Digital Image Processing

Digital Image Fundamentals and Image Acquisition

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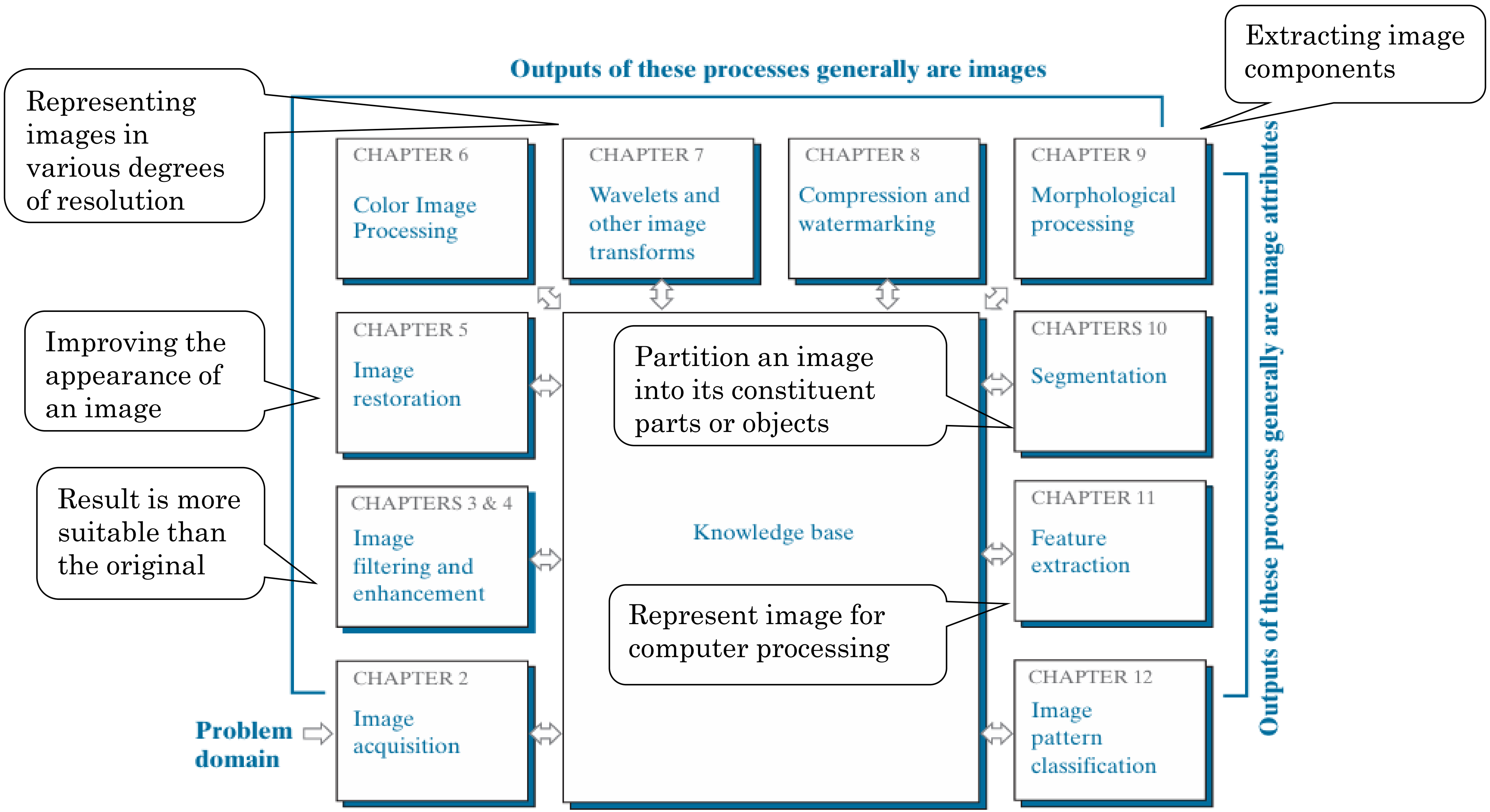
Overview

- **Fundamental steps in DIP**
- **Image Acquisition**
- **Acquisition of color images**
- **A simple image formation model**
- **Image Sampling and Quantization**
- **Representing Digital Images**
- **Image Interpolation**
- **Basic relationship between pixels**

Fundamental steps in DIP



The intention of Diagram is to convey an idea of all the methodologies that can be applied to images for different purposes.

Image Acquisition

Most of the images are generated by the combination of an "illumination" source and the reflection or absorption of energy from that source by the elements of the "scene" being imaged.

Illumination Sources

- Visible light source illuminates a familiar 3-D scene
- Electromagnetic energy, such as a radar, infrared, or X-ray system.
- Ultrasound, computer-generated illumination pattern.

Scene

- familiar objects, molecules, buried rock formations, or a human brain.

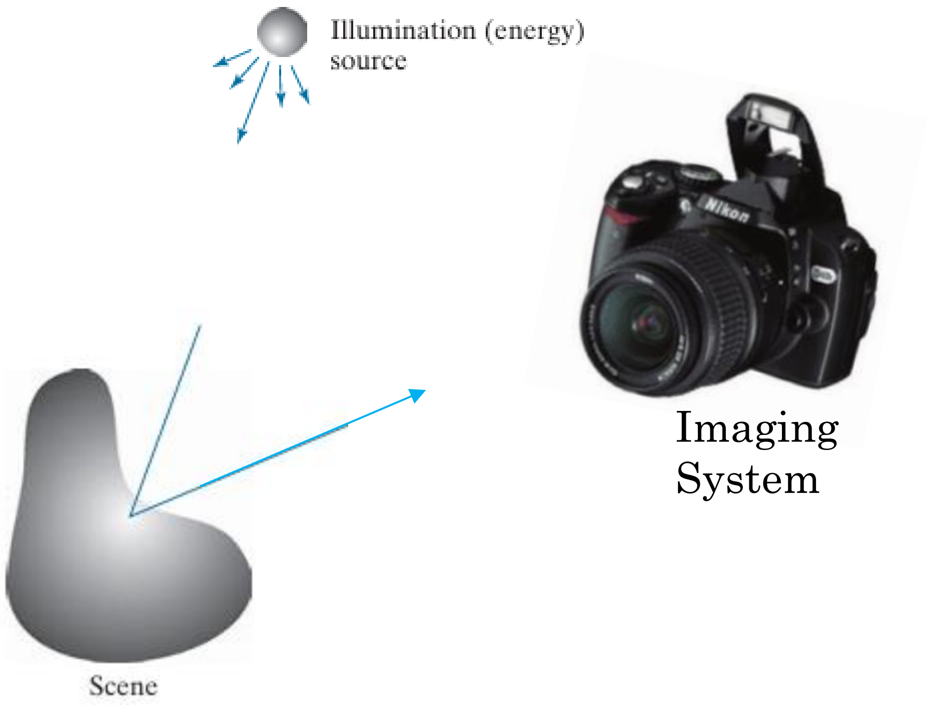


Image Acquisition

- Three principal sensor arrangements used to transform incident energy into digital images.
- Incoming energy is transformed into a voltage by a combination of the input electrical power and sensor material that is responsive to the type of energy being detected.
- The output voltage wave form is the response of the sensor, and a digital quantity is obtained by digitizing that response.
- A familiar sensor of this type is the photodiode.

