Chapter 2 Digital Image Fundamentals

2.1 Elements of Visual Perception

2.2 Light and the Electromagnetic spectrum

2.3 Image Sensing and Acquisition

2.4 Image Sampling and Quantization

2.5 Some Basic Relationships Between Pixels

2.6 An Introduction to the Mathematical Tools Used in Digital Image Processing

2.1 Elements of Visual Perception

2.1.1 Structure of the Human Eye

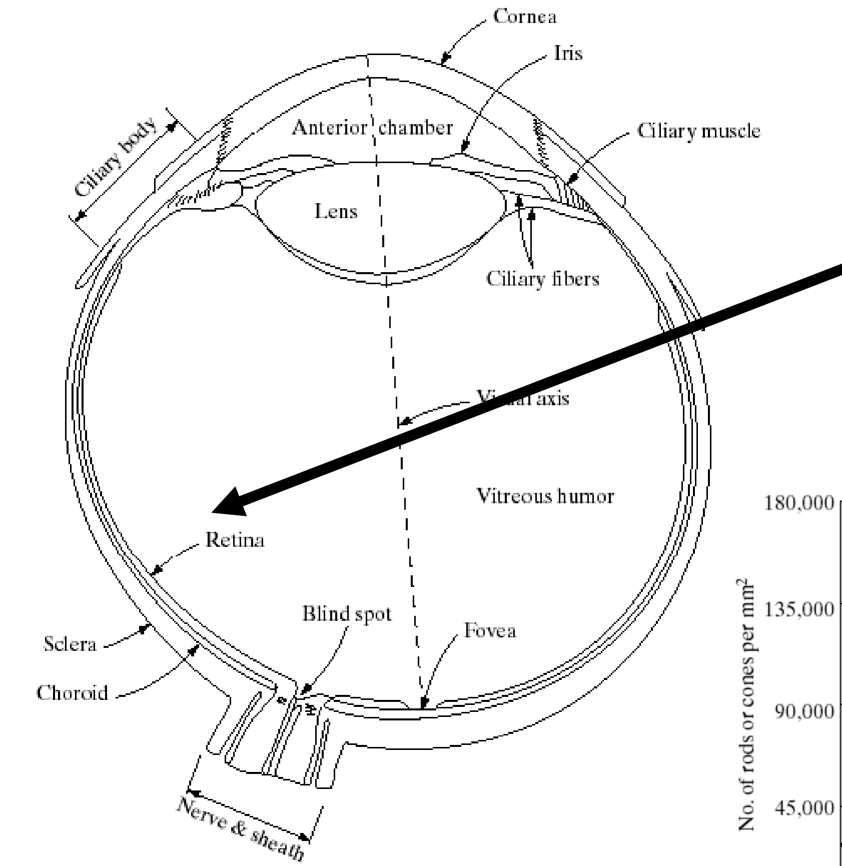


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

Cones-details-day-photopic-color

Rods-overall-night-scotopic-nocolor

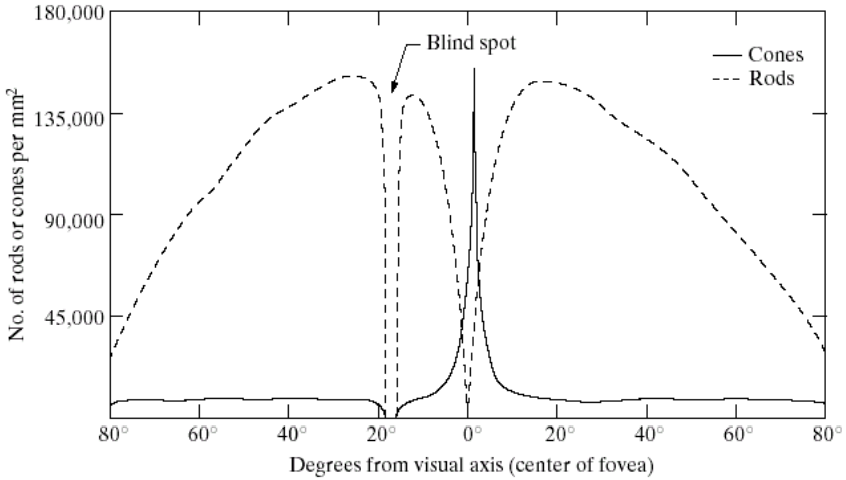
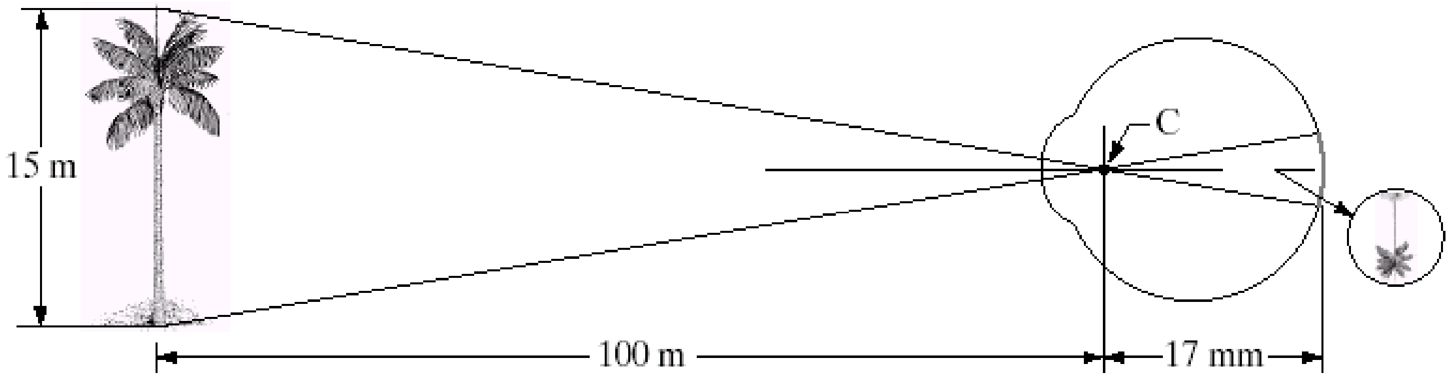


FIGURE 2.2 Distribution of rods and cones in the retina.

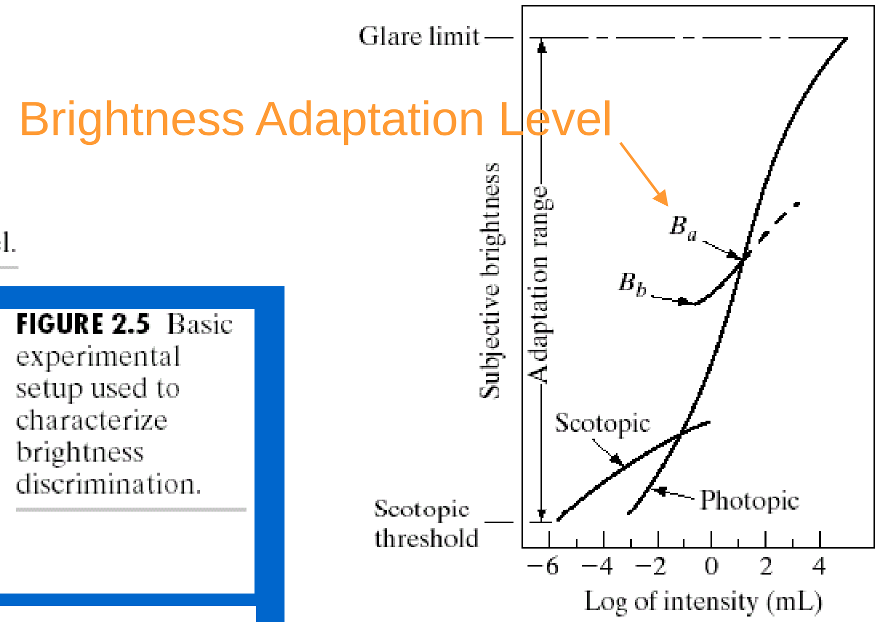
2.1.2 Image Formation in the Eye

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



2.1.3 Brightness Adaptation and Discrimination(p63)

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



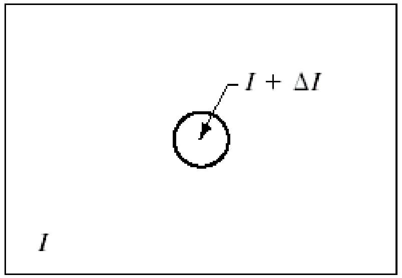
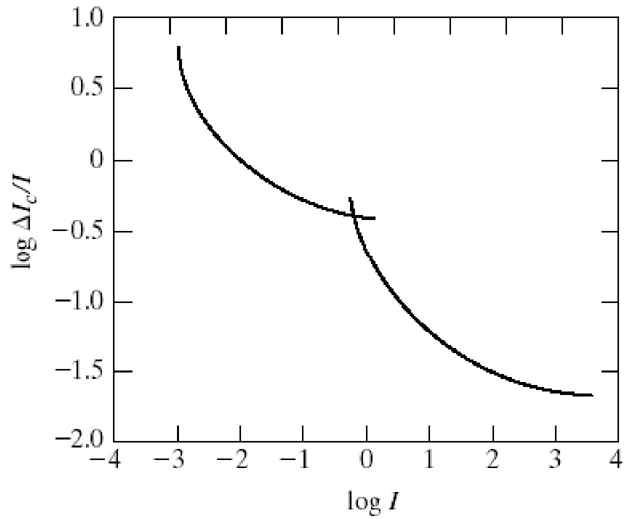


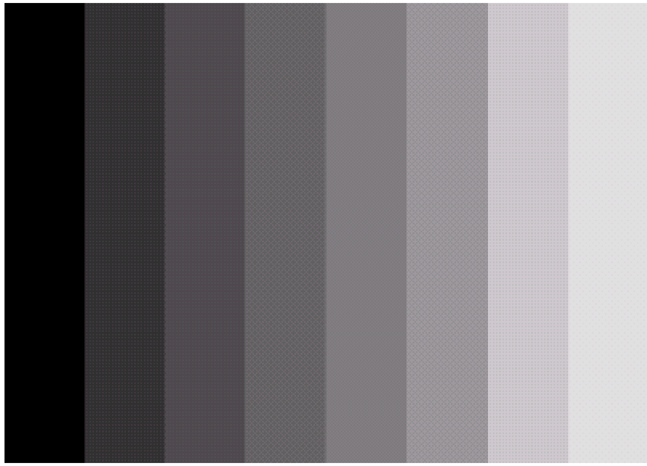
FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

FIGURE 2.6 Typical Weber ratio as a function of intensity.



12~24levels diff. intensity changes (background fixed)

2.1.3 Brightness Adaptation and Discrimination

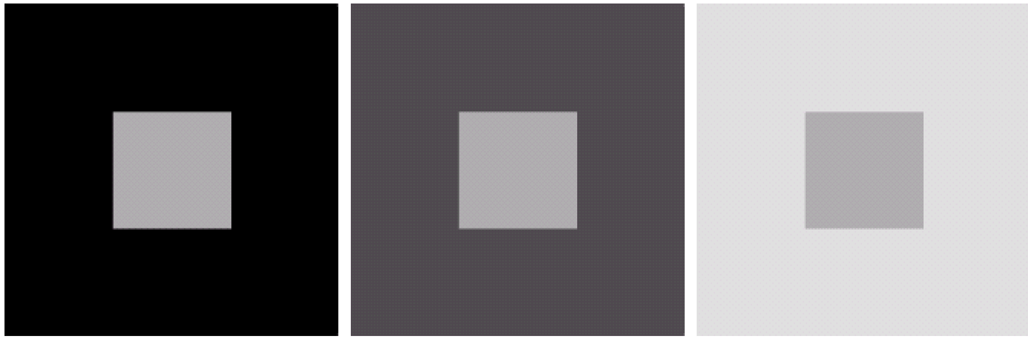


a
b

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.

