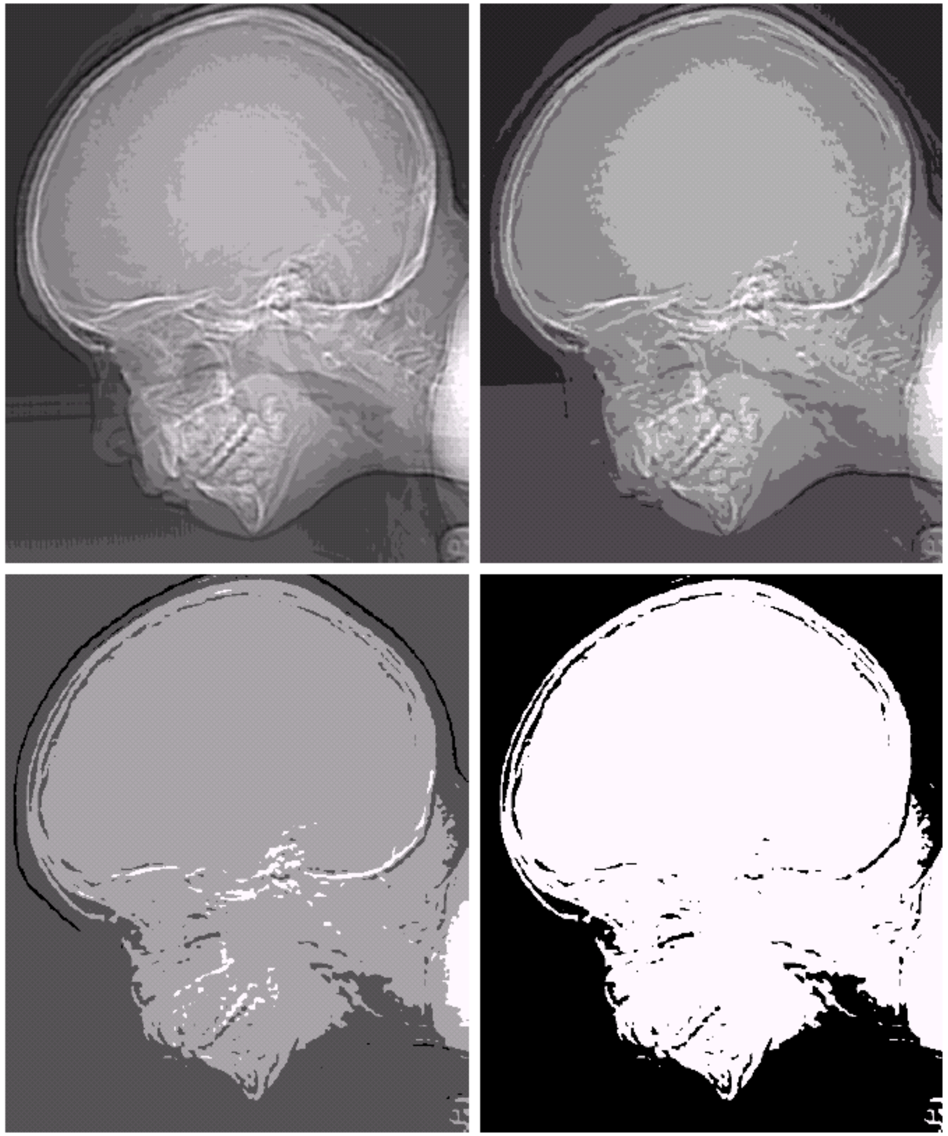


FIGURE 2.21 *(Continued)* (e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)

Image Sampling and Quantization

- **We have not considered yet any relationships that might exist between *N* and *k***

- **An early study by Huang [1965] attempted to quantify experimentally the effects on image quality produced by varying *N* and *k* simultaneously**