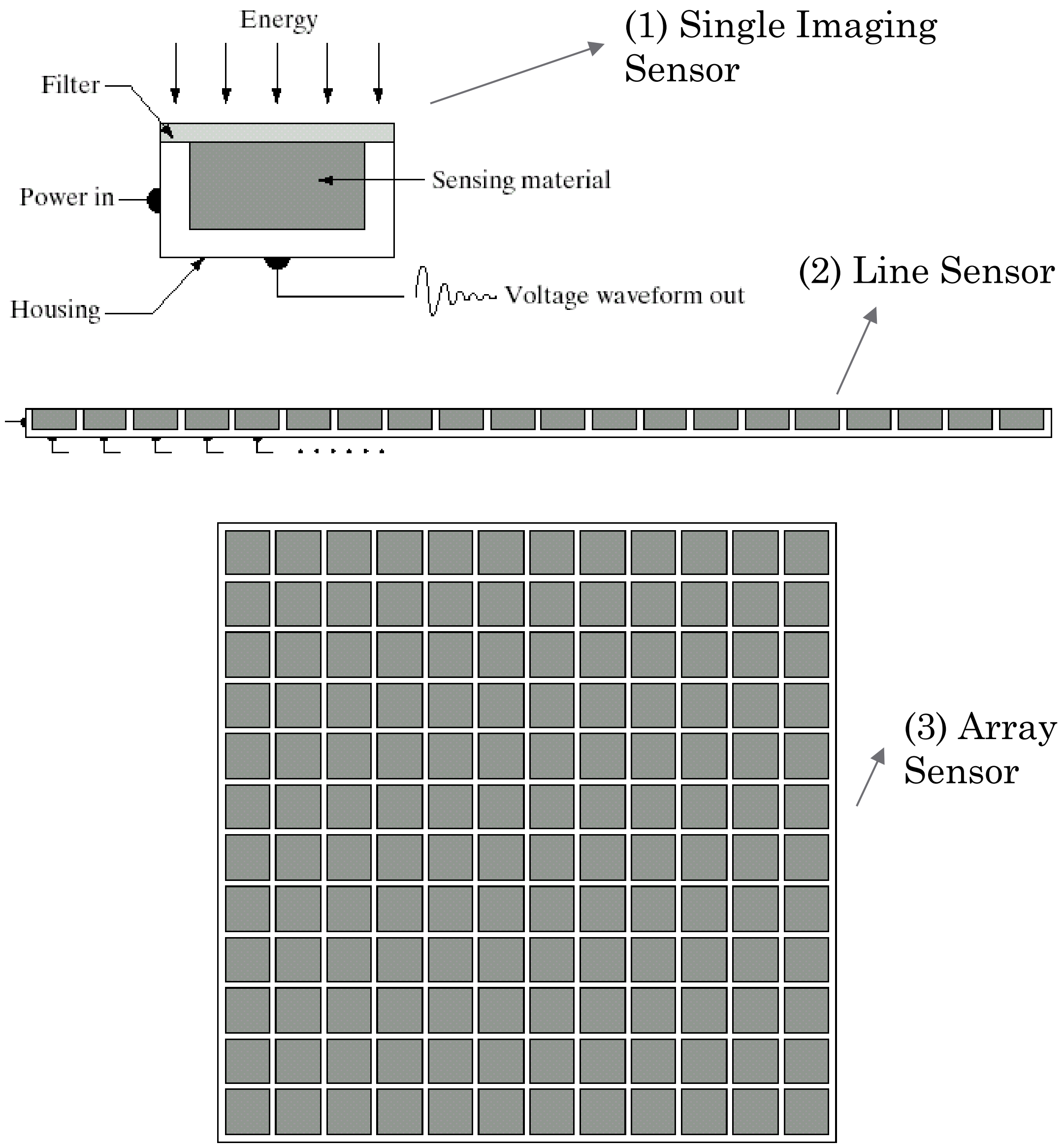
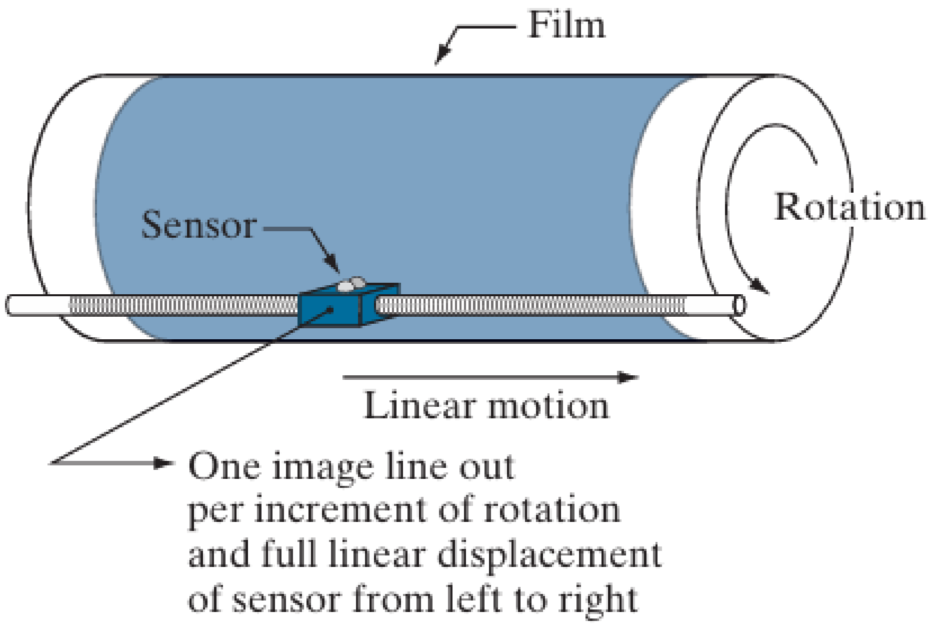


Image Acquisition

Image acquisition using a single sensing element

- An arrangement used in high-precision scanning.
- mechanical rotation of film provides displacement in one dimension.
- The sensor is mounted on a lead screw that provides motion in the perpendicular direction.
- A light source is contained inside the drum.
- As the light passes through the film, its intensity is modified by the film density before it is captured by the sensor.
- This "modulation" of the light intensity causes corresponding variations in the sensor voltage, which are ultimately converted to image intensity levels by digitization.



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

Image Acquisition

Image Acquisition using sensor strips (Line Sensor)

- In-line sensors are used routinely in airborne imaging applications.
- Sensor strips in a ring configuration are used in medical and industrial imaging to obtain cross-sectional ("slice") images of 3-D objects.

Sensing devices with 4000 or more in-line sensors are possible.