Mach band effect

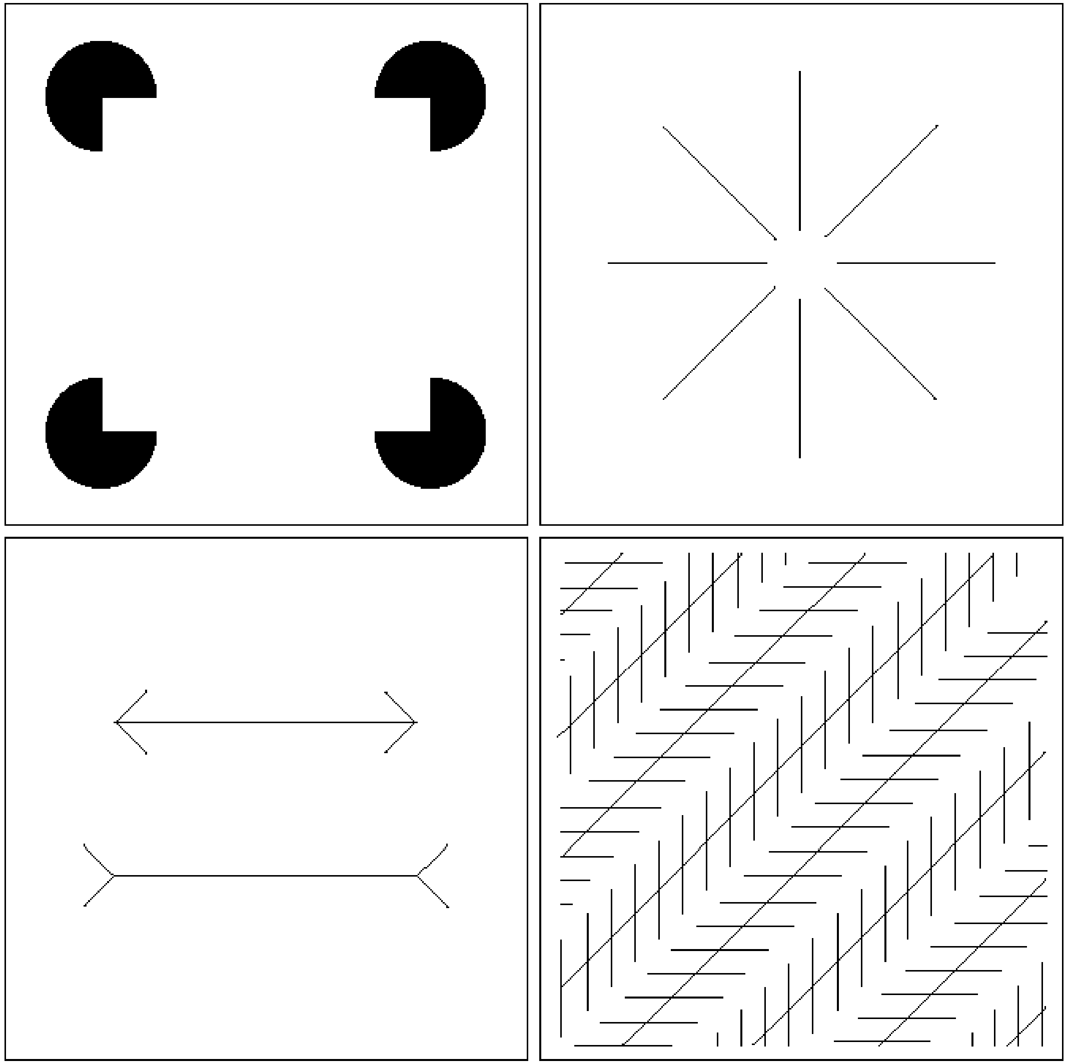
Simultaneous contrast



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.

2.1.3 Brightness Adaptation and Discrimination



a b
c d

FIGURE 2.9 Some well-known optical illusions.

2.2 Light and the Electromagnetic Spectrum(P67)

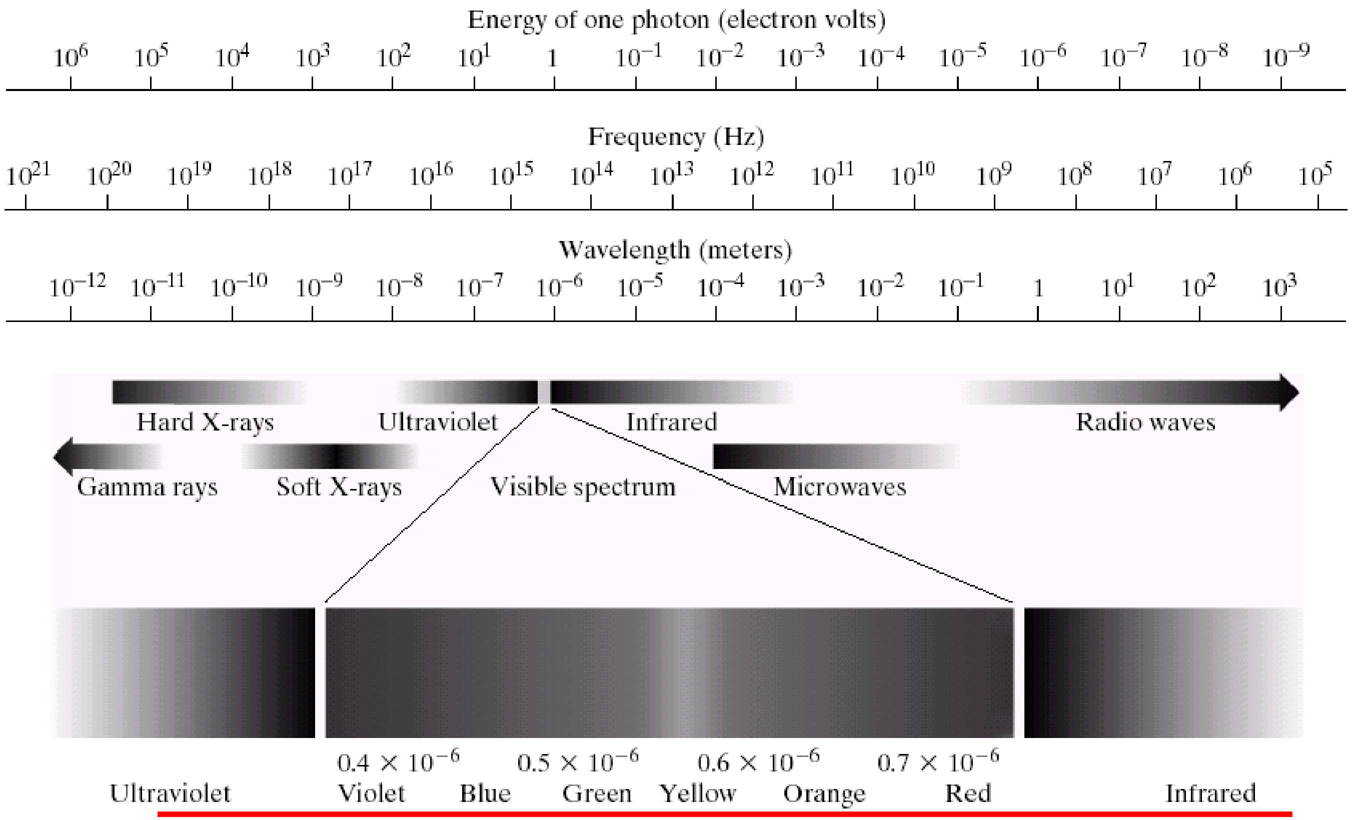


FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

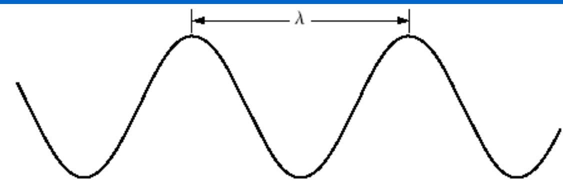
The most dangerous?

Wavelength=light velocity/frequency

Energy=h*frequency

h=Planck constant

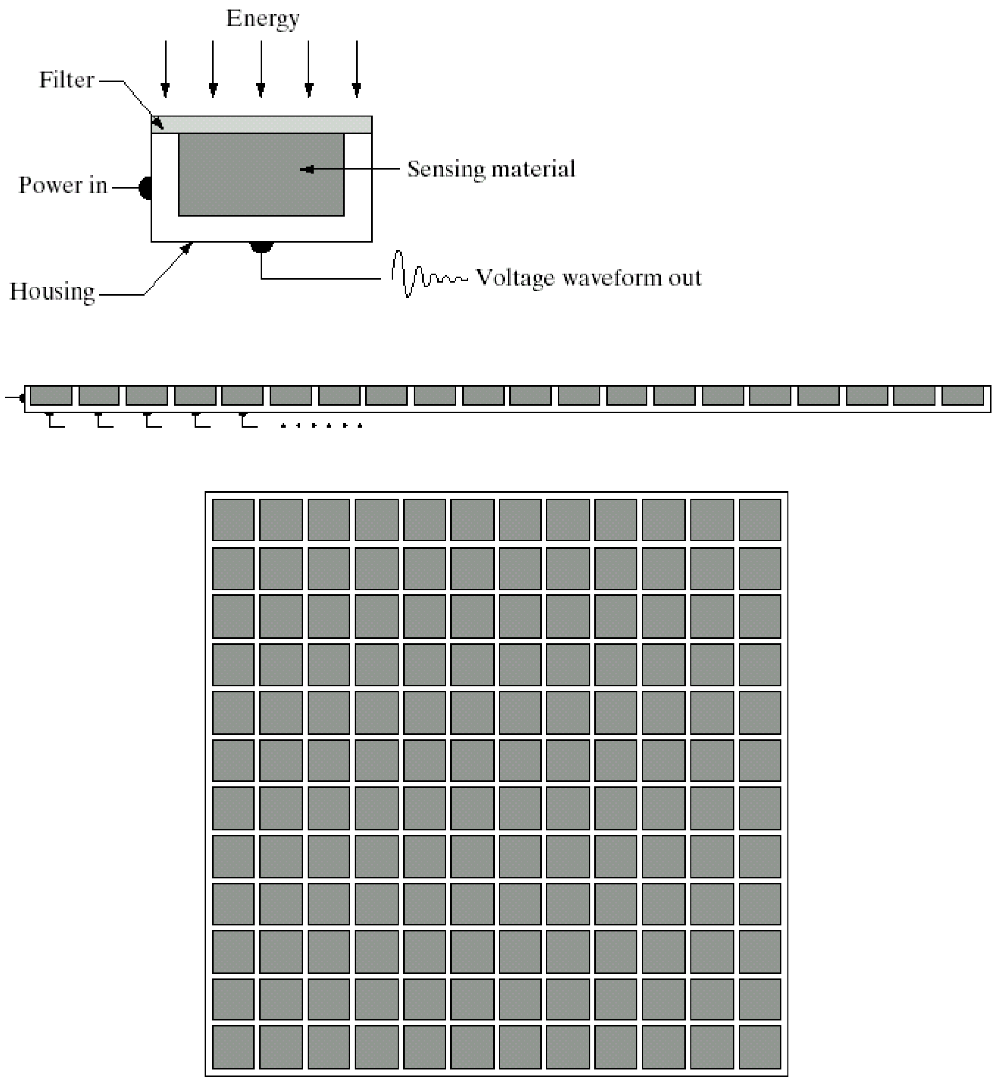
FIGURE 2.11 Graphical representation of one wavelength.



