Digital Image Processing
Subject Code: 21EC5XX

Course Instructor: Dr. Anil B. Gavade
Department of ECE, KLS GIT, Belagavi-590008

Books

Text Books:

1. Rafael Gonzalez, Richard E. Woods, “Digital Image Processing”, Fourth Edition, Pearson Education, 2018.

2. Anil K. Jain, “Fundamentals of Digital Image Processing”, PHI, 2011.

Reference Books:

1. Milan Sonka, Vaclav Hlavac, Roger Boyle, “Image Processing Analysis and Machine Vision

Unit I: Introduction
(Digital Image Processing)

Content:

- Fundamentals of Image Processing

  Introduction, applications of image processing, steps in image processing applications, digital imaging system, sampling and quantization, pixel connectivity, distance measures.

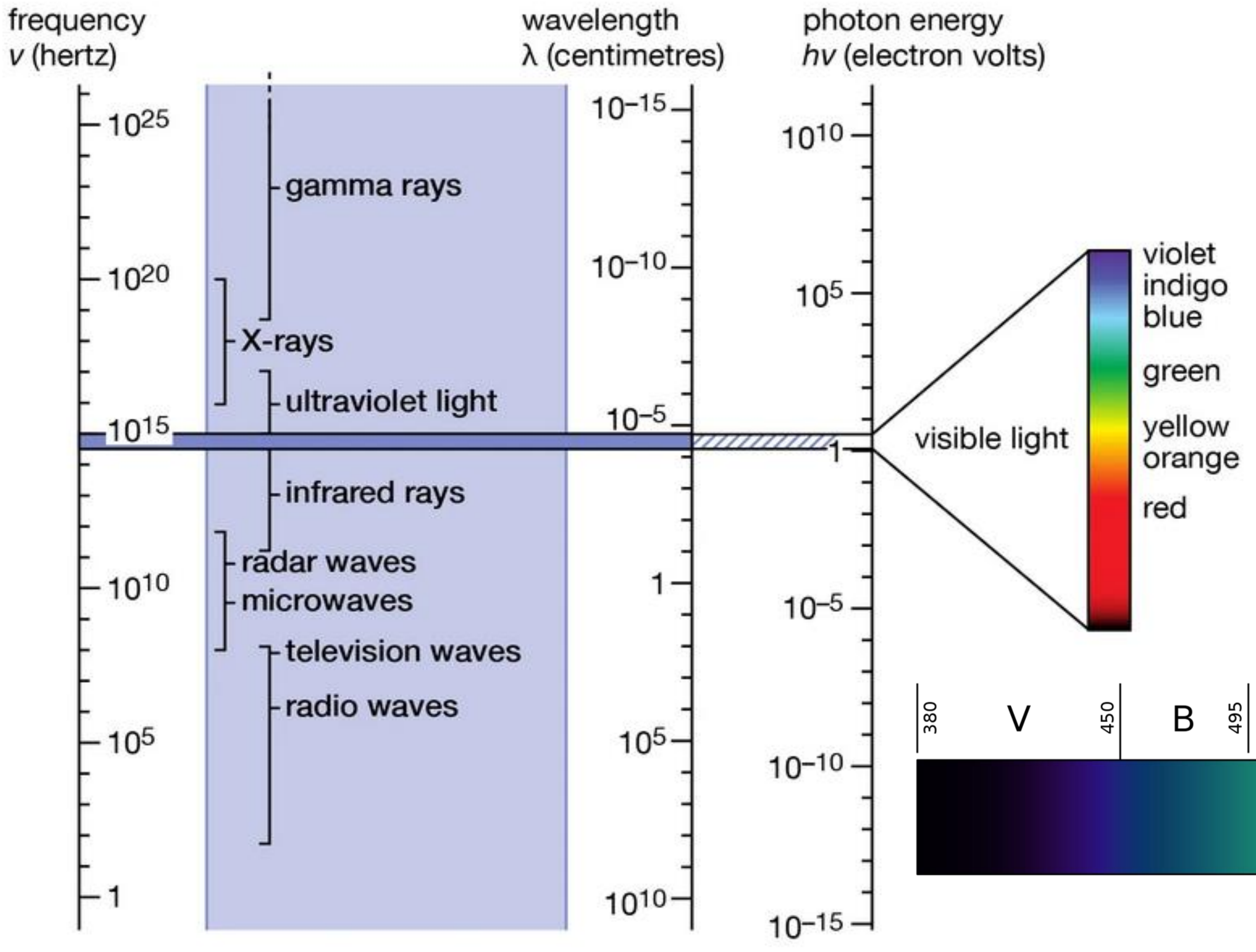
- Case Study

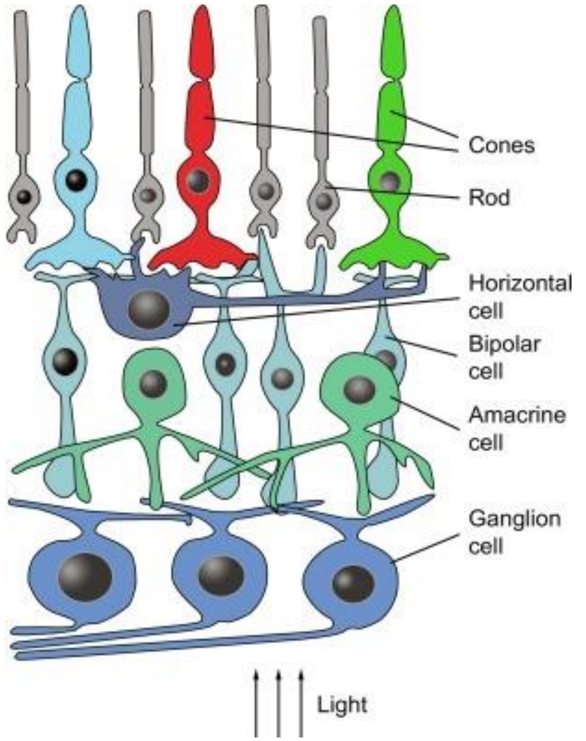
  Study of image processing toolbox and basic image processing operations using matlab and python.

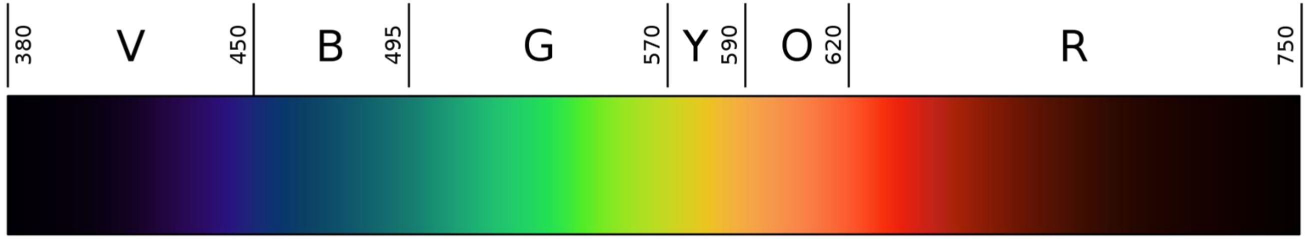
What will we learn?

- Electromagnetic Spectrum (EM)
- Fundamentals of Human Visual System (HVS)
- Human Eye, Comparison of Cones and Rods
- Experimental Curves of light absorption by the red, green and blue cones in the eye
- Color Model: HSI model
- Information Flow in an Imaging System
- Application Digital Image Processing
- Machine Vision Systems / Computer Vision Systems
- Areas where DIP is used
- Image Acquisition and Digitization
- Digital Image Representation,Image Fundamentals: Image data presentation
- Types of Resolution related to Image
- Pixel Relation, Distance measure, Image Arithmetic

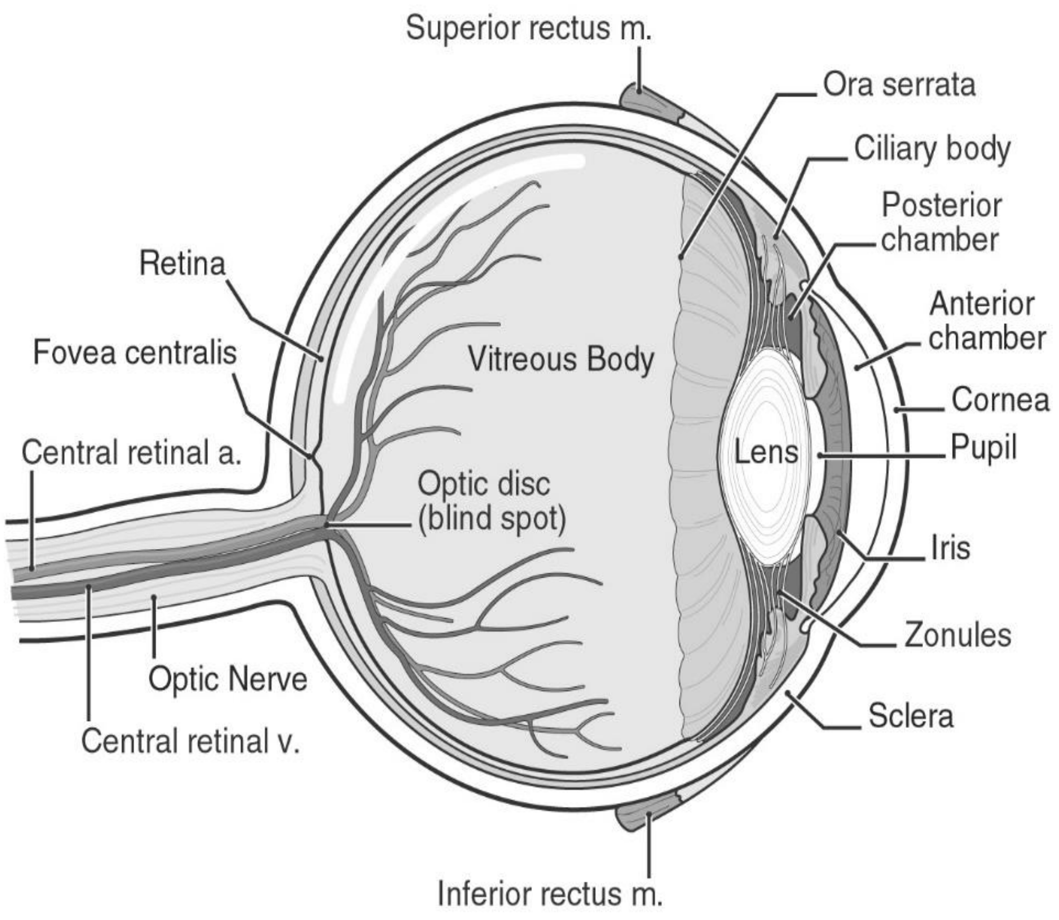
Electromagnetic Spectrum (EM):

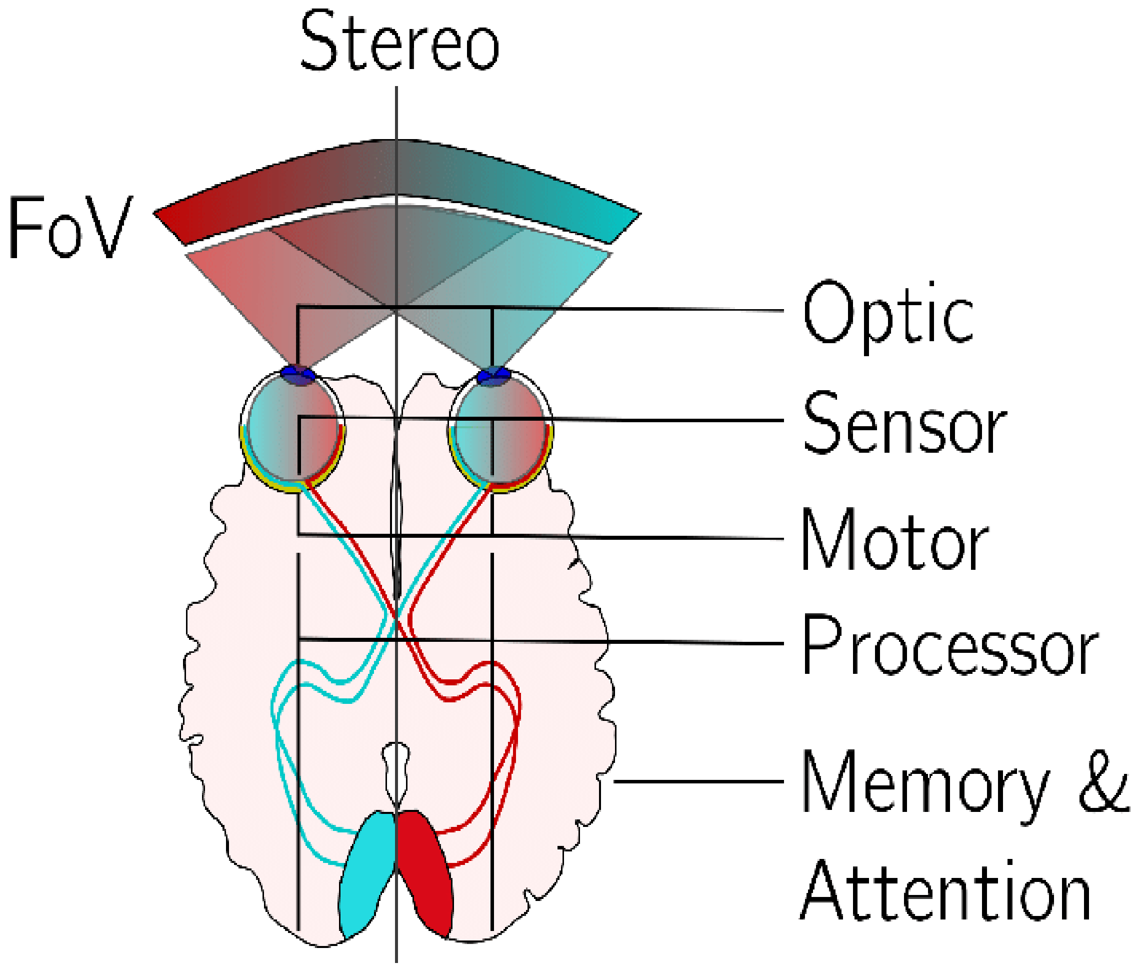




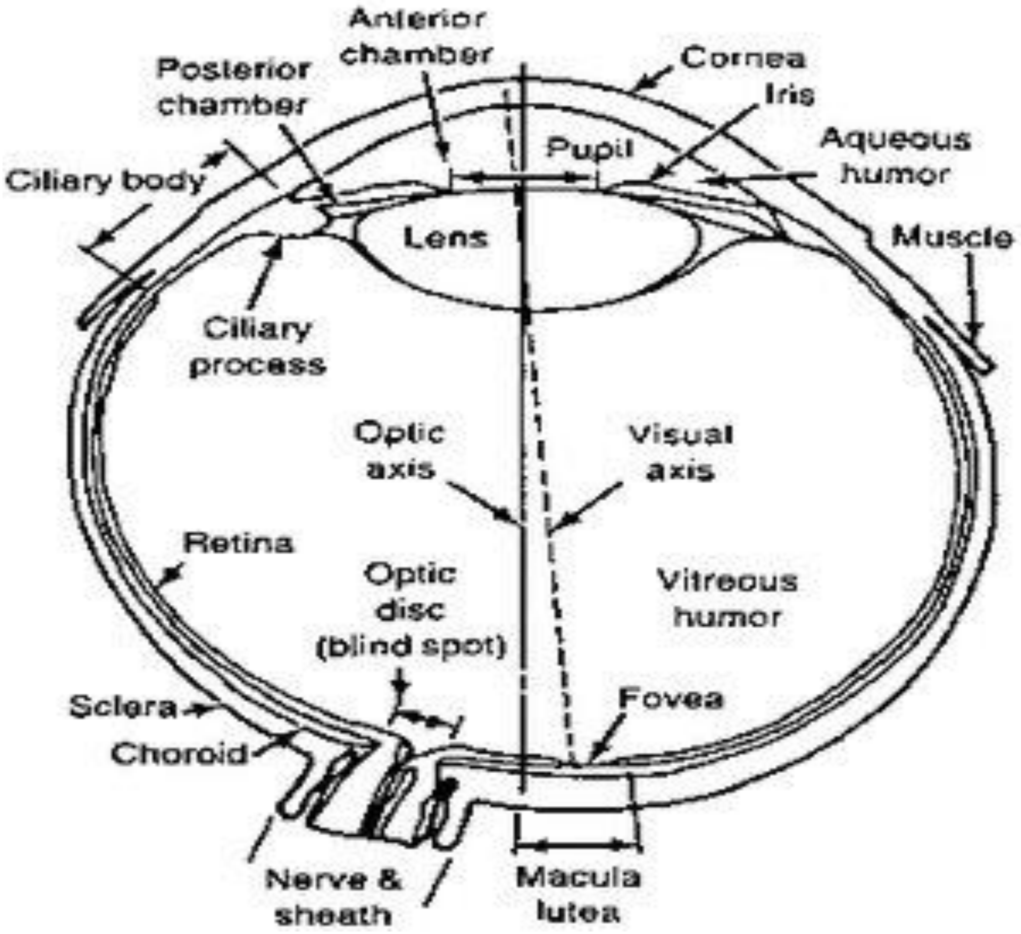


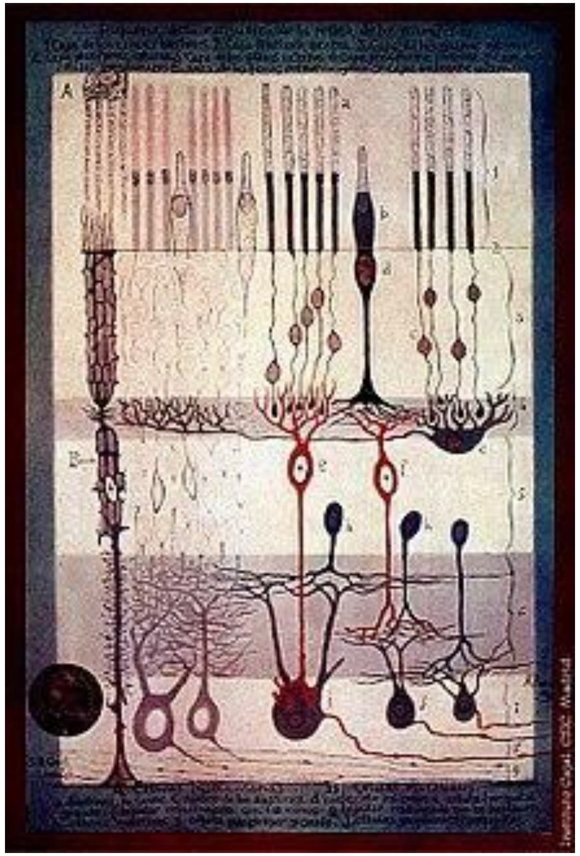
Fundamentals of Human Visual System (HVS)



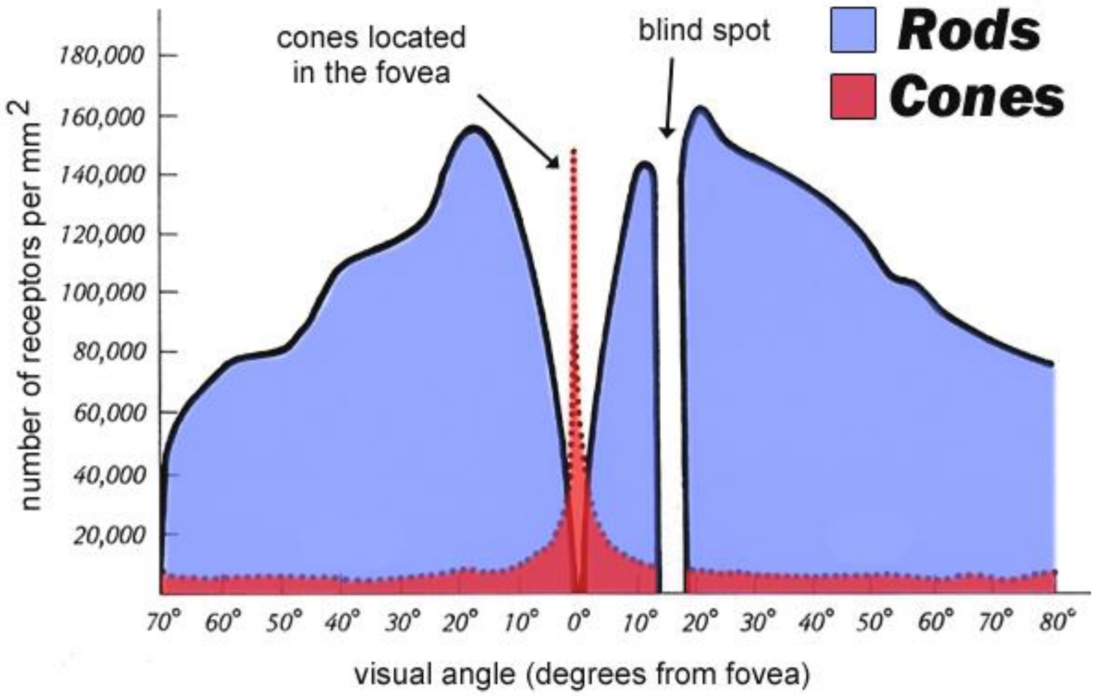


Human Eye


Anterior chamber
Posterior chamber
Cornea
Iris
Pupil
Aqueous humor
Ciliary body
Lens
Muscle
Ciliary process
Optic axis
Visual axis
Retina
Optic disc (blind spot)
Vitreous humor
Sclera
Fovea
Choroid
Nerve & sheath
Macula lutea



Comparison of Cones and Rods



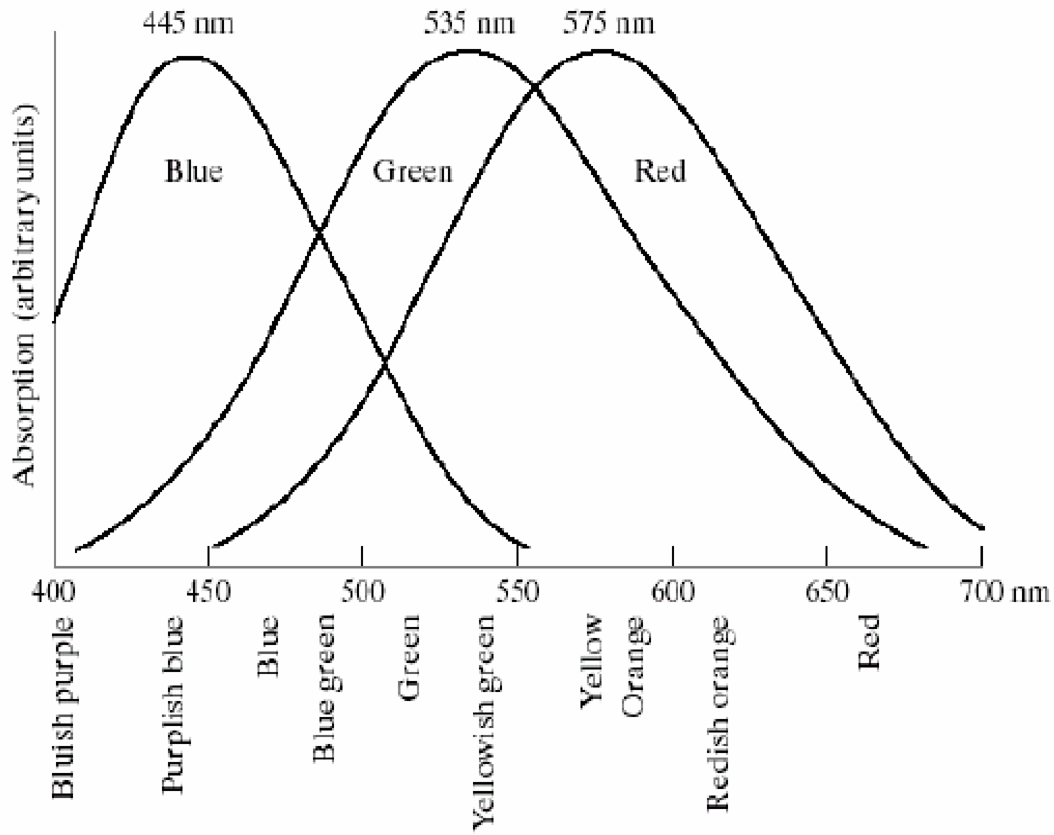
Fovea area: 1.5mm*1.5mm

Density of cones: 15000/mm^2

Cones in fovea: 337 000

	cones	rods
number	6~7 million	75~175 million
Sensitivity	color	shape
vision	Photopic (Bright-light)	Scotopic(dim-light)

