EE610 – Image Processing

M1 – Introduction to images and imaging

Early example of photography

Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Electromagnetic Spectrum

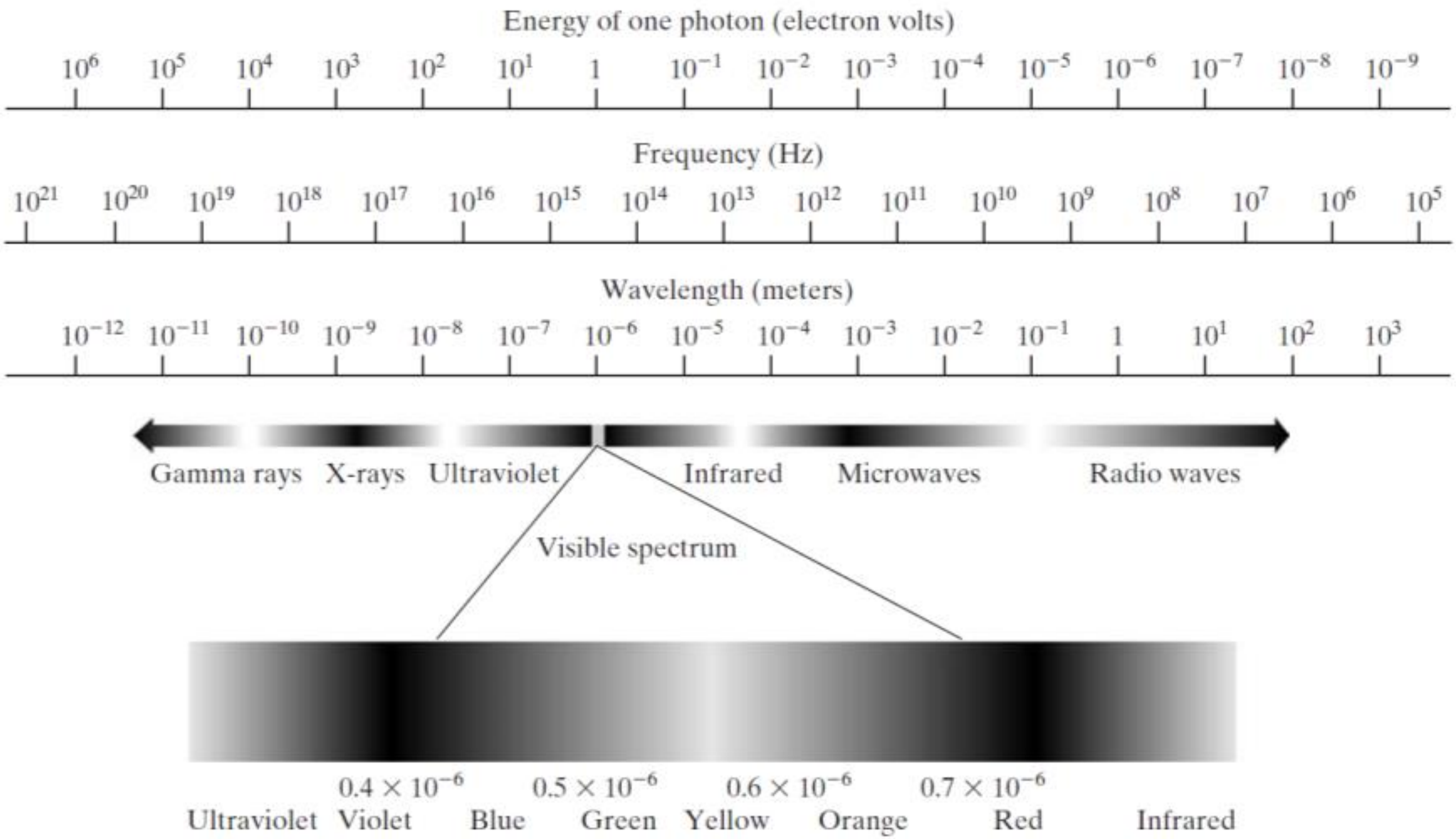


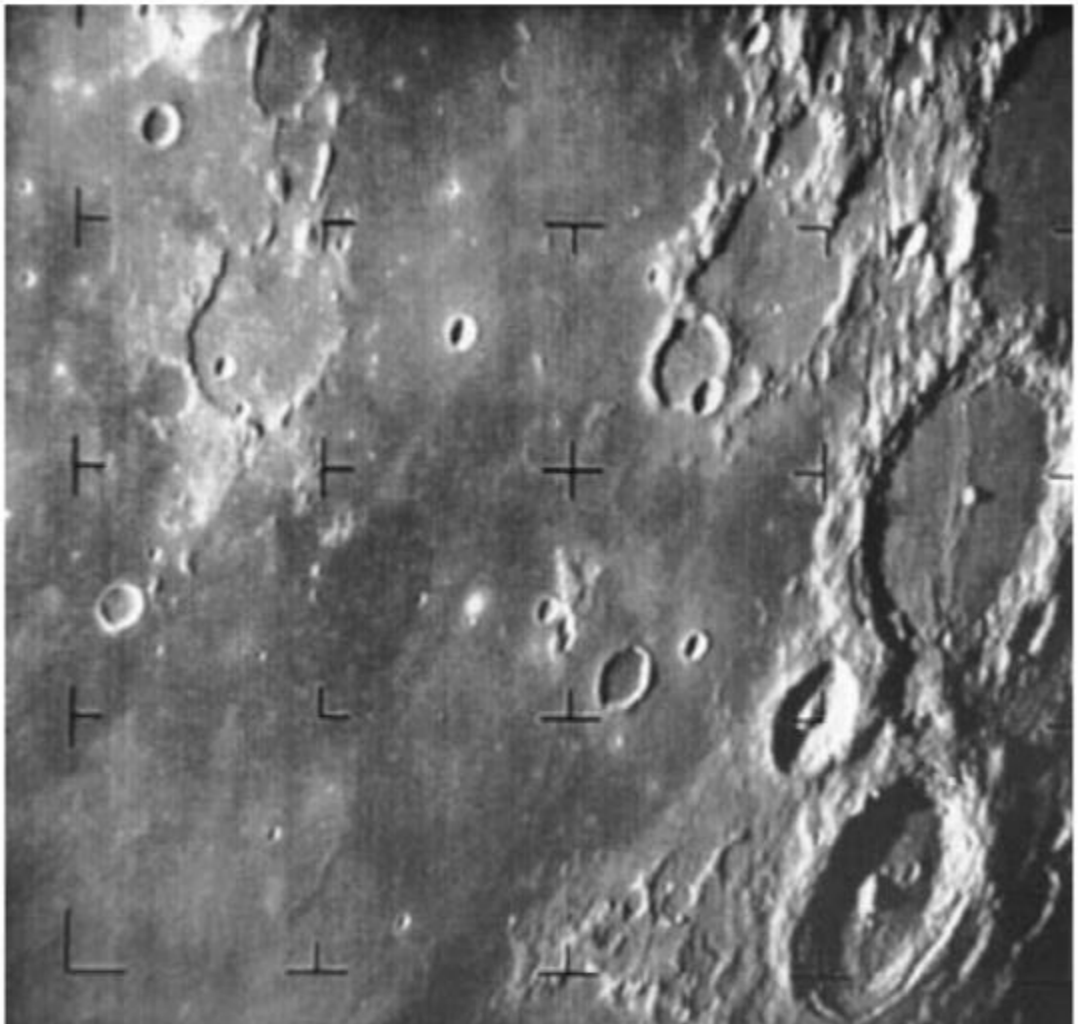
FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Some types of images

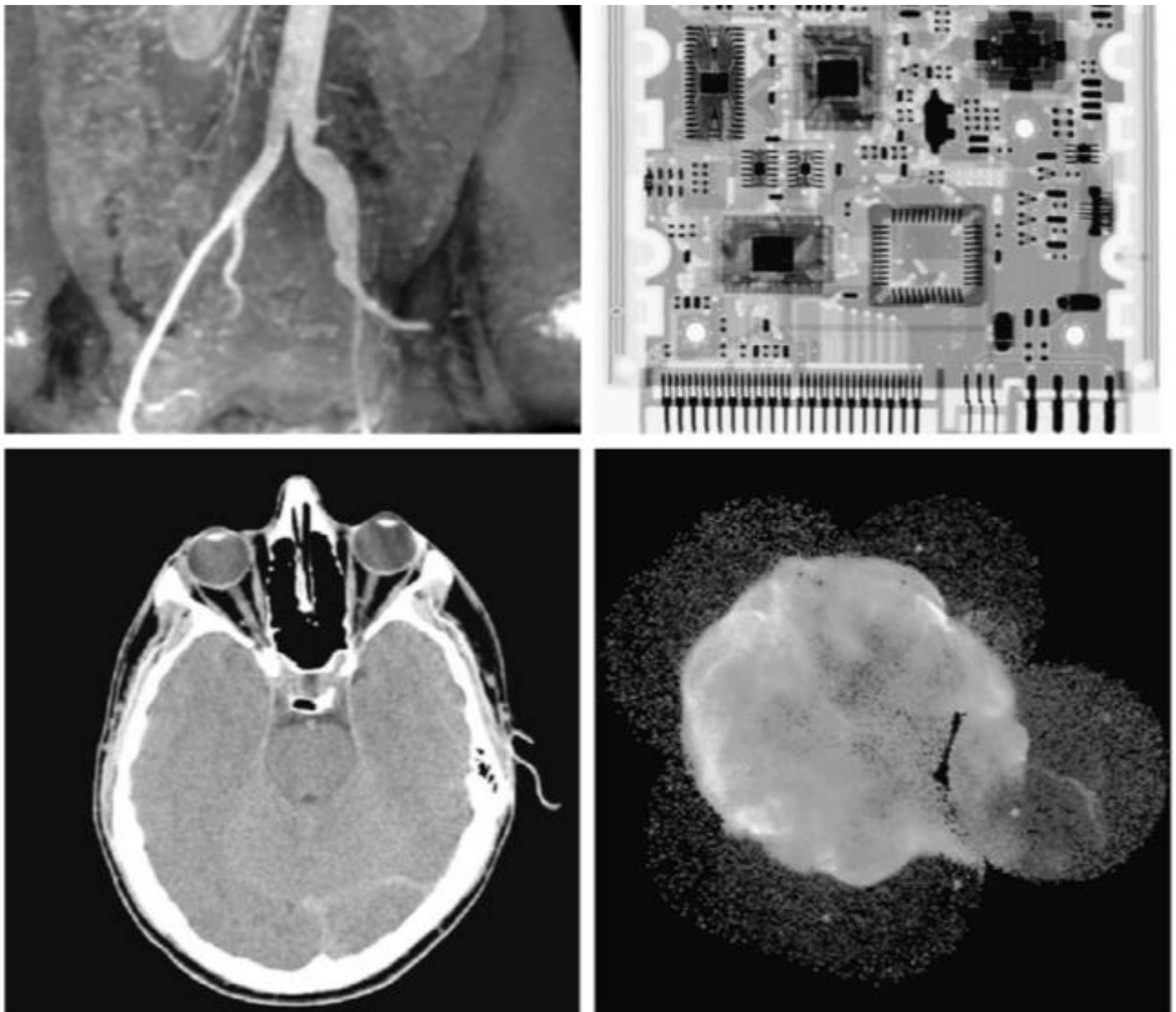
- Regular photography
- Brightfield microscopy
- Industrial photography
- Visible band satellite imagery
- IR band satellite imagery
- IR spectromicroscopy
- UV images
- X-ray images
- Electron microscopy
- …

Surface of the moon pictured by Ranger 7 in 1964



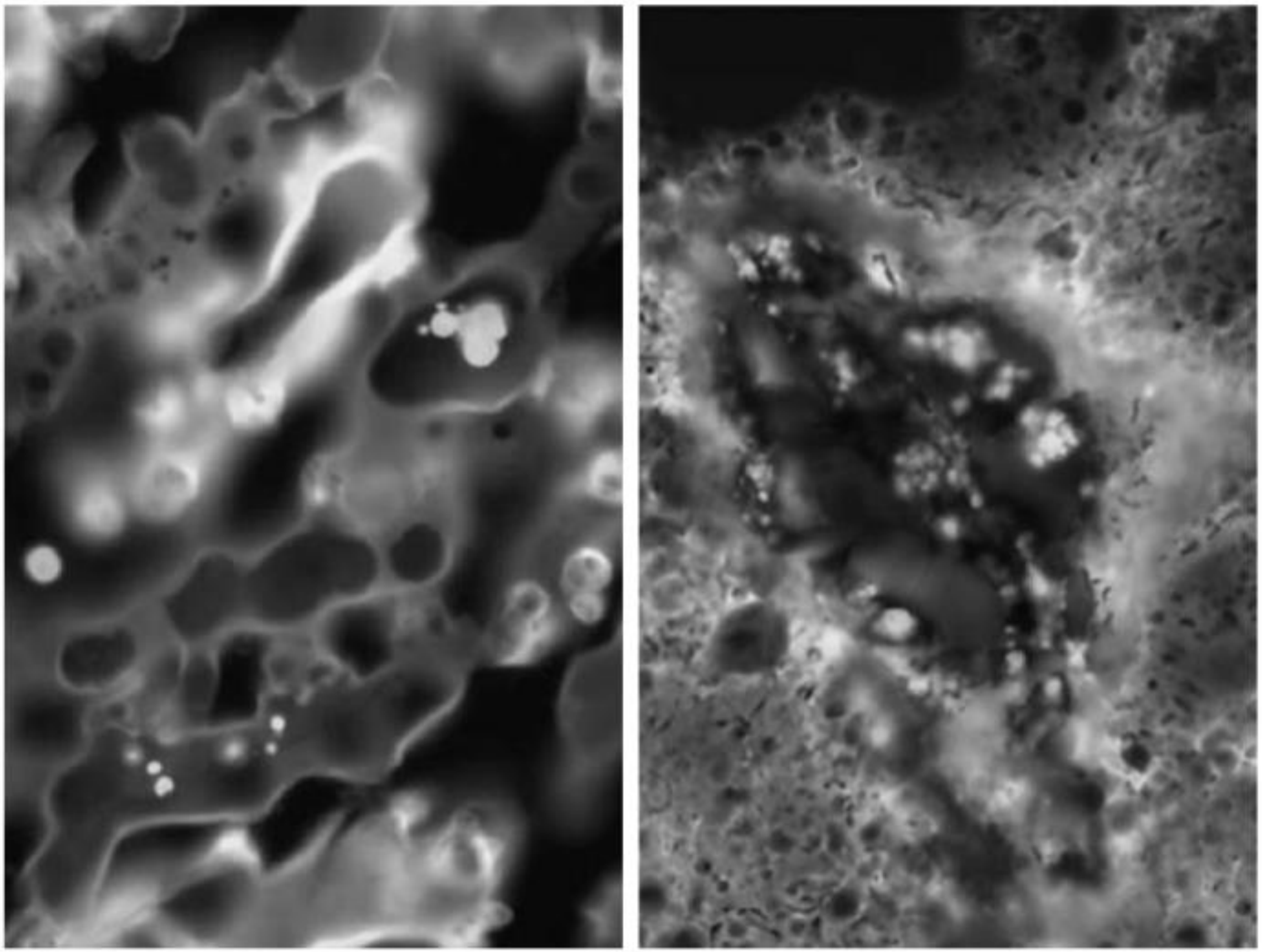
Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Examples of X-ray images