2.3 Image Sensing and Acquisition

a
b
c

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



2.3.1 Image Acquisition Using a Single Sensor

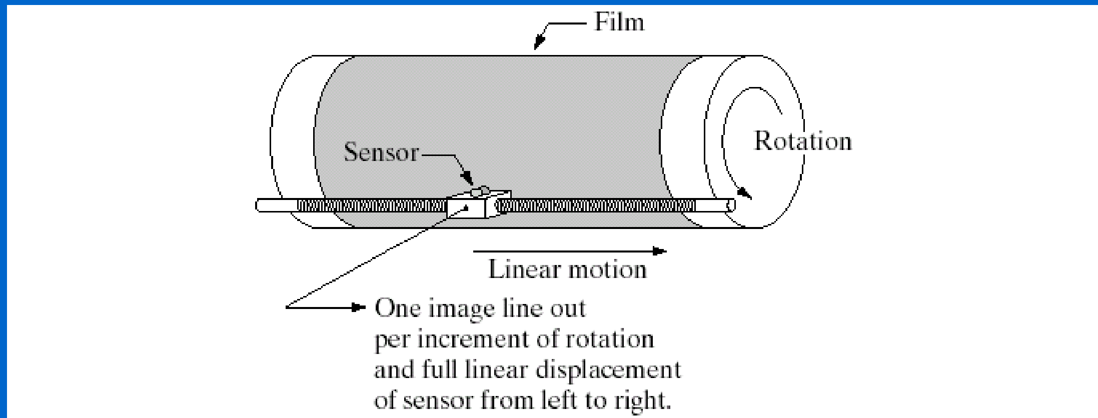


FIGURE 2.13 Combining a single sensor with motion to generate a 2-D image.

2.3.2 Image Acquisition Using Sensor Strips

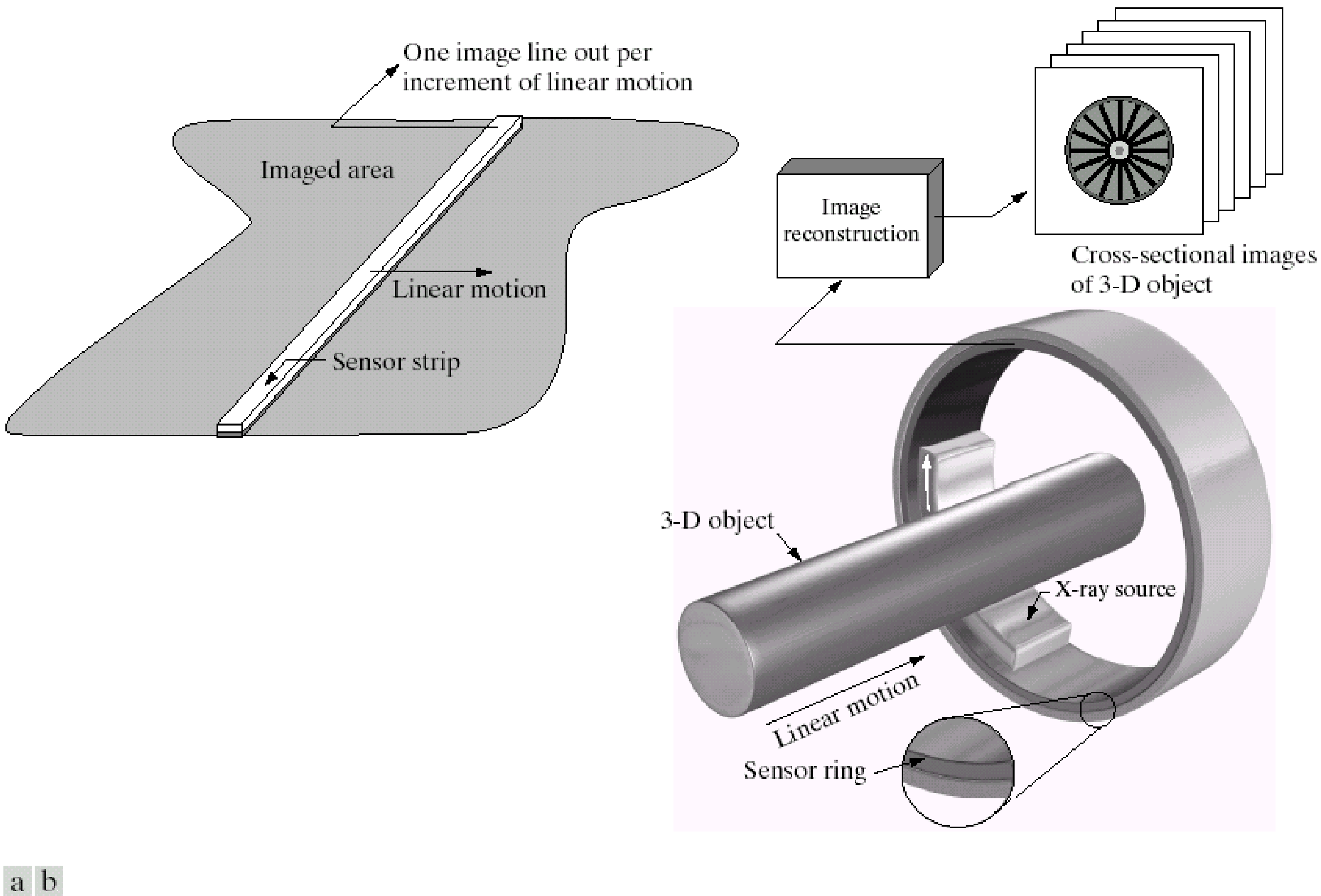


FIGURE 2.14 (a) Image acquisition using a linear sensor strip. (b) Image acquisition using a circular sensor strip.