Experimental Curves of light absorption by the red, green and blue cones in the eye



Cones	Percent
Red	65%
Green	33%
Blue	2%

But the blue cones is the most sensitive

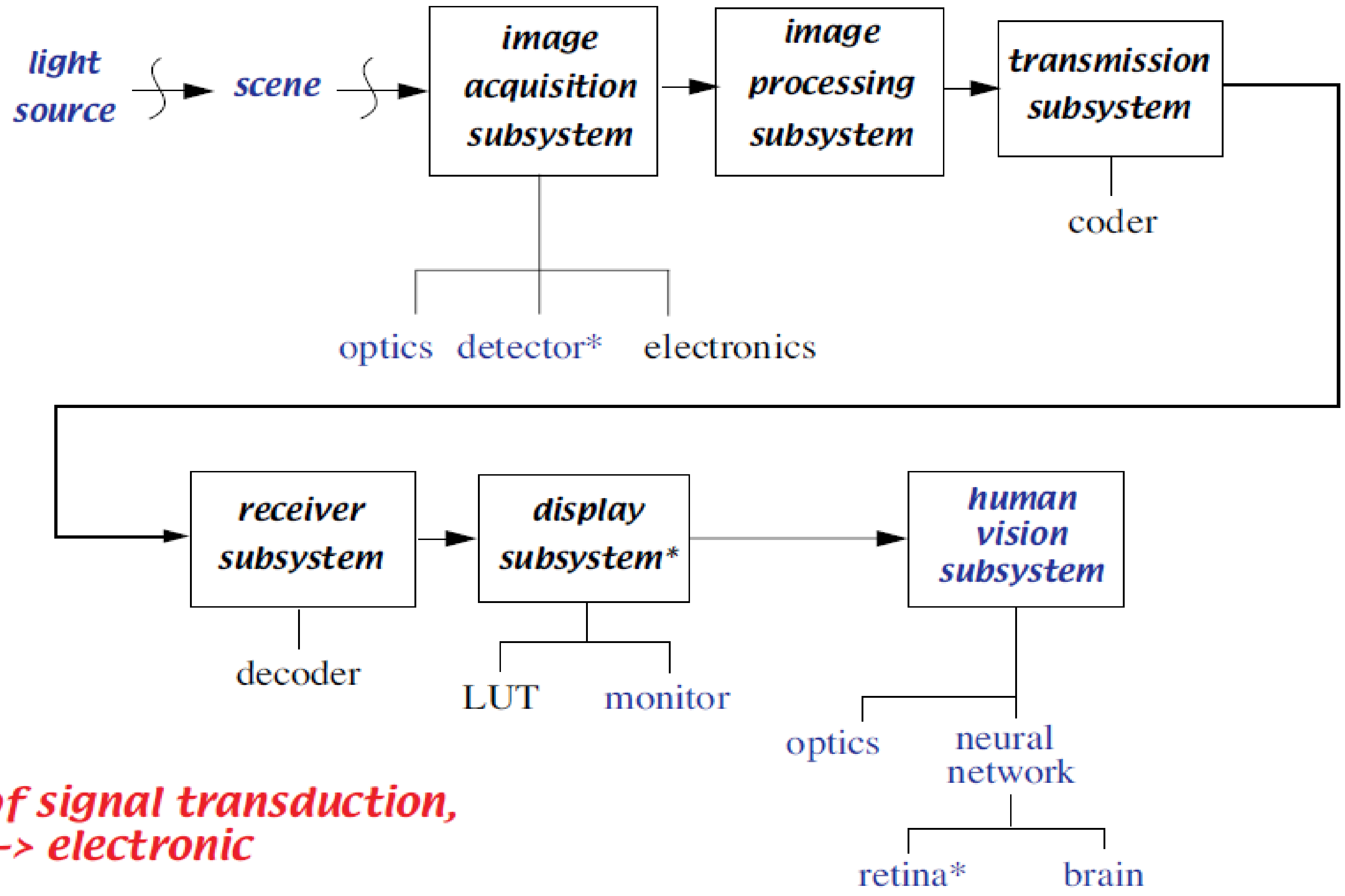
Color Model: HSI model

Hue: associated with the dominant wavelength in a mixture of light waves

Saturation: refer to the relative purity or the amount of white light mixed with hue.

Intensity: brightness

Information Flow in an Imaging System



***blue* indicates *continuous mathematical modeling* is appropriate**

*** points of signal transduction, optical <—> electronic***

Application Digital Image Processing (DIP) divided as

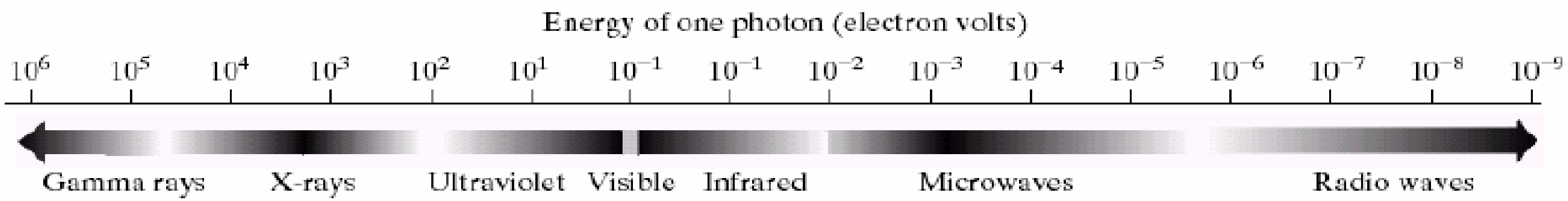
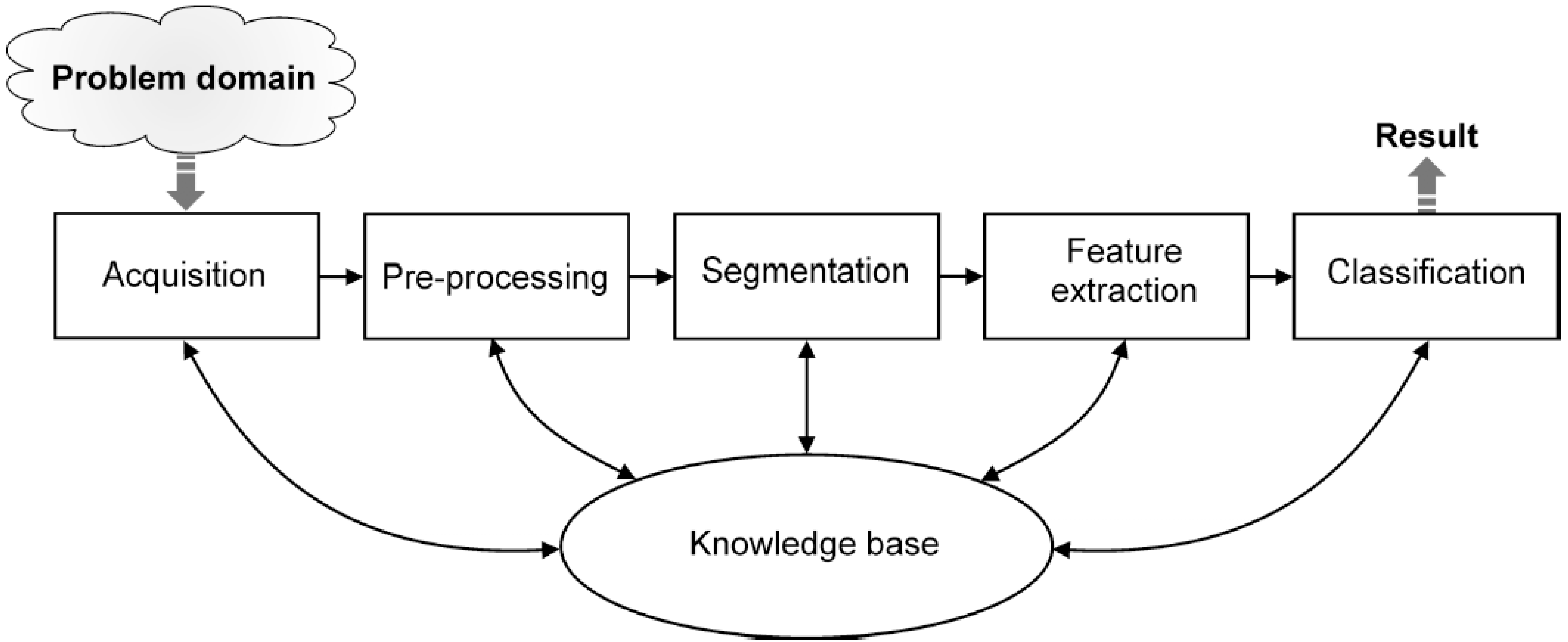


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

- Gamma-Ray Imaging
- X-Ray Imaging
- Imaging in the Ultraviolet Band
- Imaging in the Visible and Infrared Bands
- Imaging in the Microwave Band
- Imaging in the Radio Band
- Example in Which Other Modalities Are Used

Machine Vision Systems / Computer Vision Systems



Areas where DIP is used

- Multimedia technology and communication image compression VCD, DVD, HDTV, Video telephone
- Medicine
- Industrial
- Military
- Commercial
- Earth resources/Natural resource
- *etc*..,

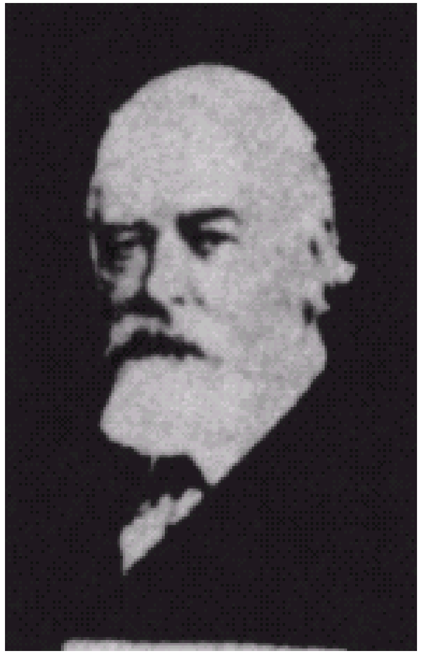
The Origins of Digital Image Processing

One of the first applications of digital images was in the newspaper industry, when pictures were first sent by submarine cable between London and New York.

FIGURE 1.1 A digital picture produced in 1921 from a coded tape by a telegraph printer with special type faces. (McFarlane.)

- Better quality

FIGURE 1.2 A digital picture made in 1922 from a tape punched after the signals had crossed the Atlantic twice. Some errors are visible. (McFarlane.)



❑15-tone equipment

FIGURE 1.3 Unretouched cable picture of Generals Pershing and Foch, transmitted in 1929 from London to New York by 15-tone equipment. (McFarlane.)

From computers, meaningful image processing tasks appeared.

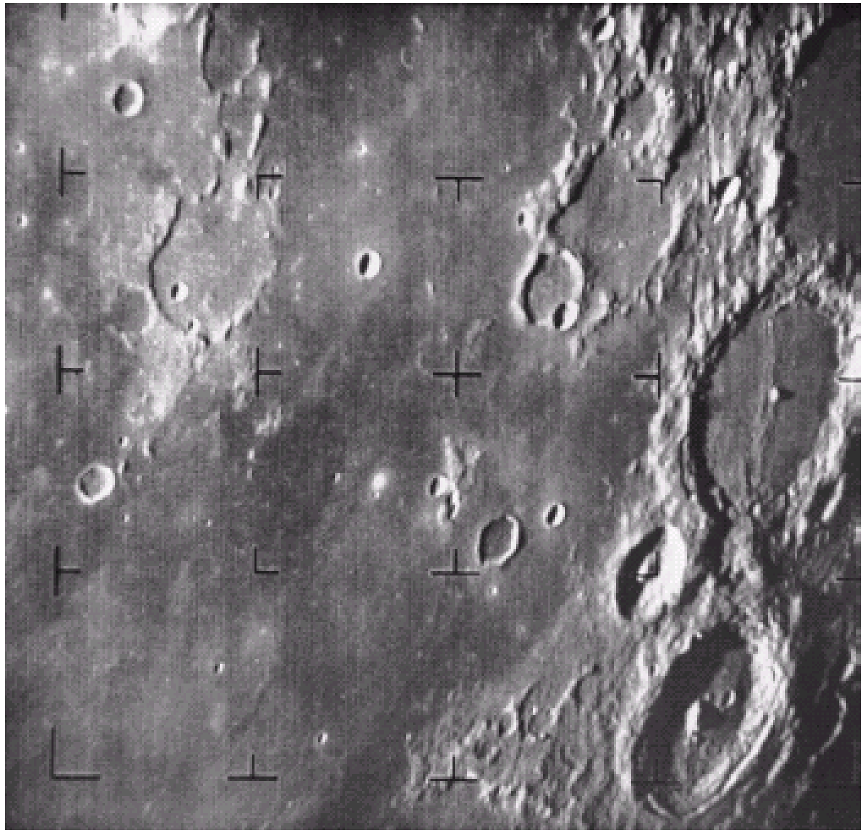


FIGURE 1.4 The first picture of the moon by a U.S. spacecraft. *Ranger 7* took this image on July 31, 1964 at 9:09 A.M. EDT, about 17 minutes before impacting the lunar surface. (Courtesy of NASA.)

Gamma-Ray Imaging

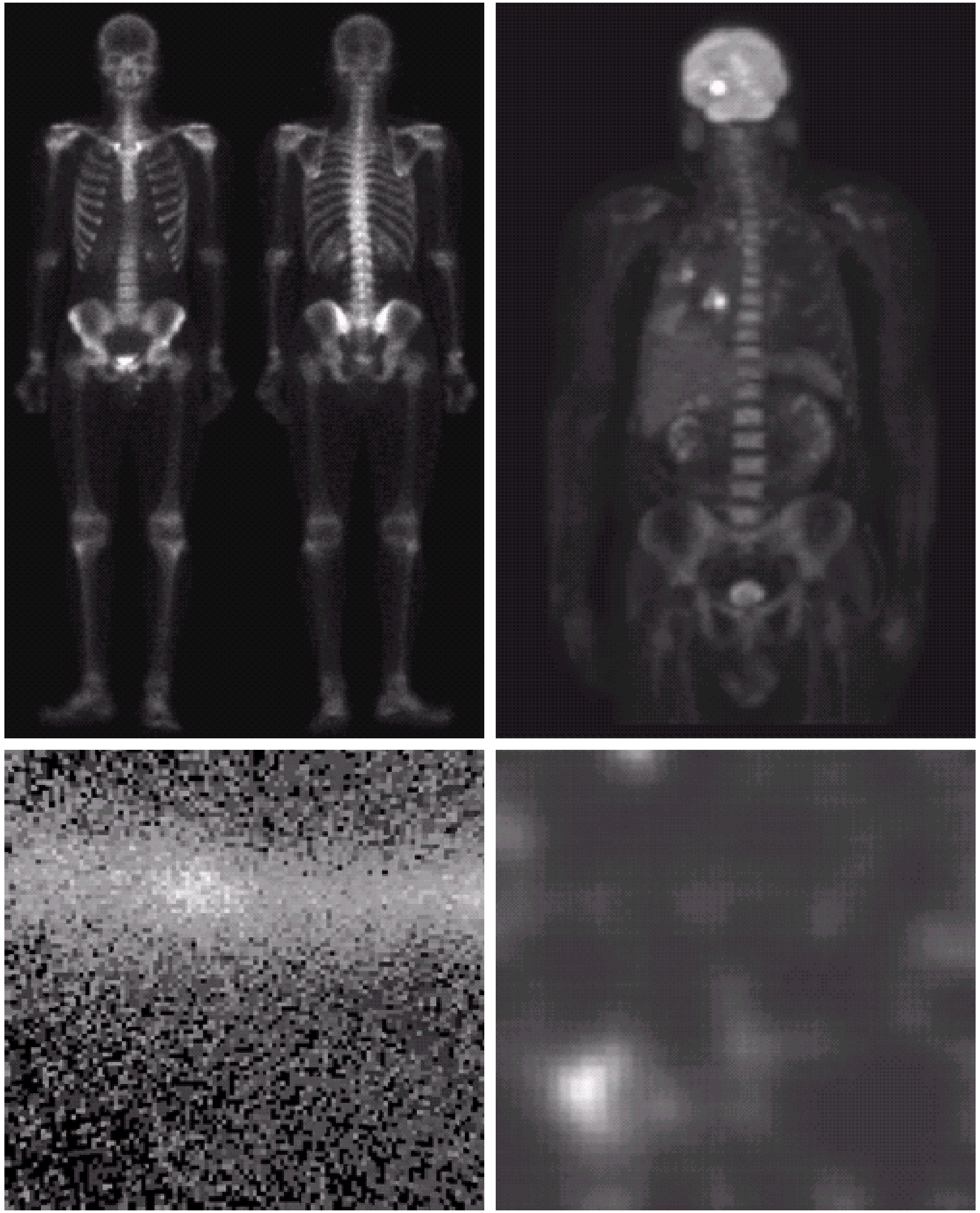
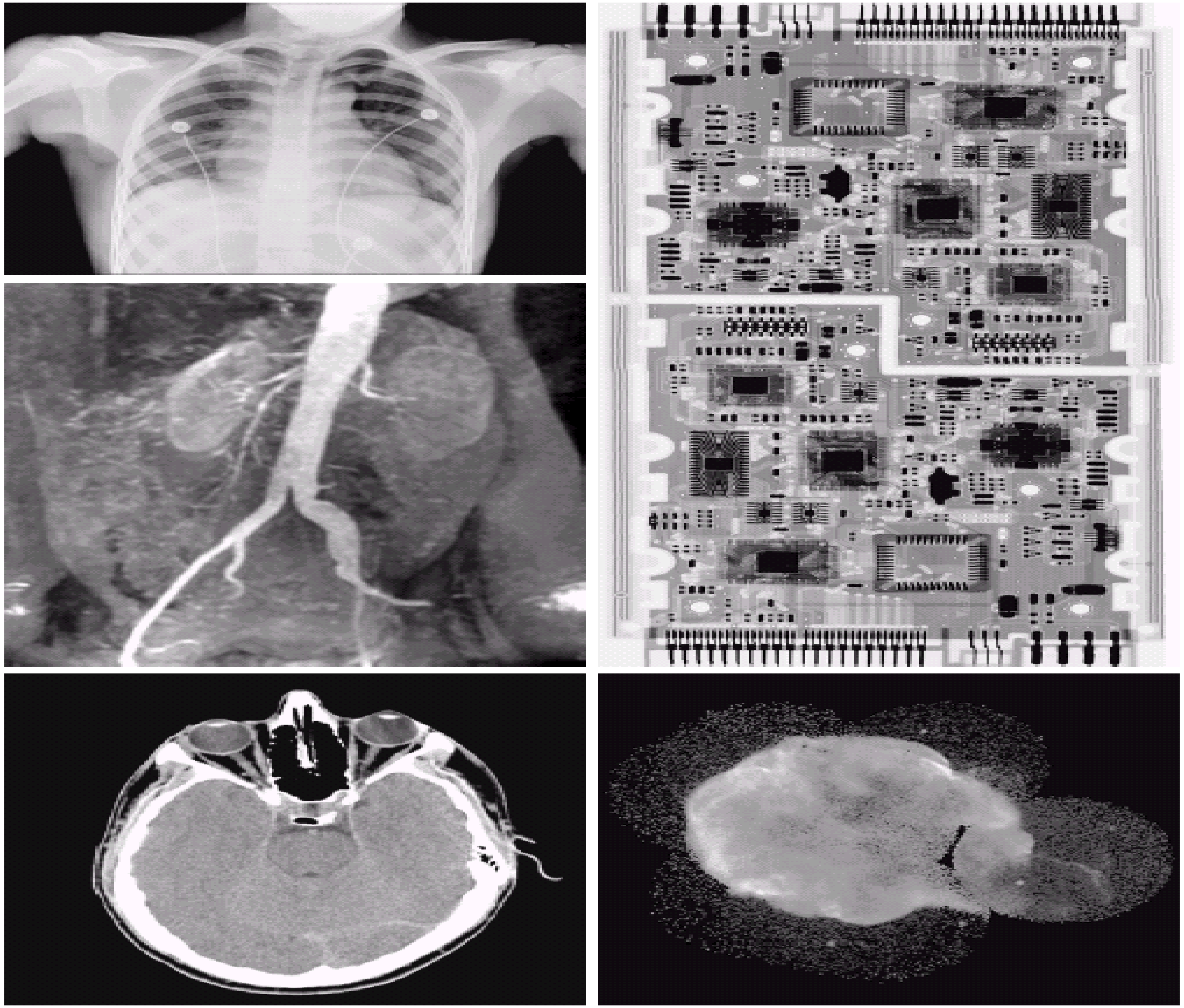


FIGURE 1.6 Examples of gamma-ray imaging. (a) Bone scan. (b) PET image. (c) Cygnus Loop. (d) Gamma radiation (bright spot) from a reactor valve. (Images courtesy of (a) G.E. Medical Systems, (b) Dr. Michael E. Casey, CTI PET Systems, (c) NASA, (d) Professors Zhong He and David K. Wehe, University of Michigan.)

X-ray Imaging



a d
b
c e

FIGURE 1.7 Examples of X-ray imaging. (a) Chest X-ray. (b) Aortic angiogram. (c) Head CT. (d) Circuit boards. (e) Cygnus Loop. (Images courtesy of (a) and (c) Dr. David R. Pickens, Dept. of Radiology & Radiological Sciences, Vanderbilt University Medical Center, (b) Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, (d) Mr. Joseph E. Pascente, Lixi, Inc., and (e) NASA.)