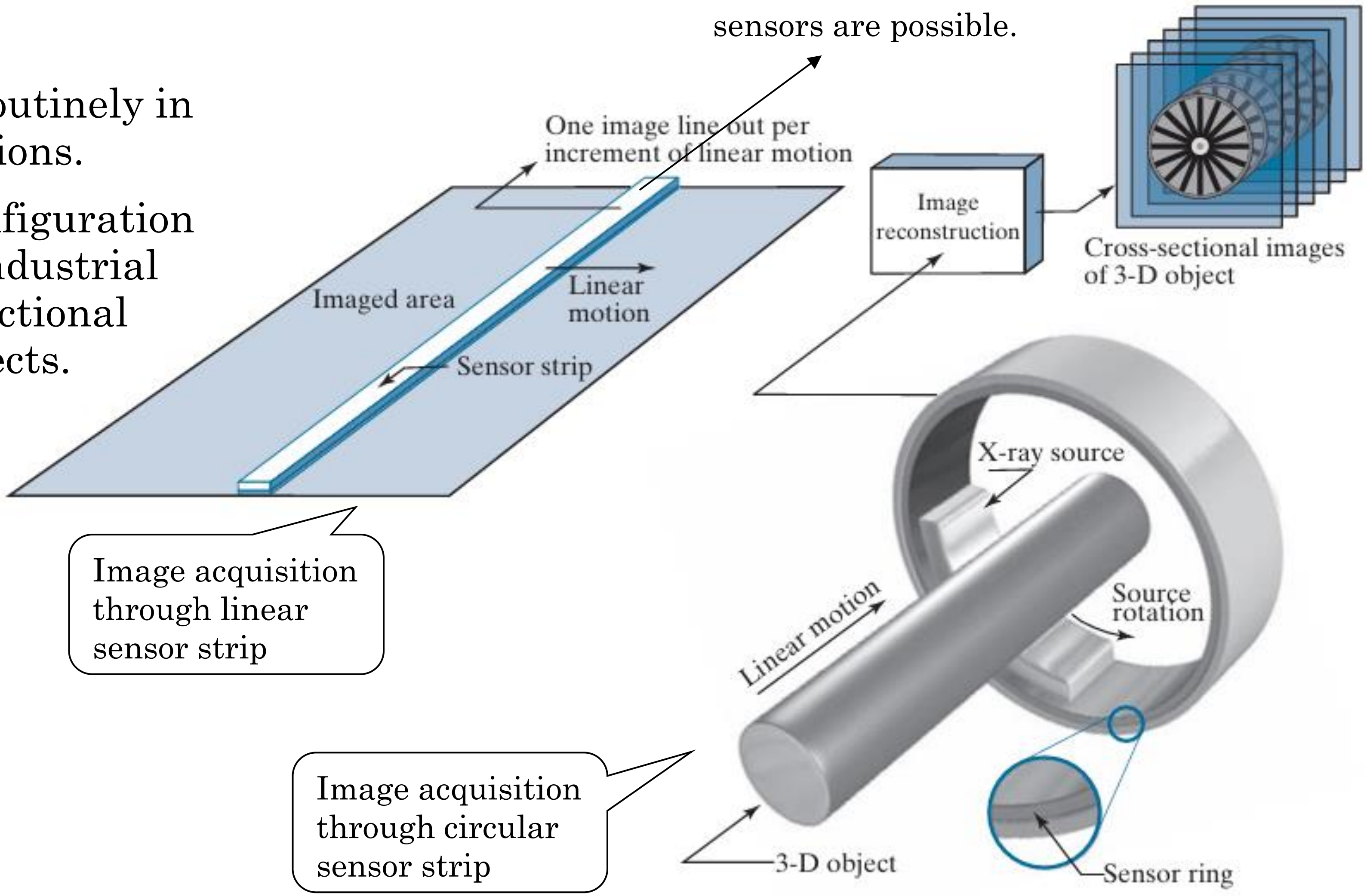


Image acquisition through linear sensor strip

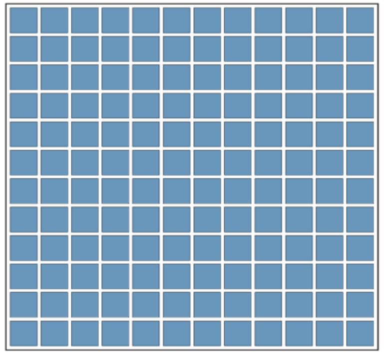
Image acquisition through circular sensor strip

Image Acquisition

Image acquisition using sensor arrays

Application

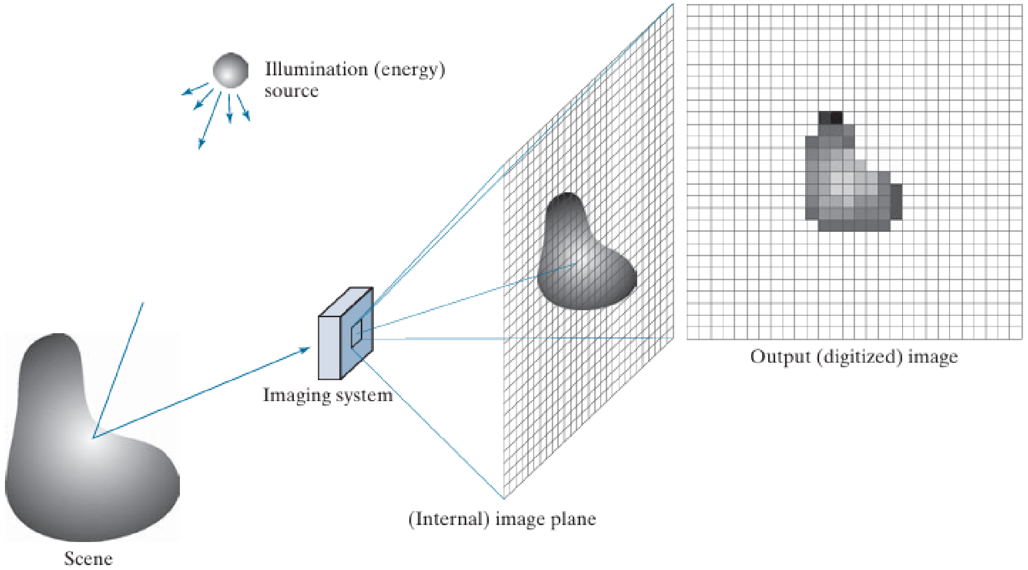
- Electromagnetic and ultrasonic sensing devices
- Digital cameras



Individual sensing elements arranged in the form of a 2-D array.

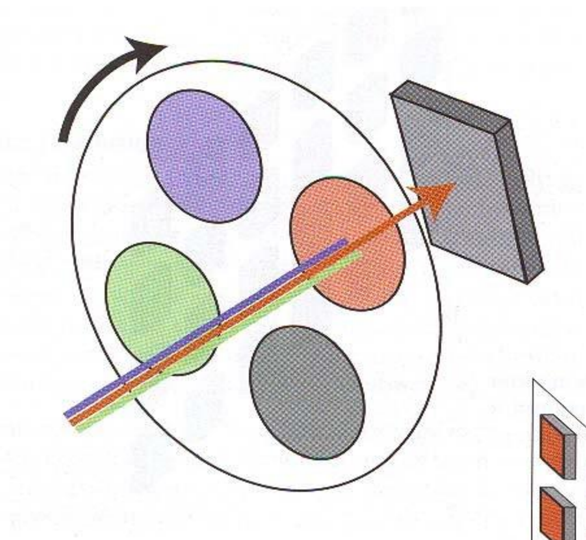
Digital Camera Technologies

- Sensor for these cameras is a CCD (charge-coupled device).
- CCD can be manufactured with a broad range of sensing properties and can be packaged in rugged arrays of 4000x4000 elements or more.
- The response of each sensor is proportional to the integral of the light energy projected onto the surface of the sensor.