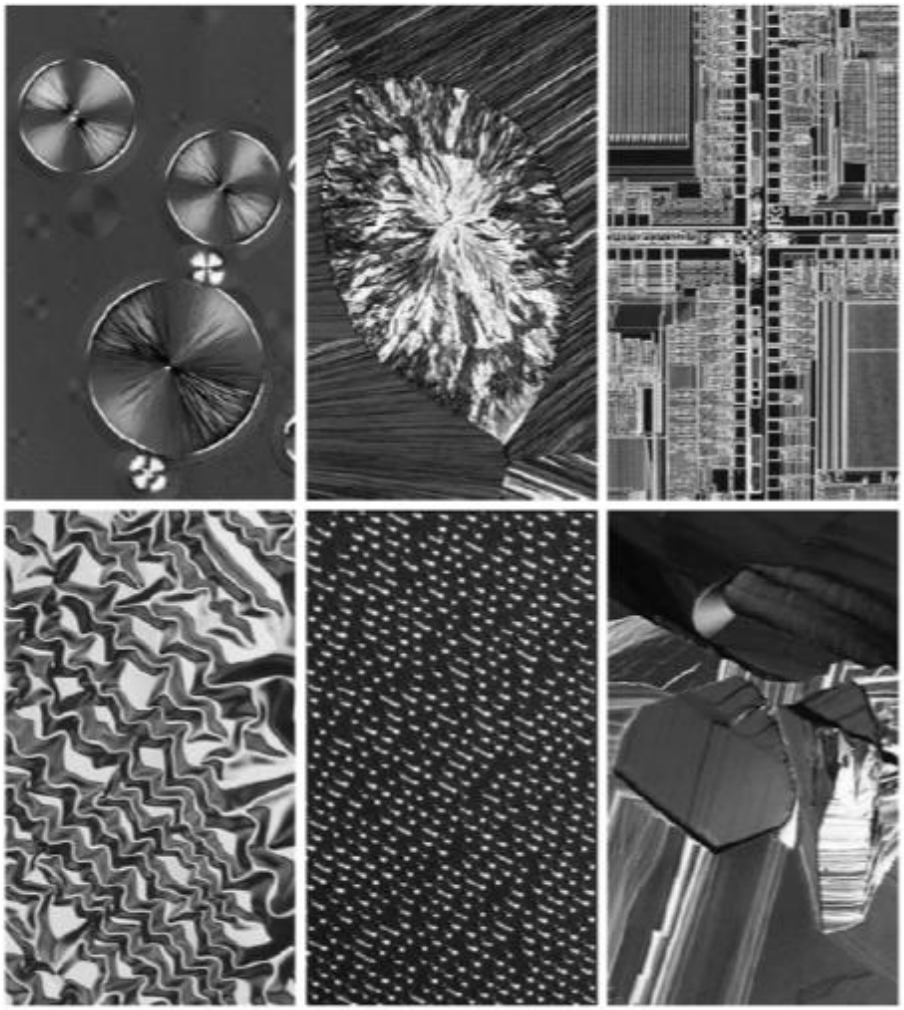
Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Examples of UV images of healthy and diseased corn



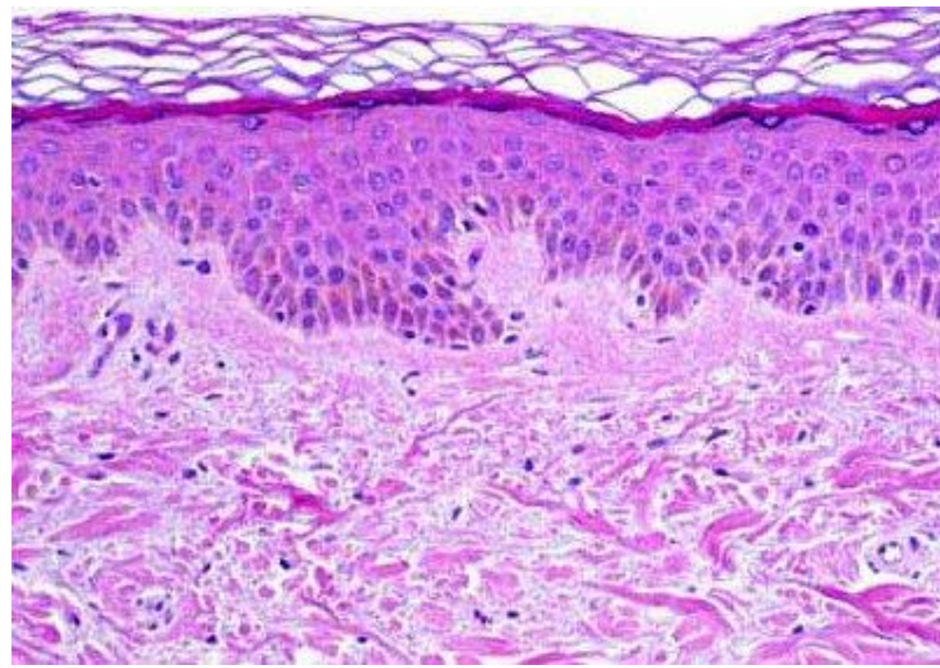
Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Examples of microscopy images



a b c
d e f

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.)



Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Thematic bands of 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

Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Same area pictured with different bands

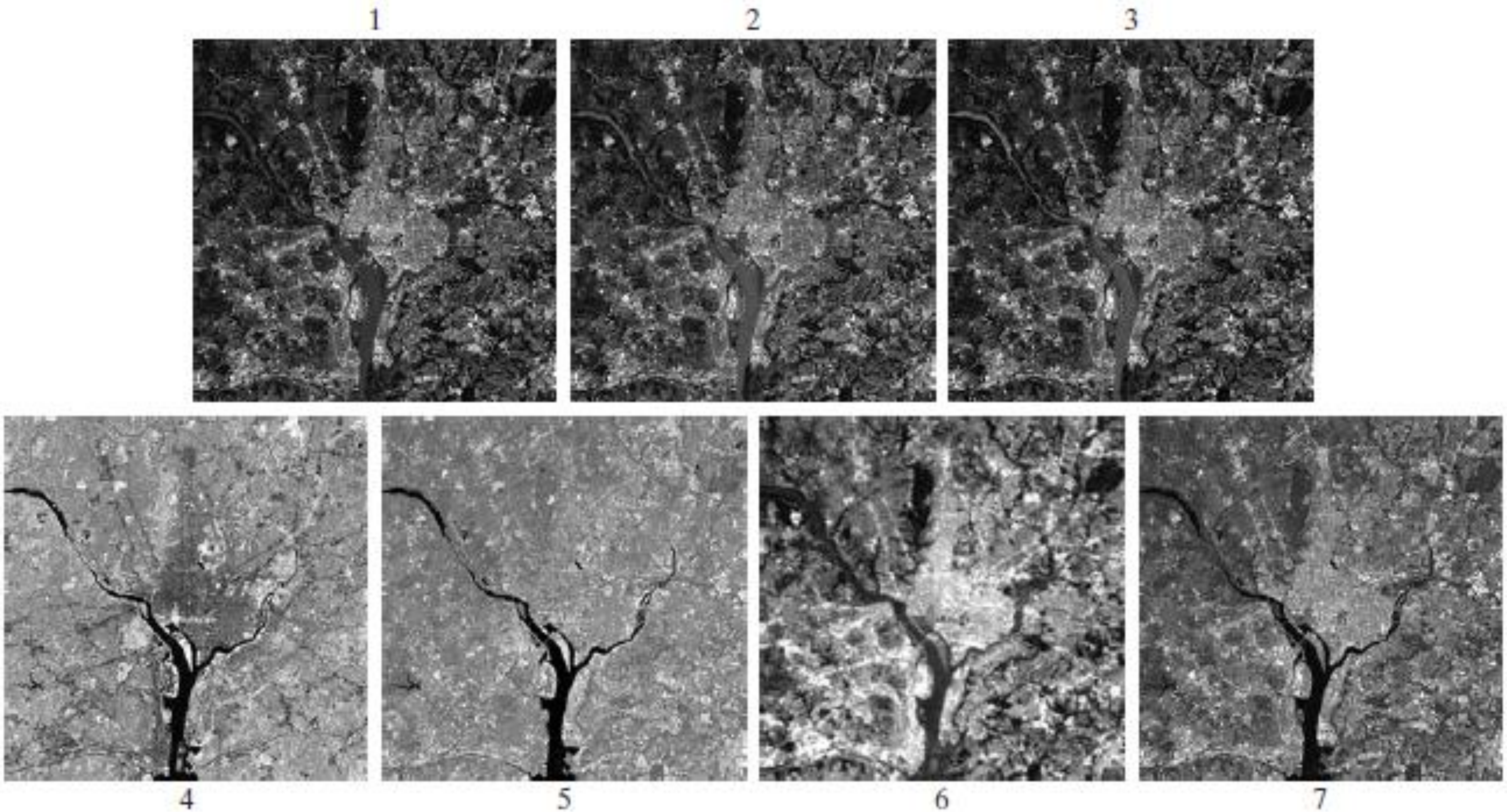
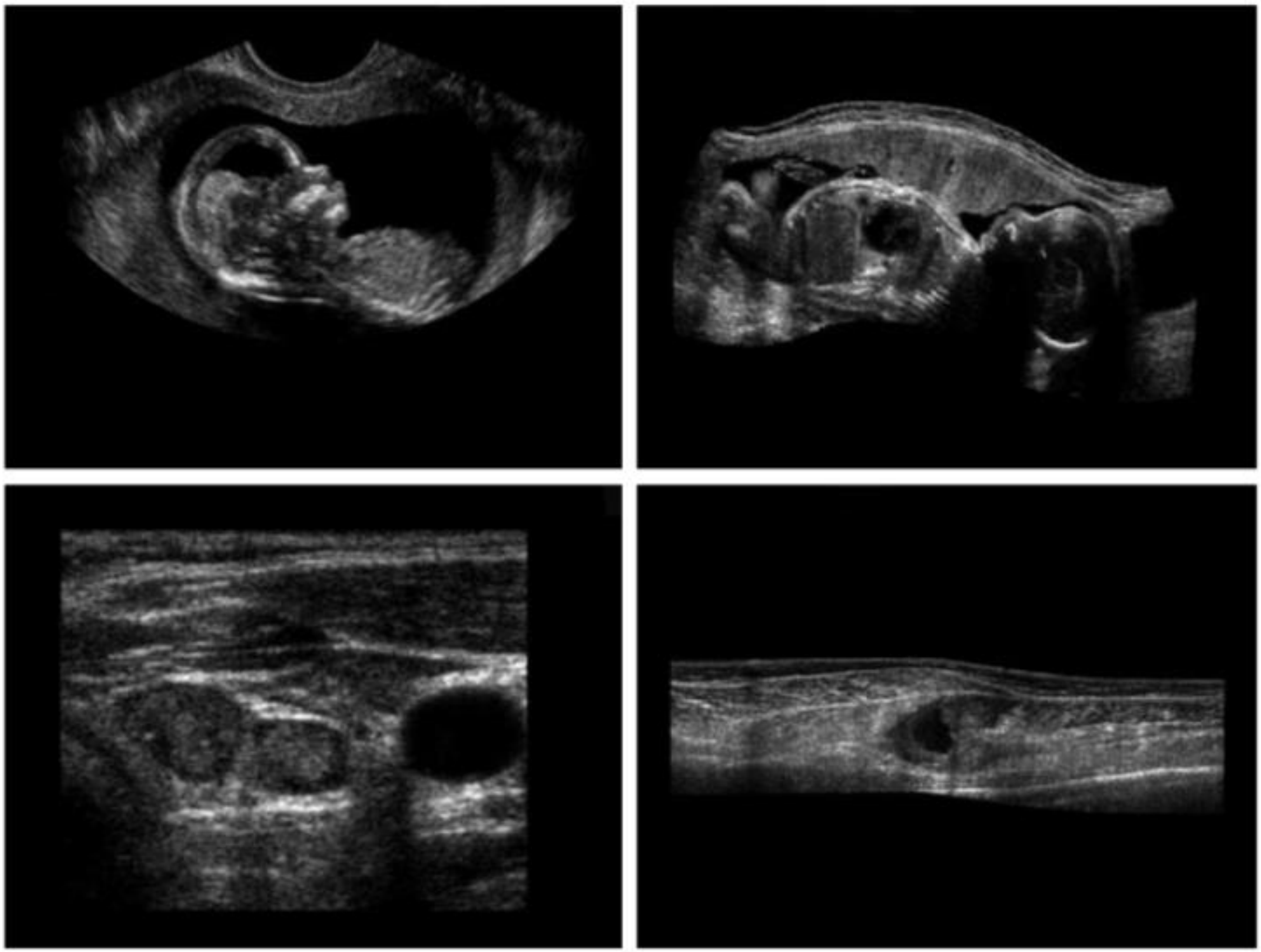


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Photography using ultrasound