Imaging in the Ultraviolet Band

a b
c

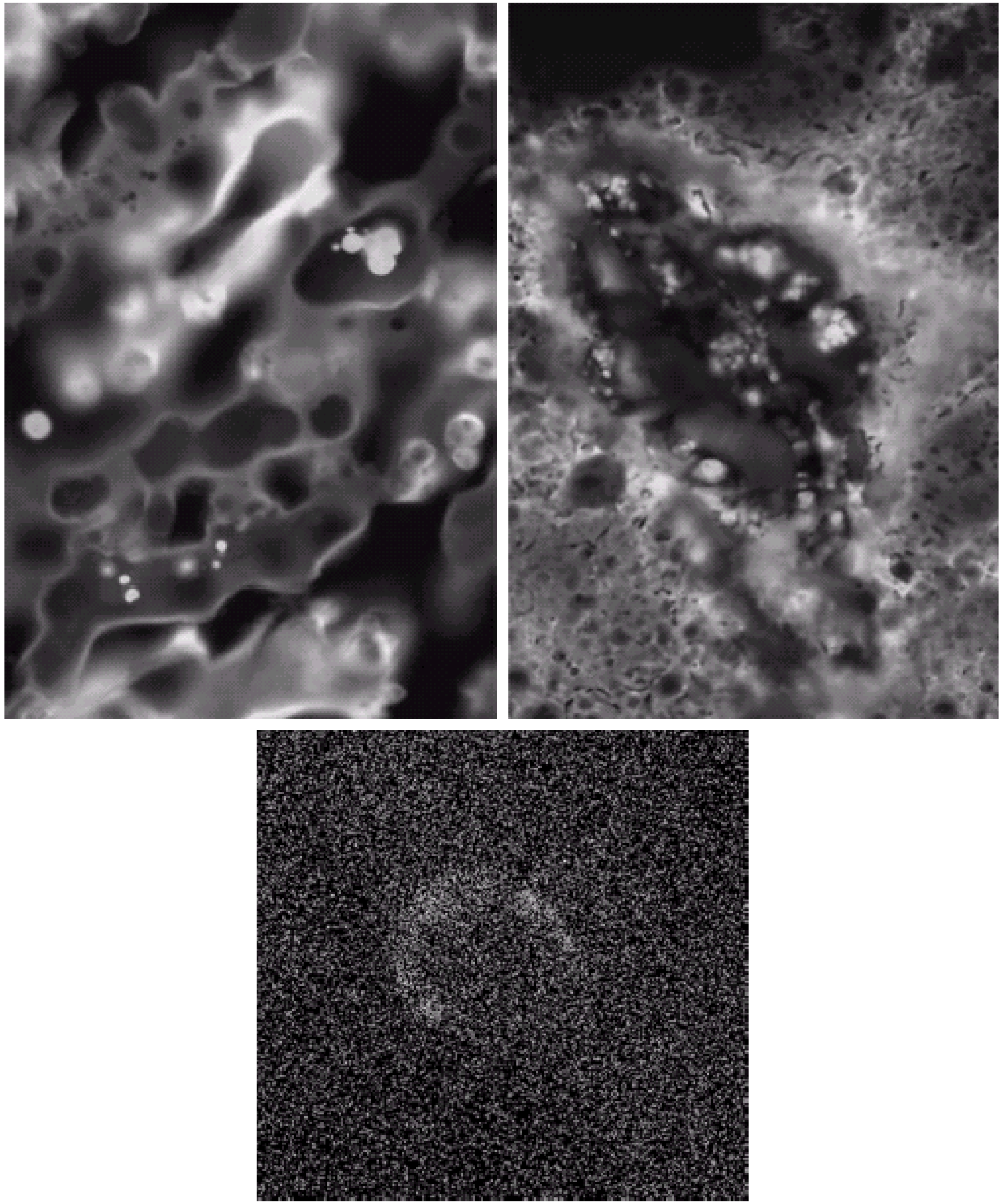


FIGURE 1.8 Examples of ultraviolet imaging. (a) Normal corn. (b) Smut corn. (c) Cygnus Loop. (Images courtesy of (a) and (b) Dr. Michael W. Davidson, Florida State University, (c) NASA.)

Imaging in the Visible and Infrared Bands

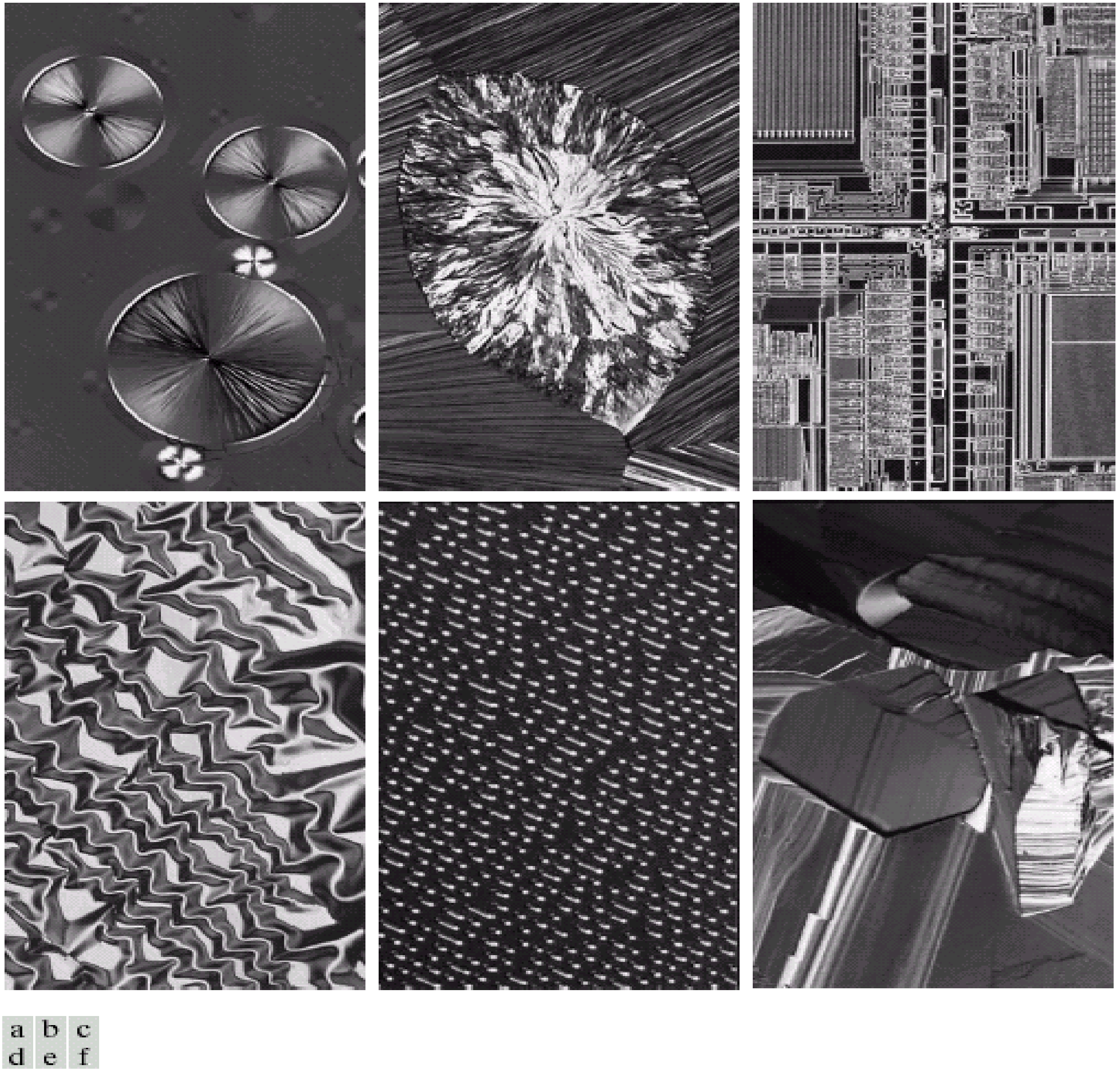


FIGURE 1.9 Examples of light microscopy images. (a) Taxol (anticancer agent), magnified 250×. (b) Cholesterol—40×. (c) Microprocessor—60×. (d) Nickel oxide thin film—600 ×. (e) Surface of audio CD—1750×. (f) Organic superconductor—450×. (Images courtesy of Dr. Michael W. Davidson, Florida State University.)

Remote sensing

TABLE 1.1 Thematic bands in NASA's LANDSAT satellite.

Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content of soil and vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Middle infrared	2.08–2.35	Mineral mapping

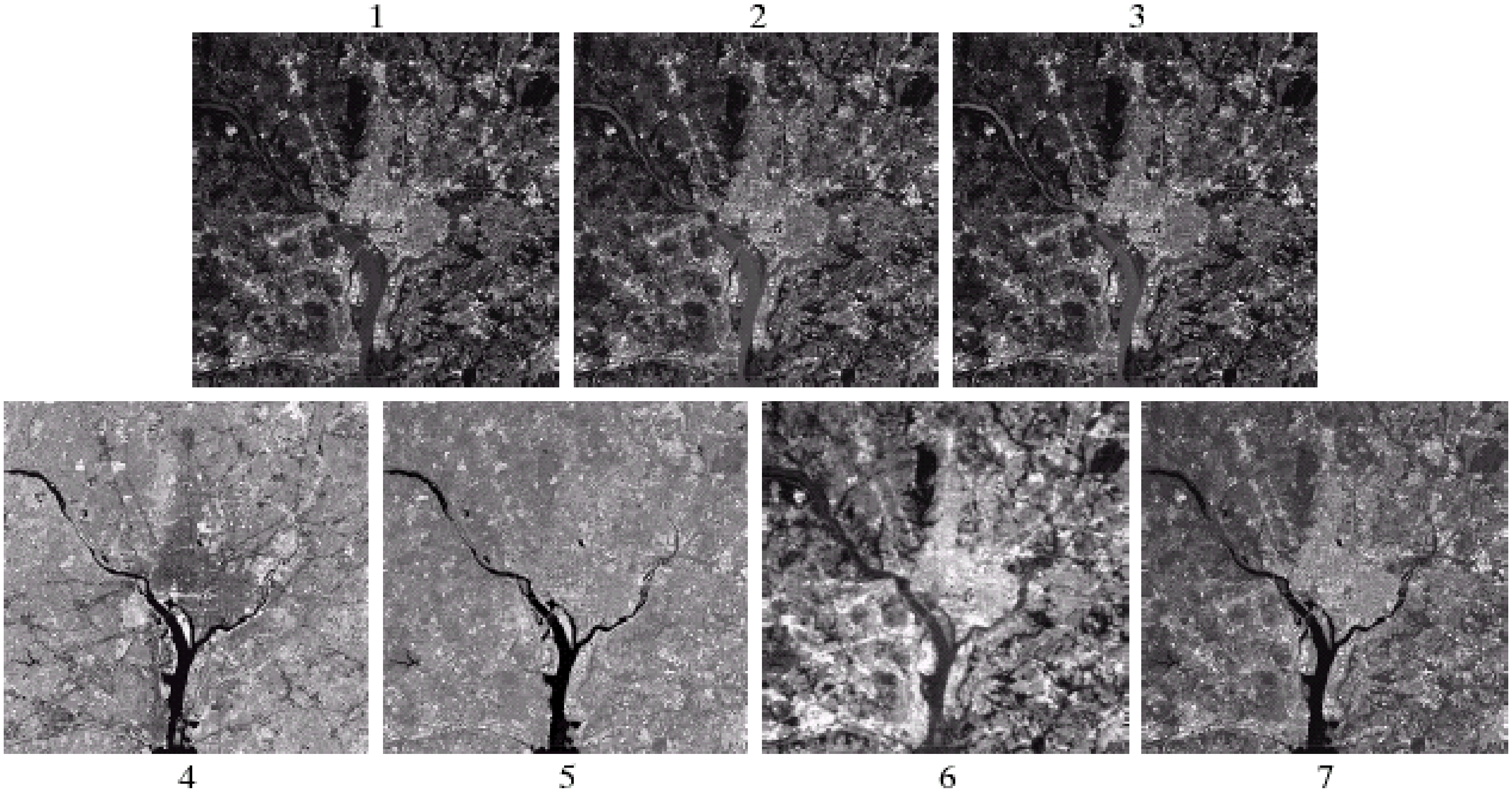


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

Weather Observation, visible and infrared bands

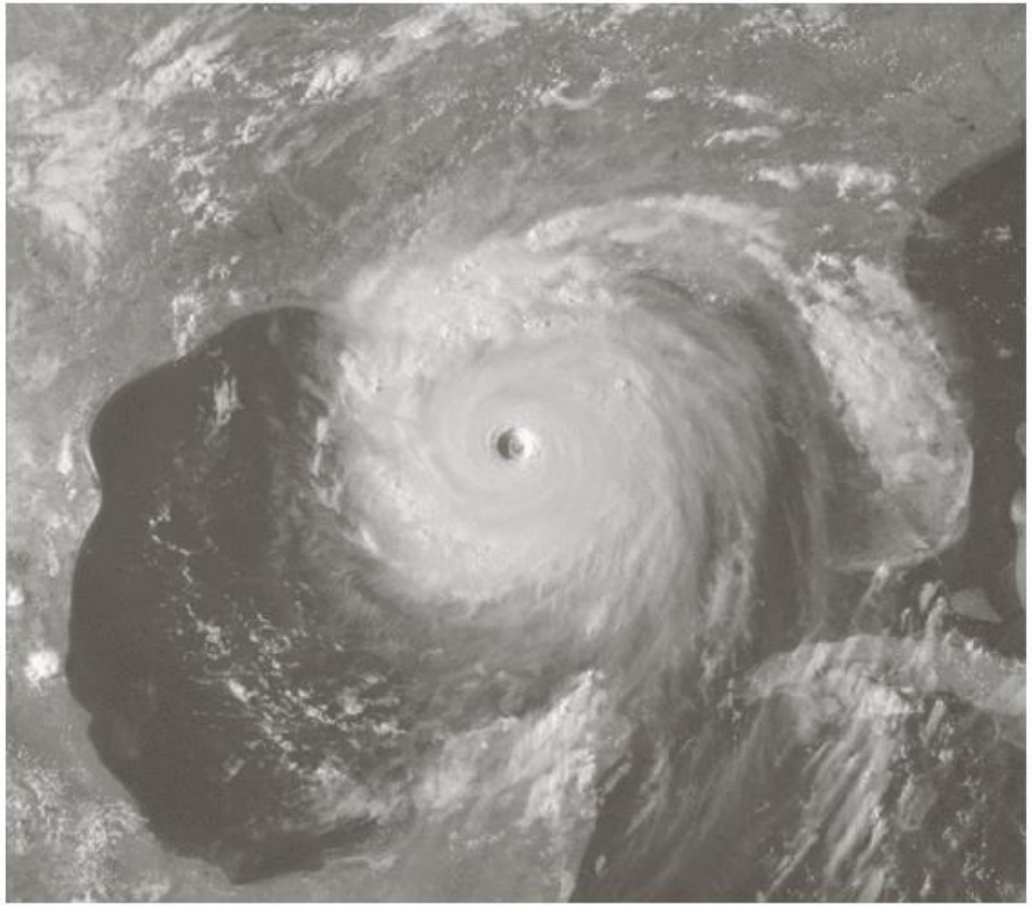


FIGURE 1.11 Satellite image of Hurricane Katrina taken on August 29, 2005. (Courtesy of NOAA.)

Infrared imaging

FIGURE 1.12 Infrared satellite images of the Americas. The small gray map is provided for reference. (Courtesy of NOAA.)

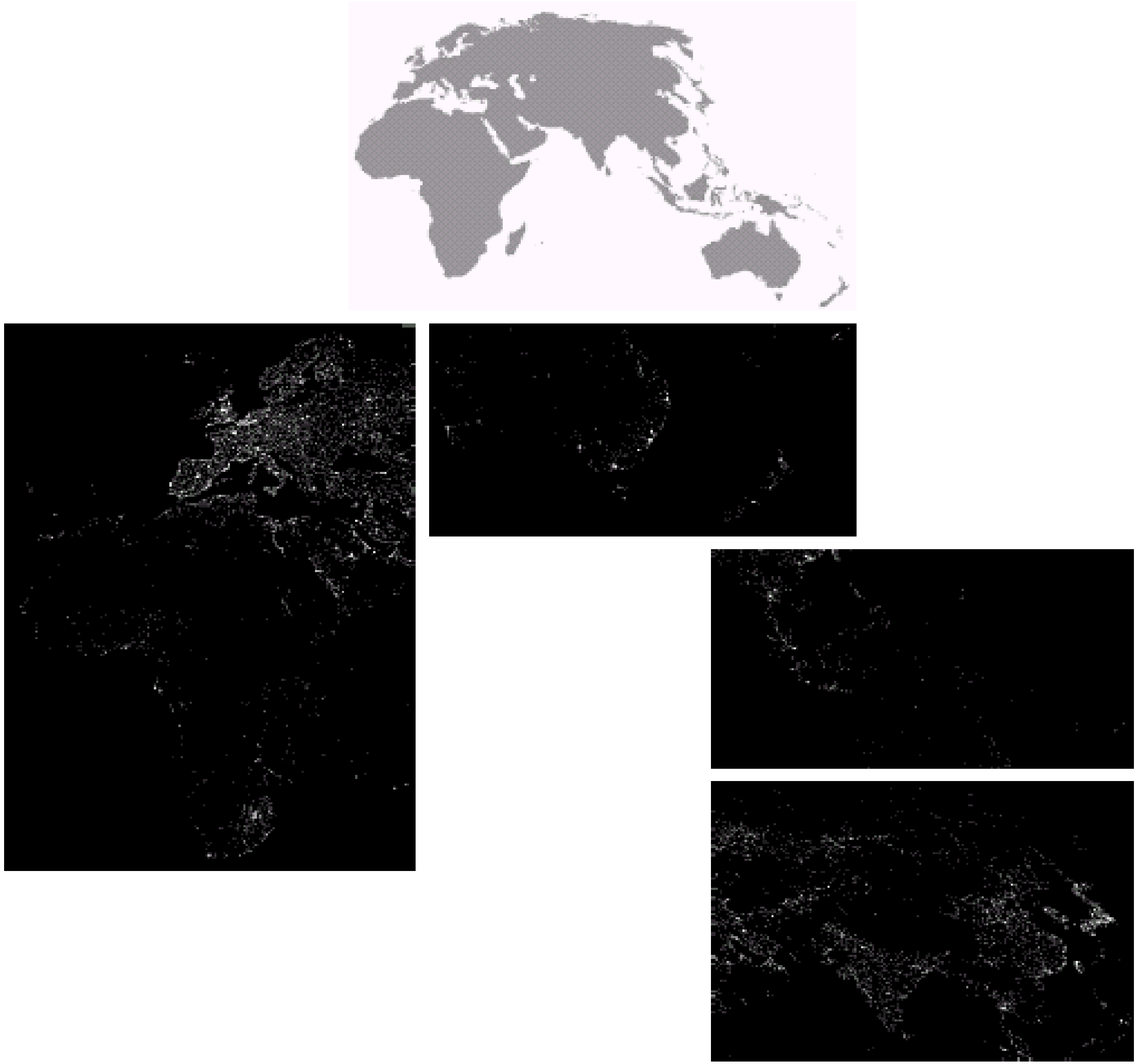
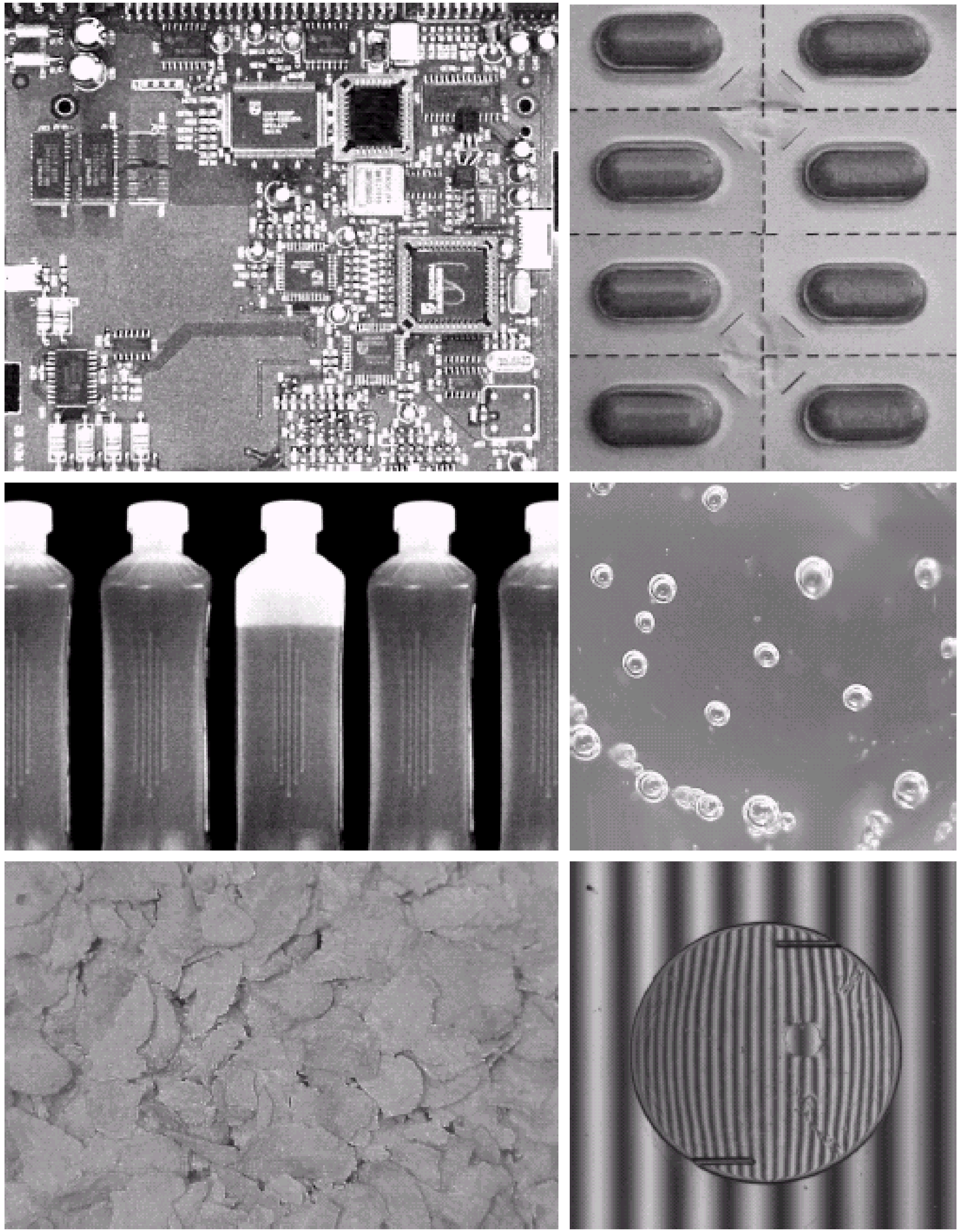


FIGURE 1.13 Infrared satellite images of the remaining populated part of the world. The small gray map is provided for reference. (Courtesy of NOAA.)