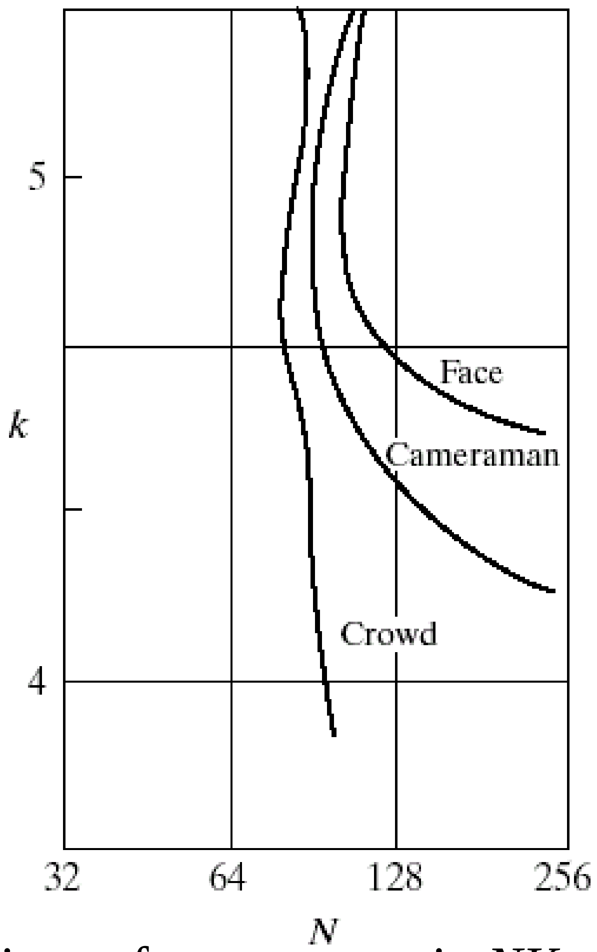
Image Sampling and Quantization

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.)

Image Sampling and Quantization

- **Isopreference curves tend to become more vertical as the detail in the image increases**
- **This result suggests that a large amount of detail only a few gray levels may be needed**



isopreference curve in *NK*-plane

Image Sampling and Quantization

- Zooming and shrinking require two steps
  - Step 1. the creation of new pixel locations
    - e.g., laying an imaginary 750×750 grid over the original image of size 500×500
  - Step 2. gray level assignment
    - nearest neighbor interpolation
    - bilinear interpolation