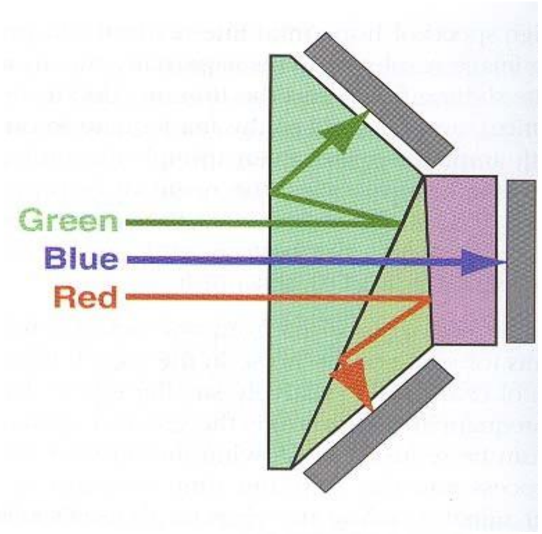


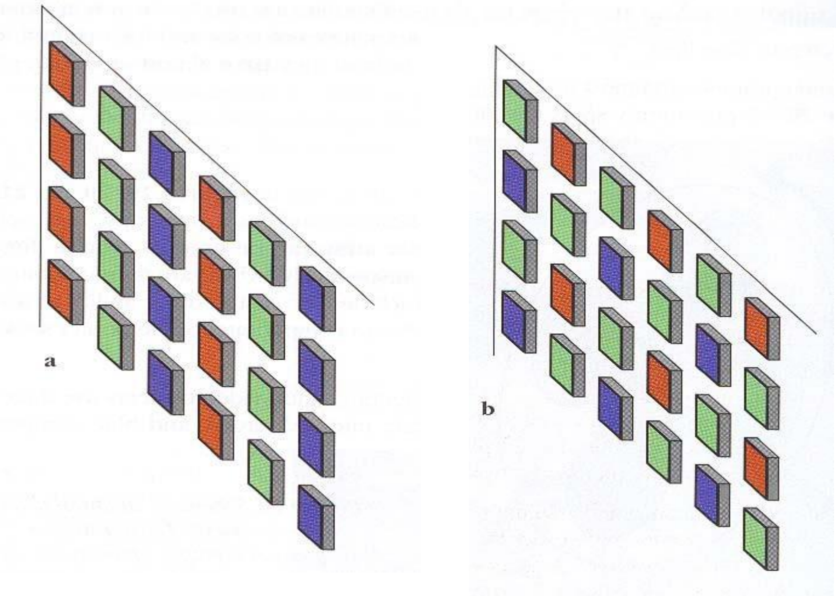
Acquisition of color images

- Single sensor assembly for still scenes



Three sensors with prisms





Sensor arrays

a. Stripe filter pattern
b. Bayers filter pattern

A simple image formation model

***f* (*x*,*y*):** intensity/brightness of the image at spatial coordinates (x , y)

$$f(x,y) = i(x, y)\, r(x, y) \qquad 0 \le f(x, y) < \infty$$

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

Illumination component i(x,y):

- The amount of source illumination incident on the scene.

Reflectance component r(x,y):

- The amount of illumination reflected by the object.

Where

$0< i(x,y)<\infty$: Determined by the light source

$0< r(x,y)<1$: Determined by the characteristics of objects

Image Sampling and Quantization

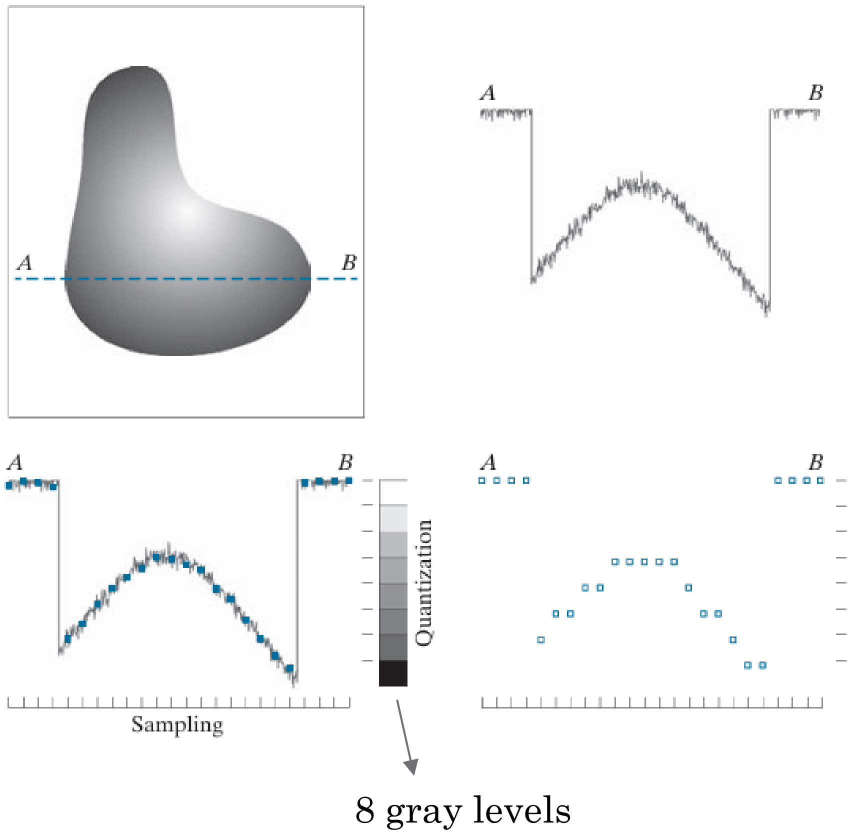
Sampling:

Digitization of the spatial coordinates (x,y)

Quantization:

Digitizing the amplitude values (gray-level quantization

- **8 bit:** $2^8 = 256$ gray levels (0: black, 255: white)
- **Binary (1 bit):** 2 gray levels (0: black, 1: white)