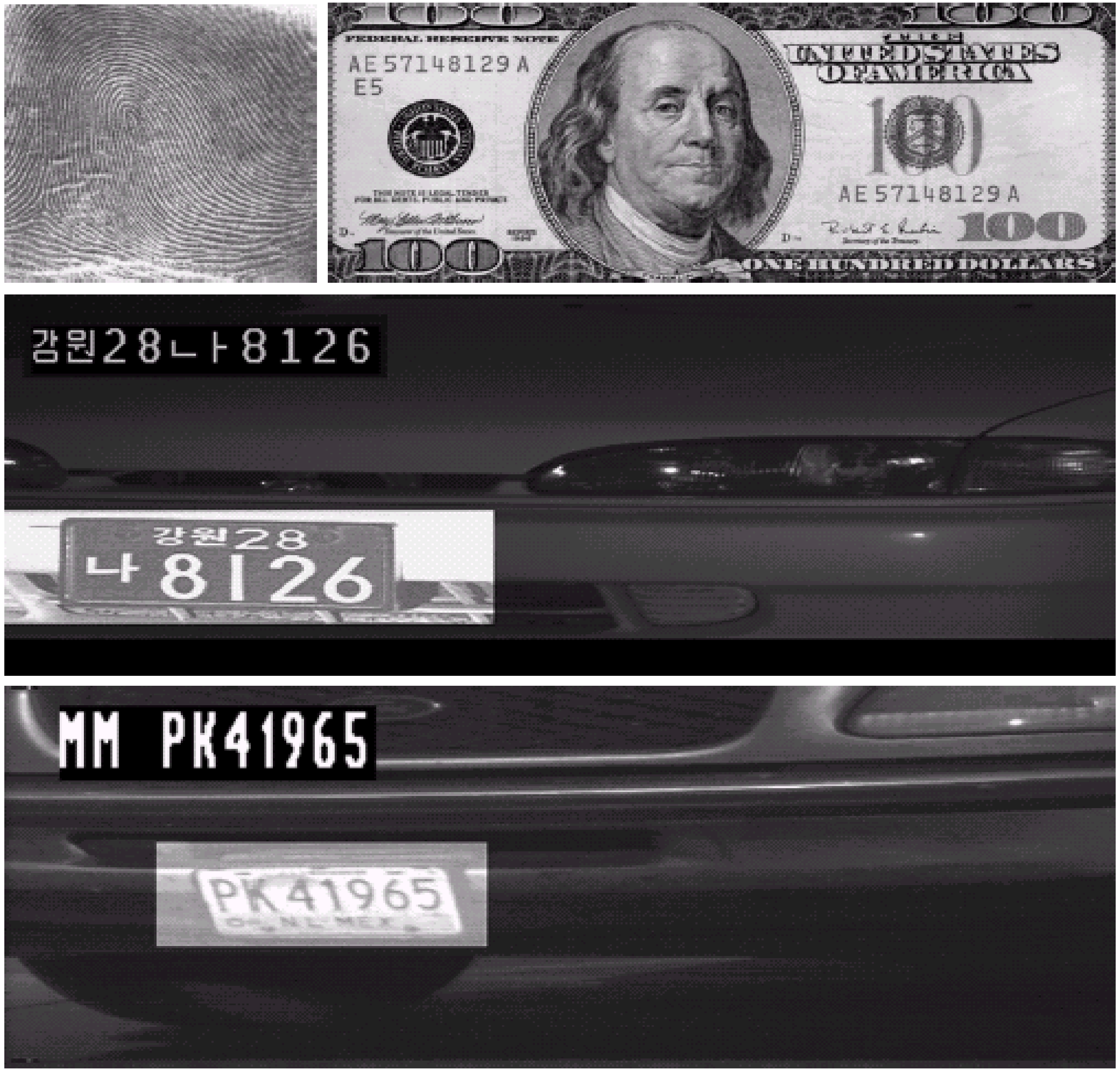
Automated visual inspection

a b
c d
e f

FIGURE 1.14 Some examples of manufactured goods often checked using digital image processing. (a) A circuit board controller. (b) Packaged pills. (c) Bottles. (d) Bubbles in clear-plastic product. (e) Cereal. (f) Image of intraocular implant. (Fig. (f) courtesy of Mr. Pete Sites, Perceptics Corporation.)



Biometric and Text Recognition and classification

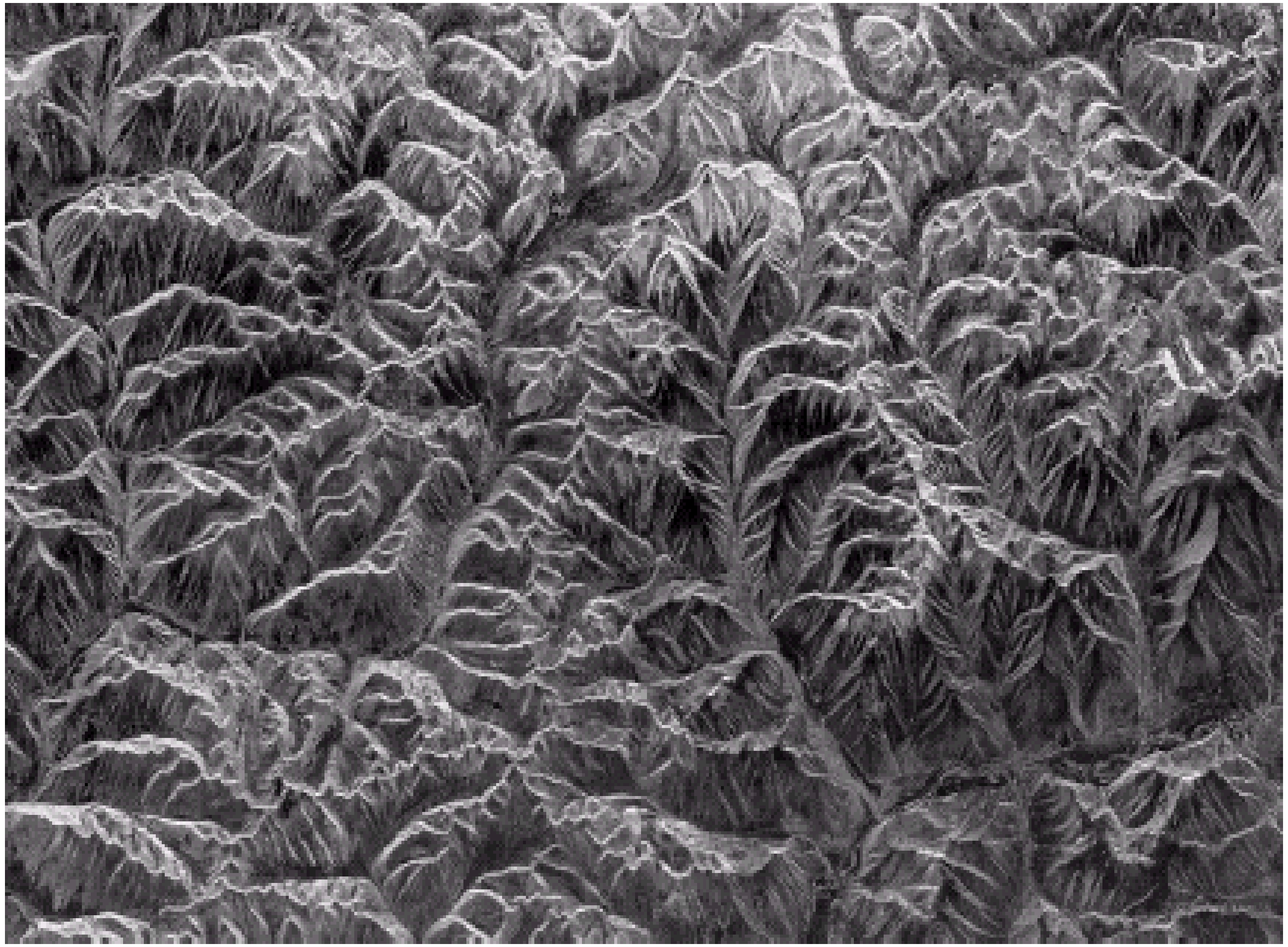


a b
c
d

FIGURE 1.15 Some additional examples of imaging in the visual spectrum. (a) Thumb print. (b) Paper currency. (c) and (d). Automated license plate reading. (Figure (a) courtesy of the National Institute of Standards and Technology. Figures (c) and (d) courtesy of Dr. Juan Herrera, Perceptics Corporation.)

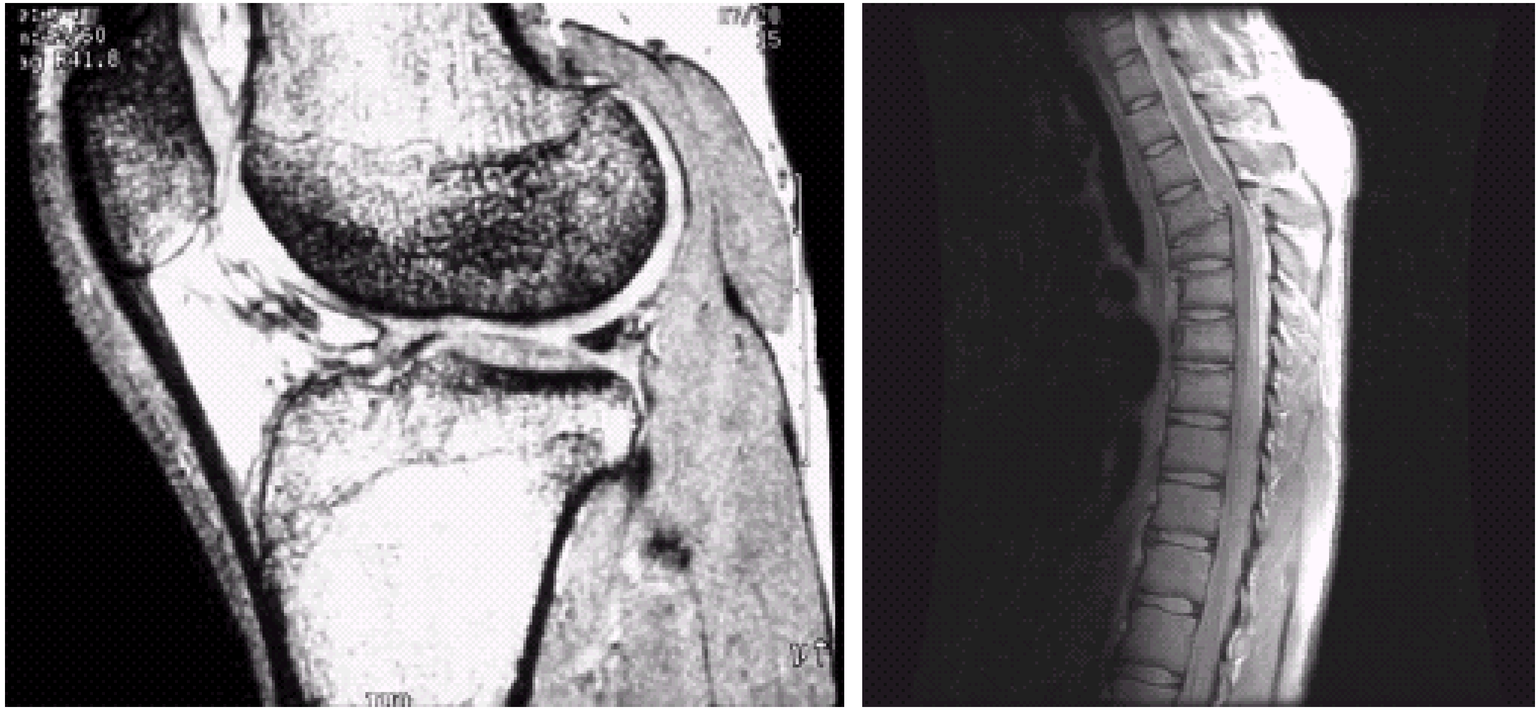
Imaging in the Microwave Band

FIGURE 1.16
Spaceborne radar image of mountains in southeast Tibet. (Courtesy of NASA.)



Imaging in the Radio Band

Magnetic Resonance Imaging(MRI)



a b

FIGURE 1.17 MRI images of a human (a) knee, and (b) spine. (Image (a) courtesy of Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, and (b) Dr. David R. Pickens, Department of Radiology and Radiological Sciences, Vanderbilt University Medical Center.)

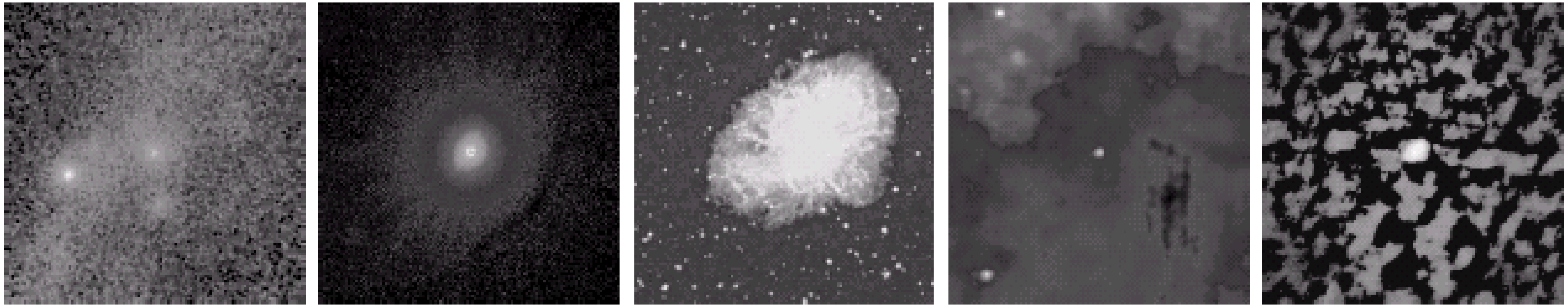
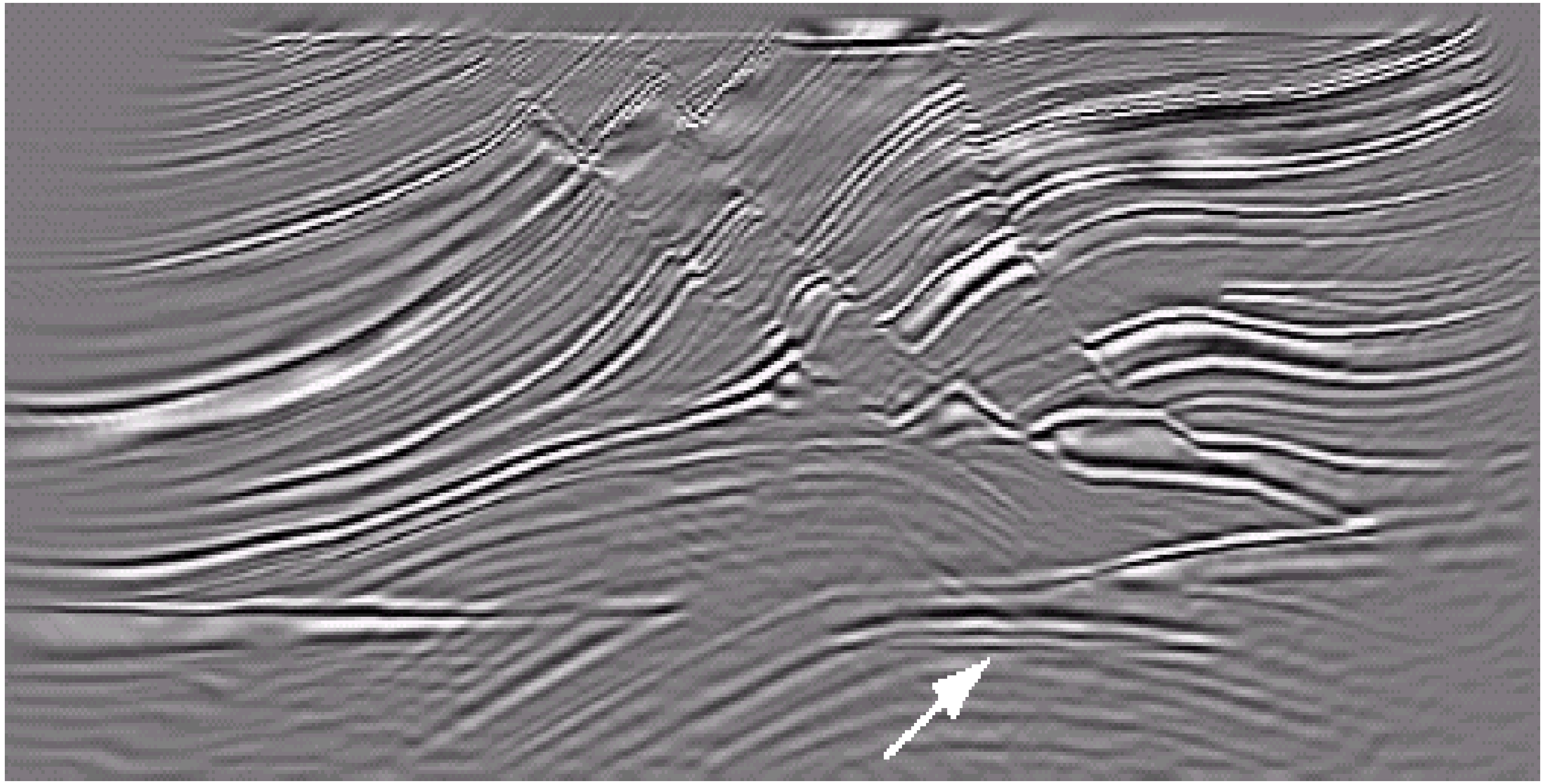


FIGURE 1.18 Images of the Crab Pulsar (in the center of images) covering the electromagnetic spectrum. (Courtesy of NASA.)

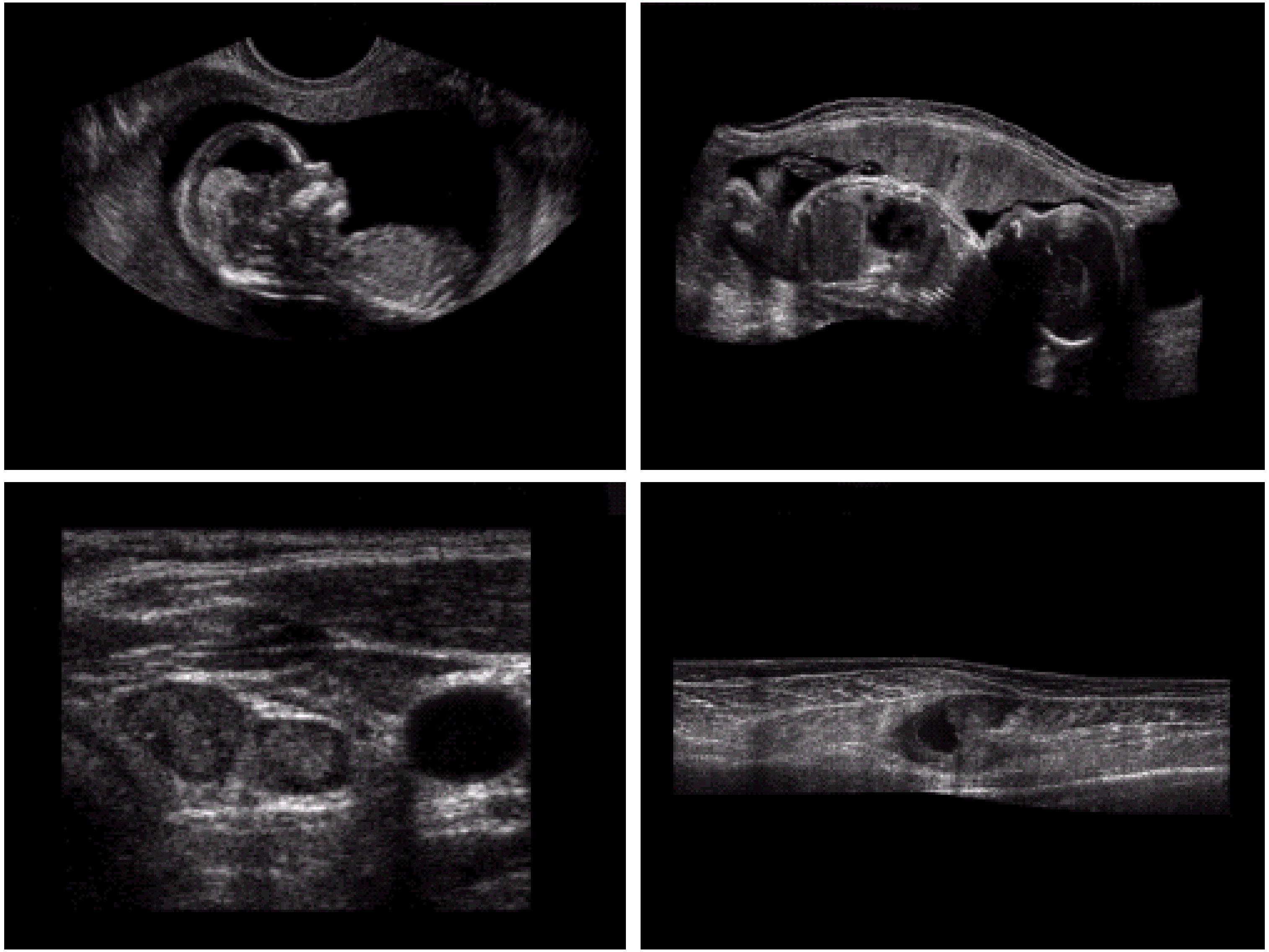
Examples in which Other Imaging Modalities Are Used

Sound

FIGURE 1.19
Cross-sectional image of a seismic model. The arrow points to a hydrocarbon (oil and/or gas) trap. (Courtesy of Dr. Curtis Ober, Sandia National Laboratories.)



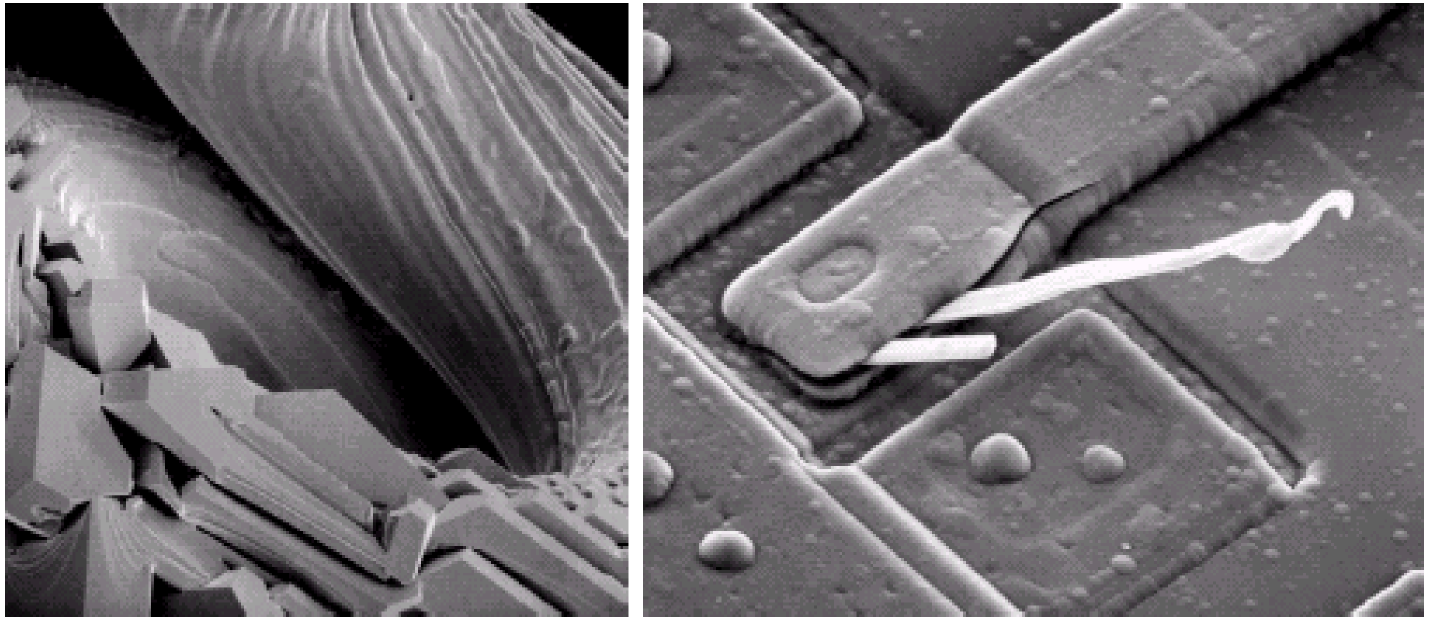
Ultrasound



a b
c d

FIGURE 1.20 Examples of ultrasound imaging. (a) Baby. (2) Another view of baby. (c) Thyroids. (d) Muscle layers showing lesion. (Courtesy of Siemens Medical Systems, Inc., Ultrasound Group.)