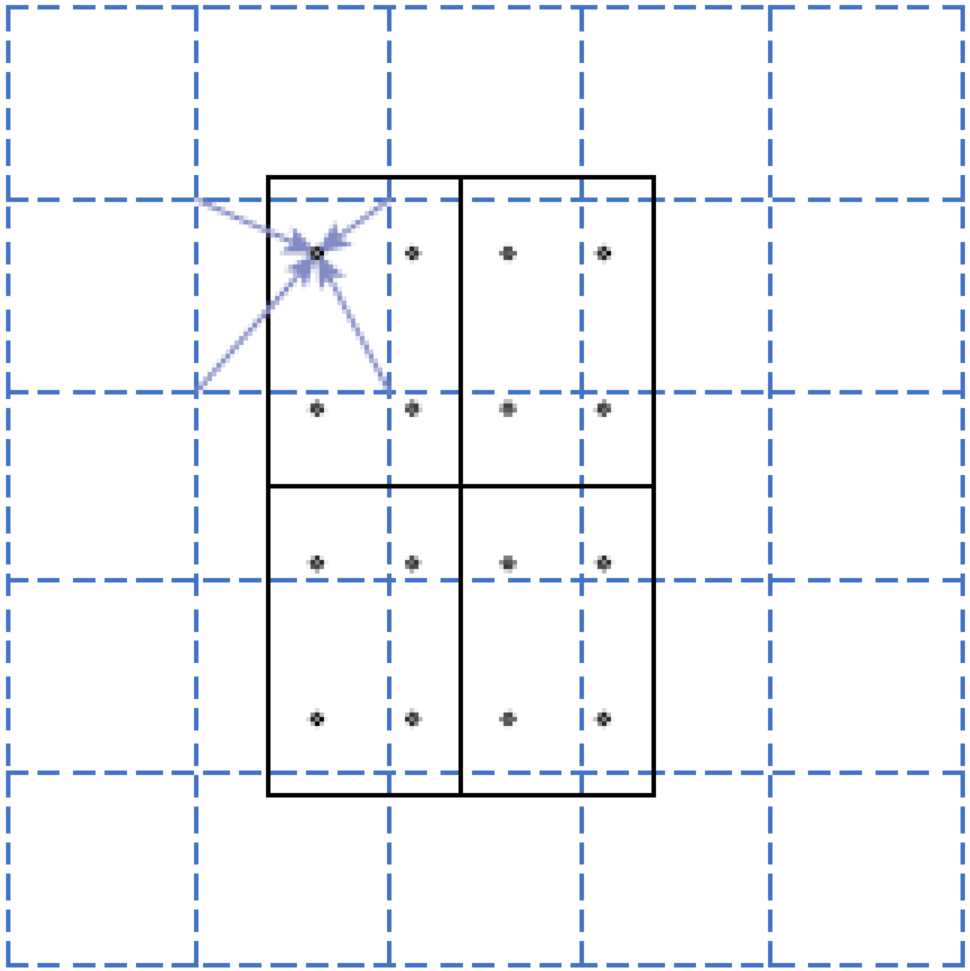


Image Sampling and Quantization

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.

Some Basic Relationships Between Pixels

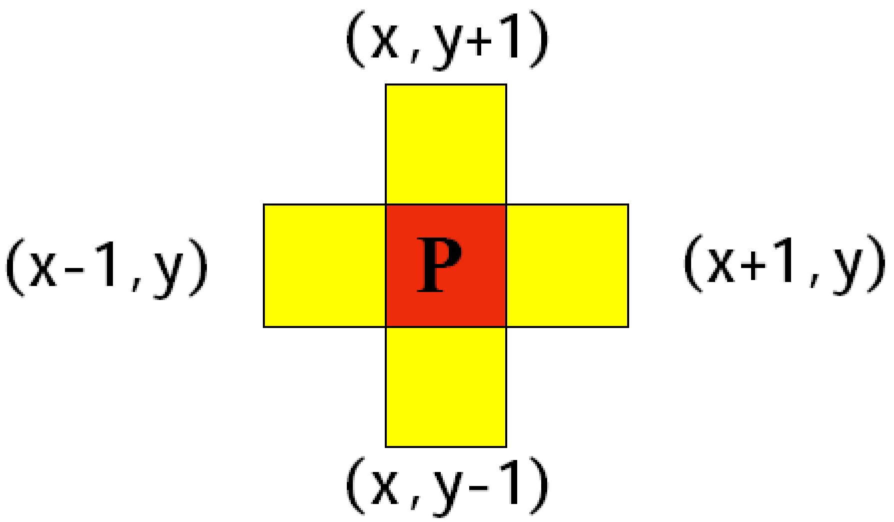
- Pixel to pixel contact (像素间联系)
- Geometric distortion correction (几何失真校正)

像素间联系

- **像素*p*的邻域**
  - **4近邻（4-neighbors）：$N_4(p)$**
  - 对角近邻（**D-neighbors**）**：$N_D(p)$**
  - **8近邻（8-neighbors）：$N_8(p)$**