Commonly used number of samples resolution

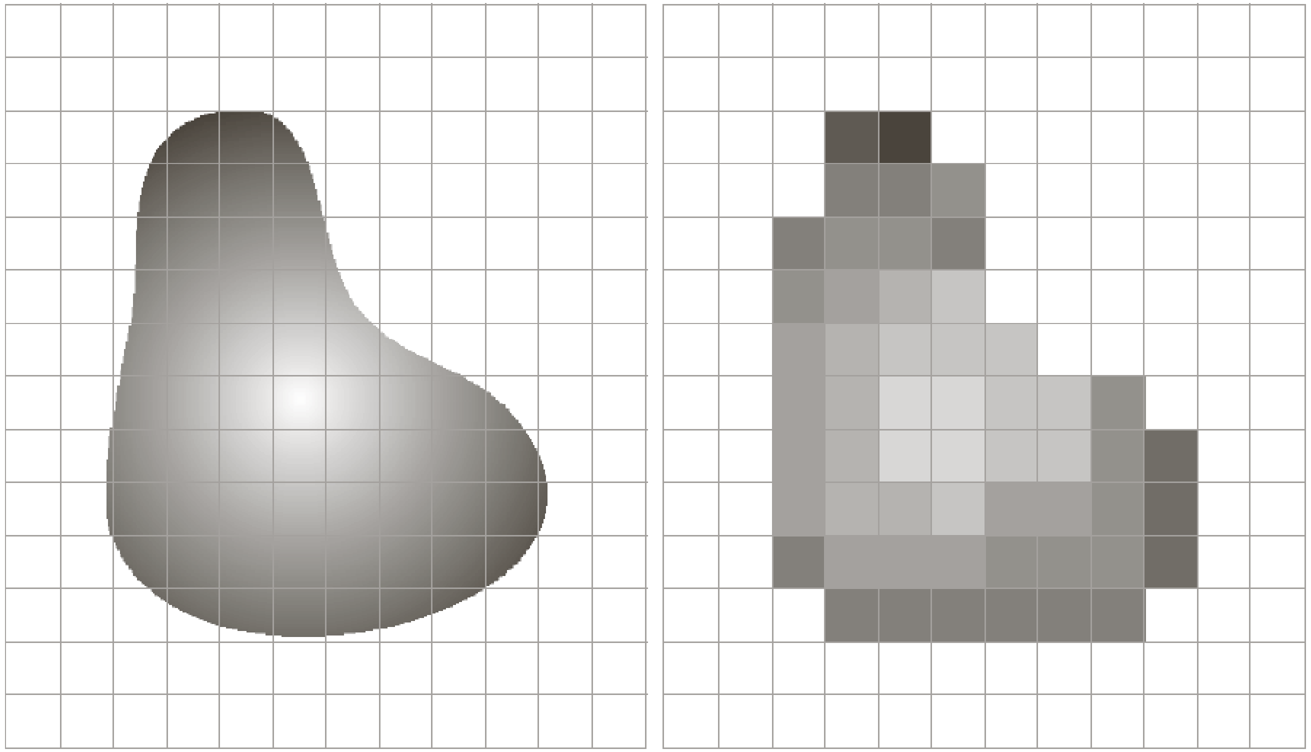
Digital still cameras:

- 640x680, 1024, 1024, up to 4064x2704

Digital video cameras:

- 640x480 at 30 frames/second
- 1920x1080 at 60 frame/second (HDTV)

Image Sampling and Quantization



a b

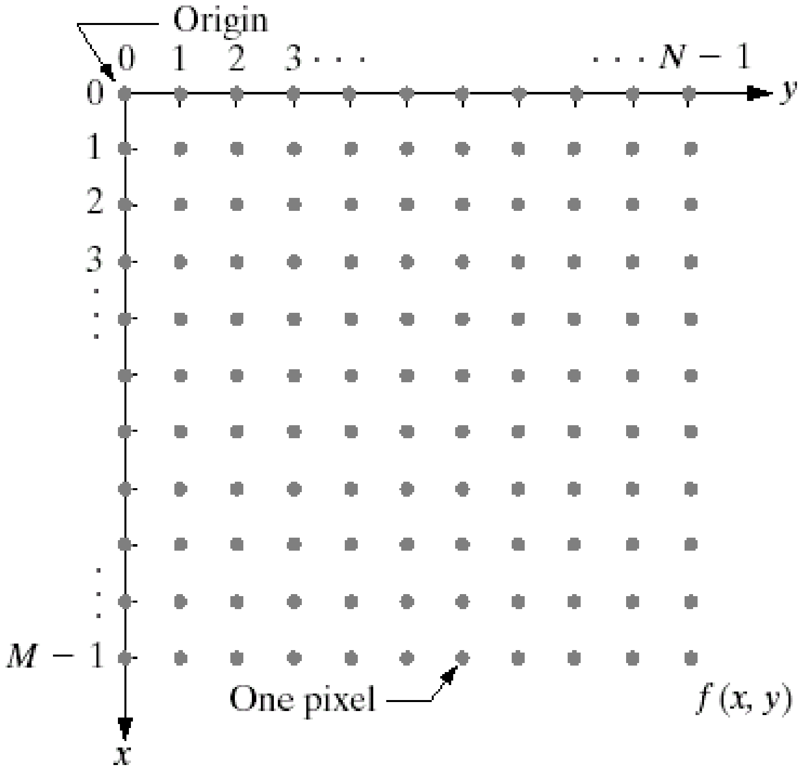
FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Representing Digital Images

- **An M x N digital image is expressed as**

$$
\begin{array}{cc}
 & \xrightarrow{\text{Columns}} \\
f(x,y)= & \begin{bmatrix} f(0,0) & f(0,1) & \dots & f(0,N-1) \\ f(1,0) & f(1,1) & \dots & f(1,N-1) \\ \dots & \dots & \dots & \dots \\ f(M-1,0) & f(M-1,1) & \dots & f(M-1,N-1) \end{bmatrix} \Big\downarrow \text{Rows}
\end{array}
$$