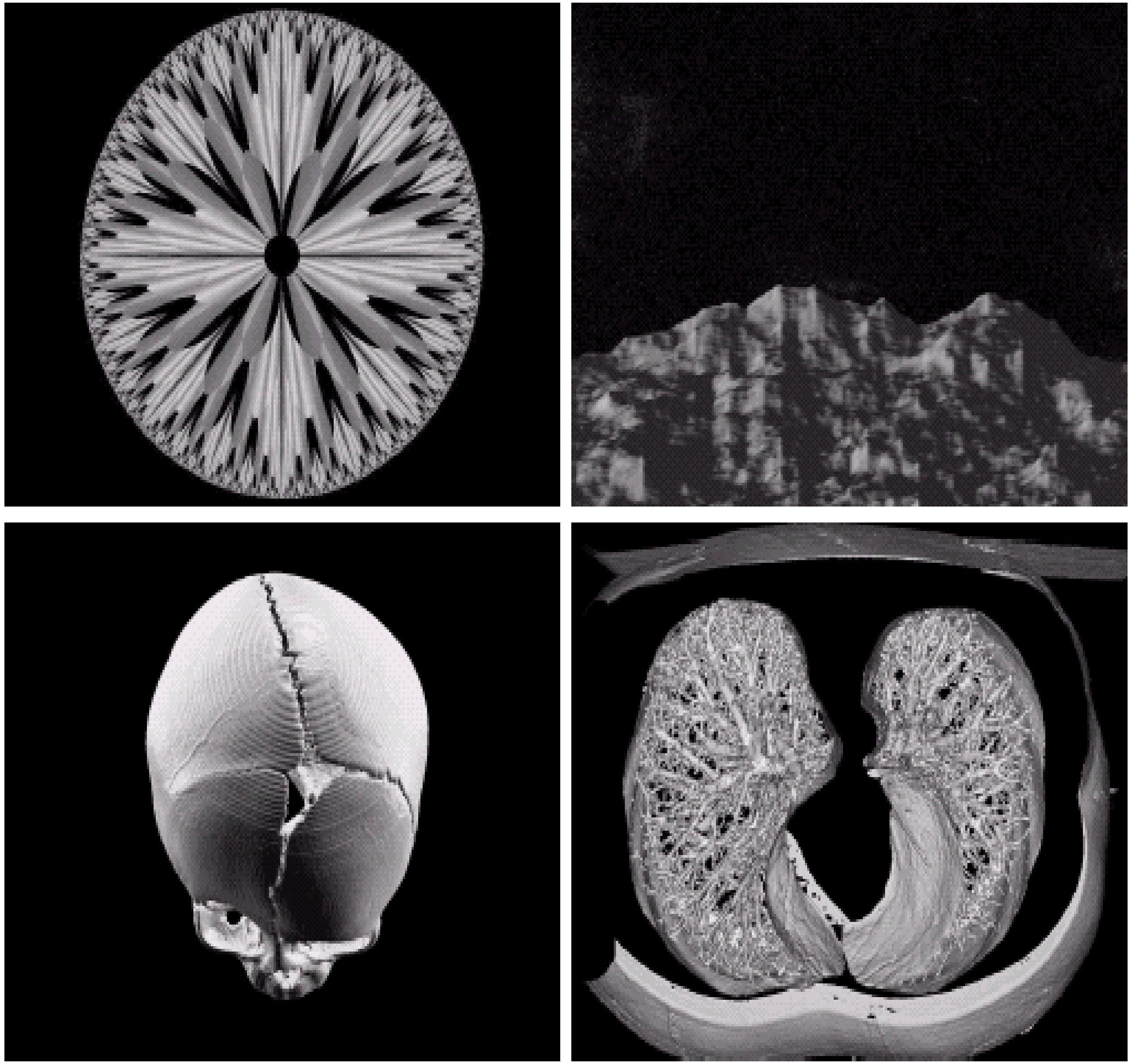
Electron Microscope



a b

FIGURE 1.21 (a) 250× SEM image of a tungsten filament following thermal failure. (b) 2500× SEM image of damaged integrated circuit. The white fibers are oxides resulting from thermal destruction. (Figure (a) courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene; (b) courtesy of Dr. J. M. Hudak, McMaster University, Hamilton, Ontario, Canada.)

Images generated by computers



a b
c d

FIGURE 1.22 (a) and (b) Fractal images. (c) and (d) Images generated from 3-D computer models of the objects shown. (Figures (a) and (b) courtesy of Ms. Melissa D. Binde, Swarthmore College, (c) and (d) courtesy of NASA.)

Fundamental Steps in Digital Image Processing

- ❑Methods whose input and output are images
- ❑Methods whose outputs are attributes extracted from those images

Image Acquisition and Digitization

Image

- Image = 2d function

$$f(x, y) \in R \qquad x, y \in R$$

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

Illumination reflectance

$$0 \leq f(x, y) \leq F$$

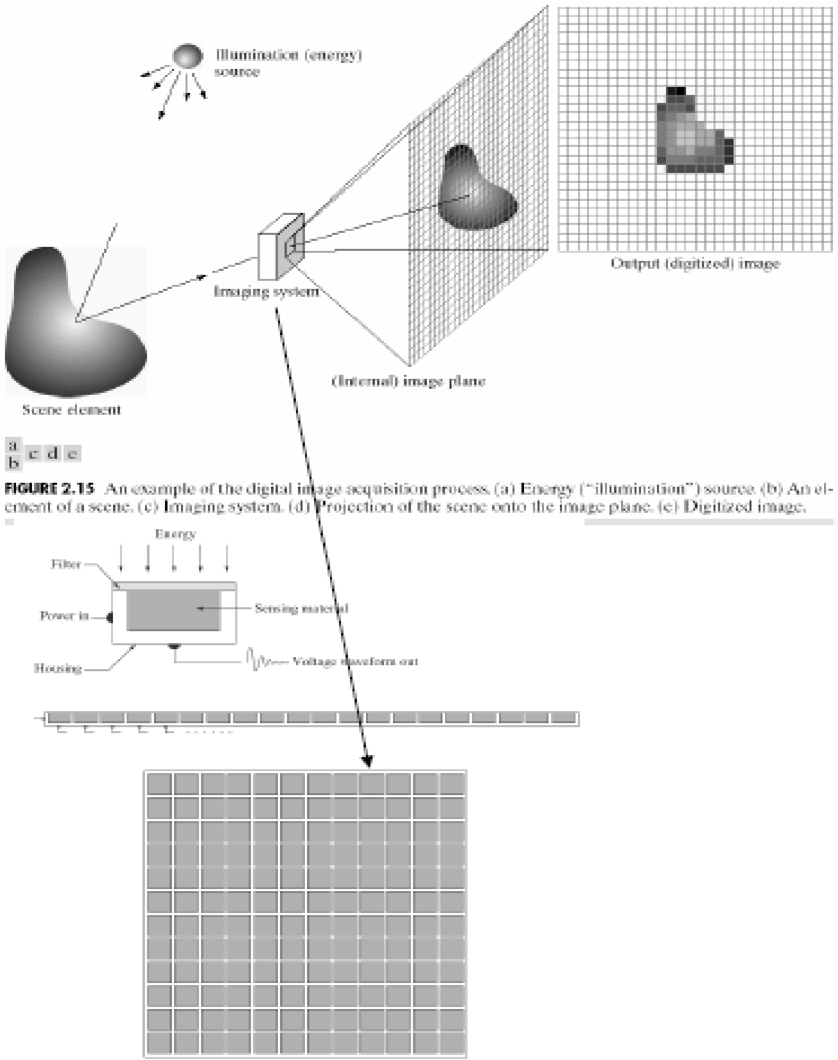


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Digital Image Representation

- Image = 2d function

$$f(x, y) \in R \qquad x, y \in R$$

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

Illumination reflectance

$$0 \leq f(x, y) \leq F$$

$$0 \leq x \leq X$$
$$0 \leq y \leq Y$$

Image Discretization: Spatial sampling and Quantization

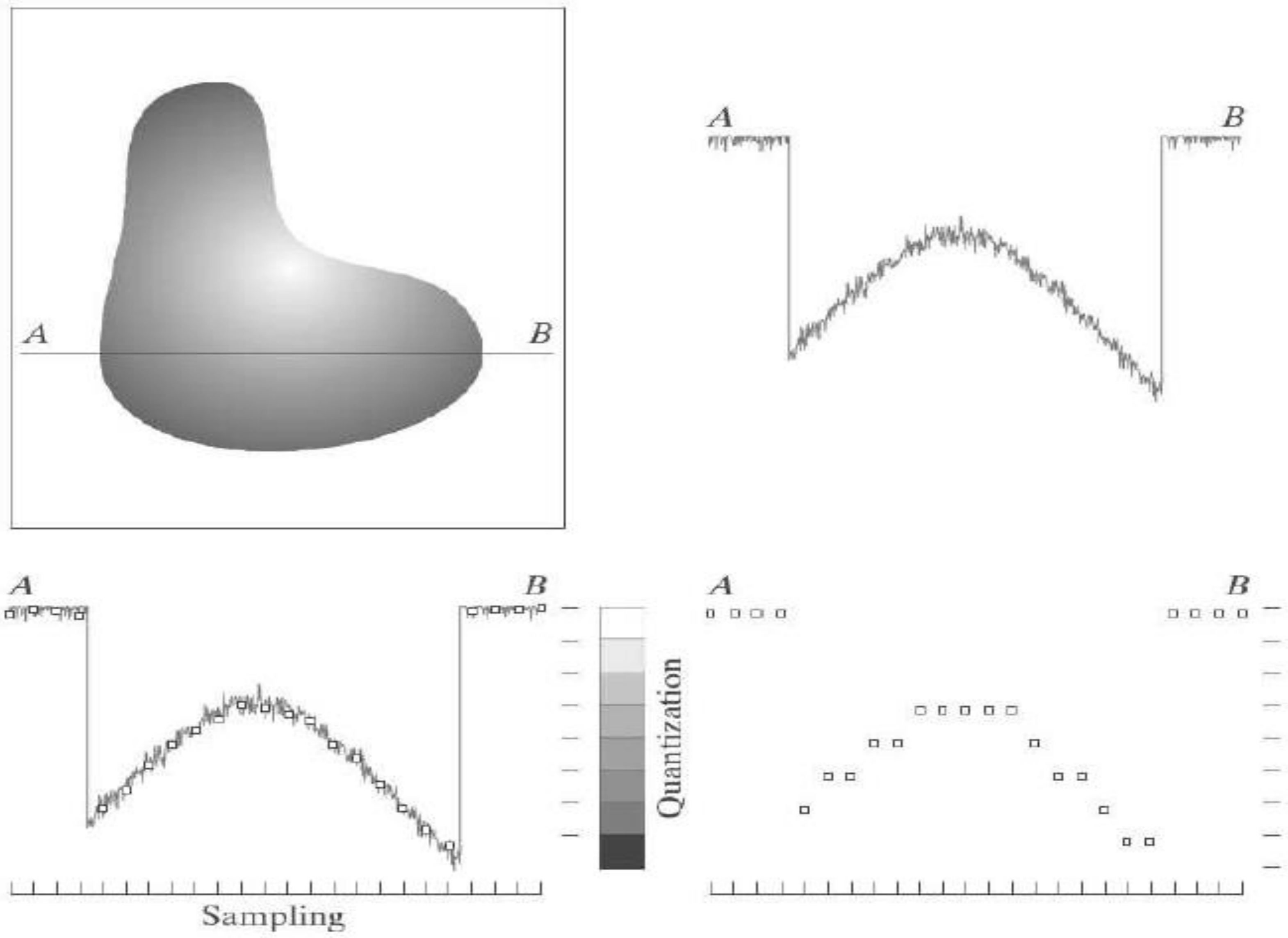


Image Fundaments: Image data presentation

Assume that an image f(x,y) is sampled so that the resulting digital image has M rows and N columns.We use integer values for those of the coordinates (x,y).

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

Image Fundaments: Image data presentation

We often use a more traditional matrix notation to denote a digital image and its elements.

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

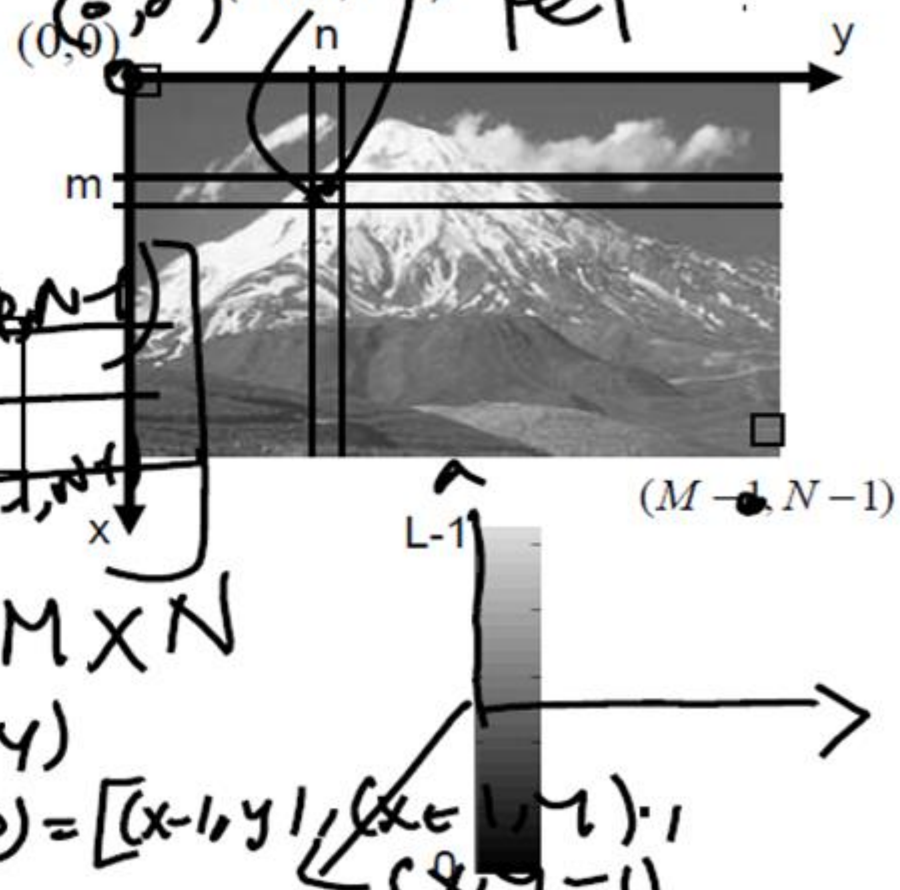
- Clearly, $a_{ij} = f(i, j)$

Digital Image

- Discretization
  - Spatial sampling
  - Quantization

$f(m,n) \in Z \qquad m,n \in Z$

$0 \le f(m,n) \le L-1, \quad 0 \le m \le M-1, \quad 0 \le n \le N-1$



voxel

Pixel / Pel

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

$M \times N$

(x,y)

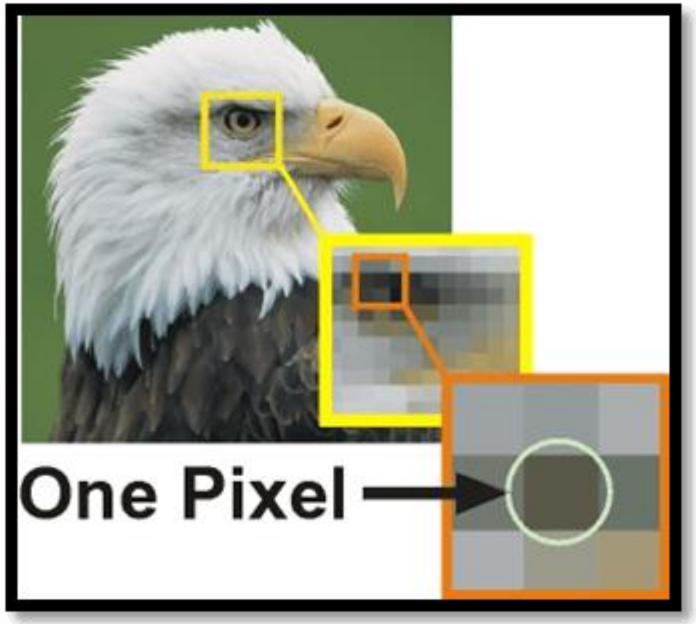
$N_4(p) = [(x-1,y), (x+1,y), (x,y-1), (x,y+1)]$

p

Image Pixel

In digital imaging, a pixel(or picture element) is **the smallest item of information in an image**. Pixels are arranged in a 2-dimensional grid, represented using squares. Each pixel is a sample of an original image, where more samples typically provide more-accurate representations of the original.

Pixel Example



A Small number of CCD pixels

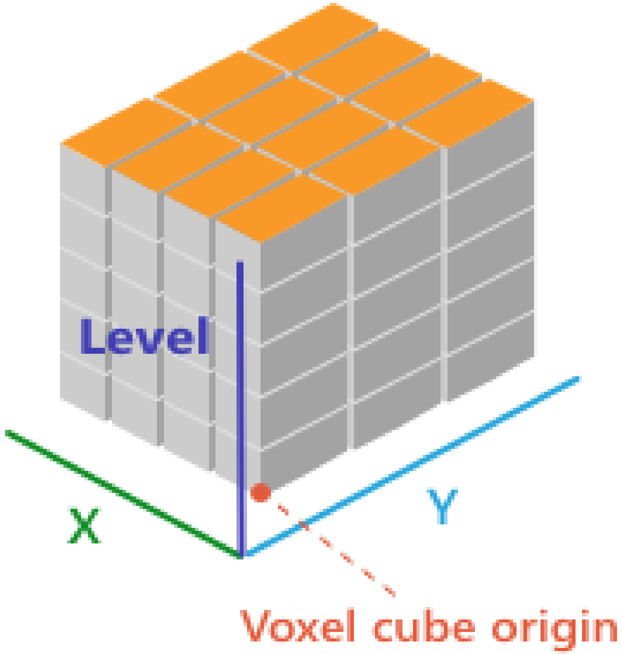
A Large number of CCD pixels

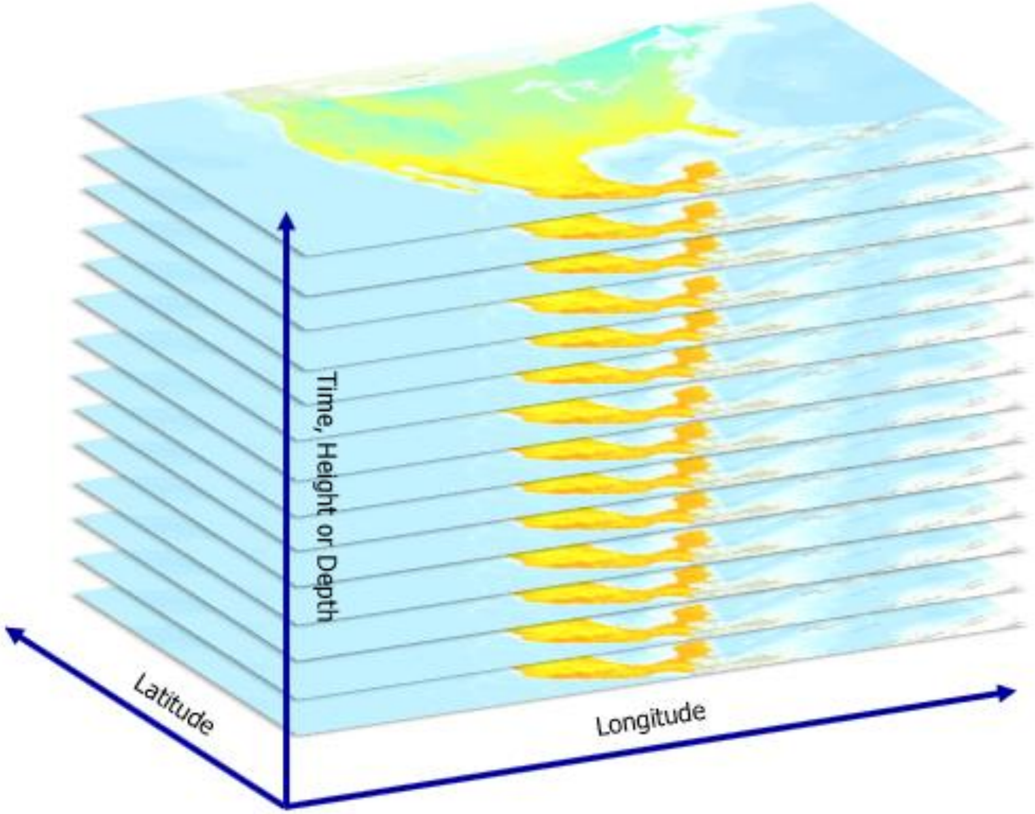
Image Voxel

A voxel represents **a single sample, or data point, on a regularly spaced, three-dimensional grid**. This data point can consist of a single piece of data, such as an opacity, or multiple pieces of data, such as a color in addition to opacity.