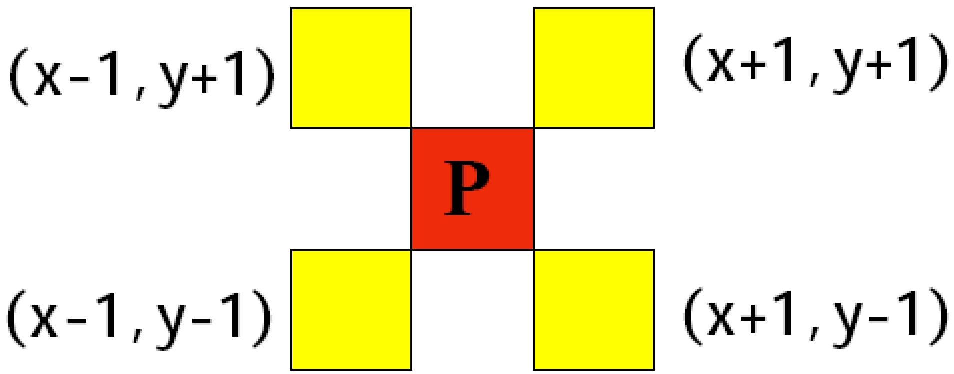
像素间联系

- 像素p的空间坐标为(x, y)，则$N_4(p)$为：



像素间联系

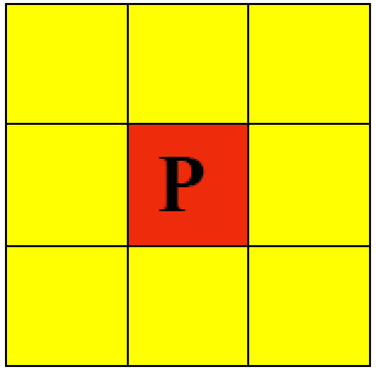
- 像素*p*的空间坐标为(x, y)，则$N_D(p)$为：



像素间联系

- 像素p的空间坐标为(x, y)，则$N_8(p)$为：

$$N_8(p) = N_4(p) + N_D(p)$$



像素间联系

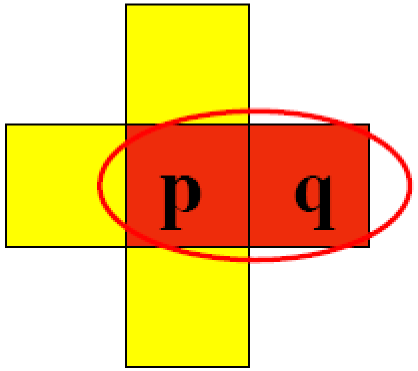
- 连通性(connectivity)是描述区域和边界的基本概念
- 两个像素具有连通性的两个必要条件
  - 两个像素是否相邻
  - 它们的灰度级是否满足相似性准则
    - 设V是具有相似灰度的集合。对于二进制图像，可令V={1}；对于具有256灰度级的灰度图像，V是这256数值中的一个子集

像素间联系

- **连通性**
  - **4连通（4-adjacency）**
  - **8连通（8-adjacency）**
  - **m连通（m-adjacency，混合连通）**