2.3.3 Image Acquisition Using Sensor Arrays

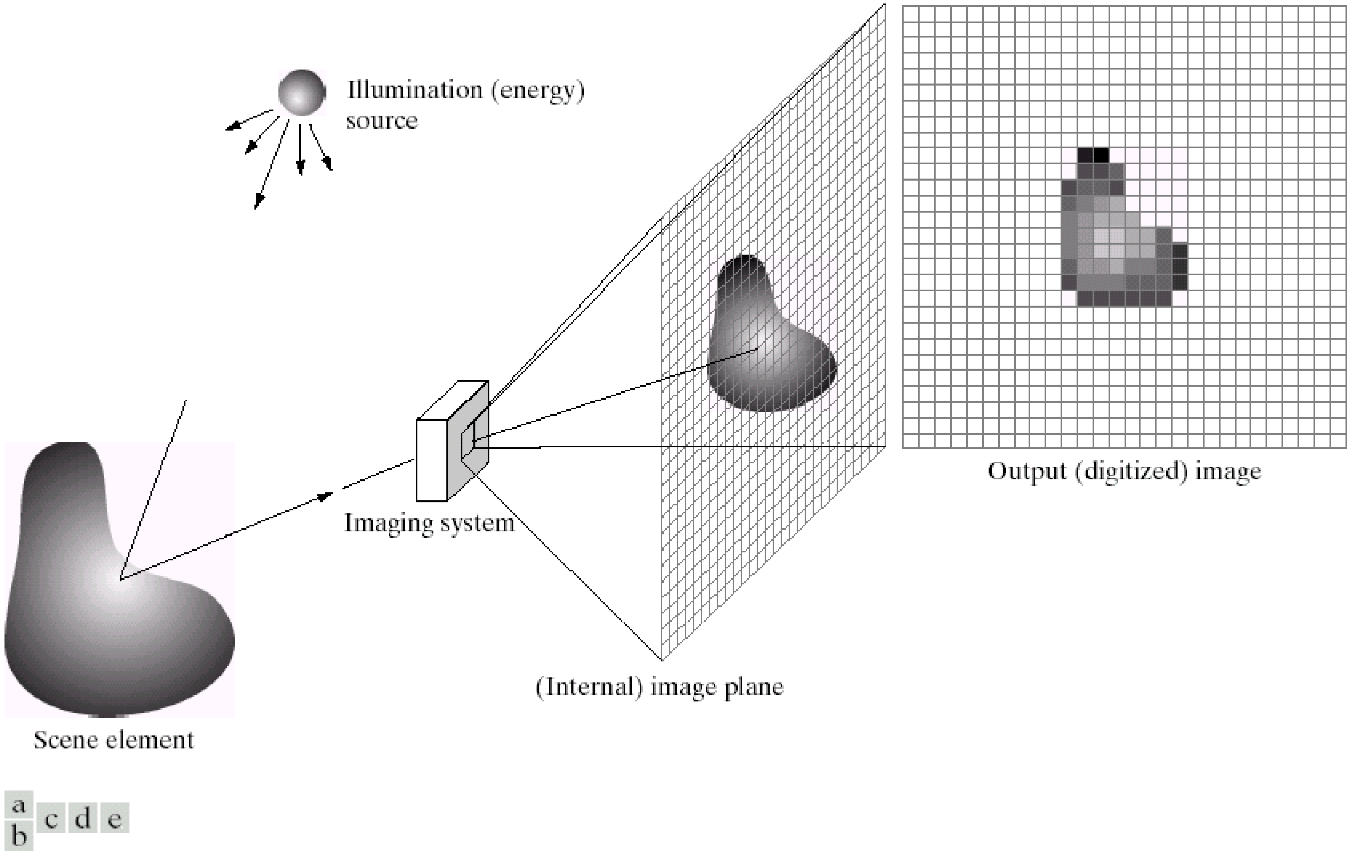


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

2.3.4 A Simple Image Formation Model

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

入射*illumination*: $0 \to \infty$

反射*reflectance* : $0 \to 1$

Gray Level: $l \in [L_{min}, L_{max}]$

2.4 Image Sampling and Quantization

2.4.1 Basic Conceptions in Sampling and Quantization

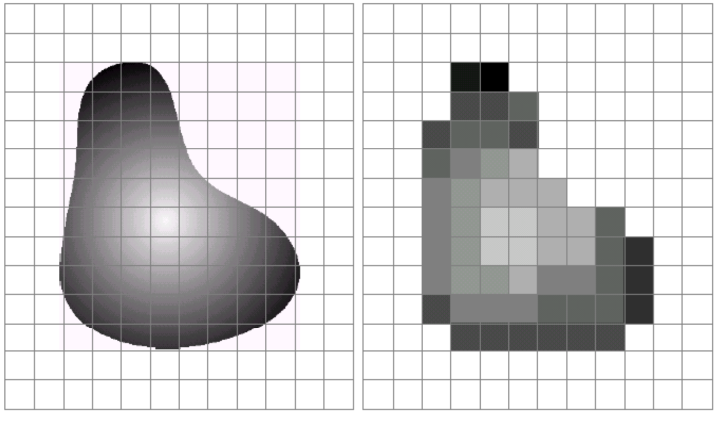


FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

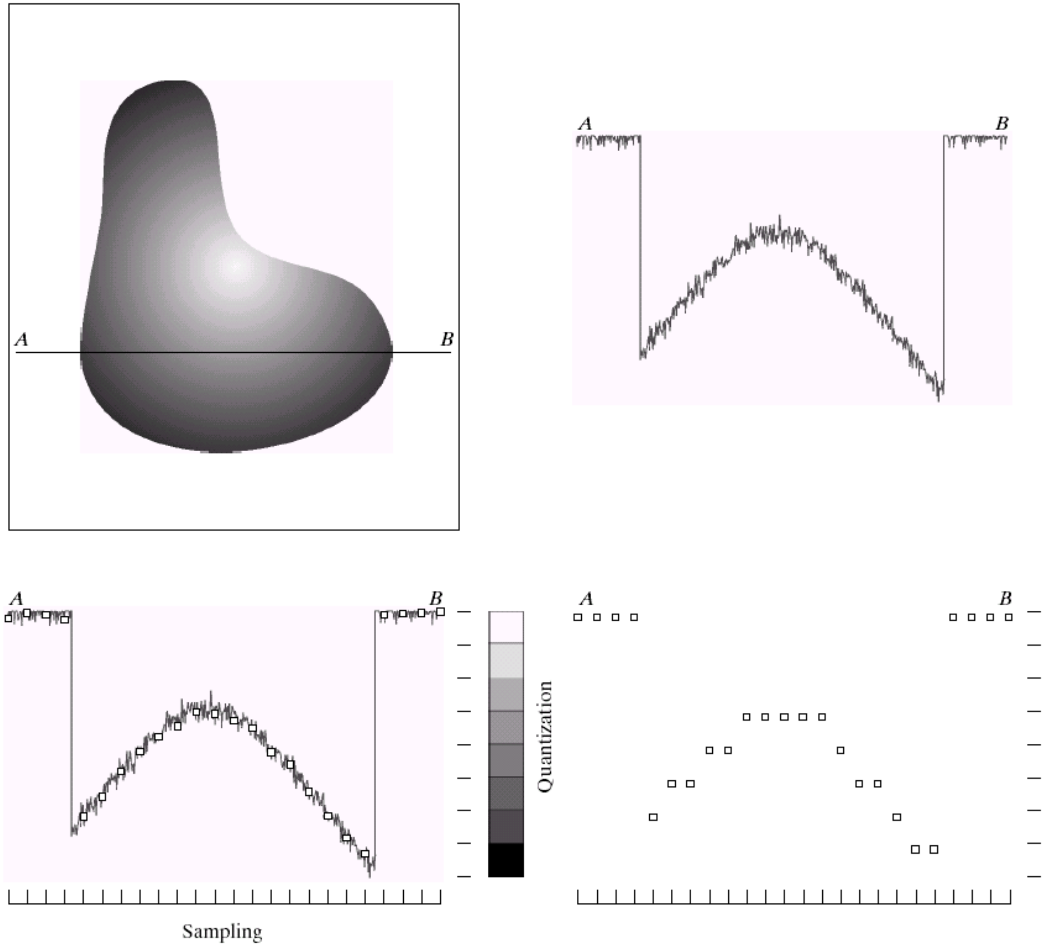
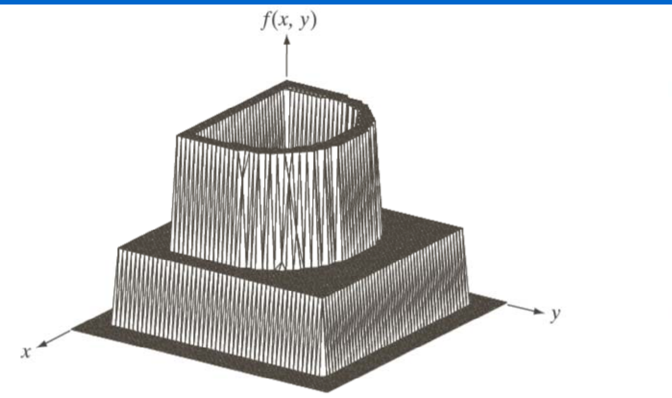
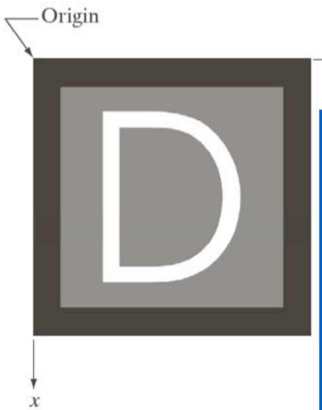
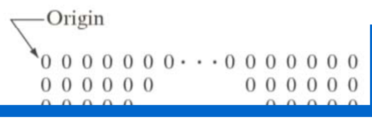


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

2.4.2 Representing Digital Images







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).

M=N

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

$\boxed{N^2k}$

2.4.2 Representing Digital Images

-Dynamic range

-Saturation

-Noise

-Contrast

(P79-80)

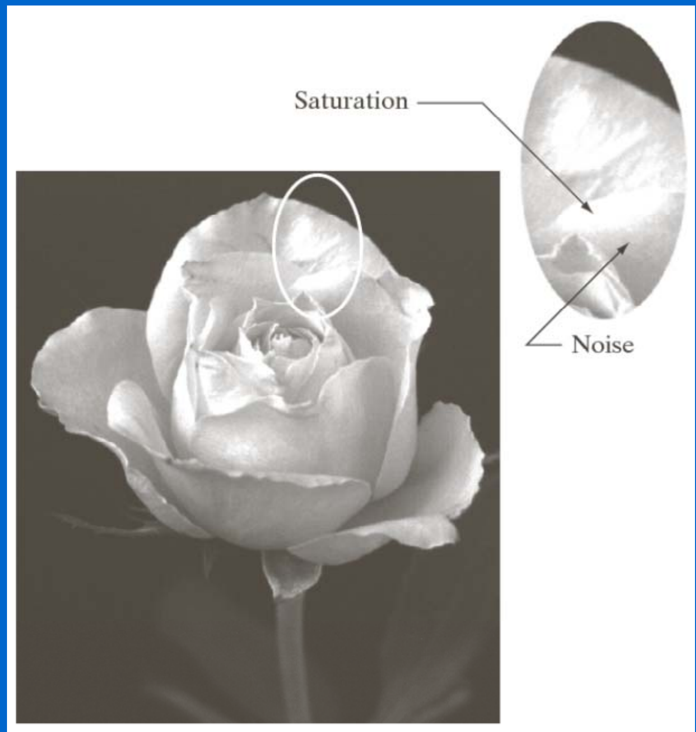


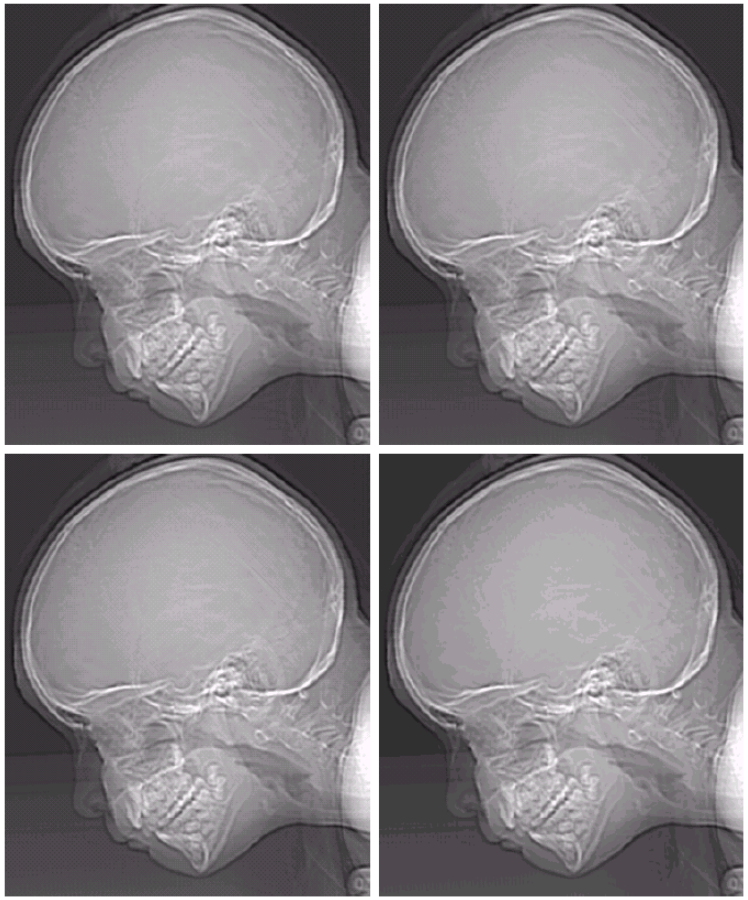
FIGURE 2.19 An image exhibiting saturation and noise. Saturation is the highest value beyond which all intensity levels are clipped (note how the entire saturated area has a high, *constant* intensity level). Noise in this case appears as a grainy texture pattern. Noise, especially in the darker regions of an image (e.g., the stem of the rose) masks the lowest detectable true intensity level.

2.4.3 Spatial and Intensity Resolution（by DPI)

a b
c d

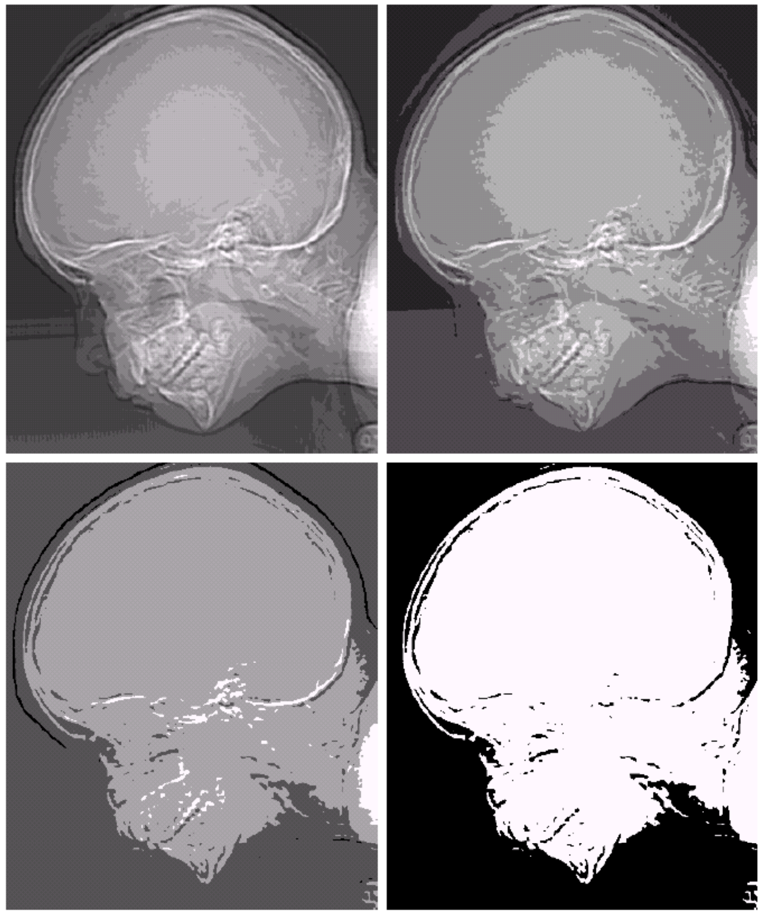
FIGURE 2.20 Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.

2.4.3 Spatial and Intensity Resolution (By gray levels)



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.



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.)

2.4.3 Spatial and Intensity Resolution (details)

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.)