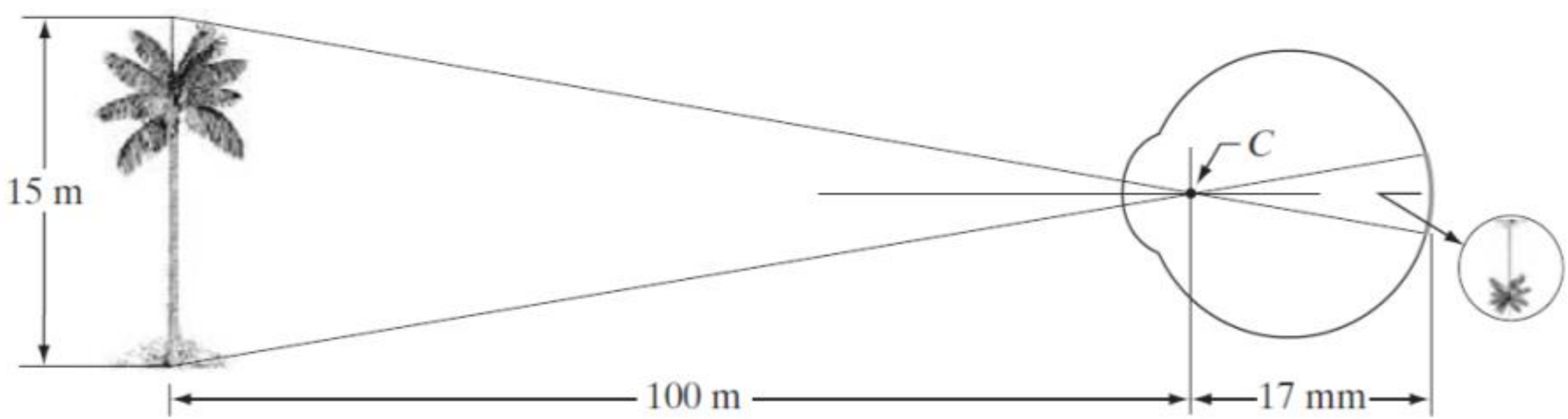


a b
c d

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

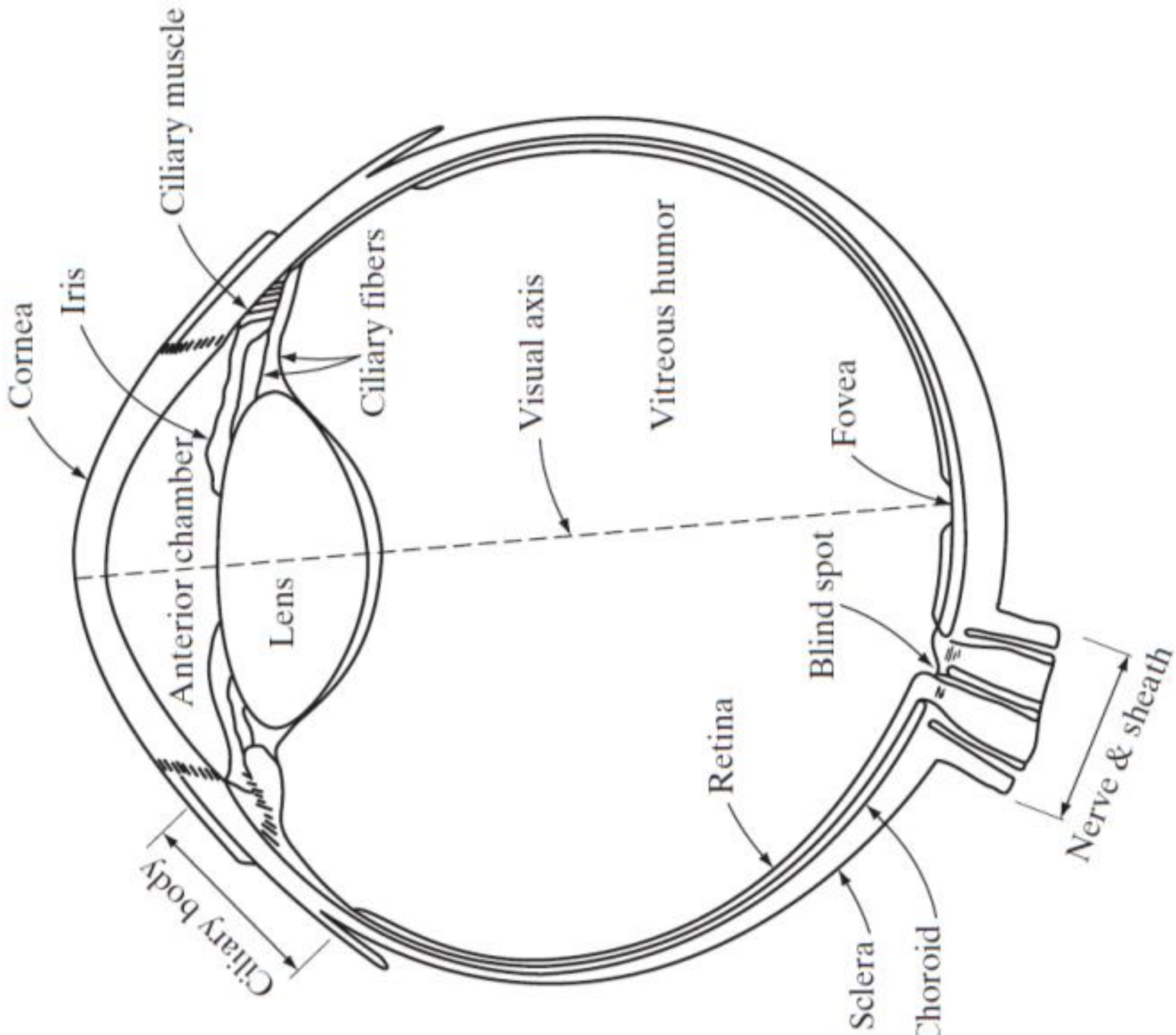
Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Image formation in the human eye



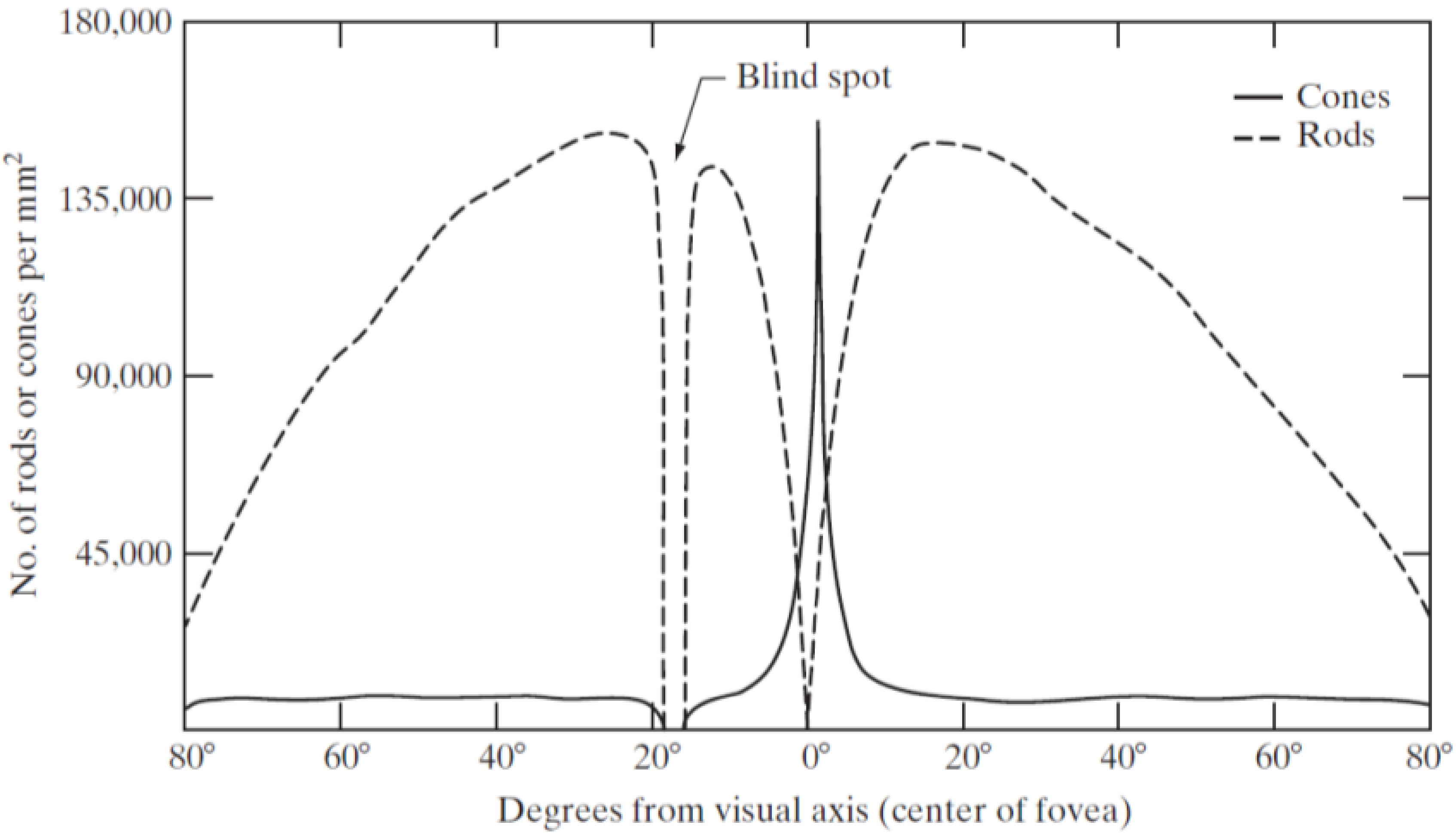
Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Structure of the human eye



Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Distribution of rods and cones



Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Image formation in a camera

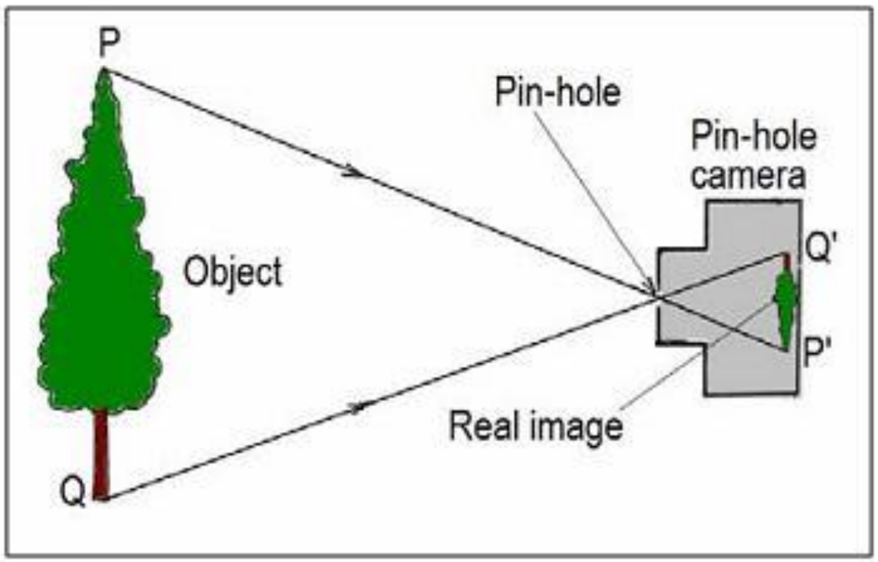


Fig.5(a) Real image by a pin-hole camera

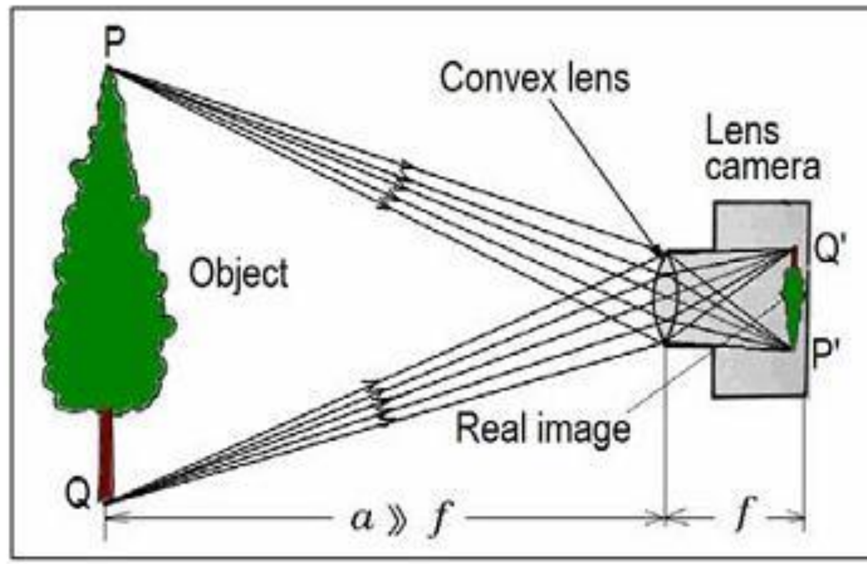
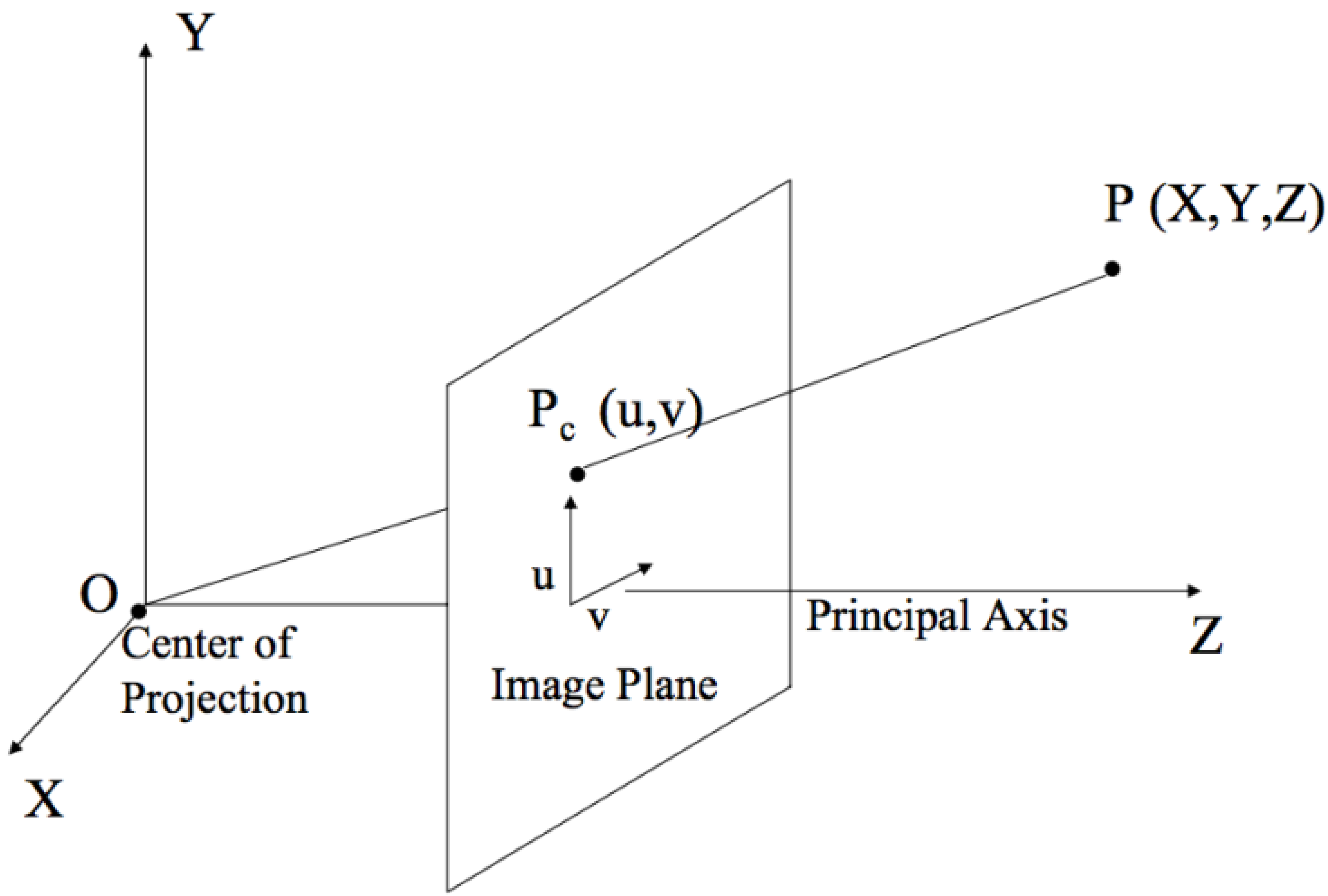