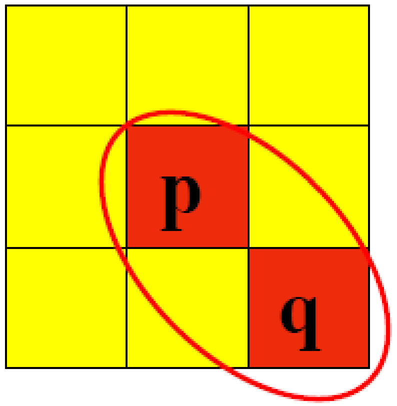
像素间联系

- **4连通（4-adjacency）**
  - 像素p和q的象素值都属于集合V，如果q属于集合$N_4(p)$，则称p和q是4连通



像素间联系

- **8连通（8-adjacency）**
  - 像素p和q的象素值都属于集合V，如果q属于集合$N_8(p)$，则称p和q是8连通



像素间联系

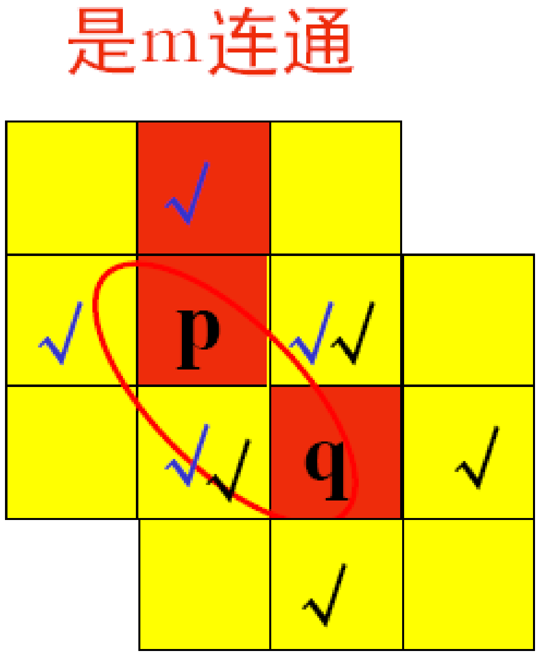
- ***m*****连通**（***m*****-adjacency**）
  - 像素p和q的象素值都属于集合V，如果

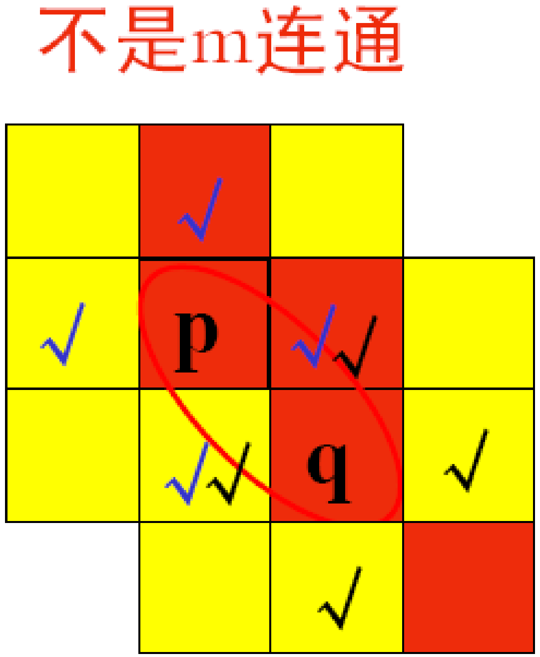
(i) q属于集合$N_4(p)$，或者

(ii) q属于集合$N_D(p)$，且$N_4(p) \cap N_4(q)$中没有像素值属于集合V的像素

则称p和q是m连通

像素间联系





像素间联系

- **通路（path）**
  - 从像素p到像素q的通路是指这样的一系列像素：(x_0, y_0) (x_1, y_1) ,…,(x_n, y_n)，其中(x_0, y_0)是像素p的坐标，(x_n, y_n)是像素q的坐标，像素(x_i, y_i) 和像素(x_{i-1}, y_{i-1}) 是连通的，$1<=i<=n$。n称为通路的长度，如果$(x_0, y_0)= (x_n, y_n)$，则称通路是闭合的。

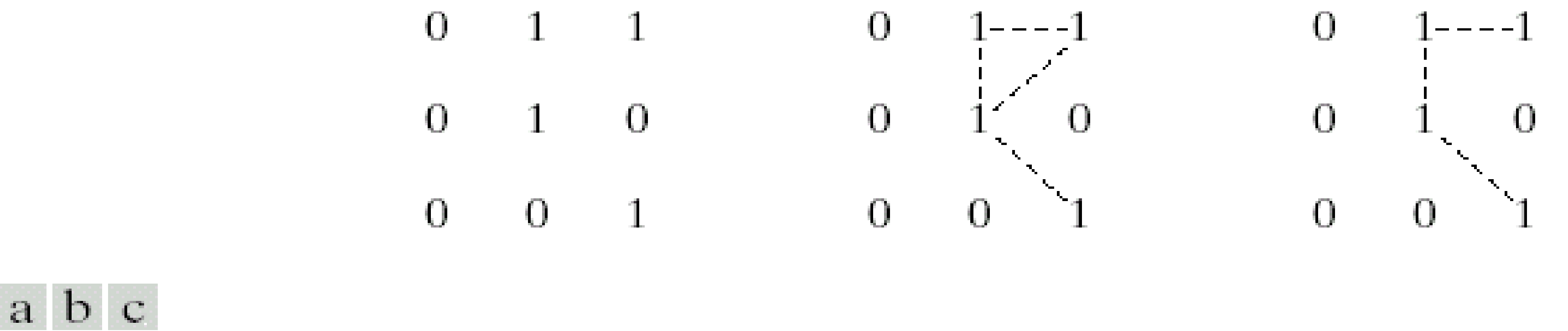


FIGURE 2.26 (a) Arrangement of pixels; (b) pixels that are 8-adjacent (shown dashed) to the center pixel; (c) *m*-adjacency.