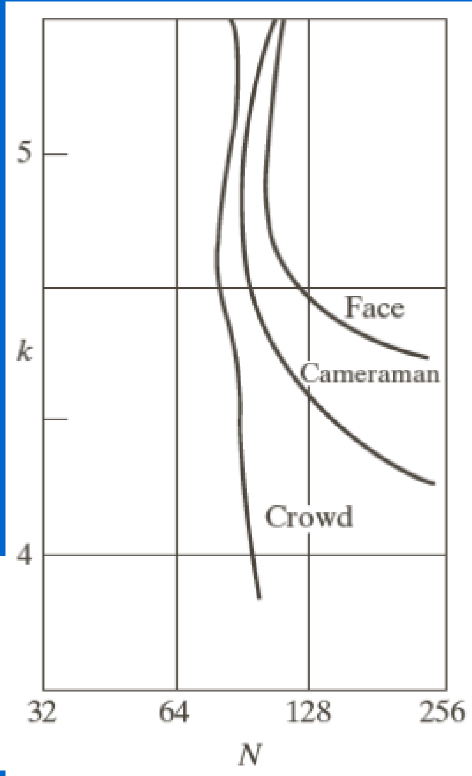
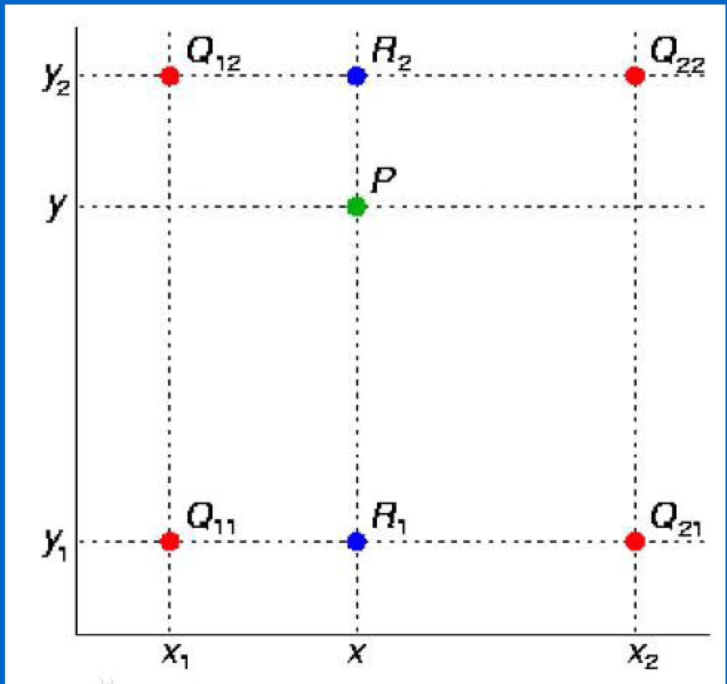


FIGURE 2.23 Typical isopreference curves for the three types of images in Fig. 2.22.

2.4.4 Image Interpolation(p88)

- Bilinear



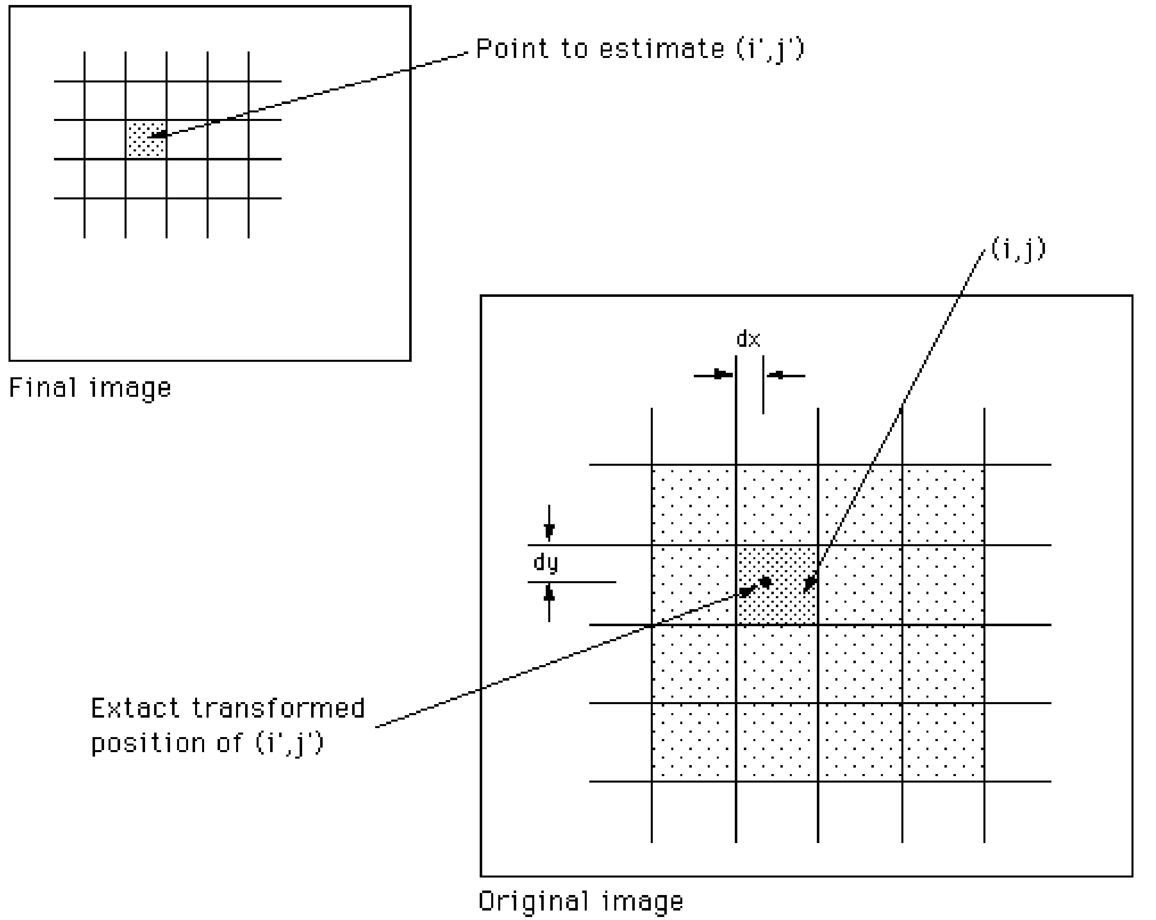
$$f(R_1) \approx \frac{x_2 - x}{x_2 - x_1} f(Q_{11}) + \frac{x - x_1}{x_2 - x_1} f(Q_{21}) \quad \text{where} \quad R_1 = (x, y_1)$$

$$f(R_2) \approx \frac{x_2 - x}{x_2 - x_1} f(Q_{12}) + \frac{x - x_1}{x_2 - x_1} f(Q_{22}) \quad \text{where} \quad R_2 = (x, y_2)$$

$$f(P) \approx \frac{y_2 - y}{y_2 - y_1} f(R_1) + \frac{y - y_1}{y_2 - y_1} f(R_2).$$

2.4.4 Image Interpolation(p88)

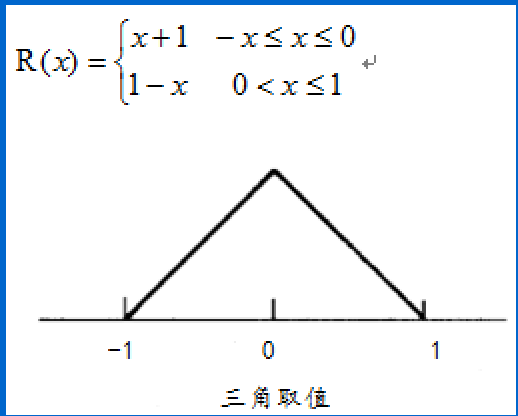
- Bicubic

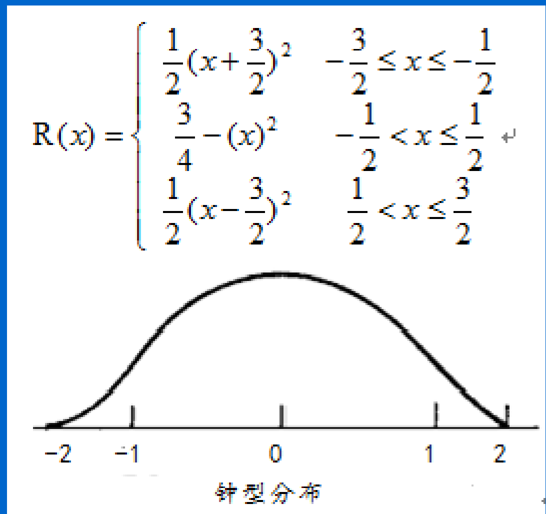


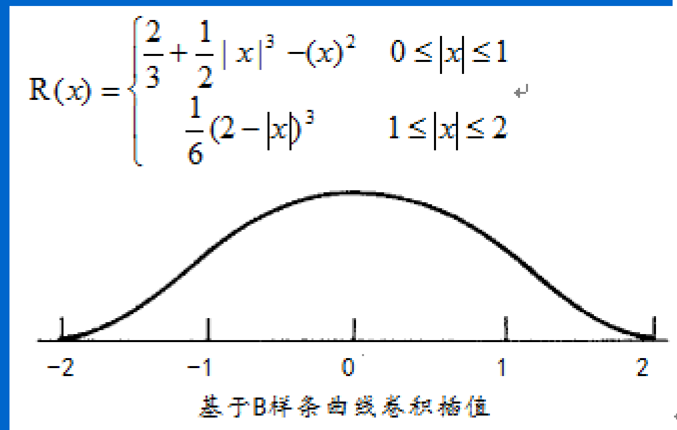
$$F(i',j') = \sum_{m=-1}^{2}\sum_{n=-1}^{2} F(i+m, j+n)R(m-dx)R(dy-n)$$

2.4.4 Image Interpolation(p88)

- Bicubic







2.4.4 Image Interpolation(p88)

Bilinear:

$$v(x,y) = ax + by + cxy + d$$

Bicubic:

$$v(x,y) = \sum\sum a_{ij} x^i y^j$$

FIGURE 2.24 (a) Image reduced to 72 dpi and zoomed back to its original size (3692 × 2812 pixels) using nearest neighbor interpolation. This figure is the same as Fig. 2.20(d). (b) Image shrunk and zoomed using bilinear interpolation. (c) Same as (b) but using bicubic interpolation. (d)–(f) Same sequence, but shrinking down to 150 dpi instead of 72 dpi [Fig. 2.24(d) is the same as Fig. 2.20(c)]. Compare Figs. 2.24(e) and (f), especially the latter, with the original image in Fig. 2.20(a).

2.5 Some Basic Relationships Between Pixels

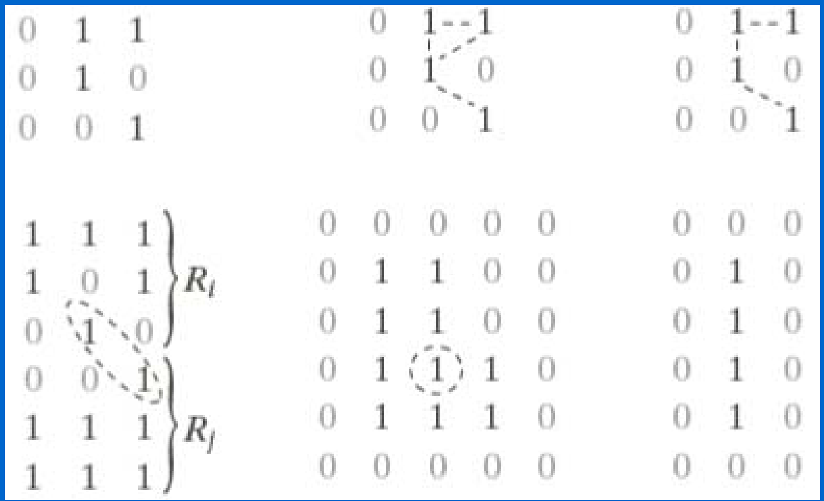
2.5.1 Neighbors of a Pixel

$N_4(p)$: horizontal & veritcal.

$N_8(p) = N_4(p) \cup N_D(p)$, where D: diagonal.