N : No of Columns
M : No of Rows



Representing Digital Image

- **Digital images are 2D arrays (matrices) of numbers:**

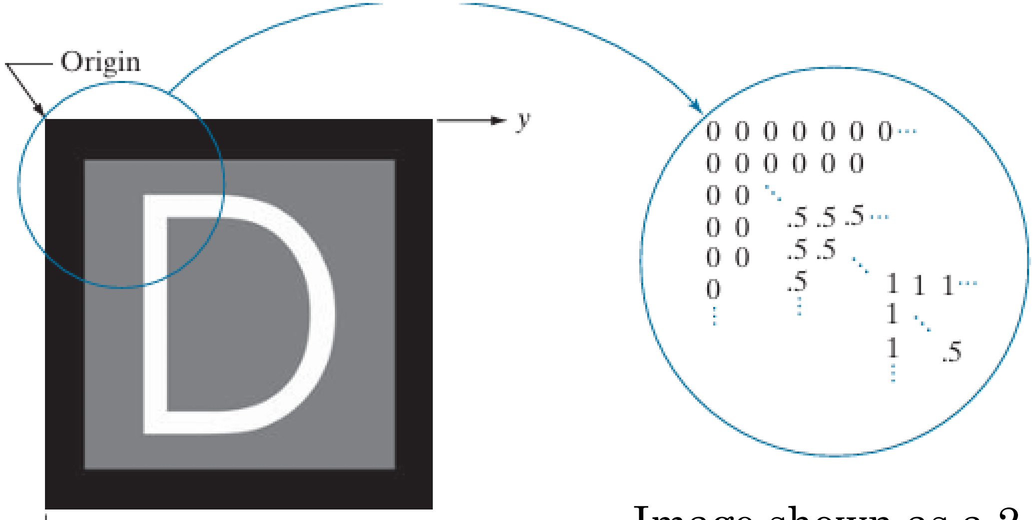
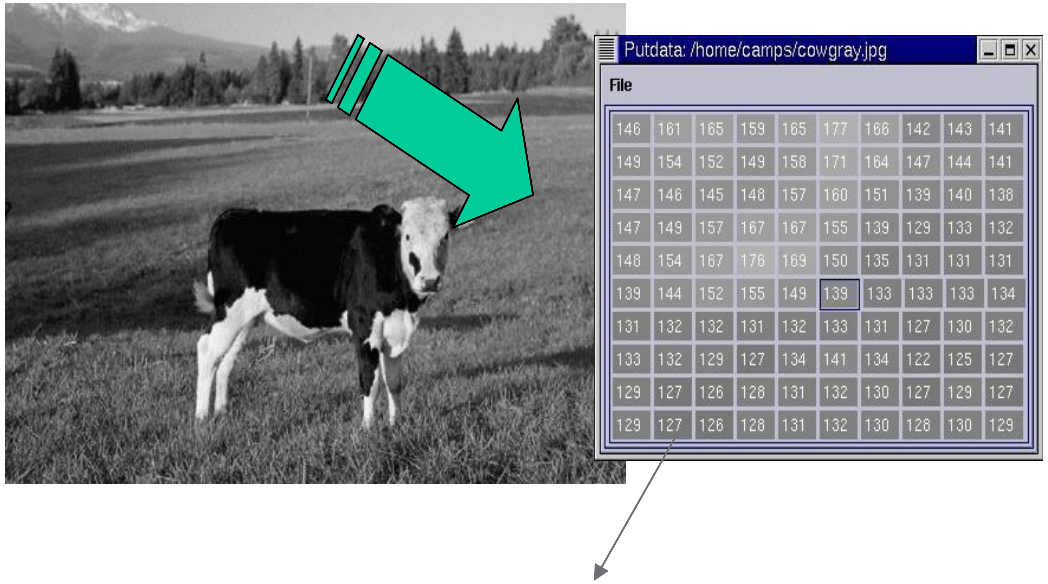


Image displayed as a visual intensity array.

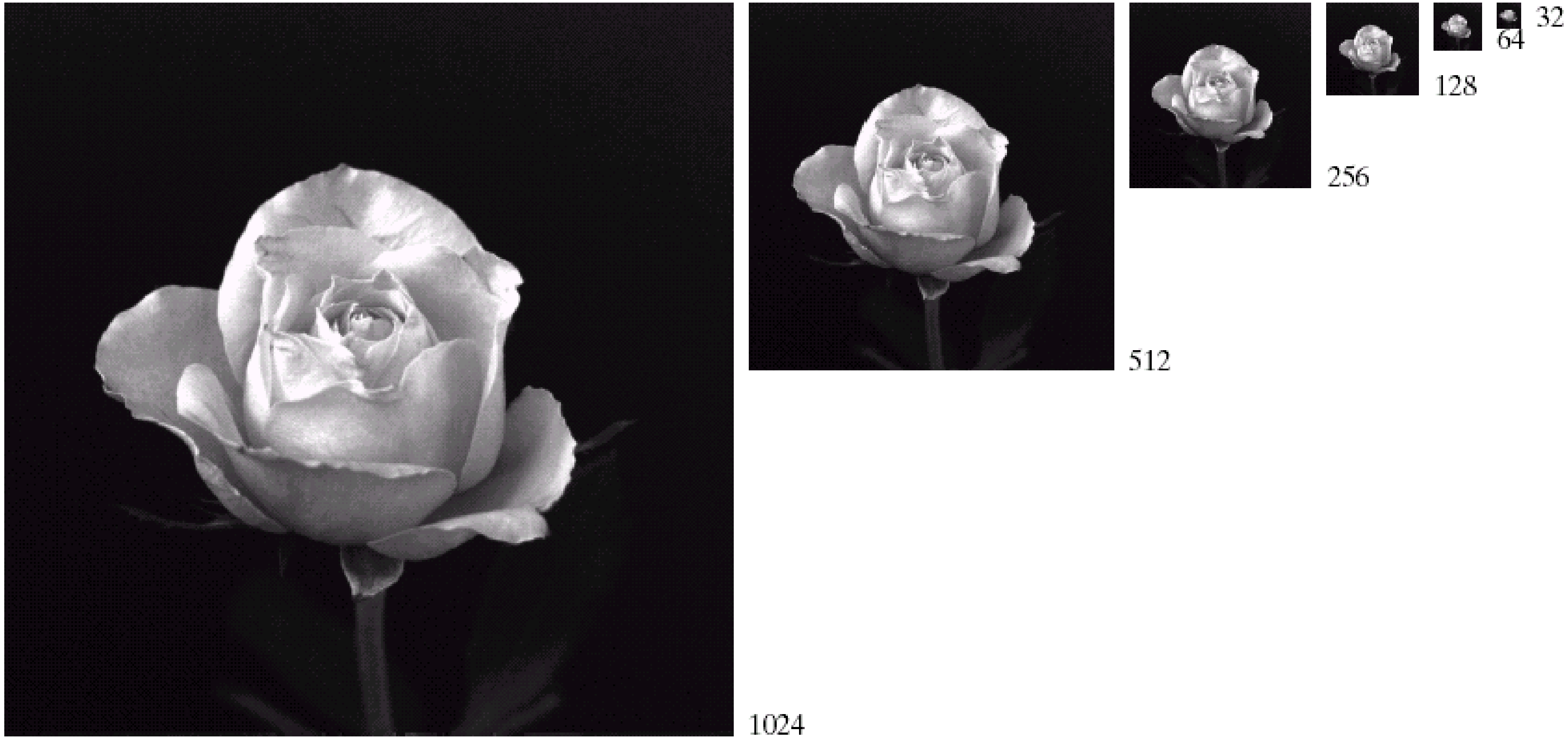
Image shown as a 2-D numerical array.