Fig.5(b) Real image by a lens camera

A simplified camera model



Typical Image Processing System

Light from subject

↓

Optics

↓

Sensor

↓

Compression

↓

Storage

↓

Information Extraction

↓

Display, attributes, synthetic images

Characteristics of an image

- A function in 2-d
- Has high spatial correlation
- Finite spatial extent
- Discretized to pixels
  - Spatial sampling
  - Intensity quantization

Sensors

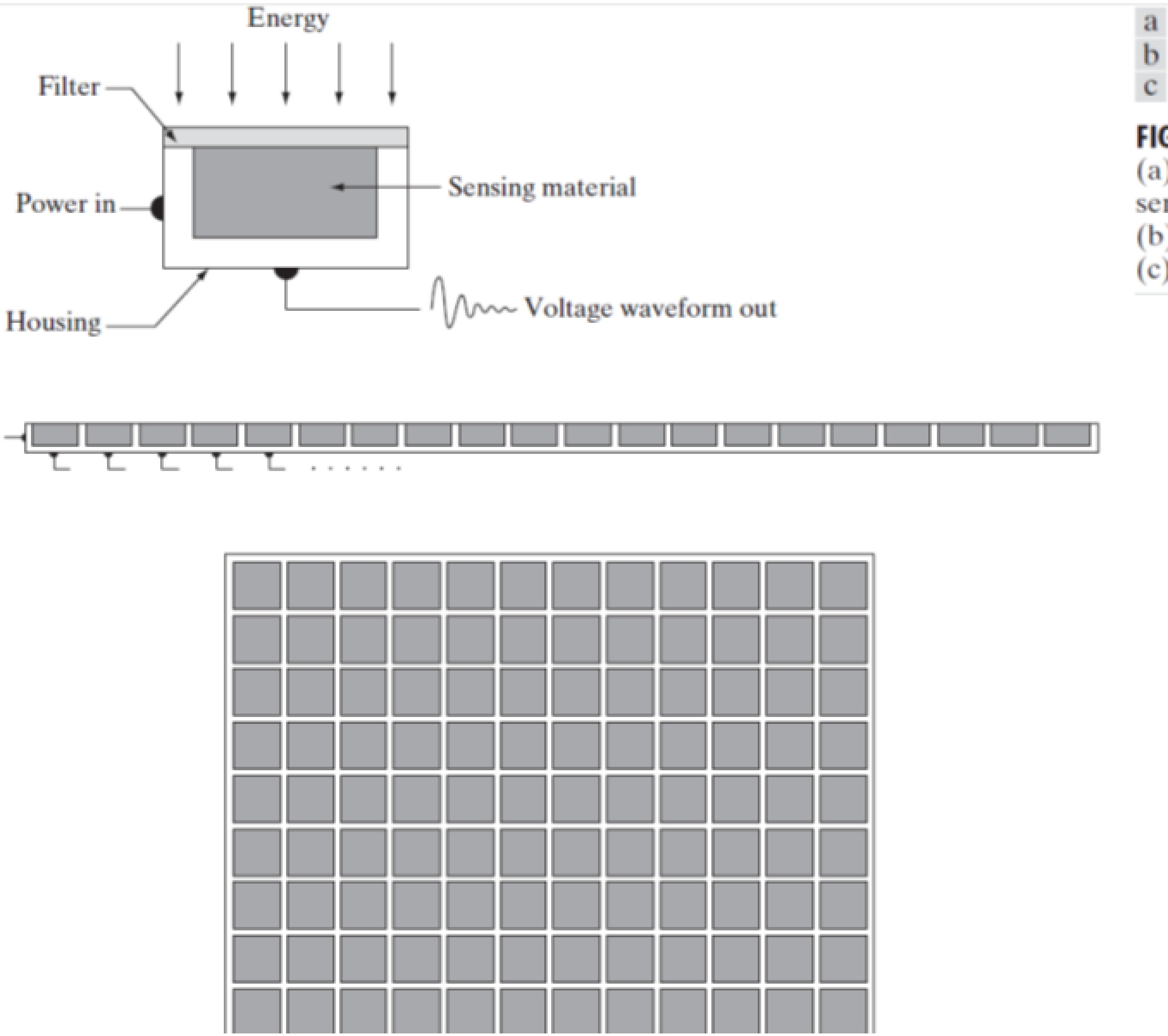
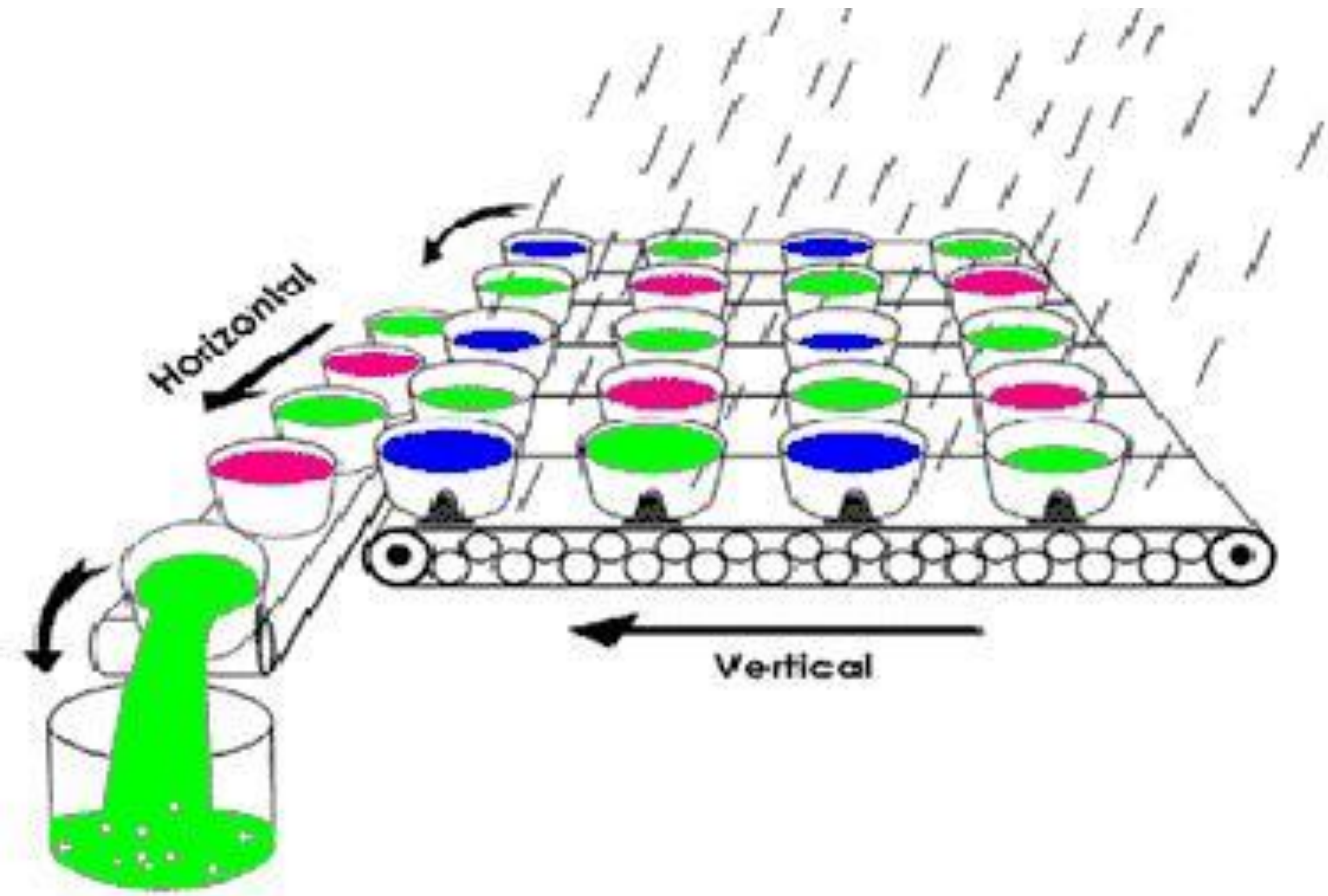


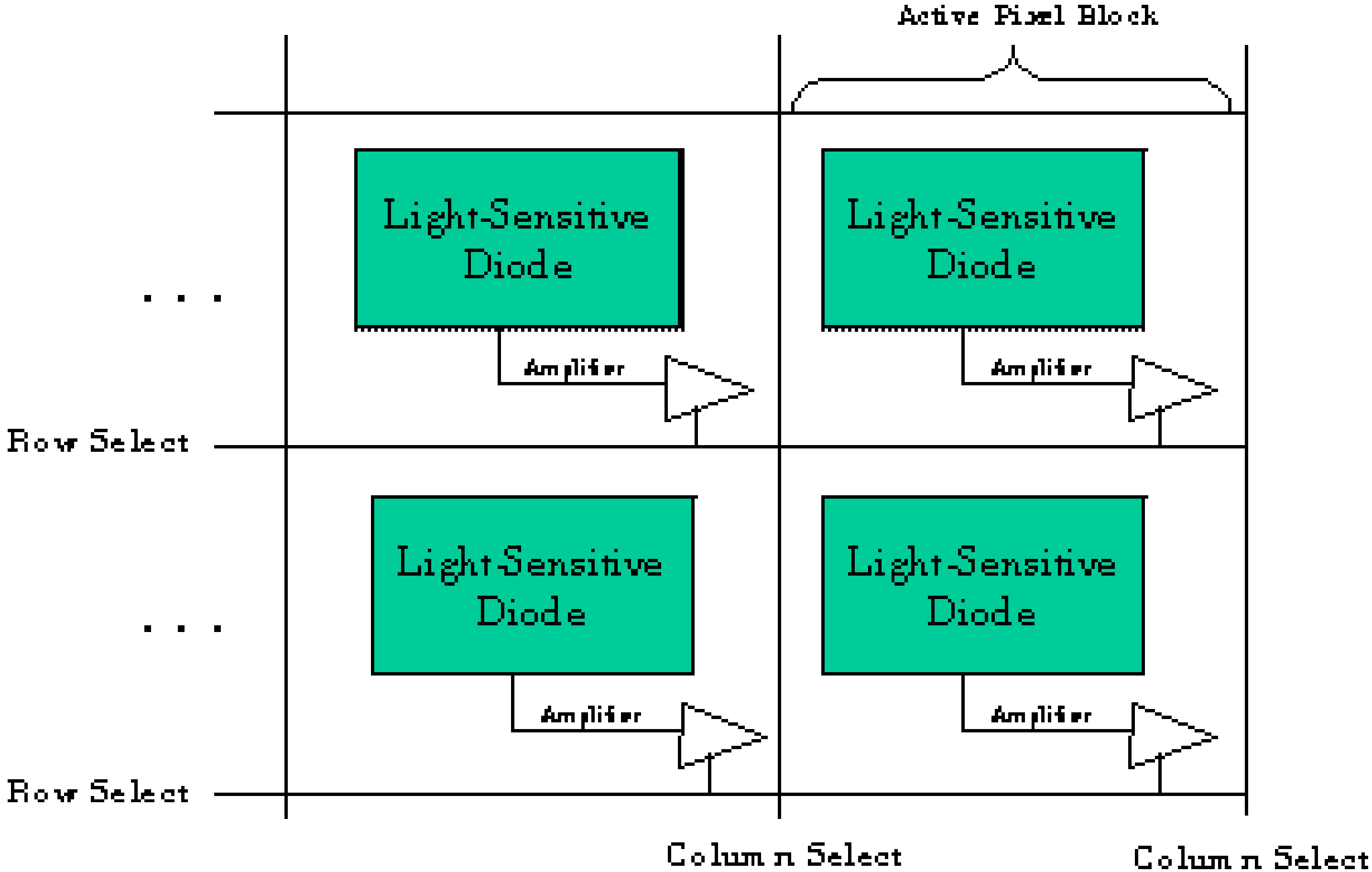
FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Depiction of CCD sensors