So its other pixel with volume. **A voxel is just a pixel that is represented in 3D**. It also stands for Volume Pixel. A voxel is a raster graphic on a 3 Dimensional grid, with the value of length, width, and depth, which is the smallest unit of volume while dividing 3D space into discrete and consistent areas

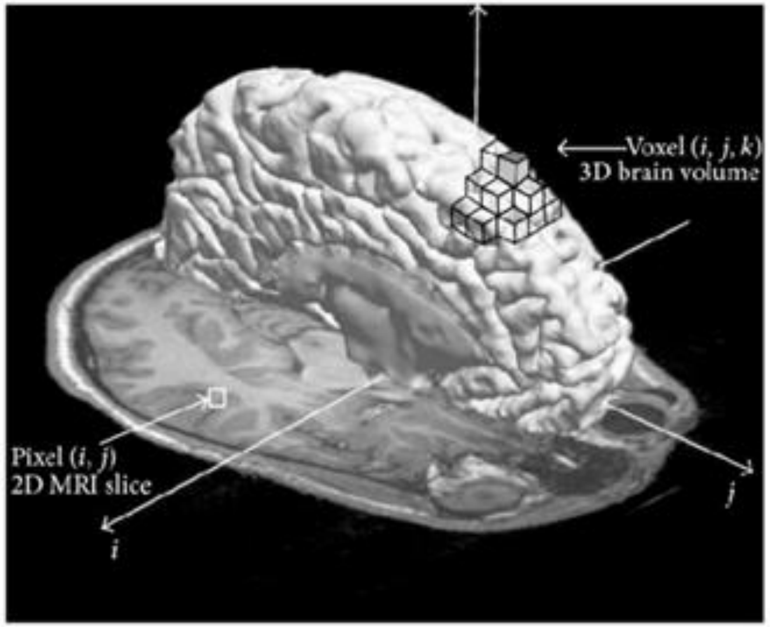
Image Voxel Example

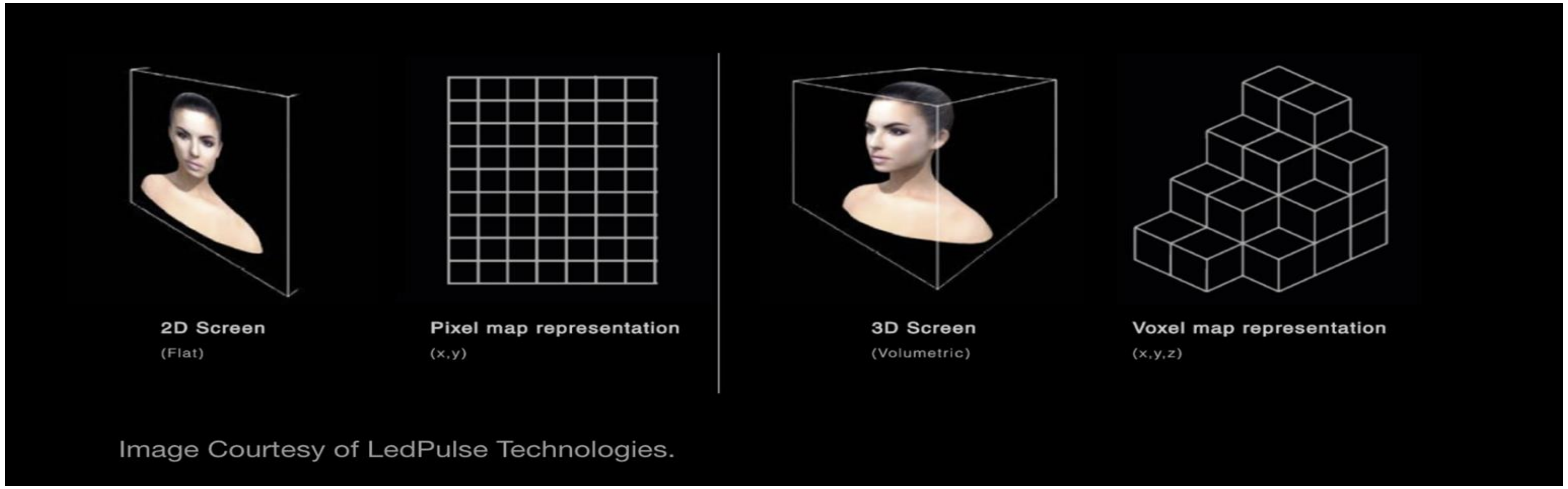




Pixels and Voxels

Parameter	Pixel	Voxel
Dimensions	**Two-dimensional**	**Three-dimensional**
Position	Absolute position is known	Relative position is known
Volume	Pixel does not have volume	Voxel has a volume. Often called as 'Volumetric Pixel'





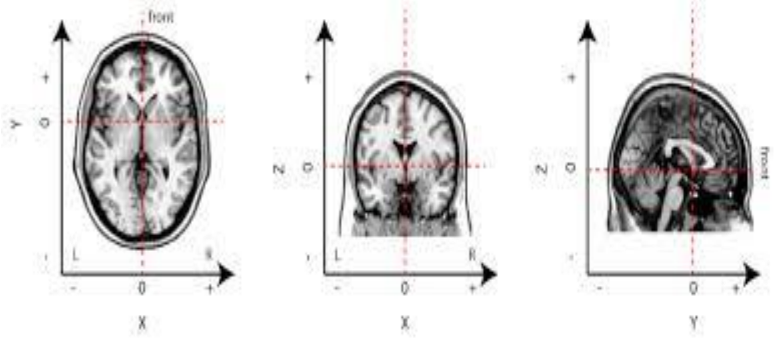


Image Fundamental: Image Types

Binary Image

Gray Image

Color Image

Types of Resolution related to Image:

The number G of discrete gray levels and the size of image are typically integer power of 2. The range of values spanned by the gray levels is called the dynamic range of an image

$$G = 2^k \qquad M = 2^m \qquad N = 2^n$$

The number b of bits required to store a digital image is :

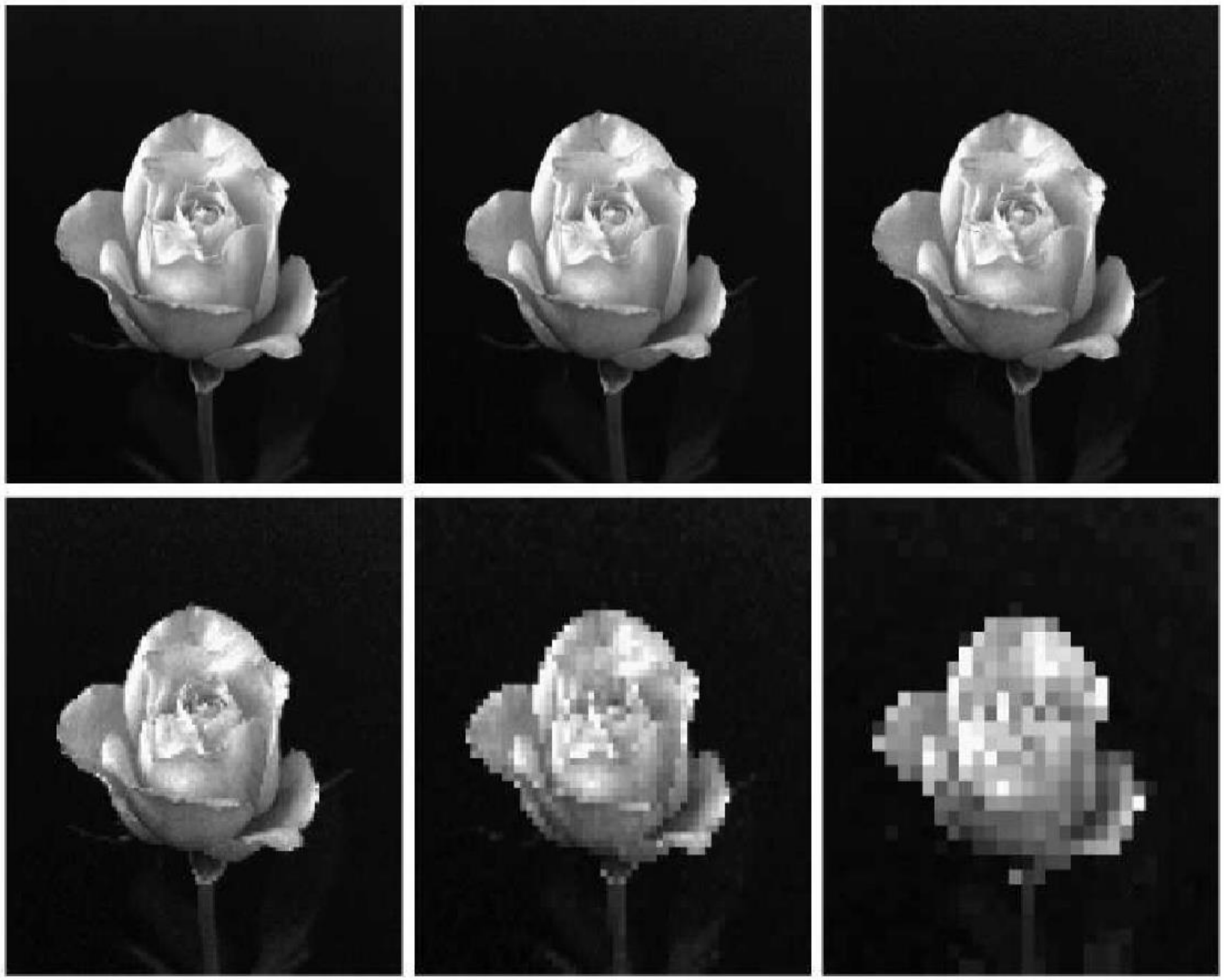
$$b = M \times N \times k$$

When $M=N$:

$$b = N^2 k$$

There are four types of resolution to consider for any dataset—radiometric, spatial, spectral, and temporal. Radiometric resolution is the amount of information in each pixel, that is, the number of bits representing the energy recorded.

Spatial Resolution: Image Resolution

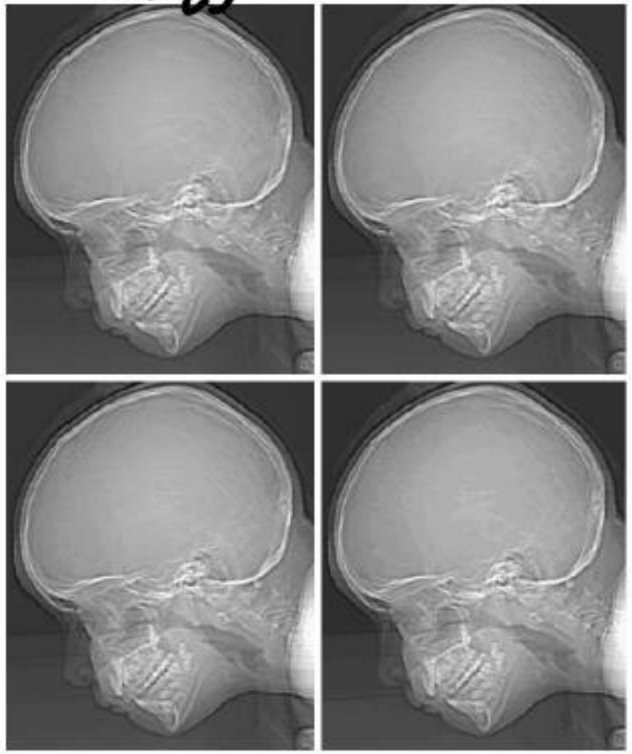


Higher the spatial resolution better the perception quality but it is expensive – large sensors (CCD/CMOS) array require

Gray-level Resolution

$L = 2^{k=8}$ $b = M \times N \times k$

256 $1024 \times 1024 \times 8$

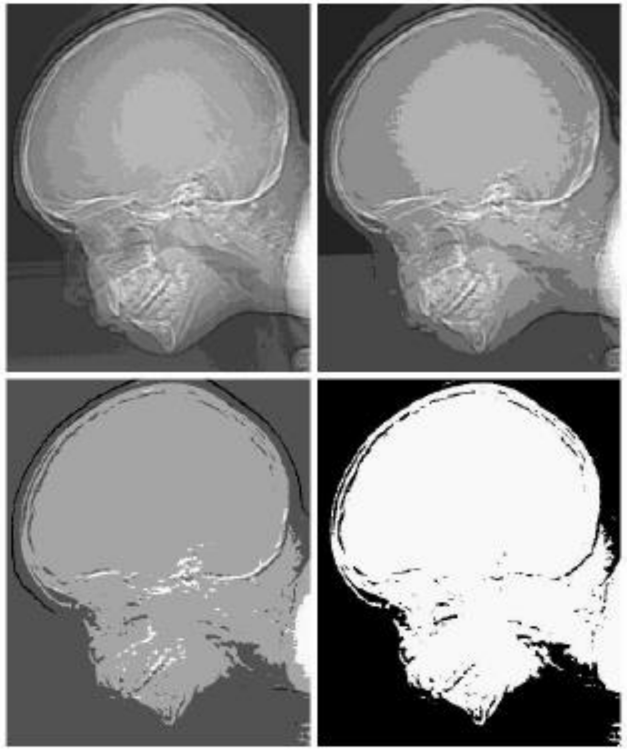


a b
c d

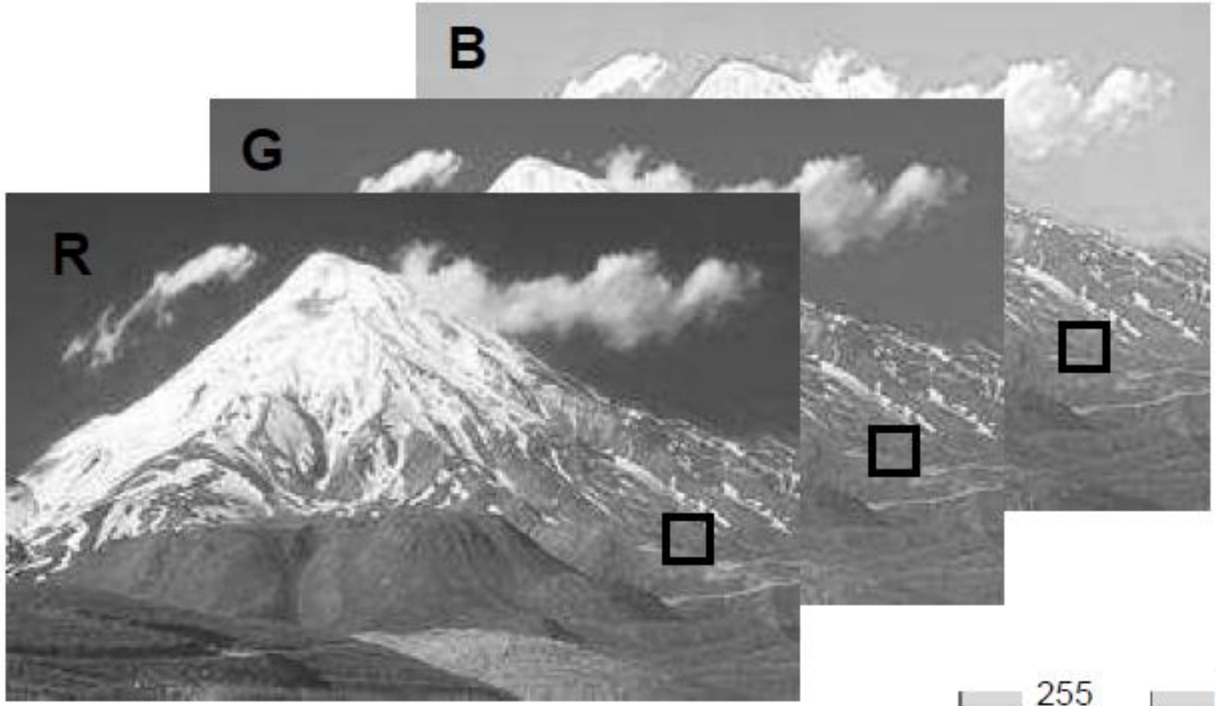
FIGURE 2.21 (a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.

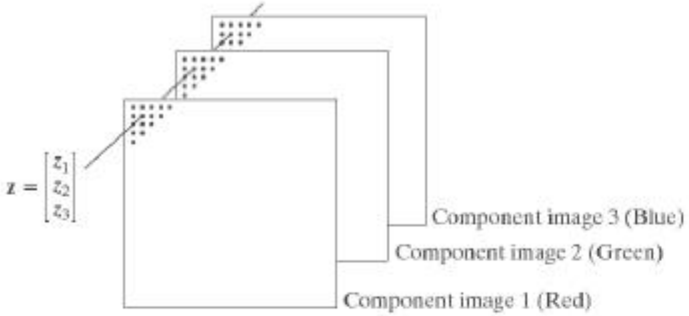
e f
g h

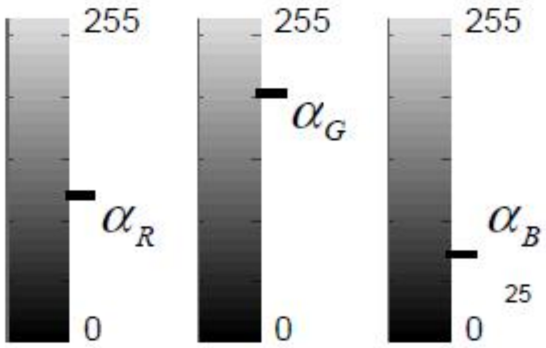
FIGURE 2.21 *(Continued)* (e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)



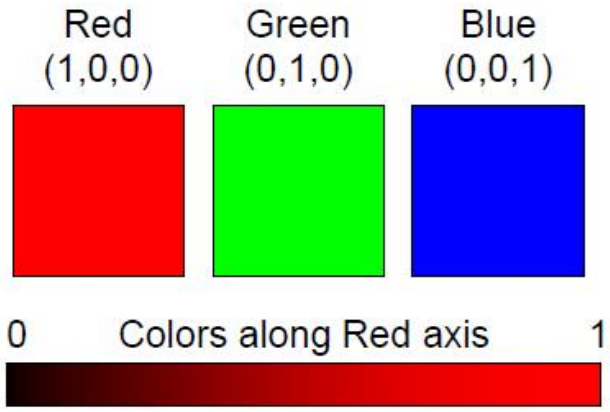
Color Image

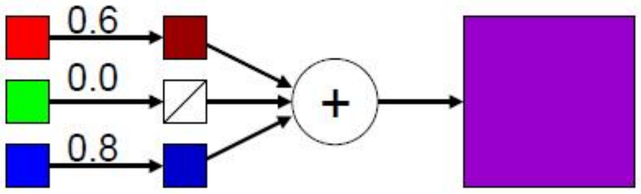

B
G
R


$z = \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix}$
Component image 3 (Blue)
Component image 2 (Green)
Component image 1 (Red)


255
α_R
0
255
α_G
0
255
α_B
25
0

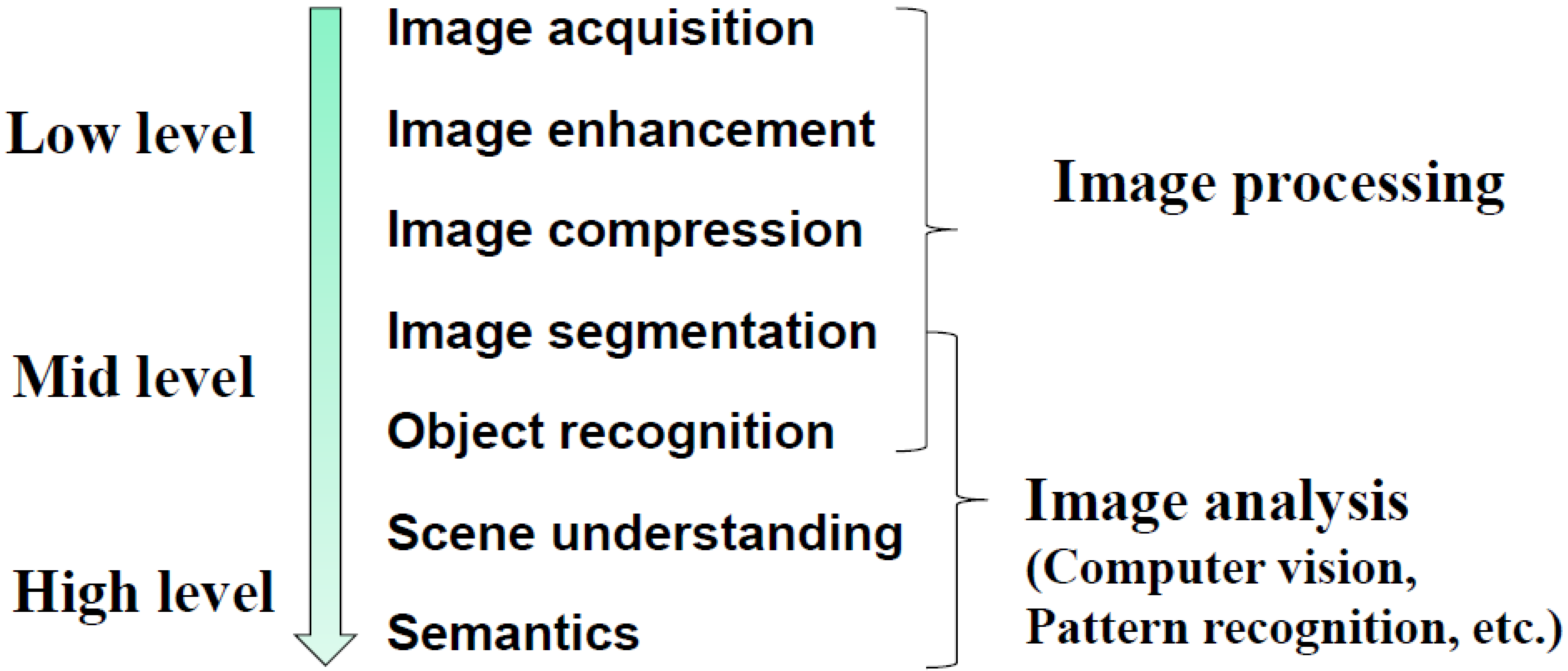
Color Image


Red
(1,0,0)
Green
(0,1,0)
Blue
(0,0,1)
0
Colors along Red axis
1


0.6
0.0
0.8
+


RGB
channels

Image Processing: Image Analysis



Example:

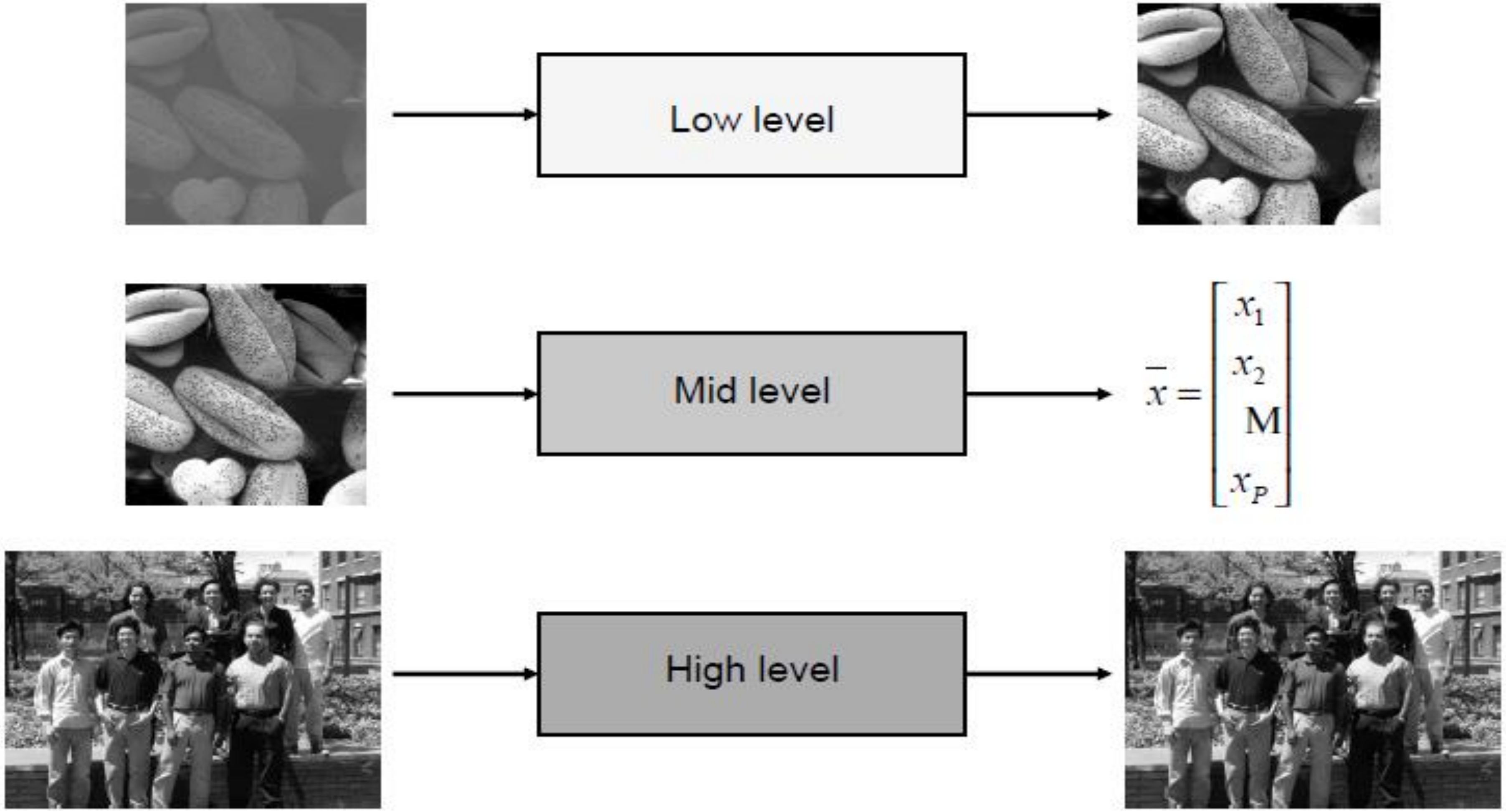
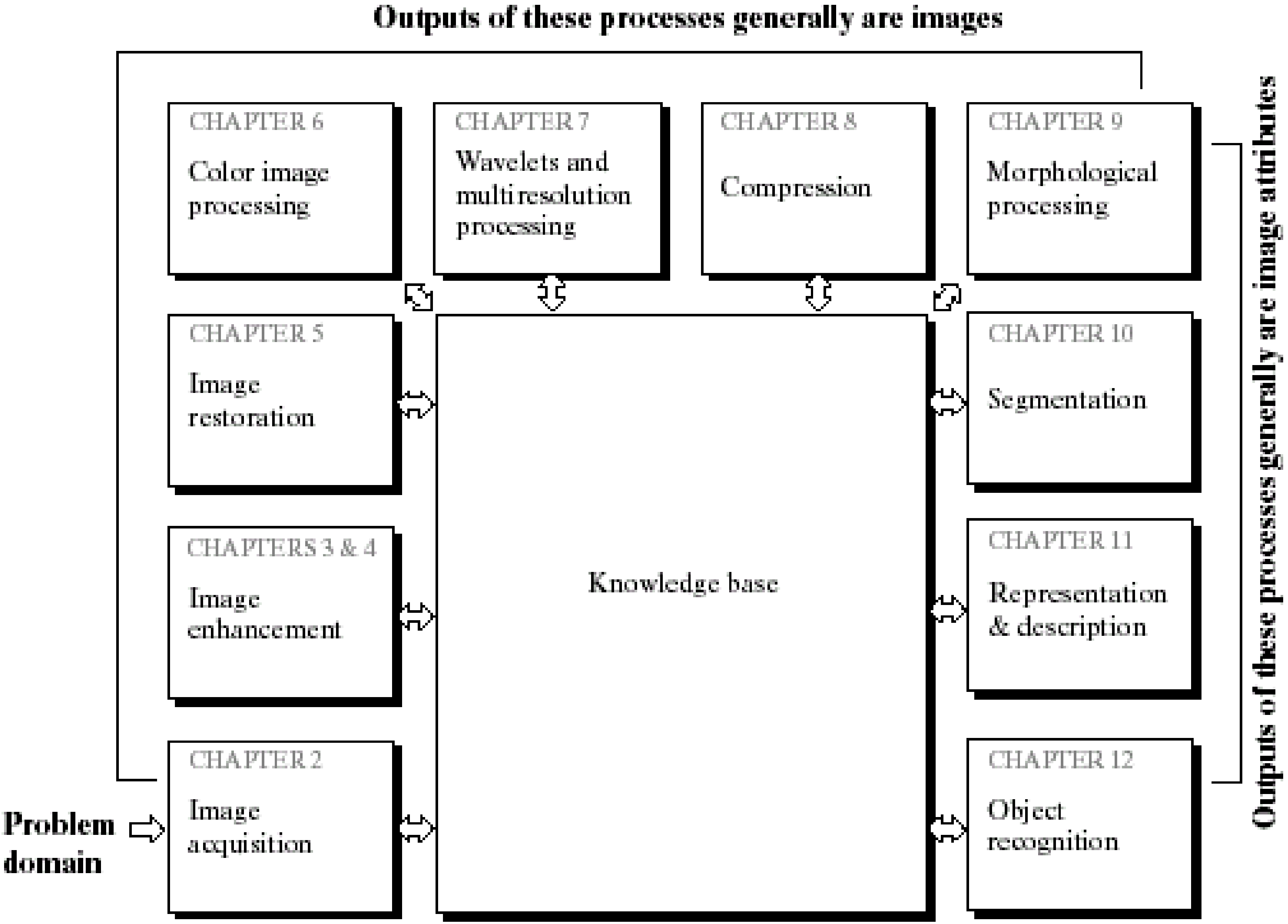
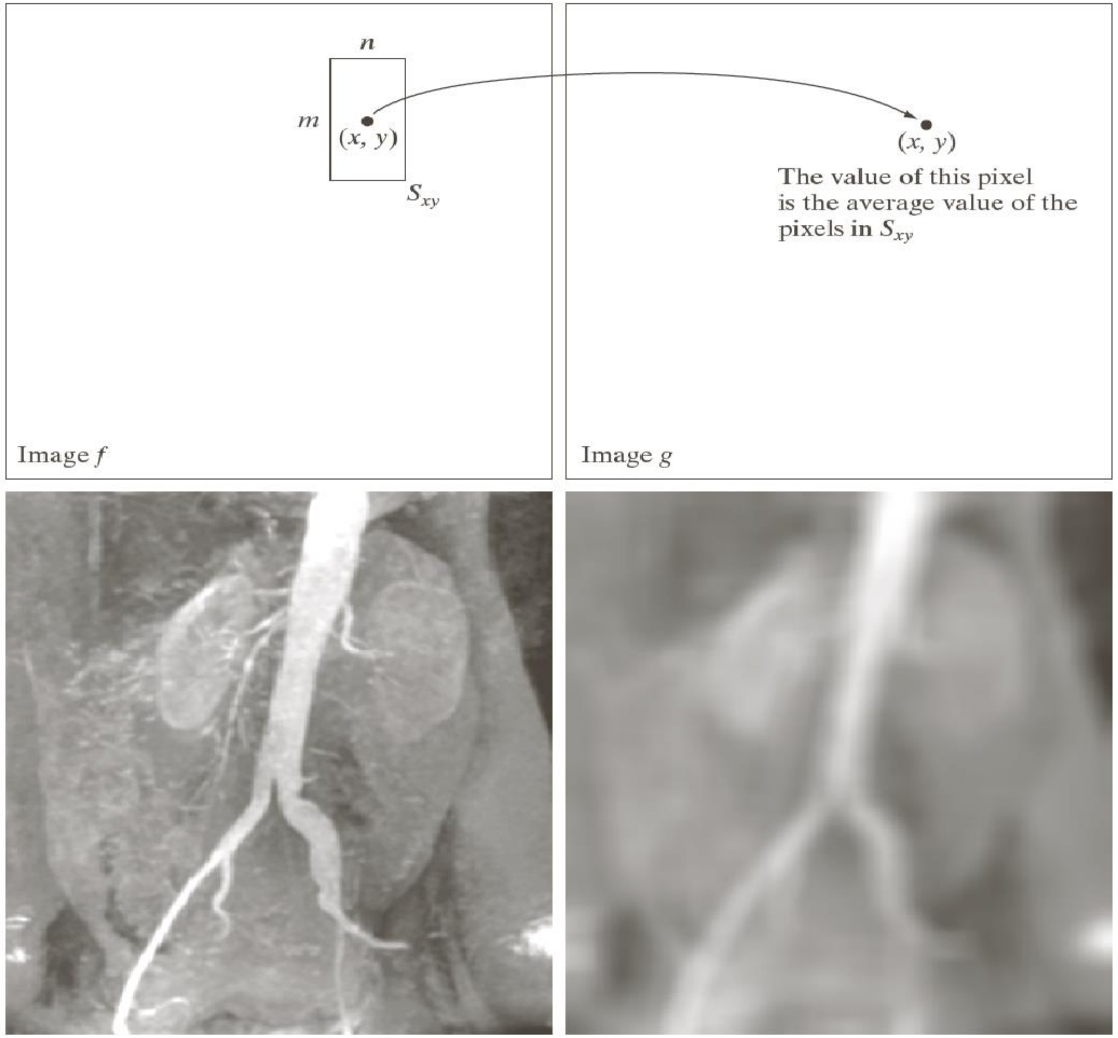

Low level
Mid level
High level
$\bar{x} = \begin{bmatrix} x_1 \\ x_2 \\ \mathrm{M} \\ x_P \end{bmatrix}$

FIGURE 1.23 Fundamental steps in digital image processing.



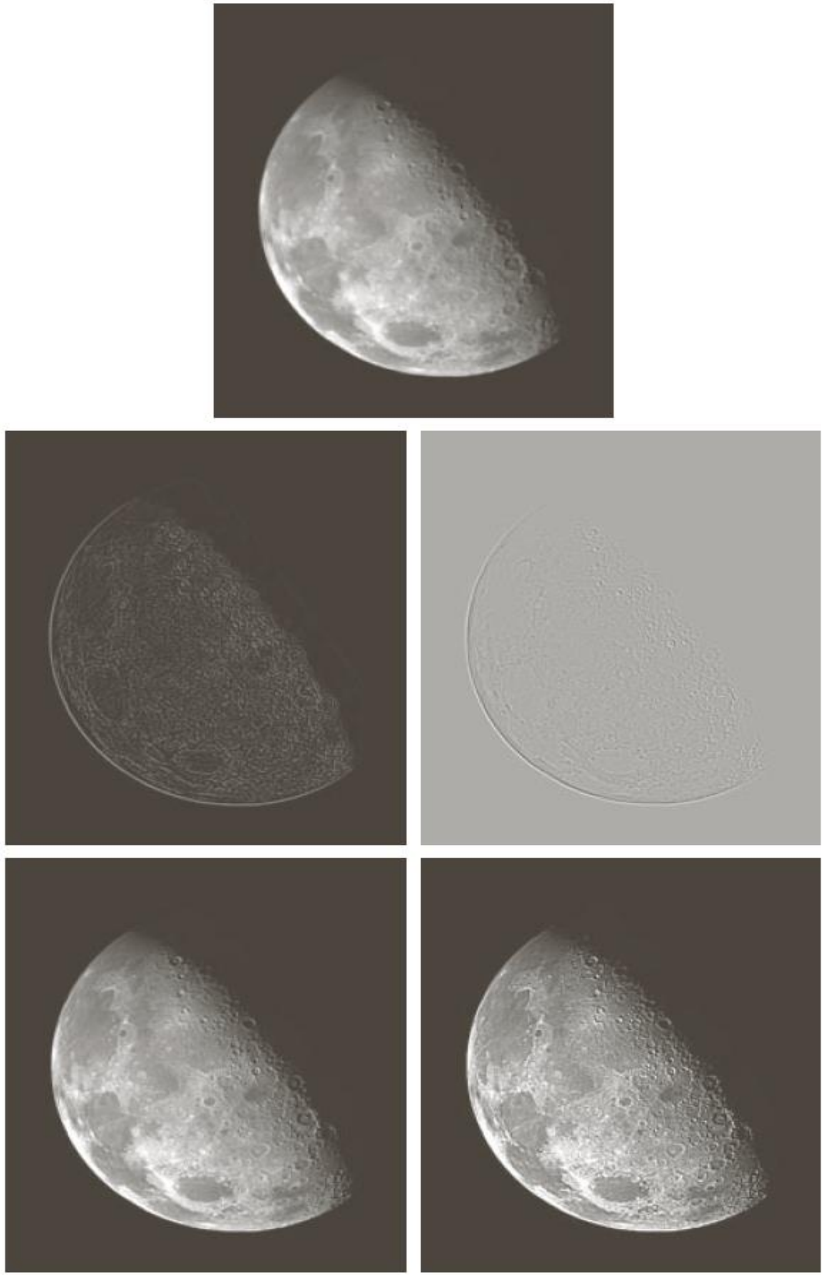
❑Image operations



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.

Spatial filtering



a
b c
d e

FIGURE 3.38 (a) Blurred image of the North Pole of the moon. (b) Laplacian without scaling. (c) Laplacian with scaling. (d) Image sharpened using the mask in Fig. 3.37(a). (e) Result of using the mask in Fig. 3.37(b). (Original image courtesy of NASA.)

Filering in the frequency domain

a b
c d
e f

FIGURE 4.48 (a) Original image. (b)–(f) Results of filtering using GLPFs with cutoff frequencies at the radii shown in Fig. 4.41. Compare with Figs. 4.42 and 4.45.

Image restoration

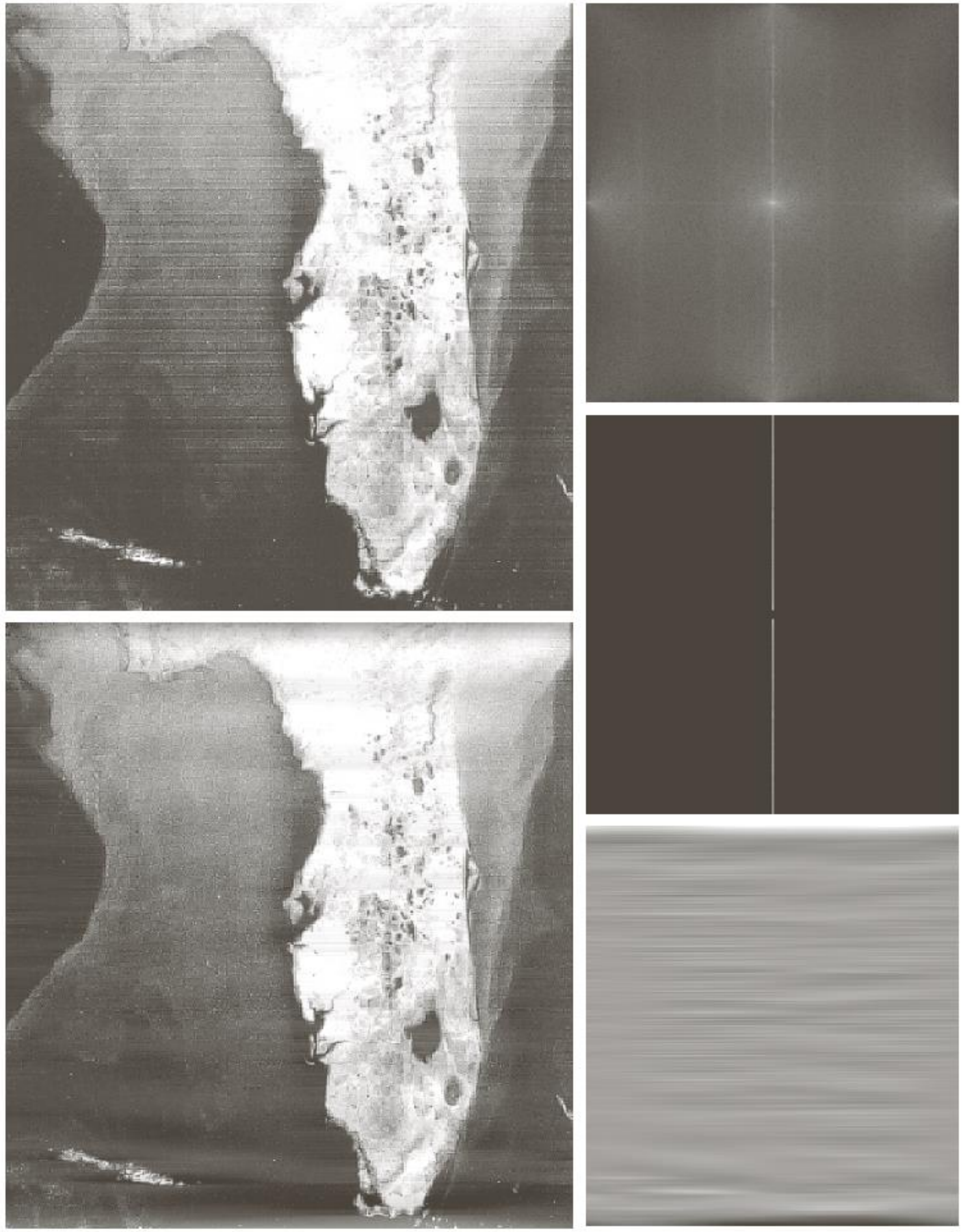


FIGURE 5.19 (a) Satellite image of Florida and the Gulf of Mexico showing horizontal scan lines. (b) Spectrum. (c) Notch pass filter superimposed on (b). (d) Spatial noise pattern. (e) Result of notch reject filtering. (Original image courtesy of NOAA.)

Color image processing

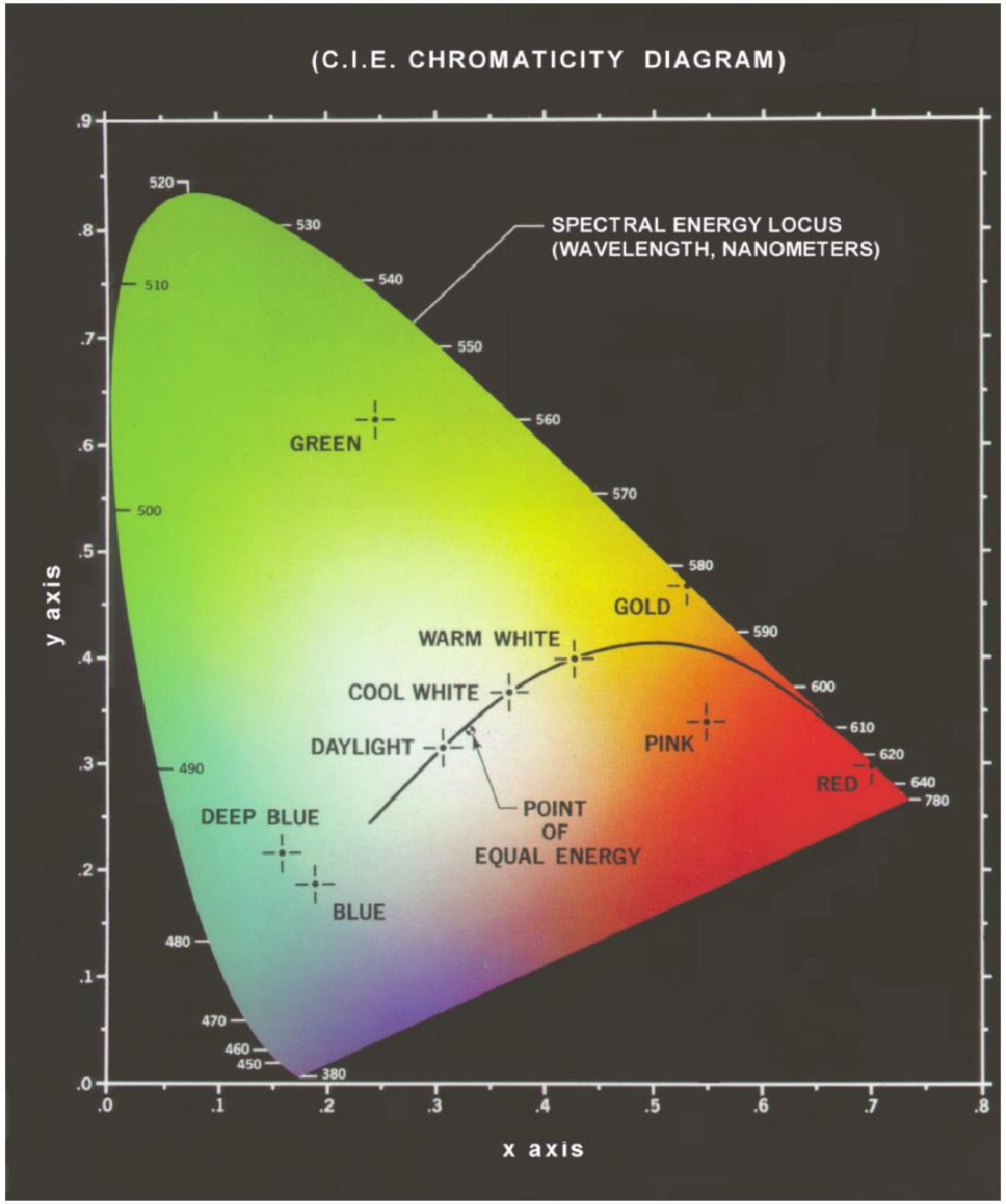


FIGURE 6.5 Chromaticity diagram. (Courtesy of the General Electric Co., Lamp Business Division.)

Components of an Image Processing System

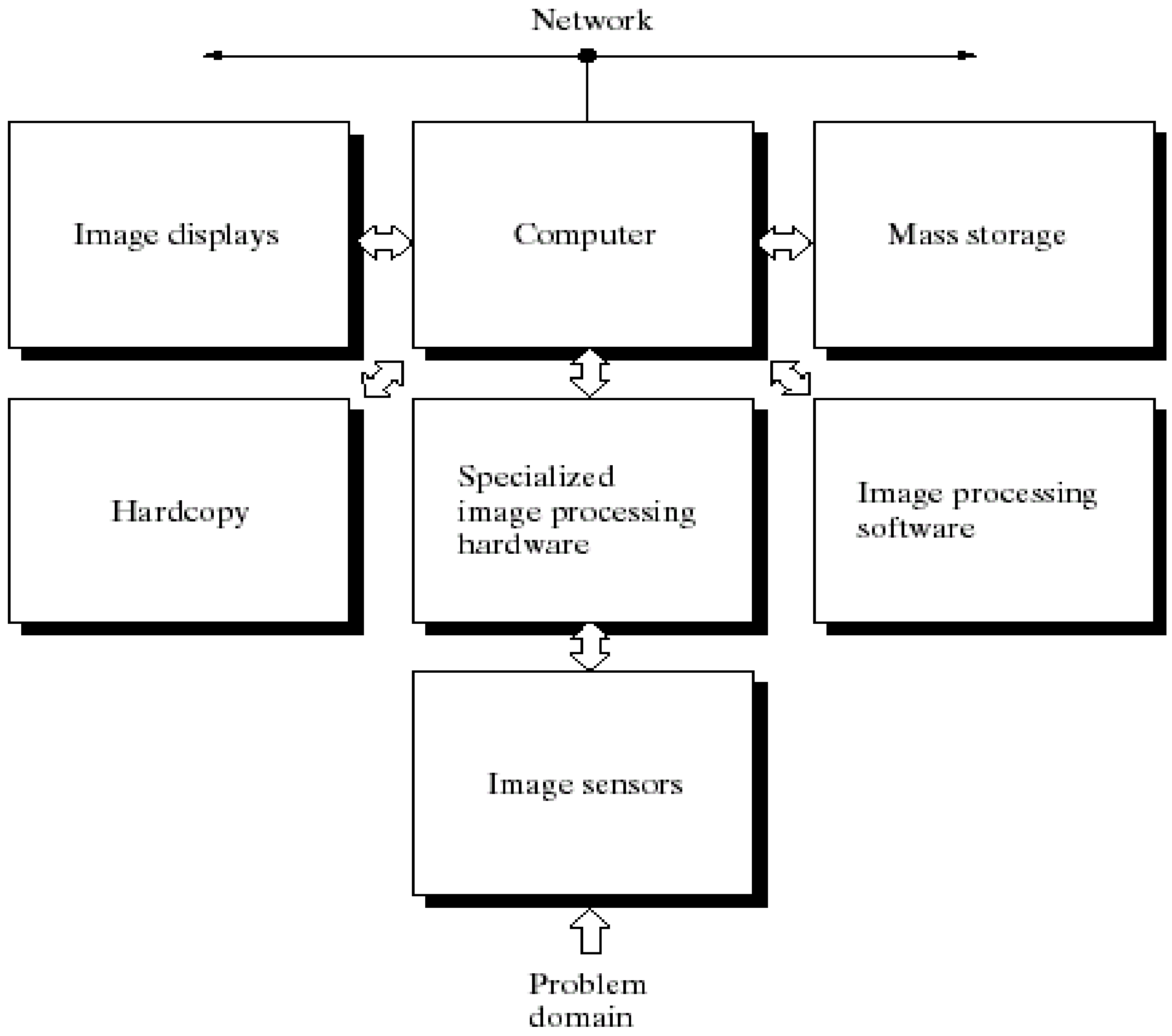


FIGURE 1.24 Components of a general-purpose image processing system.