(127)
Intensity, gray level, pixel value

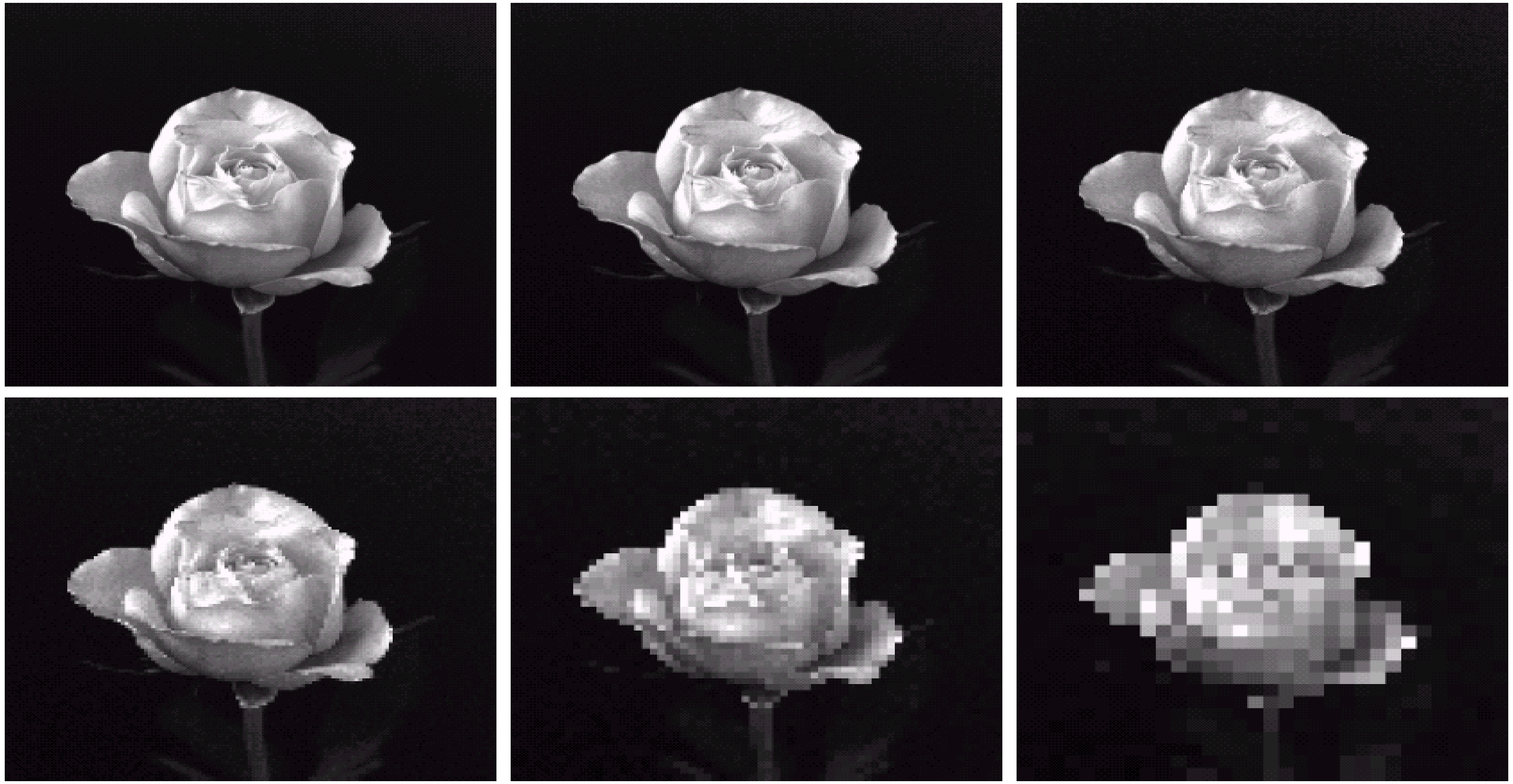
Sampling

- **Reducing the spatial resolution (down sampling)**



Sampling

- Resampling the down sampled images to original form (up sampling)



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.

Effect of Sampling and Quantization

250 x 210 samples
256 gray levels

125 x 105 samples

50 x 42 samples

25 x 21 samples

16 gray levels

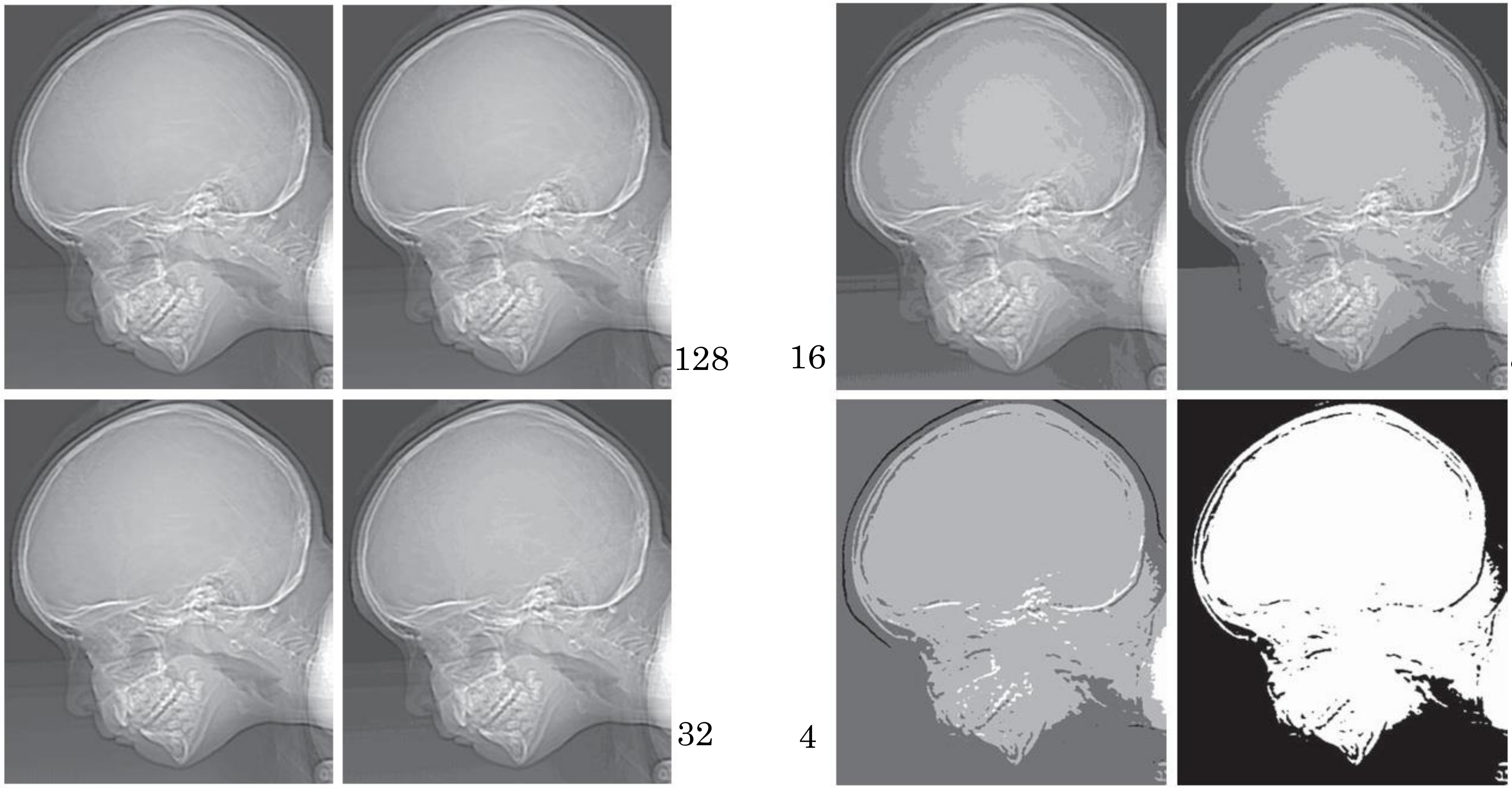
8 gray levels

4 gray levels

Binary image

Effects of Quantization

- **Effects of varying the number of intensity levels in a digital image (intensity resolution)**