2.5.2 Adjacency, Connectivity, Regions, and Boundaries

4-adjacency, 8-adjacency, *m*-adjacency.



a b c
d e f

FIGURE 2.25 (a) An arrangement of pixels. (b) Pixels that are 8-adjacent (adjacency is shown by dashed lines; note the ambiguity). (c) *m*-adjacency. (d) Two regions that are adjacent if 8-adjecency is used. (e) The circled point is part of the boundary of the 1-valued pixels only if 8-adjacency between the region and background is used. (f) The inner boundary of the 1-valued region does not form a closed path, but its outer boundary does.

2.5.3 Distance Measures(p93)

- Euclidean distance;
- The D_4 distance (city-block distance);

$$|x-s|+|y-t|$$

- The D_8 distance (chessboard distance).

$$Max(|x-s|,|y-t|)$$

?	?	?	?	?
?	?	?	?	?
?	?	x	?	?
?	?	?	?	?
?	?	?	?	?

2.6 An Introduction to the Mathematical Tools Used in DIP

2.6.1 Array versus Matrix Operations

Array operations: pixel-by-pixel

Array product $\neq$ Matrix product

2.6.2 Linear and Nonlinear Operations

H is said to be a linear operator if:

for any two images *f* and *g* and any two scalars *a* and *b*,

$$H(af + bg) = a\,H(f) + b\,H(g).$$

look for some linear operators:

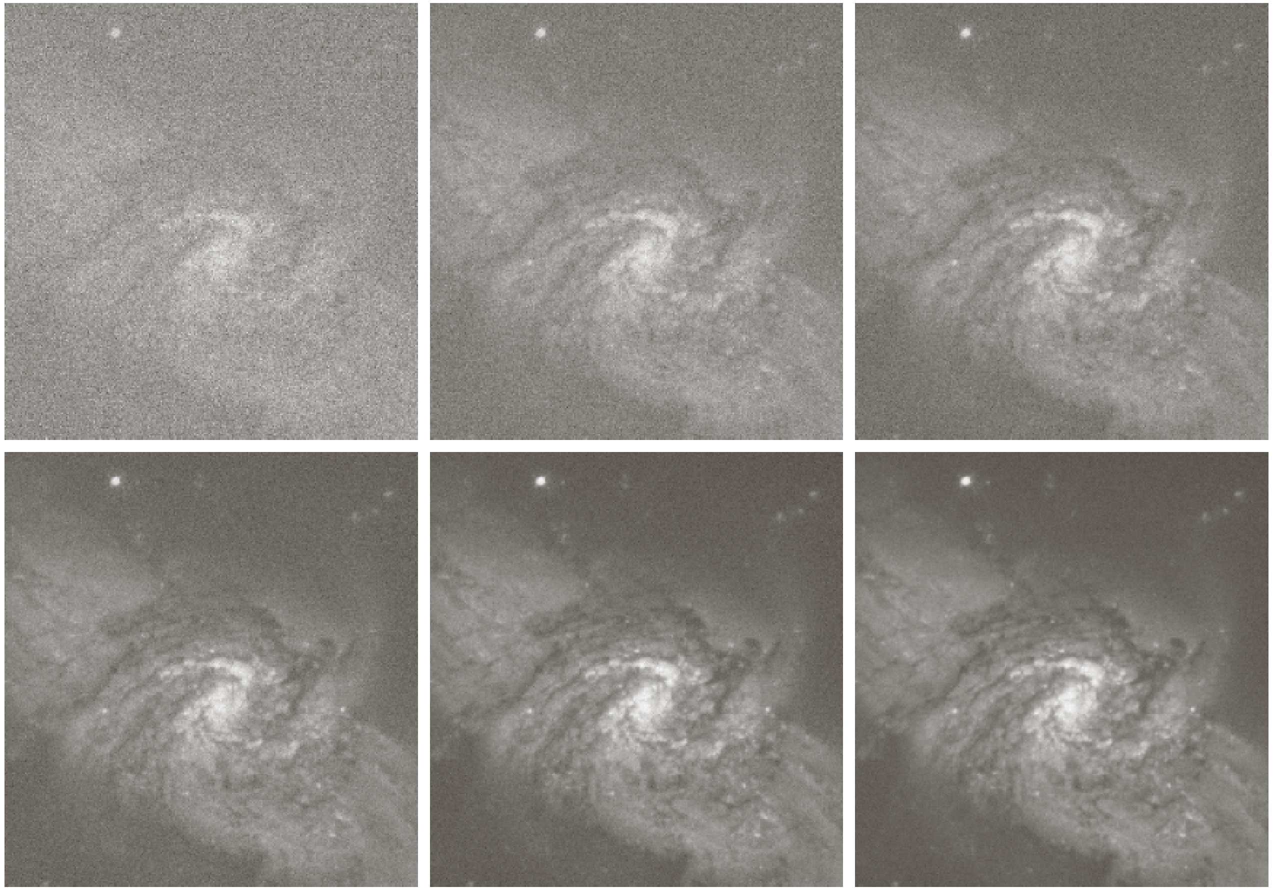
add?

abs?

Fourier transform

2.6.3 Arithmetic Operations(avg. with 5~100 images)

＋:



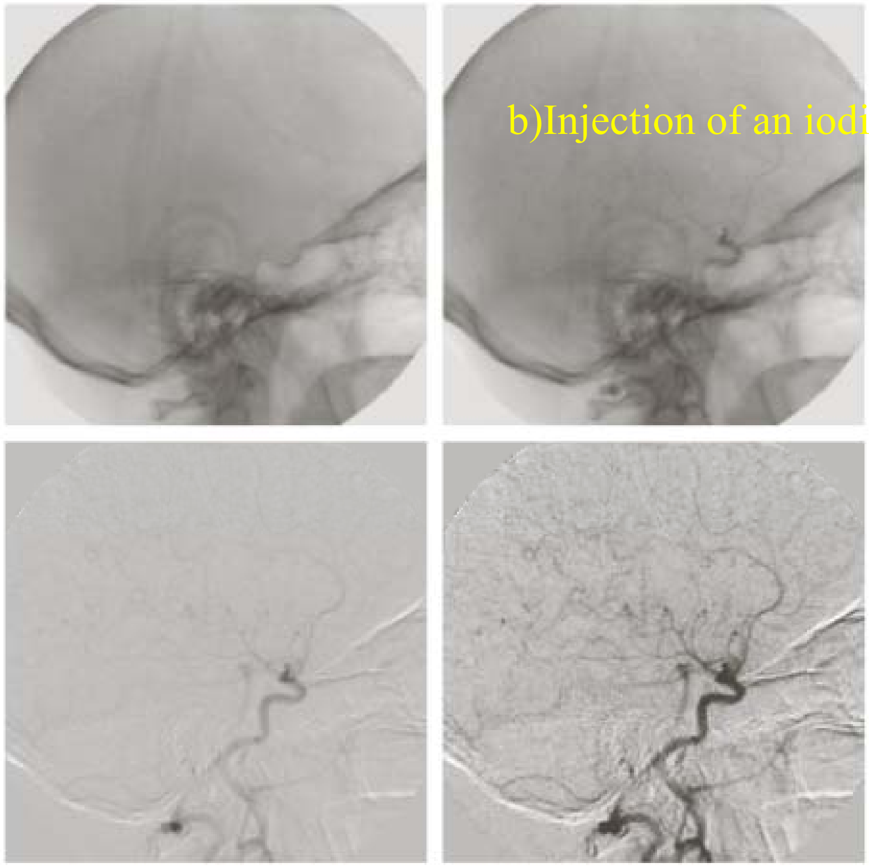
a b c
d e f

FIGURE 2.26 (a) Image of Galaxy Pair NGC 3314 corrupted by additive Gaussian noise. (b)–(f) Results of averaging 5, 10, 20, 50, and 100 noisy images, respectively. (Original image courtesy of NASA.)

一：

a b c

FIGURE 2.27 (a) Infrared image of t
significant bit of every pixel in (a). (



b)Injection of an iodine medium

a b
c d

FIGURE 2.28 Digital subtraction angiography. (a) Mask image. (b) A live image. (c) Difference between (a) and (b). (d) Enhanced difference image. (Figures (a) and (b) courtesy of The Image Sciences Institute, University Medical Center, Utrecht, The Netherlands.)

Attn: Range of results!

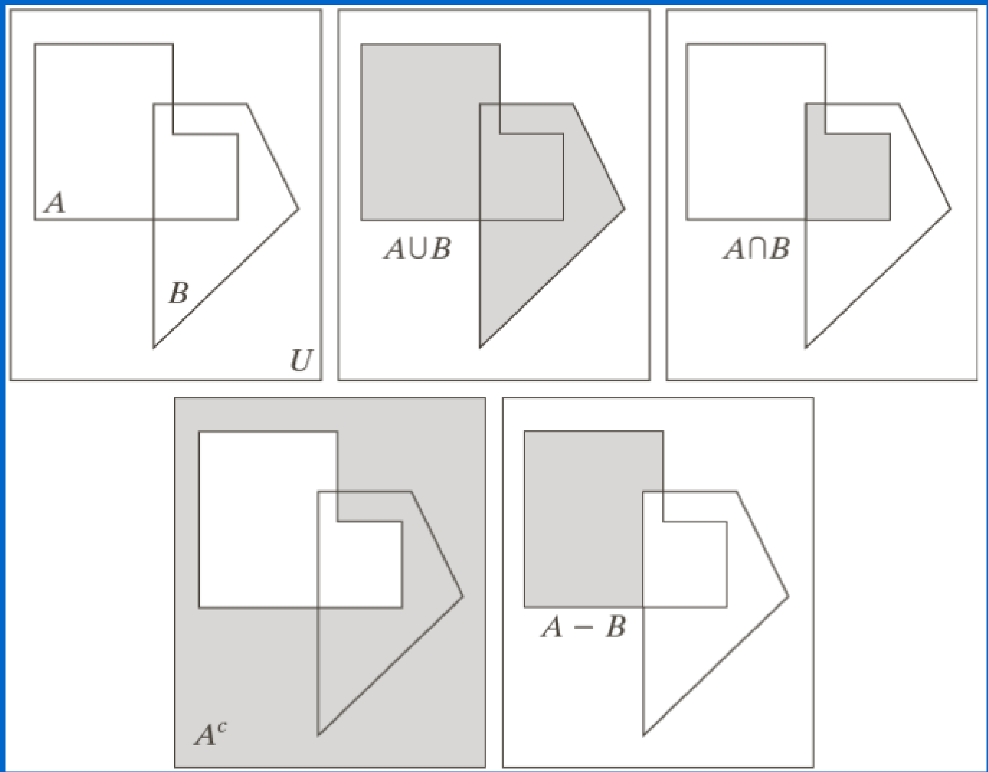
× and ÷ :

a b c

FIGURE 2.29 Shading correction. (a) Shaded SEM image of a tungsten filament and support, magnified approximately 130 times. (b) The shading pattern. (c) Product of (a) by the reciprocal of (b). (Original image courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene.)