Sampling and Quantization of Image

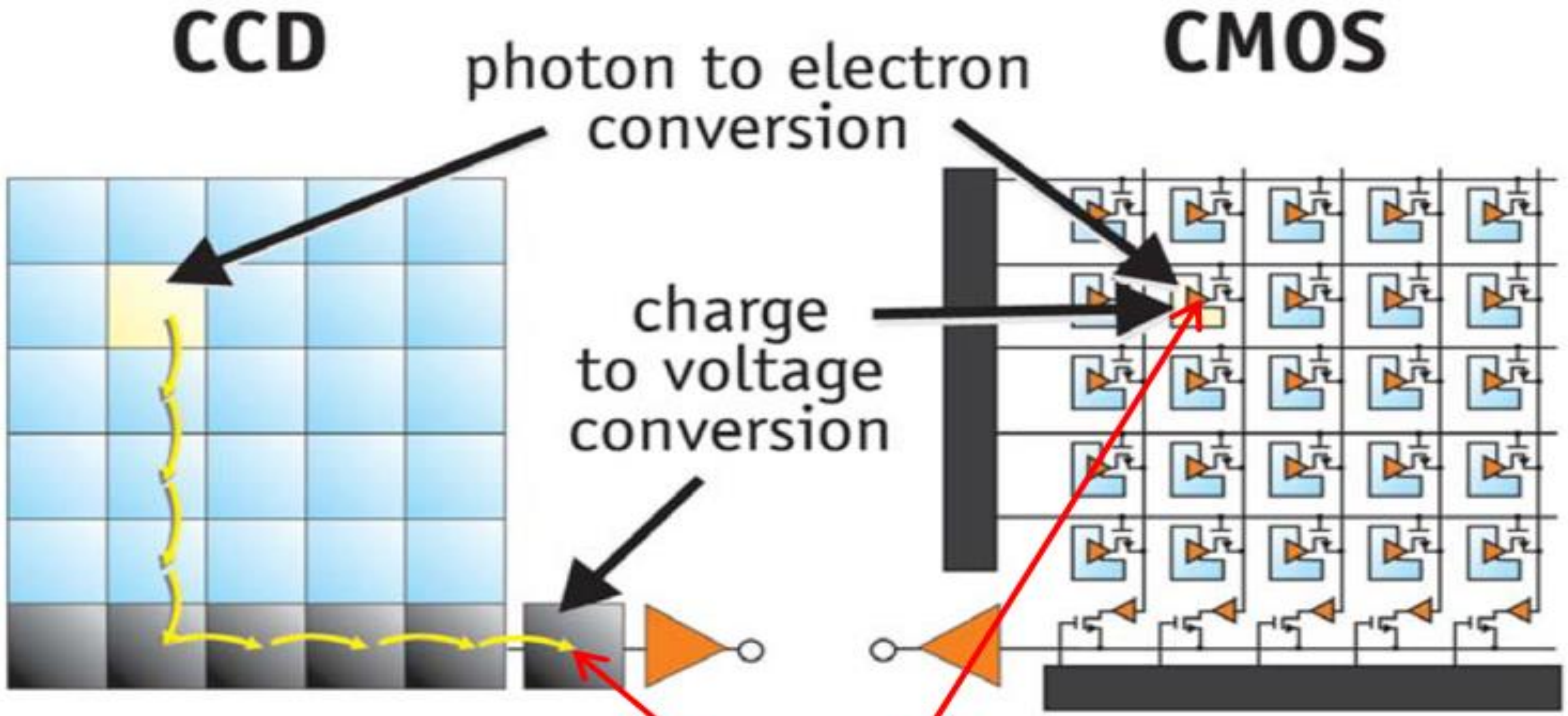
Resolution of image depends on these few factors

1. Charged Coupled Device / Complementary Metal Oxide Semiconductor sensor area

2. Sampling Rate and Quantization

Charged Coupled Device / Complementary Metal Oxide Semiconductor

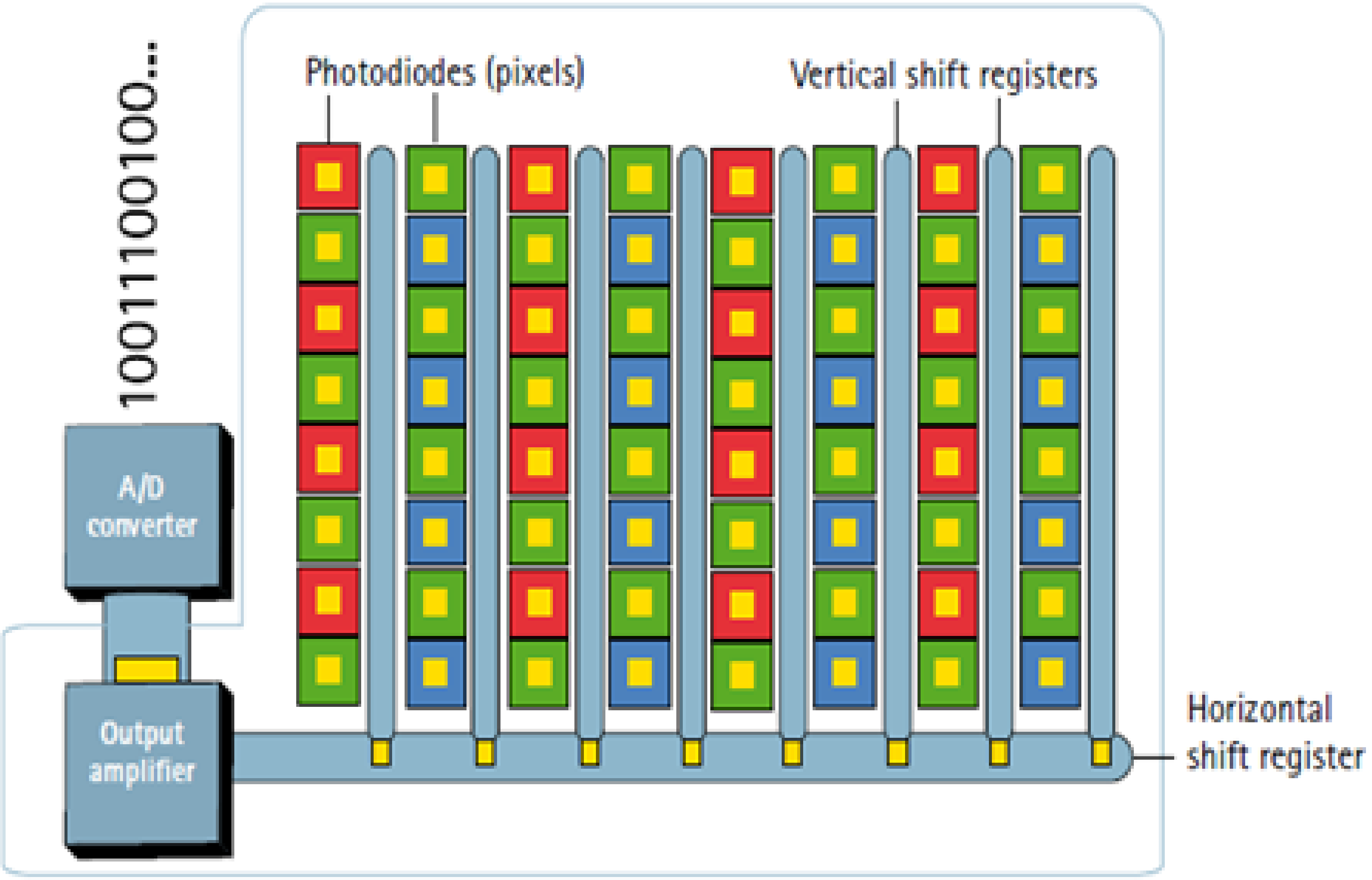
CCD and CMOS Image Sensor



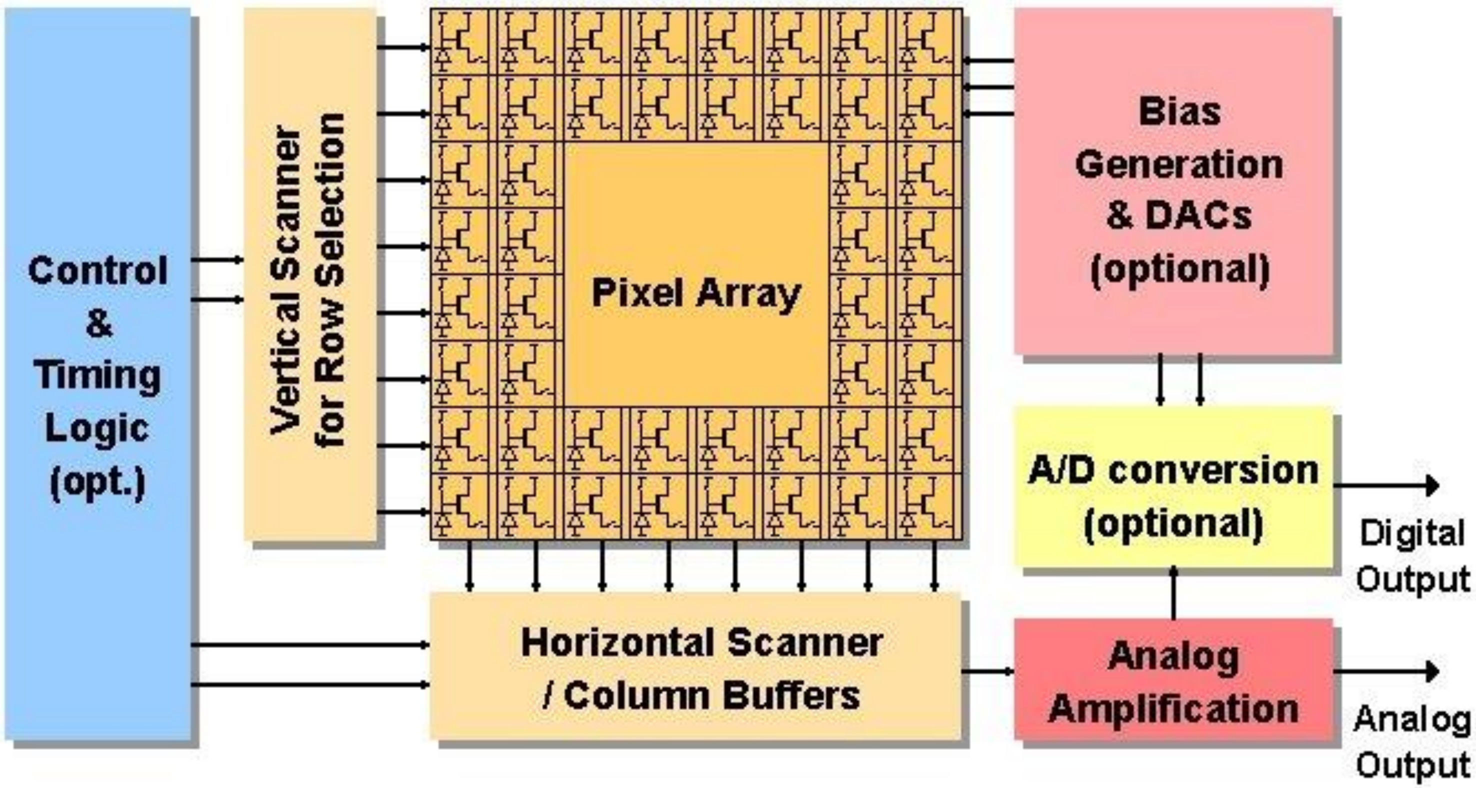
CCDs move photogenerated charge from pixel to pixel and convert it to voltage at an output node. CMOS imagers convert charge to voltage inside each pixel.

Read-out noise generated

Internal Structure of CCD:



General Architecture of CMOS-Based Image Sensors



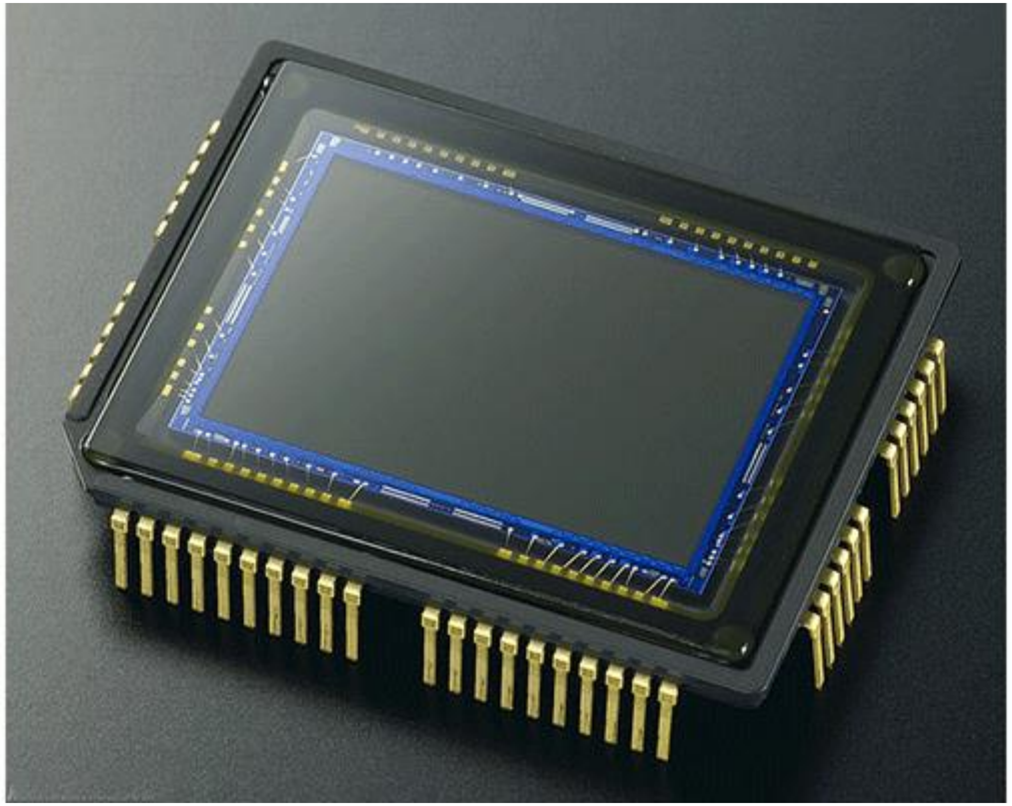


Image Interpolation

10	4	22
2	18	7
9	14	25

10	10	4	4	22	22
10	10	4	4	22	22
2	2	18	18	7	7
2	2	18	18	7	7
9	9	14	14	25	25
9	9	14	14	25	25

Relationship between Pixels

Neighborhood of a pixel

A pixel p at coordinates (x,y) has four horizontal and vertical neighbors whose coordinates are given by This set of pixels,called the 4-neighbors of p,is denoted by $N_4(p)$

0	$(x, y-1)$	0
$(x-1, y)$	(x, y)	$(x+1, y)$
0	$(x, y+1)$	0

Relationship between Pixels

Neighborhood of a pixel

The four *diagonal* neighbors of p have coordinates. and are denoted by

$N_D(p)$

$(x-1, y-1)$	0	$(x+1, y-1)$
0	(x, y)	0
$(x-1, y+1)$	0	$(x+1, y+1)$

$N_D(p)$ together with $N_4(p)$,are called the *8-neighbors* of p,denoted by $N_8(p)$

Relationship between Pixels: Connectivity

To establish if two pixels are connected,it must be determined if they are neighbors and if their gray levels satisfy a specified criterion of similarity. If V is defined as the set of gray levels, then

- *4-adjacency*: two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$

- *8-adjacency* : two pixels p and q with values from V are 8-adjacent if q is in the set $N_8(p)$

- *m-adjacency* : two pixels p and q with values from V are 4-adjacent if

  (i)q is in $N_4(p)$,or

  (ii) q is in $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ has no pixels whose values are from V.

Relationship between Pixels: Distance Measures: definitions

- The Euclidean distance is

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

- And the city-block and chessboard distances are:

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

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

- The D_m distance is defined as the shortest m-path between the points.

Relationship between Pixels

Distance Measures: example 1

City-block distance(D_4)

$$
\begin{array}{ccccc}
 & & 2 & & \\
 & 2 & 1 & 2 & \\
2 & 1 & 0 & 1 & 2 \\
 & 2 & 1 & 2 & \\
 & & 2 & &
\end{array}
$$

(a)

Chessboard distance (D_8)

$$
\begin{array}{ccccc}
2 & 2 & 2 & 2 & 2 \\
2 & 1 & 1 & 1 & 2 \\
2 & 1 & 0 & 1 & 2 \\
2 & 1 & 1 & 1 & 2 \\
2 & 2 & 2 & 2 & 2
\end{array}
$$

(b)

Relationship between Pixels

Distance Measures: example 2

$$
\begin{array}{ccccc}
 & & 0 & & 1(q) \\
 & & & \iddots & \\
0 & & 1 & & \\
 & \iddots & & & \\
1(p) & & & &
\end{array}
\qquad
D_m(p,q) = 2
$$

$$
\begin{array}{ccccc}
 & & 0 & & 1(q) \\
 & & & \iddots & \\
1 & \cdots & 1 & & \\
\vdots & & & & \\
1(p) & & & &
\end{array}
\qquad
D_m(p,q) = 3
$$

$$
\begin{array}{ccccc}
 & & 1 & \cdots & 1(q) \\
 & & \vdots & & \\
0 & & 1 & & \\
 & \iddots & & & \\
1(p) & & & &
\end{array}
\qquad
D_m(p,q) = 3
$$

$$
\begin{array}{ccccc}
 & & 1 & \cdots & 1(q) \\
 & & \vdots & & \\
1 & \cdots & 1 & & \\
\vdots & & & & \\
1(p) & & & &
\end{array}
\qquad
D_m(p,q) = 4
$$

Distance Measures: example 3

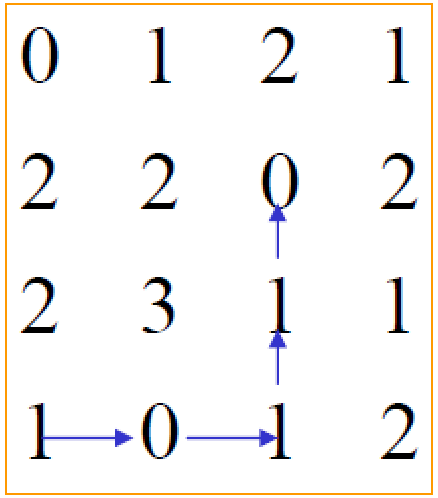
Problem: consider the image segment shown
Let V={0,1} and compute the lengths of the shortest 4- 8- and m-path between p and q. if a particular path does not exist between these two points, explain why.

q

0	1	2	1
2	2	0	2
2	3	1	1
1	0	1	2

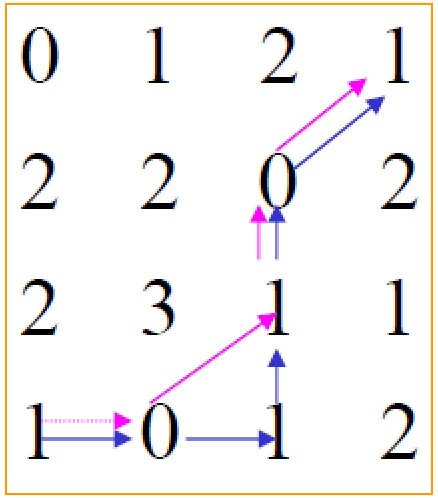
p

Distance Measures: example 3



a) When $V = \{0,1\}$, 4-path does not exist between p and q because it is impossible to get from p to q by traveling along points that are both 4-adjacent and also have values from V .

b) The shortest 8-path is shown in right Figure, its length (shown magenta) is 4. The length of shortest m-path (shown blue) is 5.



Arithmetic operation

Arithmetic operations between two pixels *p* and *q* include:

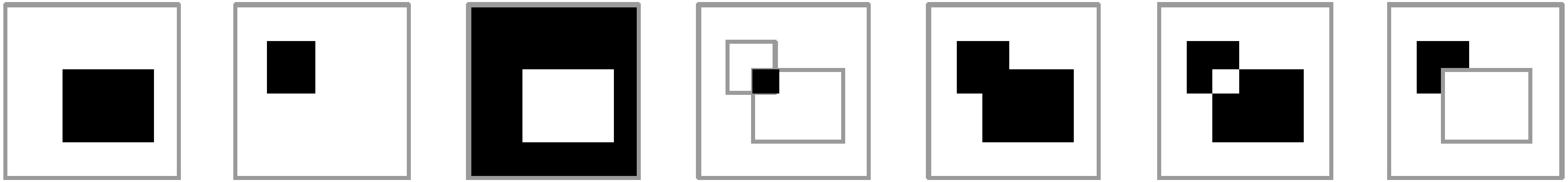
Addition: $p+q$

Subtraction: $p-q$

Multiplication: $p*q$

Division: p/q

Logical operation



S

T

NOT (S)

(S) AND (T)

(S) OR (T)

(S) XOR (T)

[NOT (S)] AND (T)

Arithmetic and Logic Operation

Point operation and Local operation:

$$A(x,y) \longrightarrow B(x,y)$$

Point Operation: $B(x,y) = f(A(x,y))$

Local Operation: $B(x,y) = f(A(x \pm s, y \pm t))$

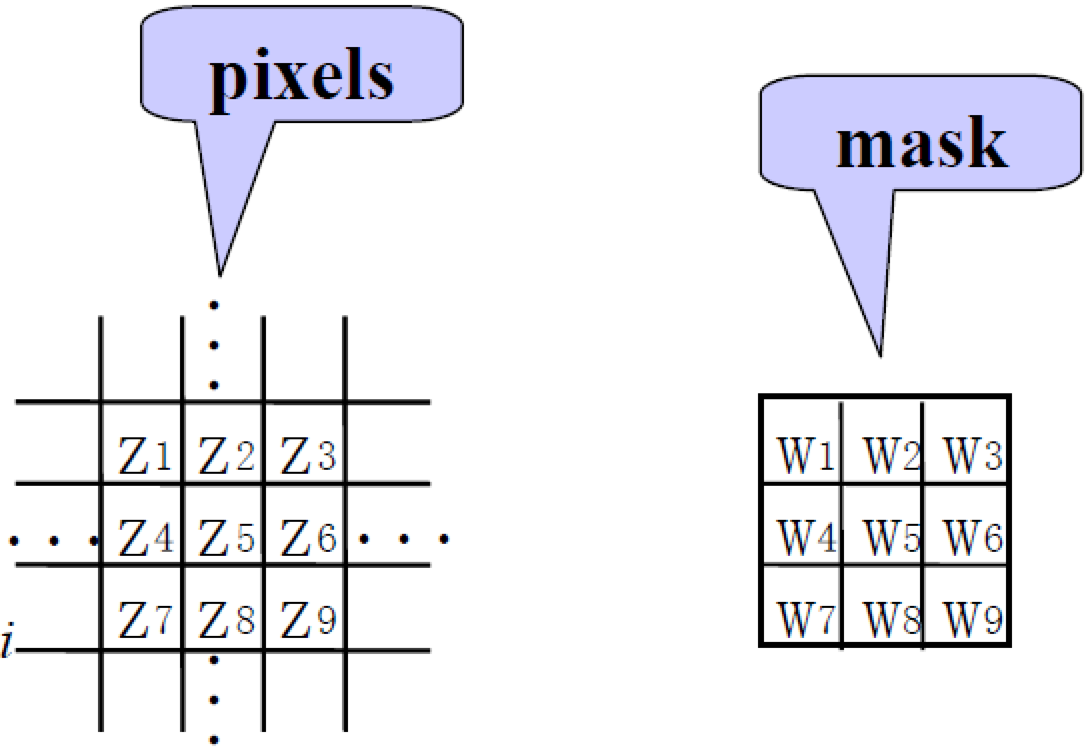
Windows: $s = 0,1,\ldots S-1 \quad t = 0,1,\ldots T-1$

Usually, *S=T=1,3,5,7…*

Local operation:

$$z = \frac{1}{9}(z_1 + z_2 + \cdots + z_9) = \frac{1}{9}\sum_{i=1}^{9} z_i$$

$$z = w_1 z_1 + w_2 z_2 + w_n z_n = \sum_{i=1}^{9} w_i z_i$$



(a) (b)

summary

- Basic idea of the eye in perceiving pictorial information
- Color fundamentals and color models
- Fundamentals of images, include presentation, read, write display, sampling and quantization, relationship between pixels, and so on.

Question and Answers…..?

Thank you.