像素间联系

- **距离度量**
  - 对于像素 p, q 和 z，坐标分别为 (x, y)，(s, t) 和 (v, w)，如果满足：
    - (a). $D(p, q) >= 0$ ($D(p, q)=0$ if $p=q$)
    - (b). $D(p, q) = D(q, p)$
    - (c). $D(p, z) <= D(p, q) + D(q, z)$

  则称 D 是一个距离函数

像素间联系

- **欧式距离（Euclidean distance）**

$$D_e(p,q) = [(x-s)^2 + (y-t)^2]^{\frac{1}{2}}$$

像素间联系

- **D_4距离（或city-block距离）**

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

		2		
	2	1	2	
2	1	0	1	2
	2	1	2	
		2		

像素间联系

- **D_8 距离（或chessboard距离）**

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

2	2	2	2	2
2	1	1	1	2
2	1	0	1	2
2	1	1	1	2
2	2	2	2	2

几何失真校正

- 在许多实际的图像采集过程中，图像中像素之间的空间关系会发生变化，这时可以说图像产生了几何失真或几何畸变
  - 原始场景中各部分之间的空间关系与图像中各对应像素间的空间关系不一致
  - 如：显示器上出现的枕形或桶形失真

几何失真校正

- 图像的几何失真校正主要包括两个步骤：
  - 空间变换：对图像平面上的像素进行重新排列以恢复原空间关系
  - 灰度插值：对空间变换后的像素赋予相应的灰度值以恢复原位置的灰度值

空间变换

模型

图像$f(x, y)$受几何形变的影响变成失真图像 $g(x', y')$

$$x' = s(x, y) \quad y' = t(x, y)$$

线性失真

$$s(x, y) = k_1 x + k_2 y + k_3$$

$$t(x, y) = k_4 x + k_5 y + k_6$$

（非线性）二次失真

$$s(x, y) = k_1 + k_2 x + k_3 y + k_4 x^2 + k_5 xy + k_6 y^2$$

$$t(x, y) = k_7 + k_8 x + k_9 y + k_{10} x^2 + k_{11} xy + k_{12} y^2$$

空间变换

约束对应点方法

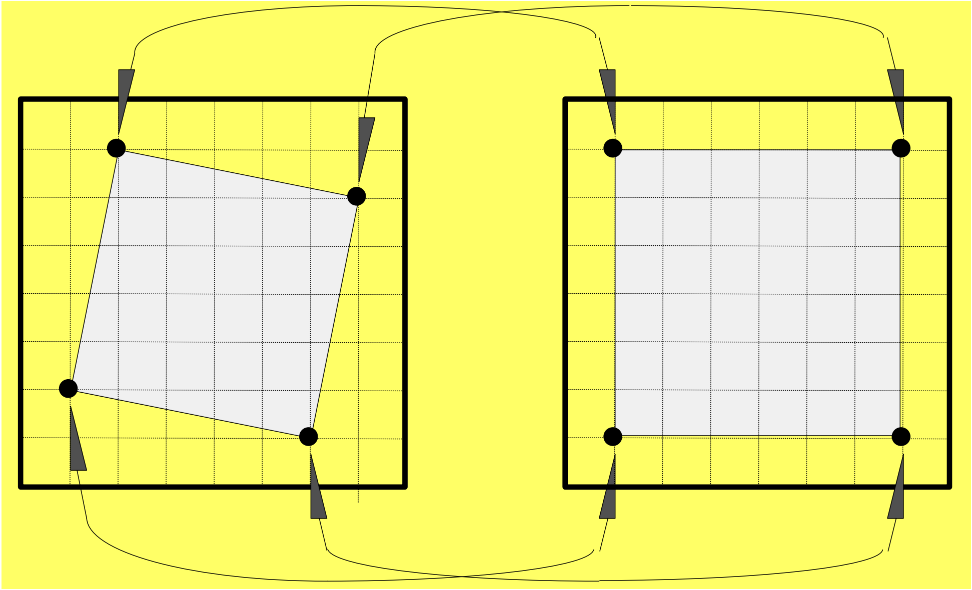
在输入图（失真图）和输出图（校正图）上找一些其位置确切知道的点，然后利用这些点建立两幅图间其它点空间位置的对应关系