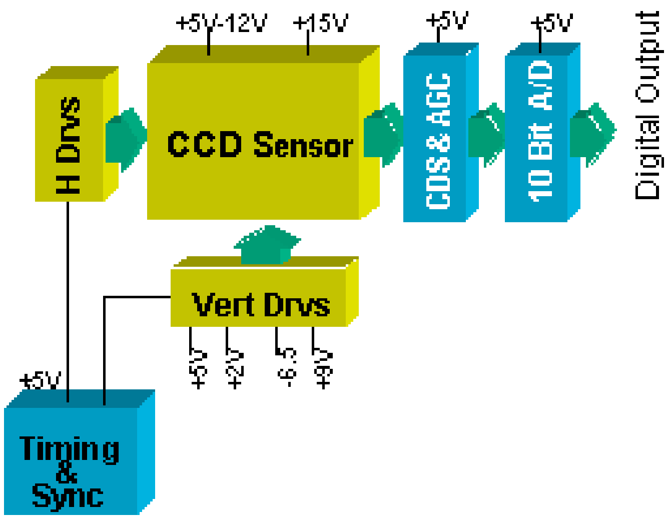


Depiction of CMOS



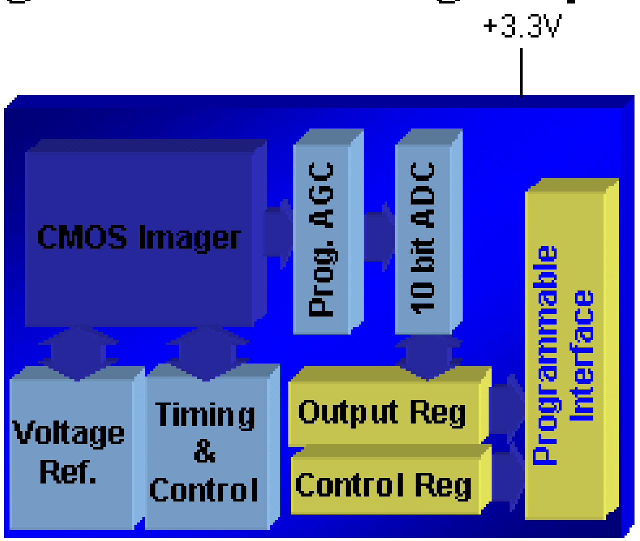
CCD vs. CMOS

Basic CCD Imager System



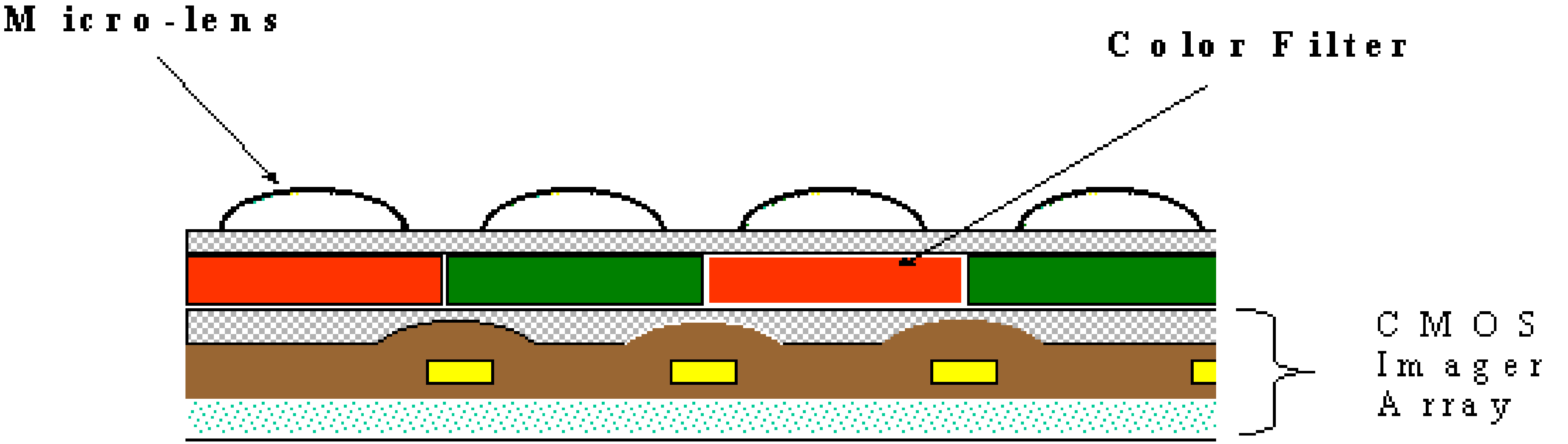
Multiple support chips required
Multiple supply voltages
Dedicated manufacturing and production needs

Integrated CMOS Imager System

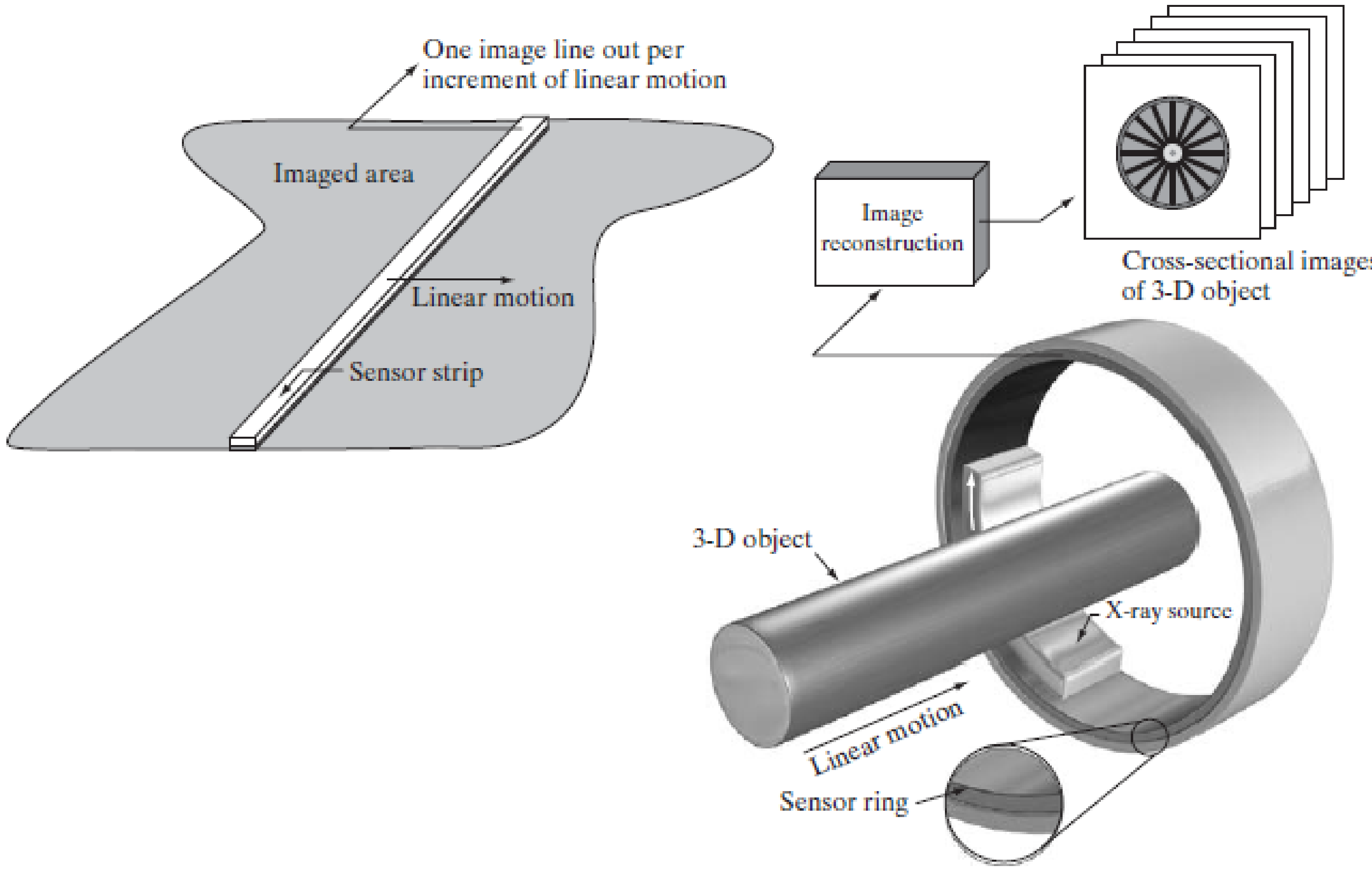


Lower system-level cost
Lower power consumption (3 to 10 times lower)
Smaller size / greater integration
Streamlined manufacturing and production
Ease of use for end users
Accelerated time to market

Concentrating light and color filtering



Some other sensor configurations



a b

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

Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

A Simple Image Formation Model

- $0 < f(x, y) < \infty$

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

Image Sampling and Quantization

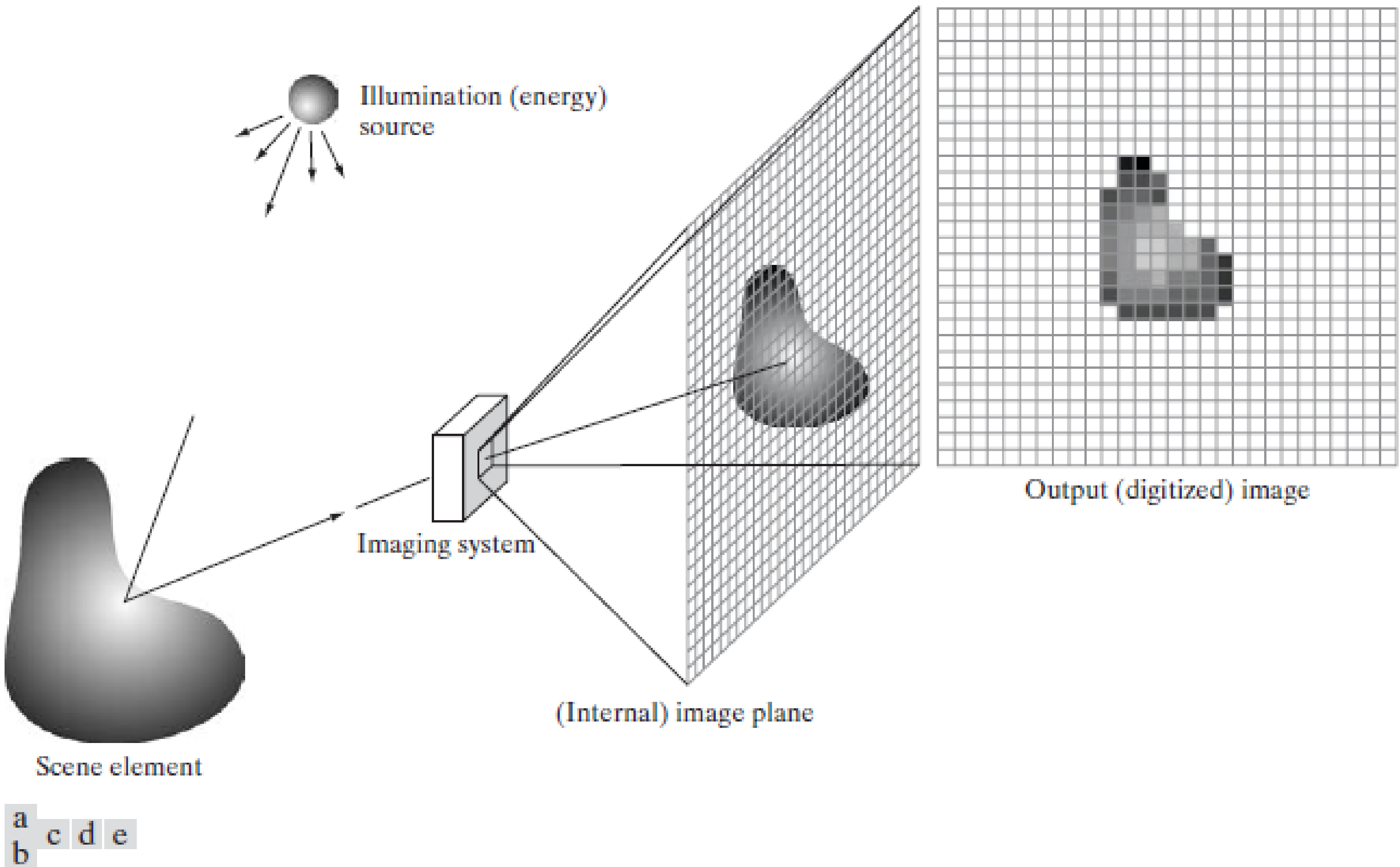
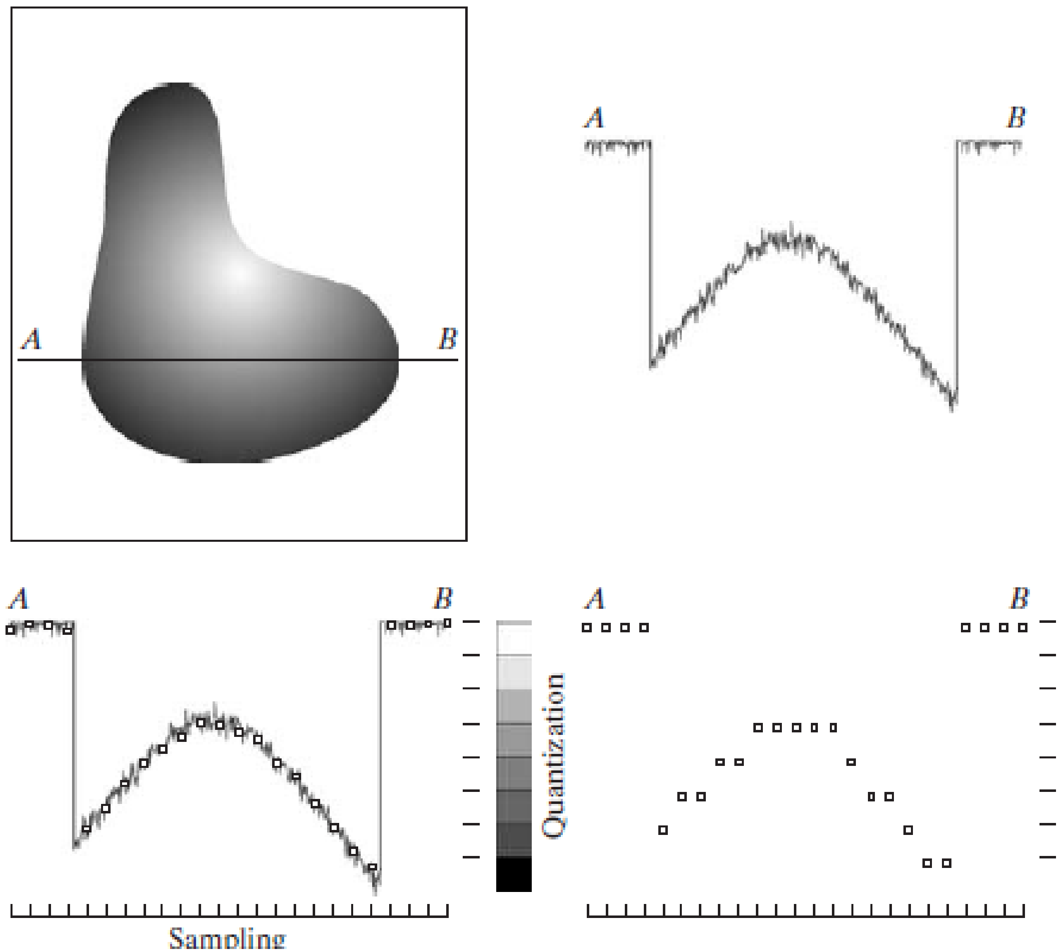