2.6.4 Set and Logical Operations

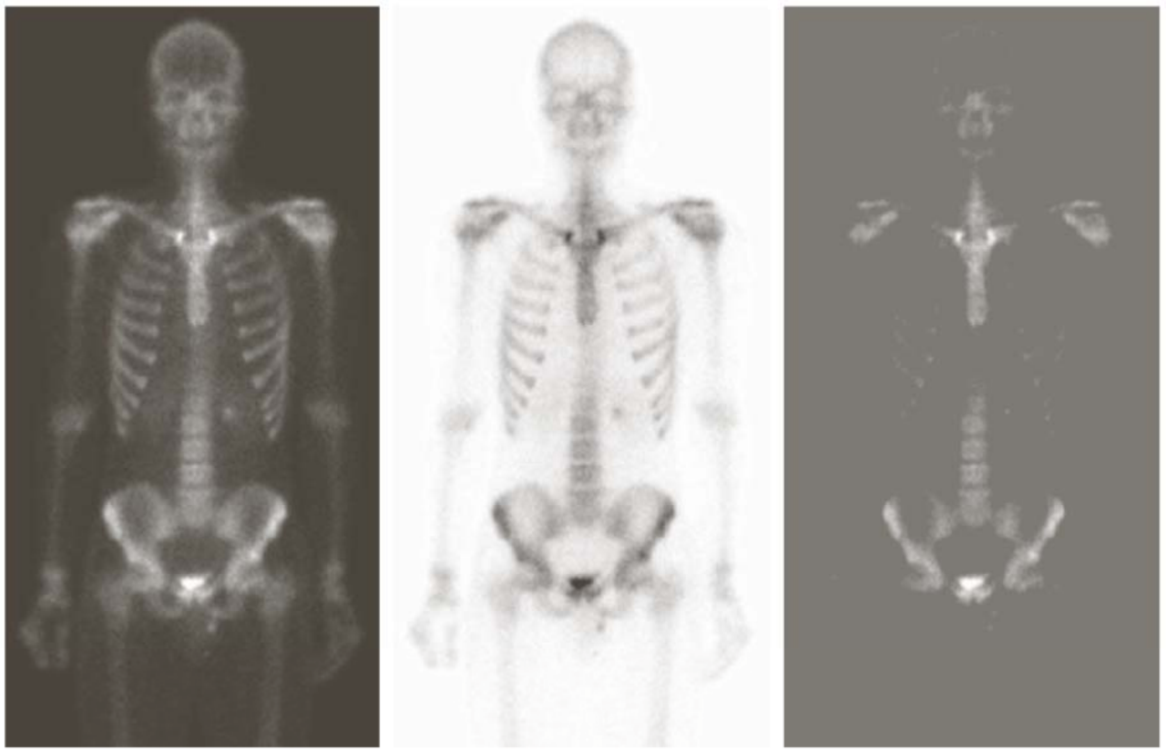
- Basic set operations:(spatially)



a b c
d e

FIGURE 2.31 (a) Two sets of coordinates, A and B, in 2-D space. (b) The union of A and B. (c) The intersection of A and B. (d) The complement of A. (e) The difference between A and B. In (b)–(e) the shaded areas represent the member of the set operation indicated.

Basic set operations: gray-scale images(intensity)



a b c

FIGURE 2.32 Set operations involving gray-scale images. (a) Original image. (b) Image negative obtained using set complementation. (c) The union of (a) and a constant image. (Original image courtesy of G.E. Medical Systems.)

a) b)negativeImg c)Union of a and a constant

- Logical operations:

FIGURE 2.33 Illustration of logical operations involving foreground (white) pixels. Black represents binary 0s and white binary 1s. The dashed lines are shown for reference only. They are not part of the result.

- Fuzzy sets

2.6.5 Spatial Operations

- Single-pixel operations:

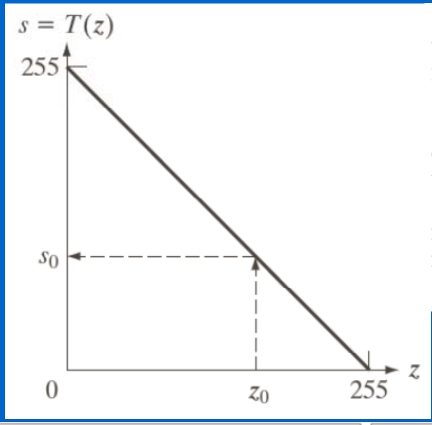
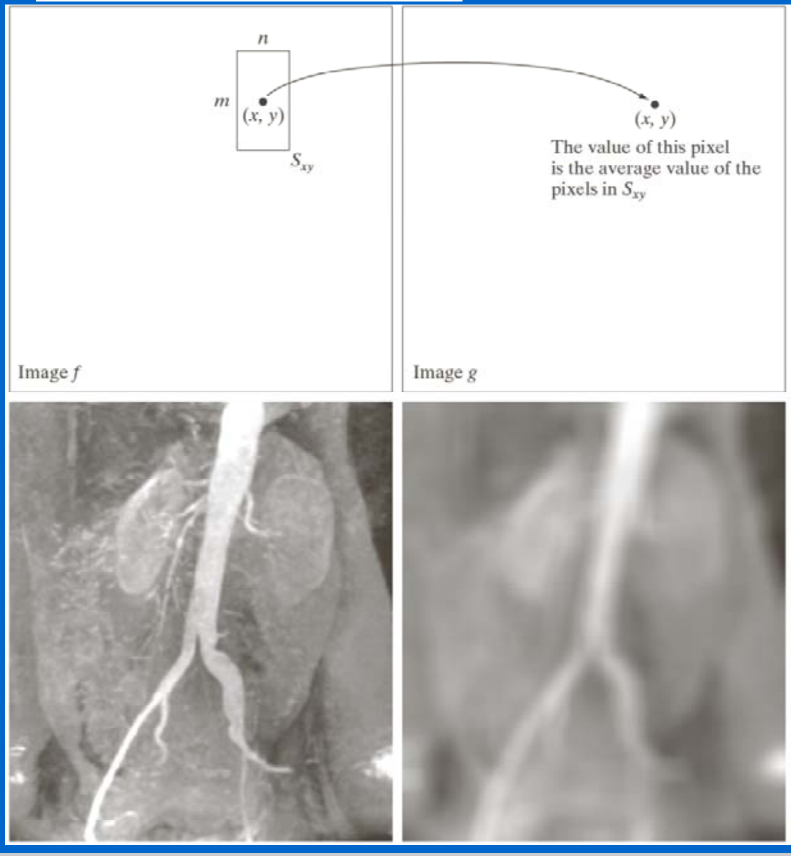


FIGURE 2.34 Intensity transformation function used to obtain the negative of an 8-bit image. The dashed arrows show transformation of an arbitrary input intensity value z_0 into its corresponding output value s_0.

- Neighborhood average operations:



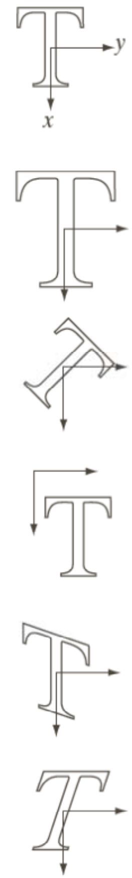
a b
c d

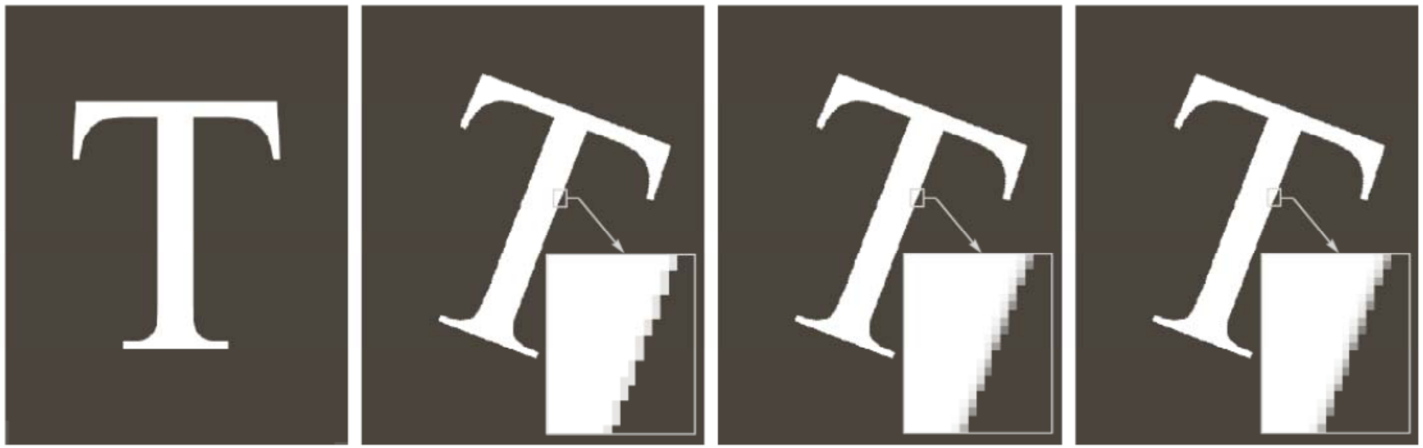
FIGURE 2.35 Local averaging using neighborhood processing. The procedure is illustrated in (a) and (b) for a rectangular neighborhood. (c) The aortic angiogram discussed in Section 1.3.2. (d) The result of using Eq. (2.6-21) with $m = n = 41$. The images are of size 790×686 pixels.

- Geometric spatial transformations:

TABLE 2.2
Affine transformations based on Eq. (2.6.–23).

Transformation Name	Affine Matrix, T	Coordinate Equations	Example
Identity	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v$ $y = w$	
Scaling	$\begin{bmatrix} c_x & 0 & 0 \\ 0 & c_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = c_x v$ $y = c_y w$	
Rotation	$\begin{bmatrix} \cos\theta & \sin\theta & 0 \end{bmatrix}$	$x = v\cos\theta - w\sin\theta$	

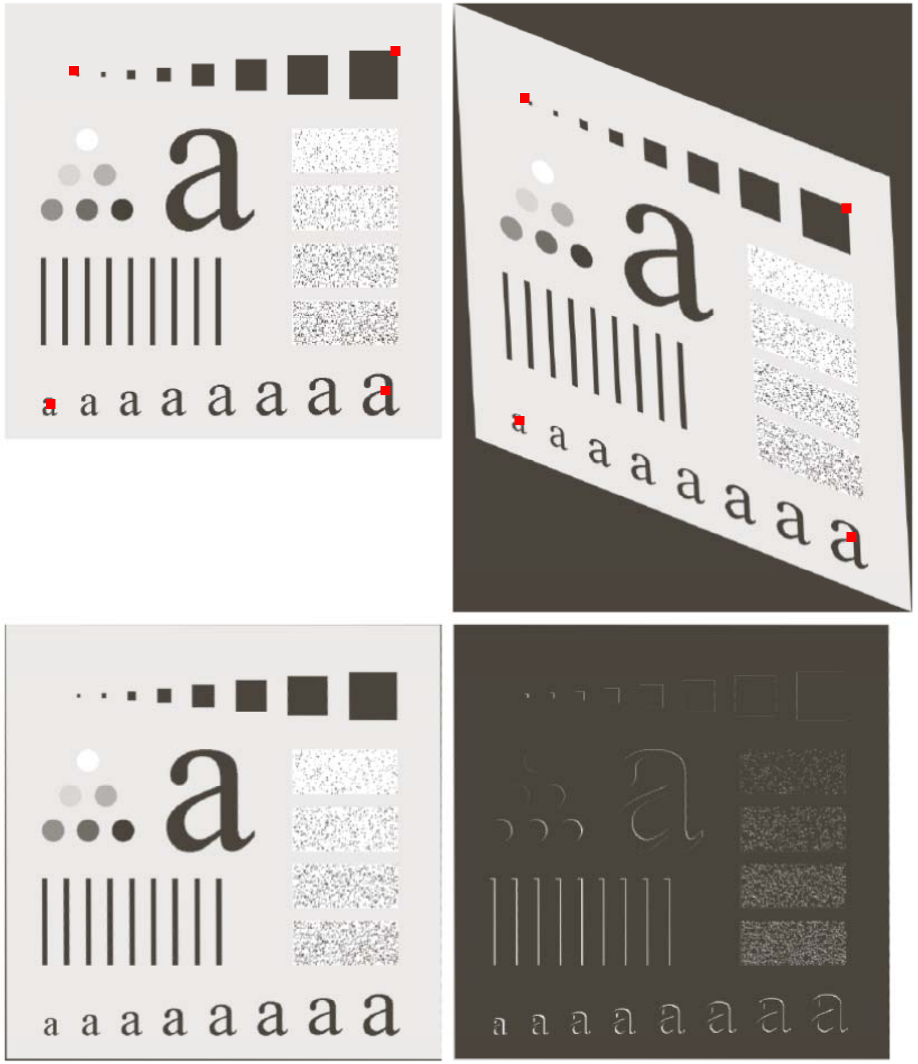




a b c d

FIGURE 2.36 (a) A 300 dpi image of the letter T. (b) Image rotated 21° clockwise using nearest neighbor interpolation to assign intensity values to the spatially transformed pixels. (c) Image rotated 21° using bilinear interpolation. (d) Image rotated 21° using bicubic interpolation. The enlarged sections show edge detail for the three interpolation approaches.