选取四边形顶点

$$x' = k_1x + k_2y + k_3xy + k_4$$

$$y' = k_5x + k_6y + k_7xy + k_8$$

四组对应点解八个系数



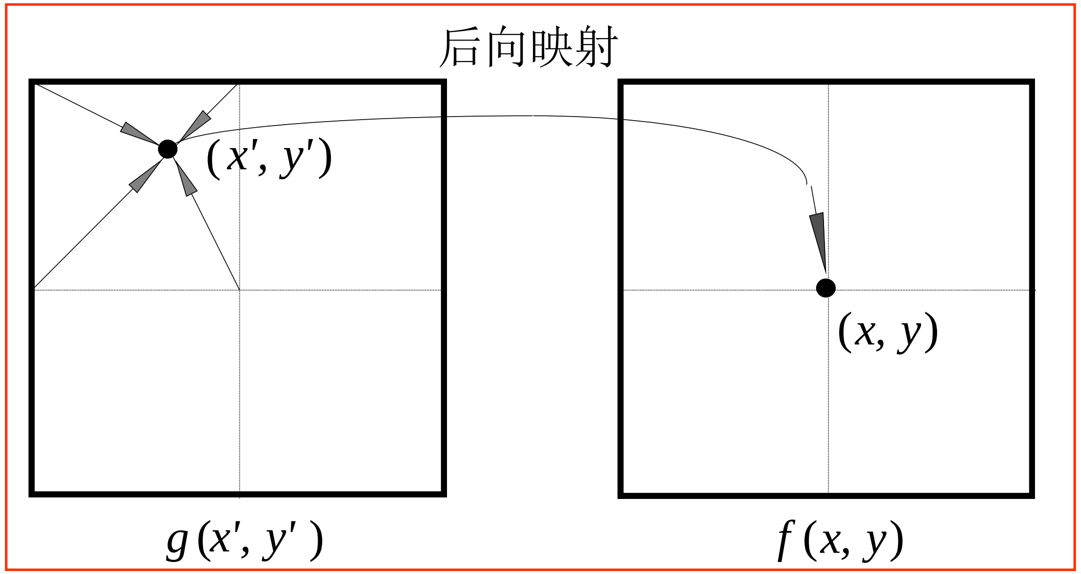
$g(x', y')$

灰度插值

灰度插值

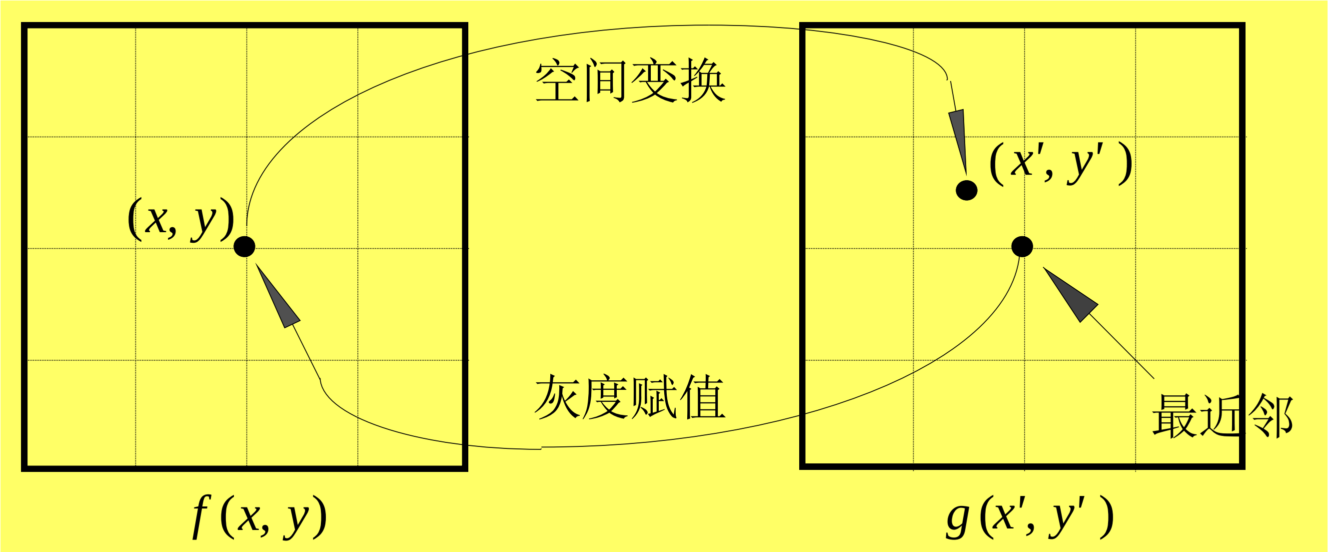
实际失真图中四个像素之间的位置对应不失真图的某个像素，则先根据插值算法计算出该位置的灰度，再将其映射给不失真图的对应像素

用整数处的像素值来计算在非整数处的像素值。(x, y)总是整数，但(x’, y’)值可能不是整数



灰度插值

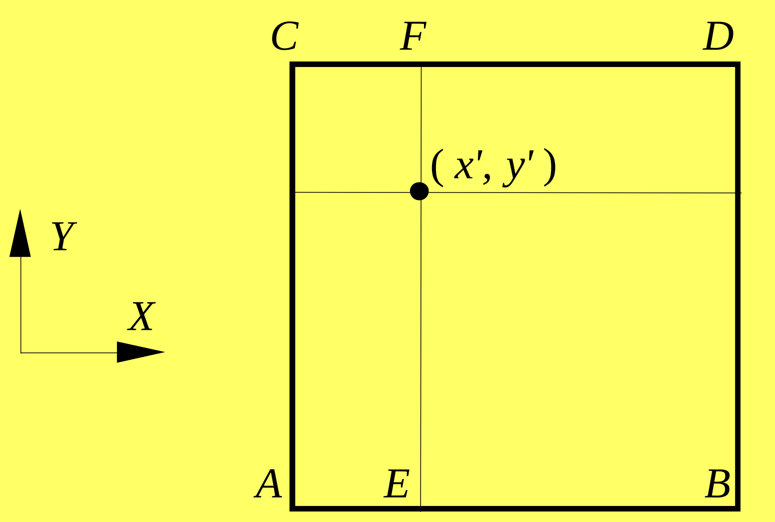
- **最近邻插值，也常称为零阶插值**
  - 将离(x’, y’)点最近的像素的灰度值作为(x’, y’)点的灰度值赋给原图(x, y)处像素



灰度插值

双线性插值

利用(x', y')点的四个最近邻像素*A*、*B*、*C*、*D*，灰度值分别为$g(A)$、$g(B)$、$g(C)$、$g(D)$



(a)

$$g(E) = (x' - i)[g(B) - g(A)] + g(A)$$

$$g(F) = (x' - i)[g(D) - g(C)] + g(C)$$

$$g(x', y') = (y' - j)[g(F) - g(E)] + g(E)$$

Summary

- Elements of Visual Perception
- Image Sensing and Acquisition
- Image Sampling and Quantization
- Some Basic Relationships Between Pixels

谢谢大家！