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Sampling and quantization

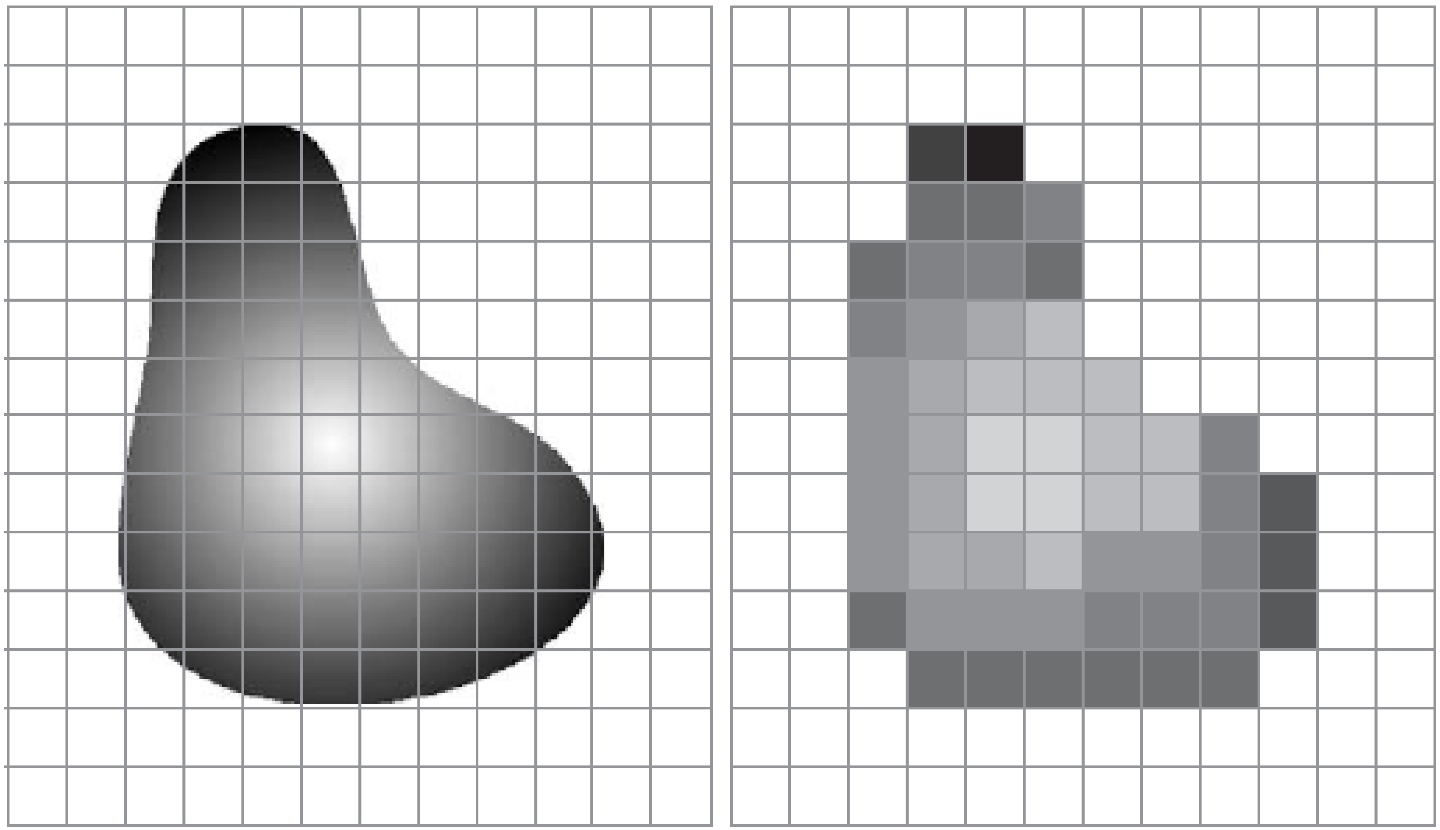


a b
c d

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.

Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Sampling and quantization

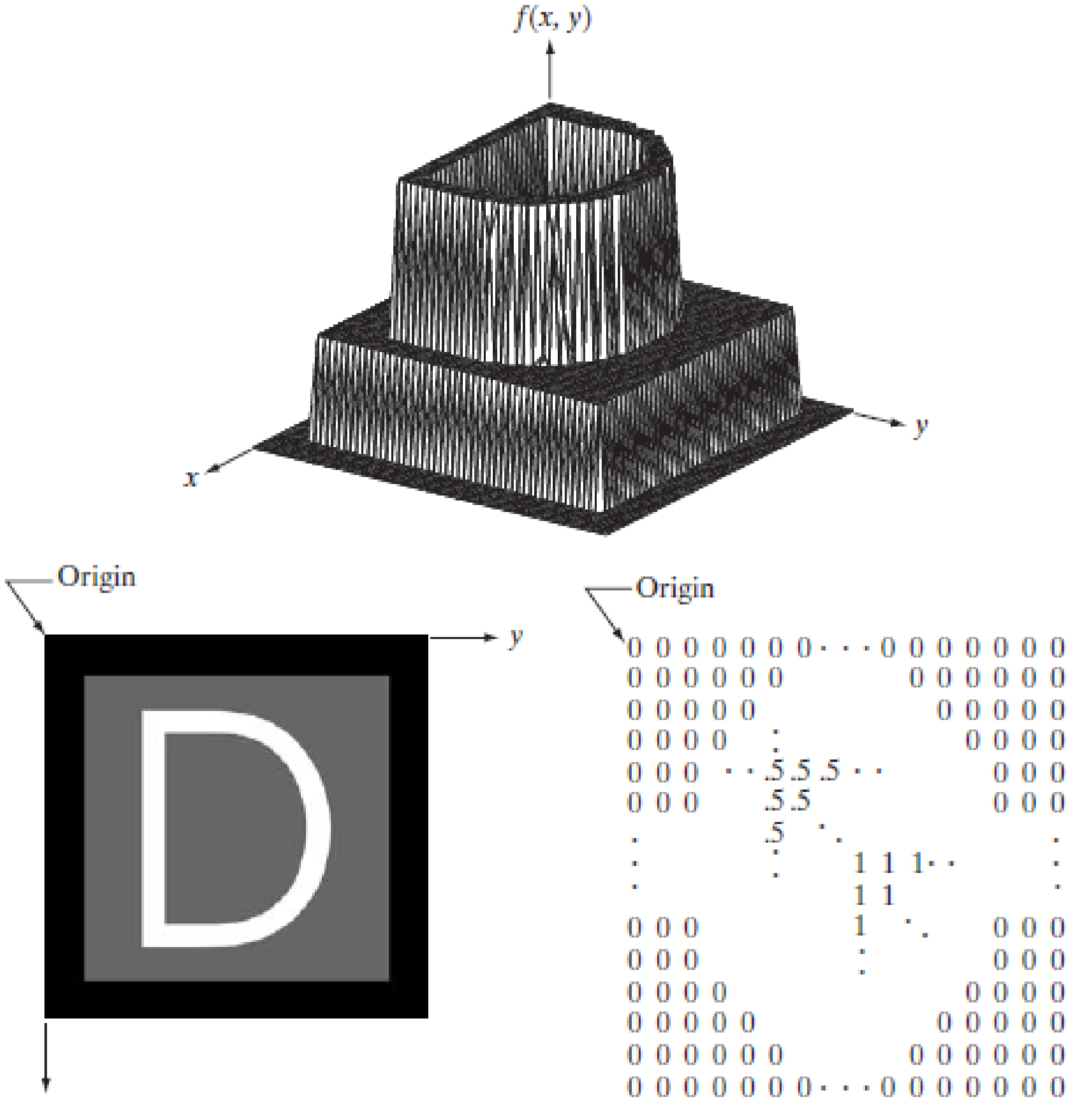


a b

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

Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Surfaces and contours of intensity



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).

Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Arrays, matrices, and vectors

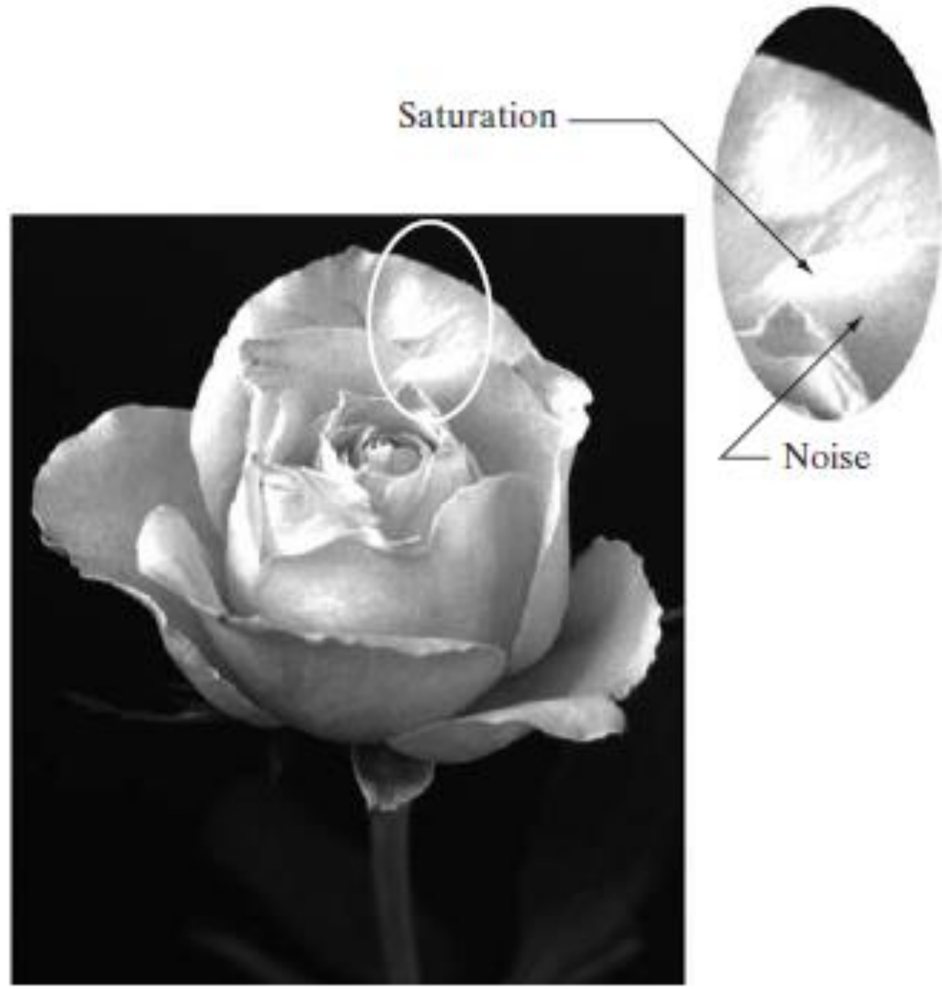
- Image is a 2-d (or 3-d) array
  - Not a matrix (or a tensor)
- Image pixels can be represented as a vector
  - Vectorizing an image
- RGB can be represented as a vector

Image sizes and intensity levels

- Intensity levels are usually powers of 2
  - Why?
- Image sizes are preferably powers of 2, but not always
  - Why?
- There are different ways to describe resolution

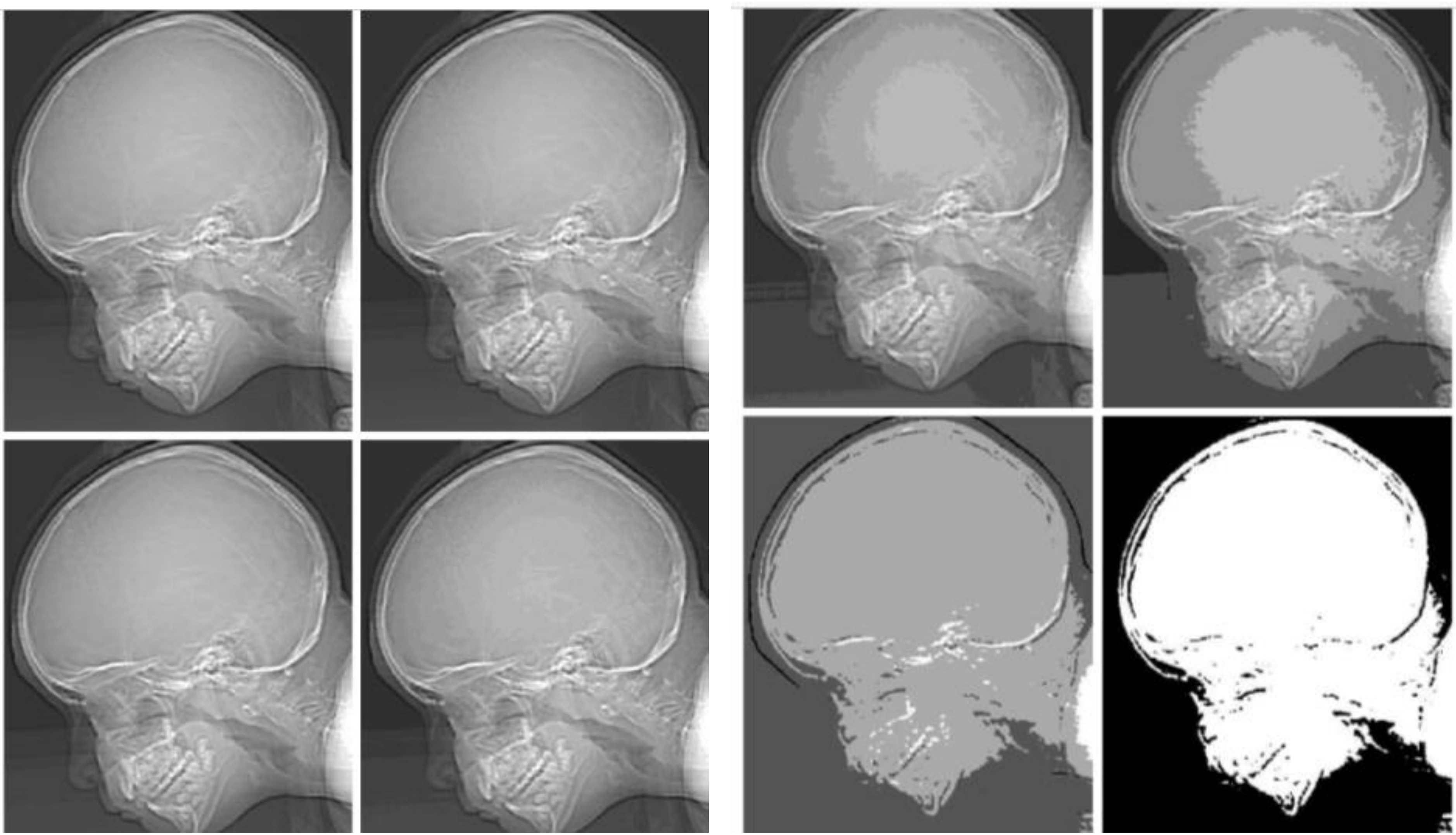
When pixel intensities are outside the range represented

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.