• Image registration:



a b
c d

FIGURE 2.37 Image registration. (a) Reference image. (b) Input (geometrically distorted image). Corresponding tie points are shown as small white squares near the corners. (c) Registered image (note the errors in the borders). (d) Difference between (a) and (c), showing more registration errors.

2.6.6 Vector and Matrix Operations

- Multispectral images:

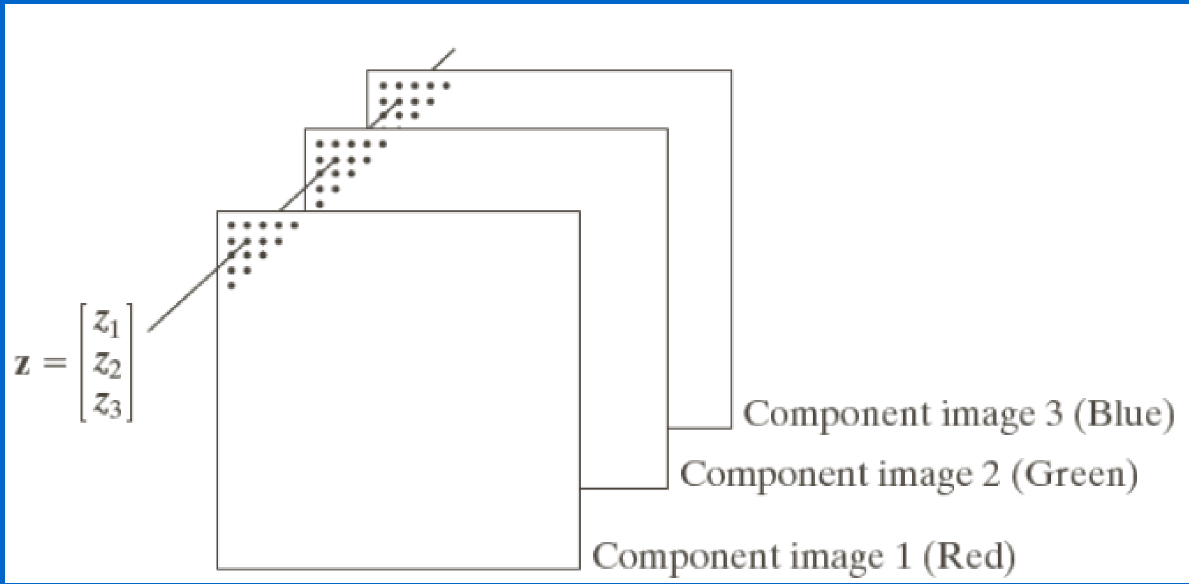


FIGURE 2.38 Formation of a vector from corresponding pixel values in three RGB component images.

- Image linear processes:

Example: $\boldsymbol{g} = \boldsymbol{H}\boldsymbol{f} + \boldsymbol{n}$ where $\boldsymbol{f}$: MNx1; $\boldsymbol{H}$: MNxMN; $\boldsymbol{g}$: MNx1.

2.6.7 Image Transforms

$$g(u,v) = \sum \sum f(x,y)\, r(x,y,u,v)$$

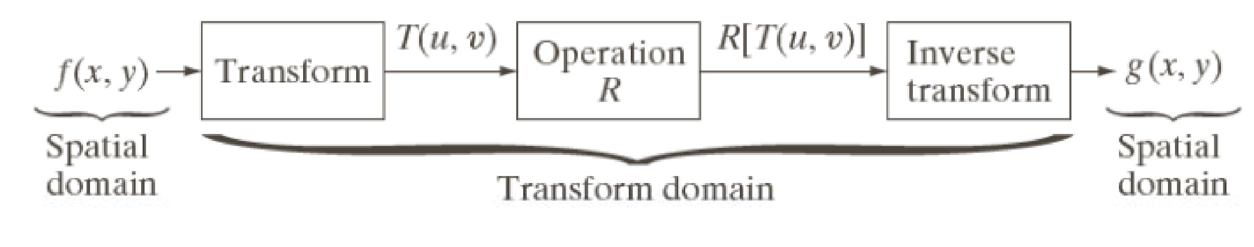
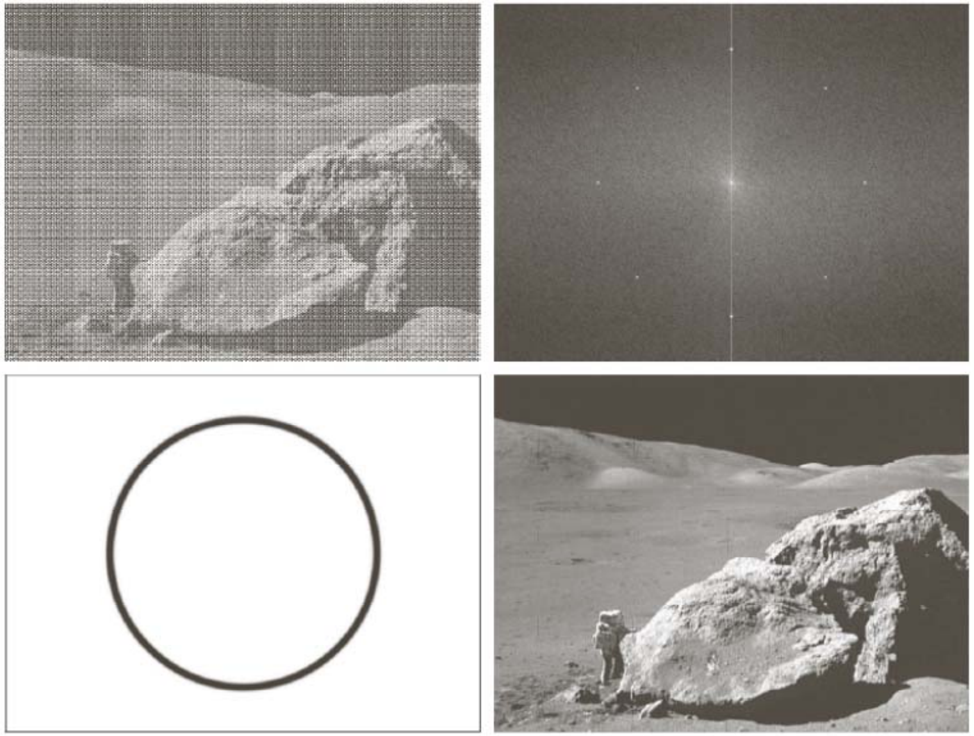


FIGURE 2.39 General approach for operating in the linear transform domain.



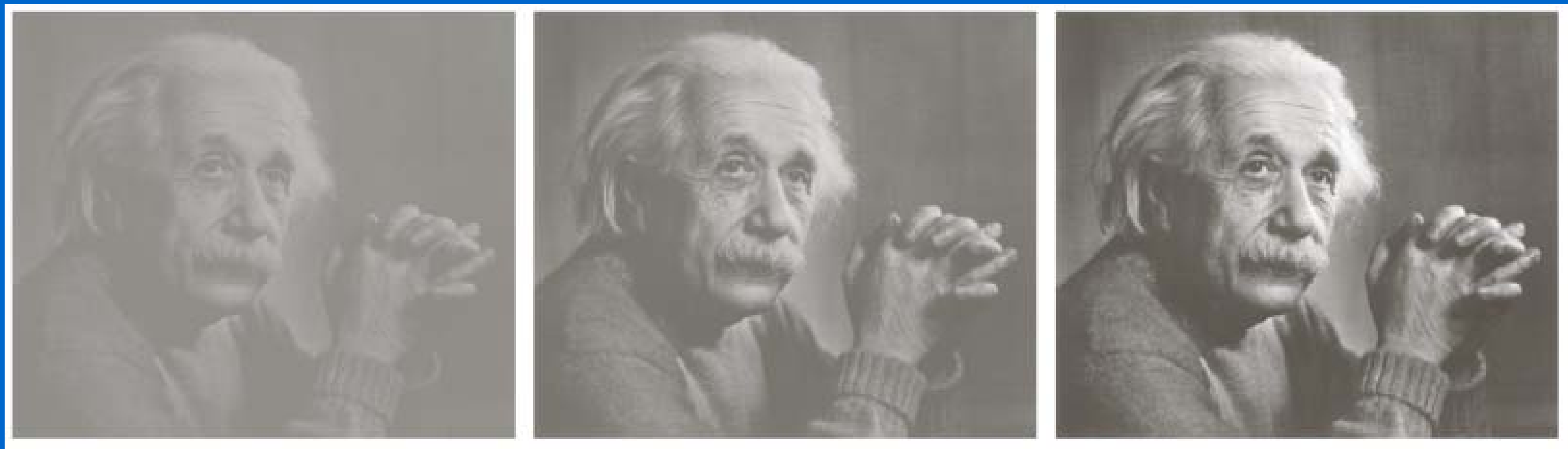
a b
c d

FIGURE 2.40 (a) Image corrupted by sinusoidal interference. (b) Magnitude of the Fourier transform showing the bursts of energy responsible for the interference. (c) Mask used to eliminate the energy bursts. (d) Result of computing the inverse of the modified Fourier transform. (Original image courtesy of NASA.)

2.6.8 Probabilistic Methods

$$p(z_k) = n_k / MN \text{(to be continued)}$$

-Mean, Variance or Standard deviation, the *n*th moment.



a b c

FIGURE 2.41 Images exhibiting (a) low contrast, (b) medium contrast, and (c) high contrast.

Summary of the Chapter 2

- Elements of Visual Perception
  - Structure of the eye, brightness & contrast, Mach bands.
- Light and the Electromagnetic spectrum
- Image Sensing and Acquisition
  - Image formation model
- Image Sampling and Quantization
  - Spatial and Gray-Level Resolution; Zooming and shrinking.
- Some Basic Relationships Between Pixels
  - Adjacency; Distance measure
- Mathematical Tools

Summary of Chapter1-2

- Digital image: Pixels+Intensity
- Image vs Graphic
- Three level DIP
- Electromagnetic energy spectrum(which is the most dangerous)
- Different EM spectra create different images for same object
- Cone/rod vision
- Brightness adaptation & Discrimination-Weber ratio
- Image sensing & acquisition(point, linear, area array,ring)
- A simple image formation model
- Gray level-bits to be needed for storage
- Spatial/intensity resolution-DPI, Gray level, Bilinear interpolation
- 4/8 neighbors, city-block distance/chessboard distance
- Array product/matrix product
- Linear operations
- Set and logical operations
- Geometric spatial transformations&registration