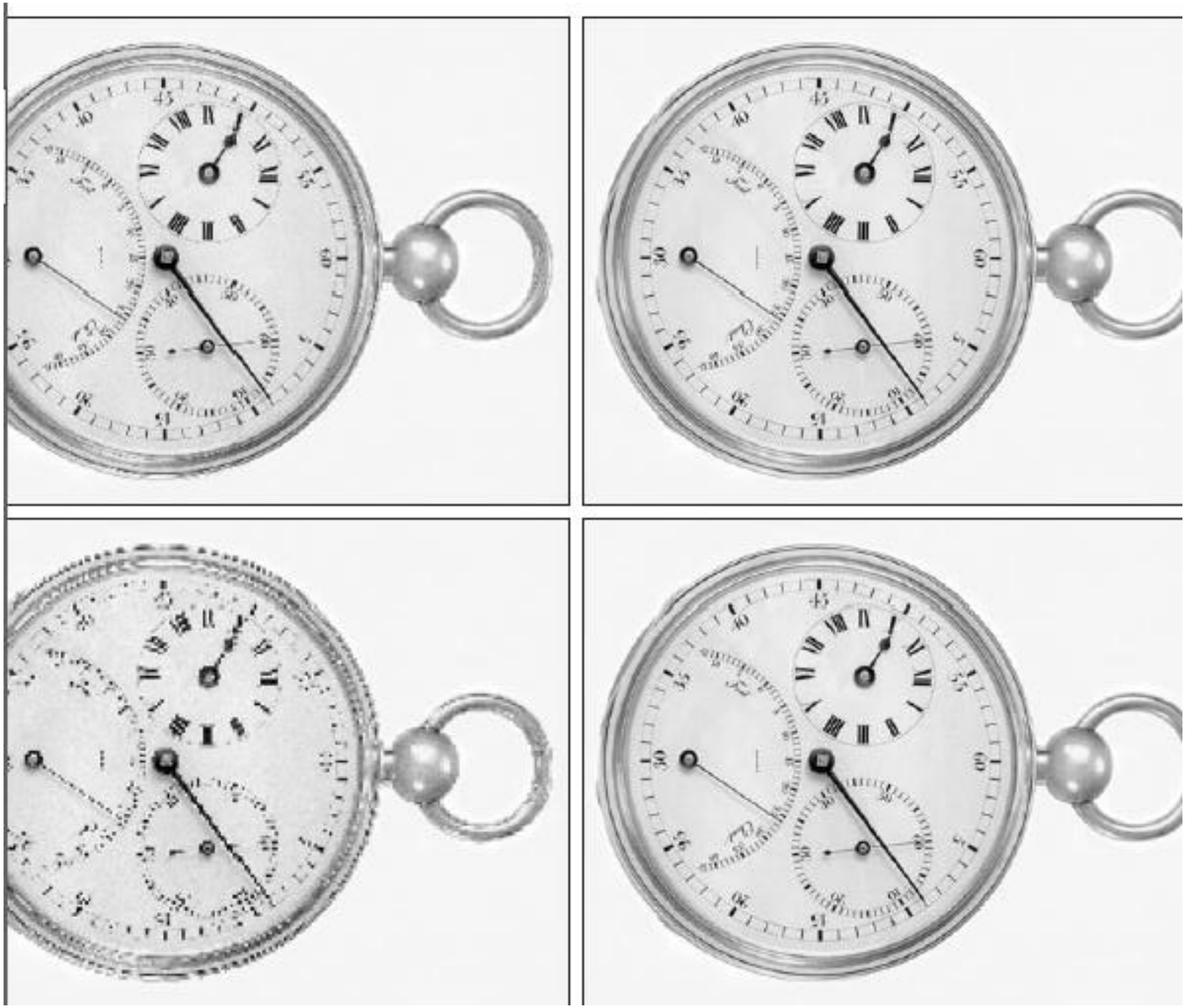
Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Effect of intensity levels



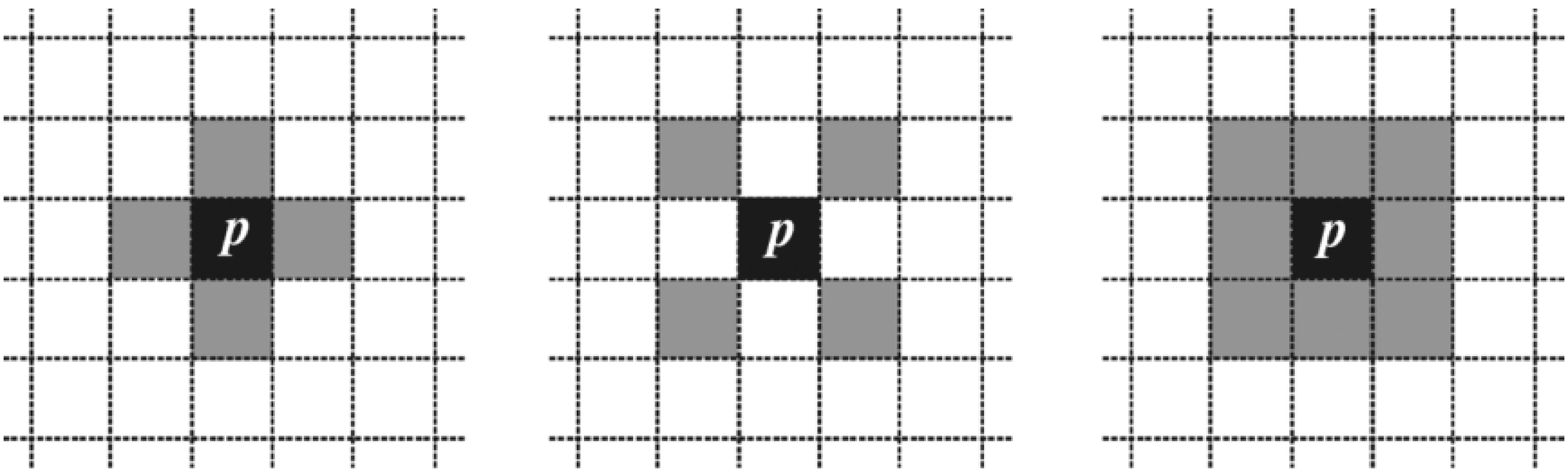
Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Effect of spatial resolution



Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Neighbors of a pixel



(a) (b) (c)

Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Adjacency

- Neighboring pixels are said to be adjacent if their values belong to a set V
- E.g. V = {1} means all pixel pairs that have value 1, and are neighbors are adjacent.
- Examples
  - 4-adjacency
  - 8-adjacency
  - Mixed adjacency (first check 4, if not then check D)

Paths and connected components

- A series of adjacent pixels is a path
- A set of adjacent pixels in which a path from any pixel to any other pixel exists is a connected component
- Connected components have inner and outer boundaries

Distance measures

- $D(p,q) \geq 0$
- $D(p,q) = D(q,p)$
- $D(p,q) \leq D(p,z) + D(z,q)$

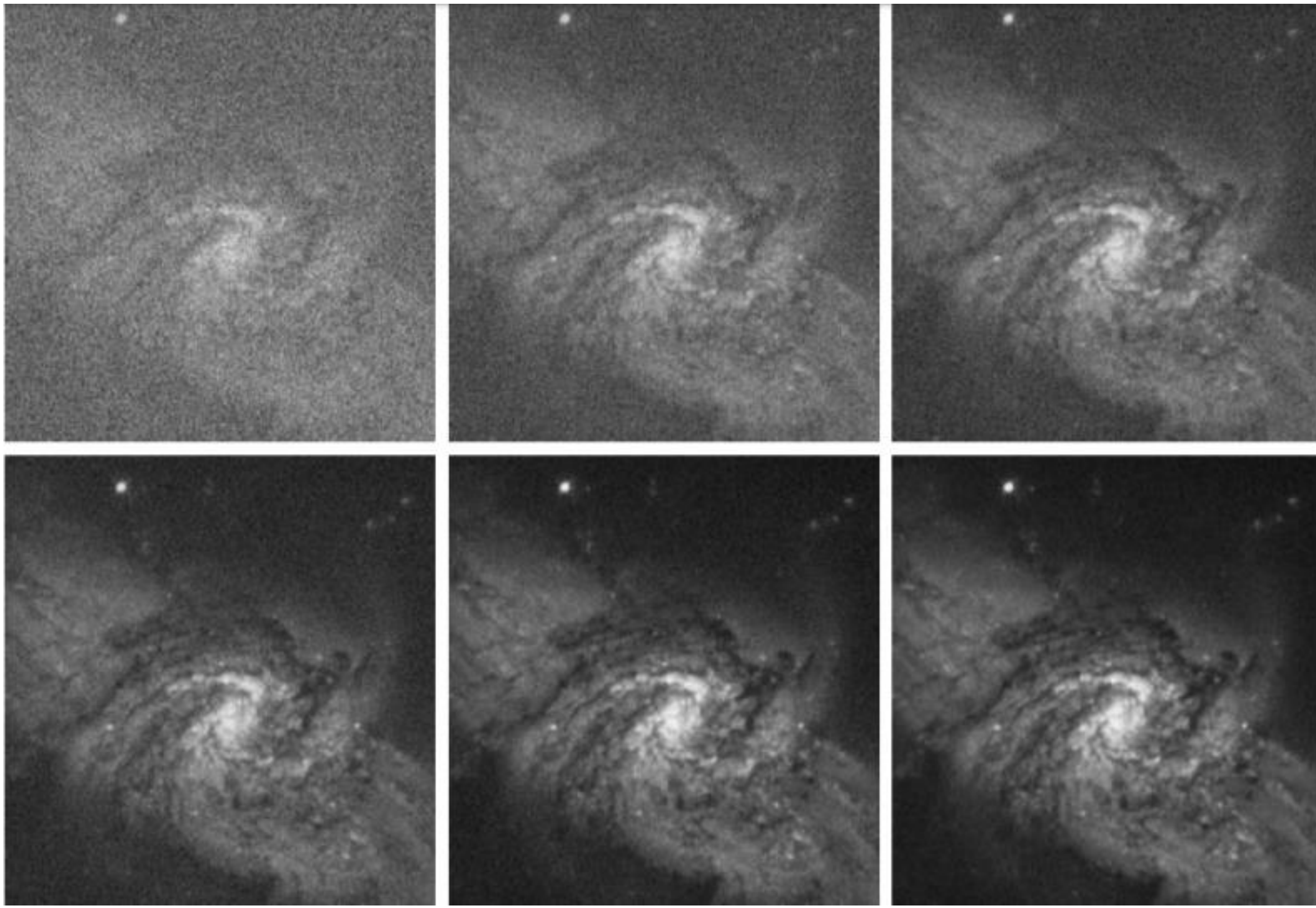
- Examples
  - Euclidean distance
  - D_4 distance
  - D_8 distance

Array vs. Matrix Ops

- Array ops are element wise
- E.g.
  - Element-wise products
  - Element-wise sums
  - Element-wise linear operation
  - Element-wise nonlinear operation

Example: Averaging of K images

- Noise std. dev. reduces by $K^{-1/2}$

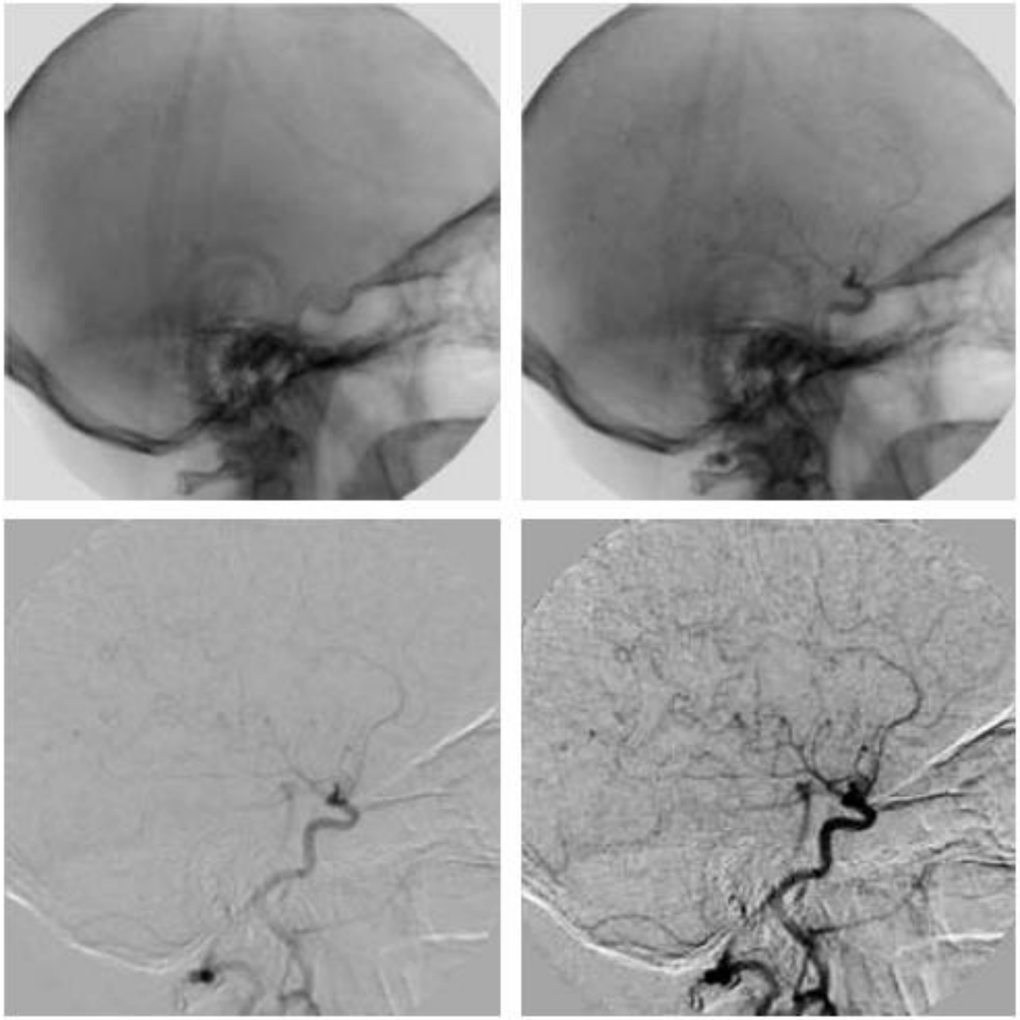


Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Subtraction of images

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.)



Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

ROI masking

FIGURE 2.30 (a) Digital dental X-ray image. (b) ROI mask for isolating teeth with fillings (white corresponds to 1 and black corresponds to 0). (c) Product of (a) and (b).

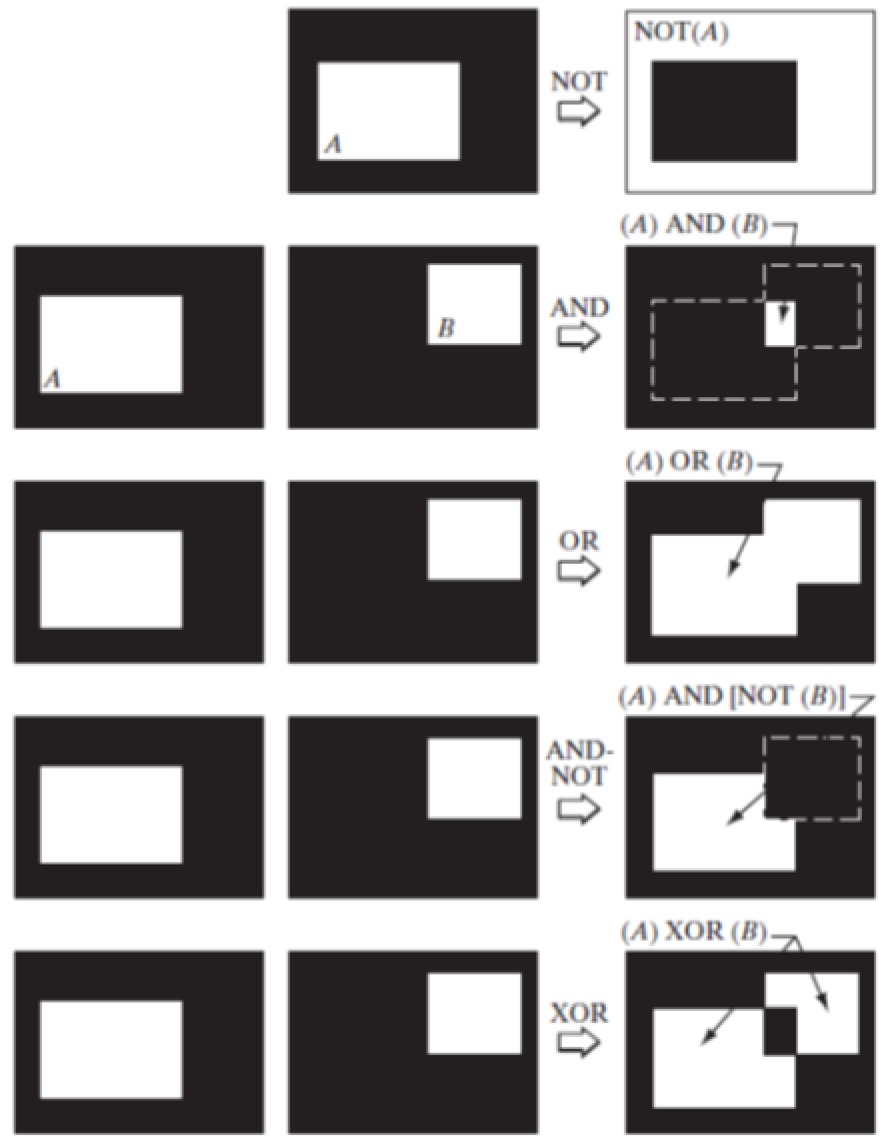
Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

How will you enhance contrast?

- Lnew = $(L_{old} – L_{min}) / (L_{max} – L_{min})$
- Instead of max and min, one can use 1st percentile and 99th percentile.

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.

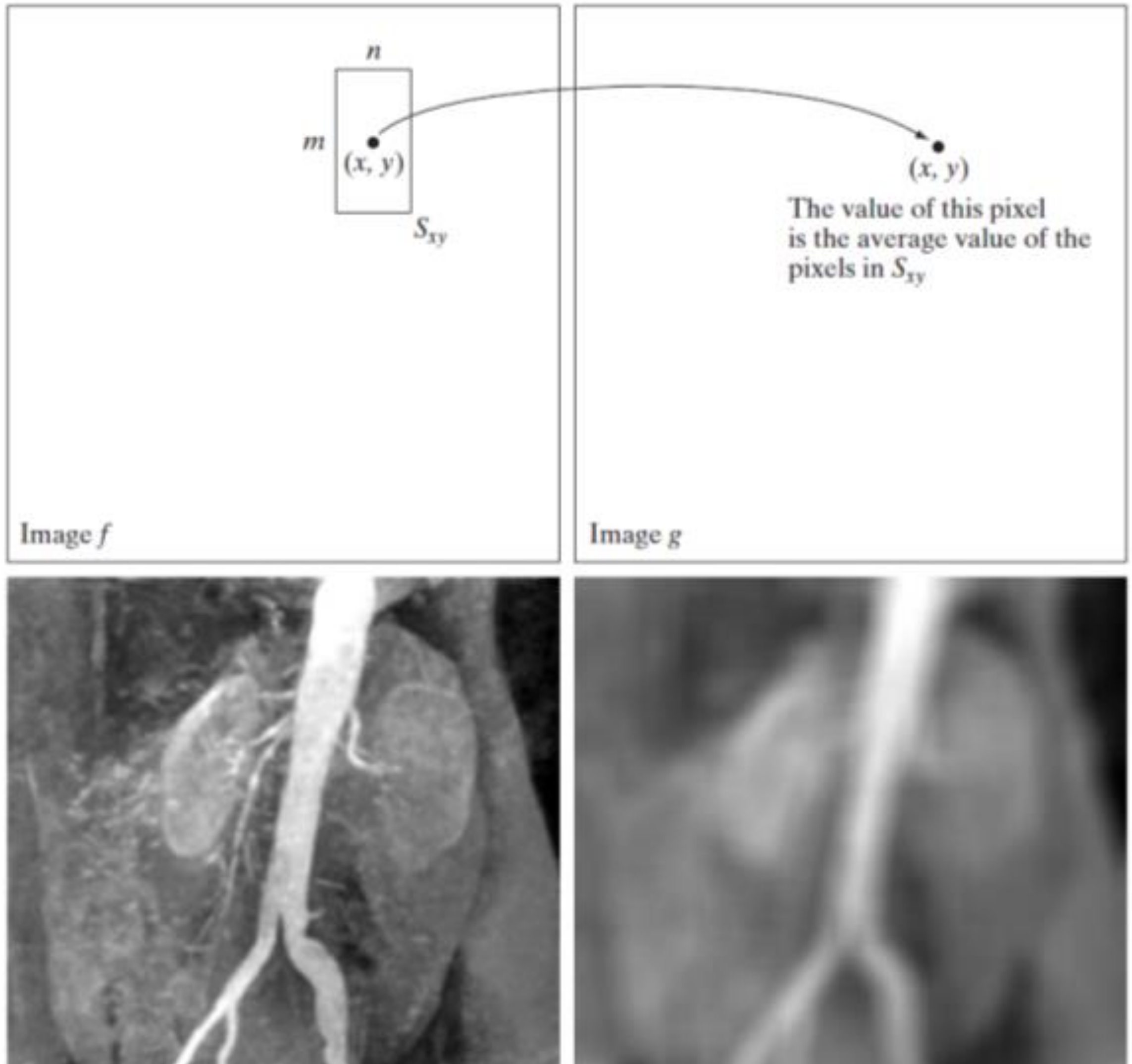


Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Going beyond single pixels to use spatial neighborhoods

a b
c d

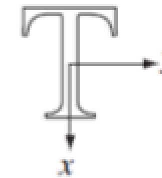
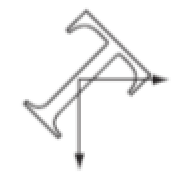
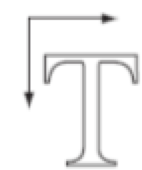
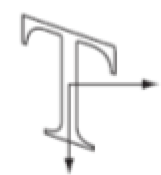
FIGURE 2.35 Local averaging using neighborhood processing. The procedure is illustrated in (a) and (b) for a rectangular neighborhood. (c) The aortic angiogram discussed in Section 1.3.2. (d) The result of using Eq. (2.6-21) with $m = n = 41$. The images are of size 790×686 pixels.



Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Coordinate transformation

- (x, y)
  = T{(v, w)}

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	$\begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v\cos\theta - w\sin\theta$ $y = v\cos\theta + w\sin\theta$	
Translation	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ t_x & t_y & 1 \end{bmatrix}$	$x = v + t_x$ $y = w + t_y$	
Shear (vertical)	$\begin{bmatrix} 1 & 0 & 0 \\ s_v & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x = v + s_v w$ $y = w$	
Shear (horizontal)	$\begin{bmatrix} 1 & s_h & 0 \end{bmatrix}$	$x = v$	

Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Vectorizing an image

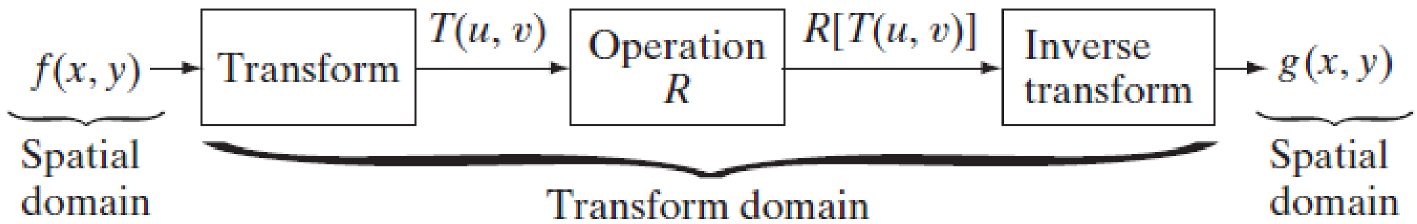
- Express an MxN image as an MNx1 vector

- Now, you can define matrix operations

  e.g. $\mathbf{g} = \mathbf{Hf} + \mathbf{n}$

Working in a *transform* domain

$$T(u, v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y) r(x, y, u, v)$$



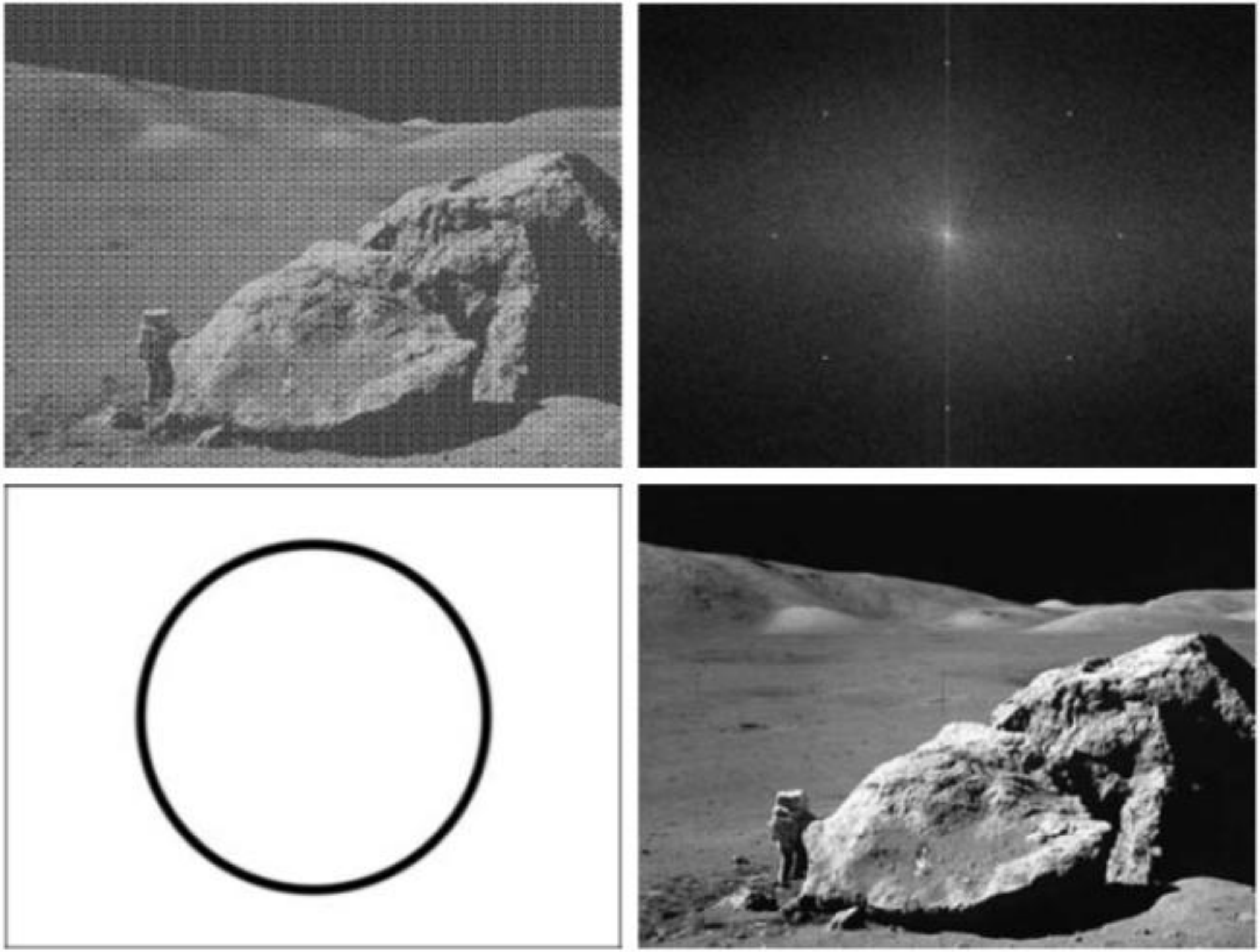
are the row and column dimensions of f. Variables u and v are called the *transform variables*. $T(u, v)$ is called the *forward transform* of $f(x, y)$. Given $T(u, v)$, we can recover $f(x, y)$ using the *inverse transform* of $T(u, v)$,

$$f(x, y) = \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} T(u, v) s(x, y, u, v) \qquad (2.6\text{-}31)$$

for $x = 0, 1, 2, \ldots, M - 1$ and $y = 0, 1, 2, \ldots, N - 1$, where $s(x, y, u, v)$ is called the *inverse transformation kernel*. Together, Eqs. (2.6-30) and (2.6-31) are called a *transform pair*.

Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall

Example: Cleaning sinusoidal interference



Source: Digital Image Processing, Gonzalez and Woods, Prentice Hall