RGB (Color) Images

Red + Blue + Green

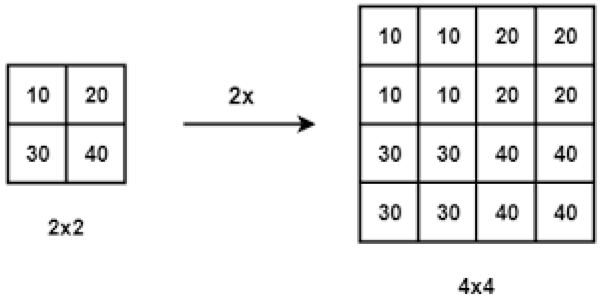
Red

Green

Blue

Image Interpolation

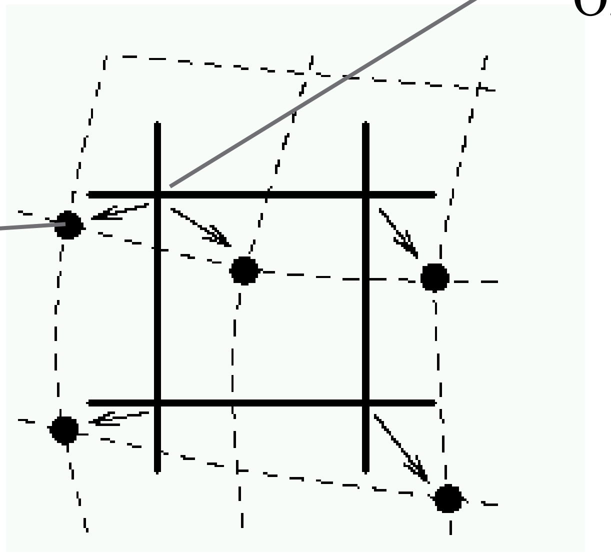
- Process of using known data to estimate unknown values
- Used in tasks such as zooming, shrinking, rotating, and geometrically correcting digital images.



Nearest Neighbor Interpolation

- Assigns to each new location the intensity of its nearest neighbor in the original image

$f(x_1, y_1)$
Original Image



New image
$f_1(x_2,y_1) = f(\text{round}(x_2), \text{round}(y_1))$
$f_1(x_2,y_1) = f(x_1,y_1)$

Image Interpolation

Bilinear Interpolation

- Use the four nearest neighbors to estimate the intensity at a given location.

$$
\begin{aligned}
f_2(x,y) = {} & (1-a)*(1-b)*f(l,k) \\
& +a*(1-b)*f(l+1,k) \\
& +(1-a)*b*f(l,k+1) \\
& +a*b*f(l+1,k+1)
\end{aligned}
$$

$$
l = floor(x), \qquad k = floor(y)
$$
$$
a = x - l, \qquad b = y - k
$$

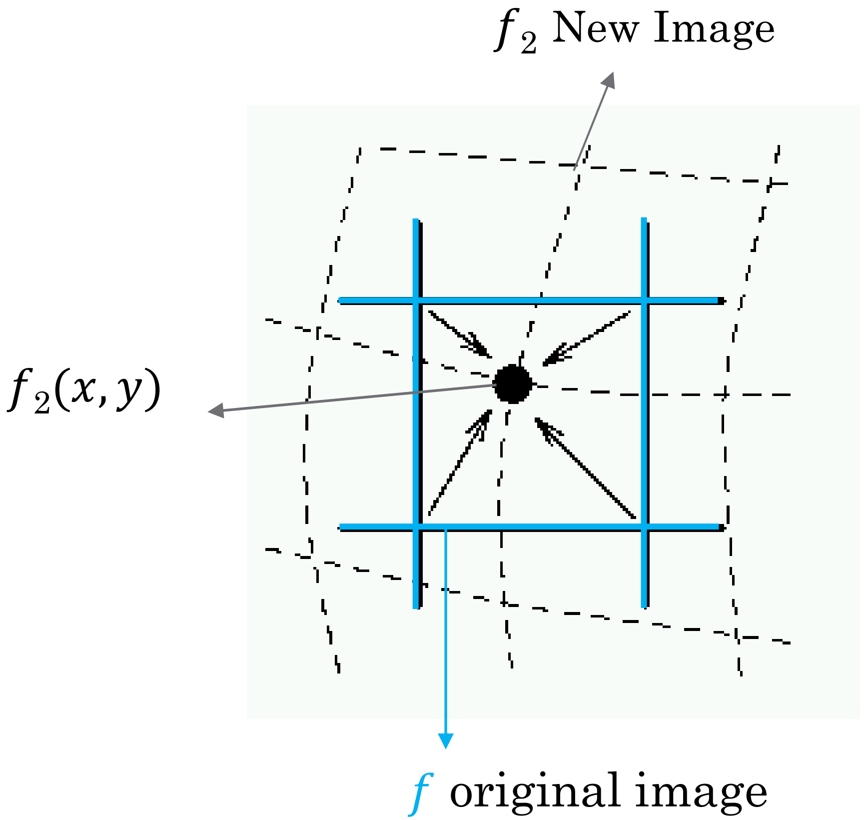
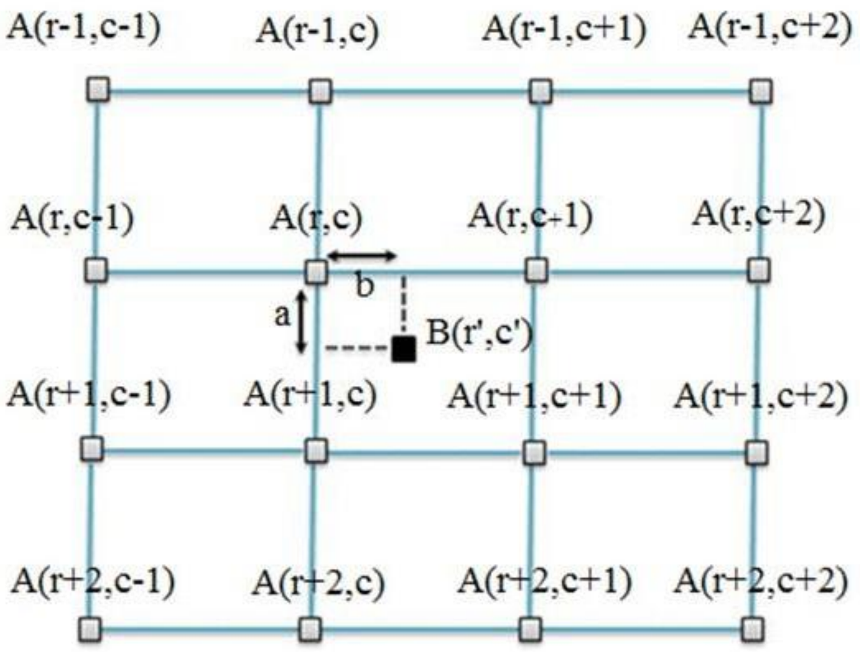


Image Interpolation

Bicubic Interpolation

- Bicubic interpolation involves the sixteen nearest neighbors of a point.
- Generally, does a better job of preserving fine detail than its bilinear counterpart.
- Used in commercial image editing applications, such as Adobe Photoshop and Corel Photopaint.



Basic relationship between pixels

Neighborhood

Neighbors of a pixel p at coordinates (x,y)

- **4-neighbors of p**, denoted by $\mathbf{N_4(p)}$:

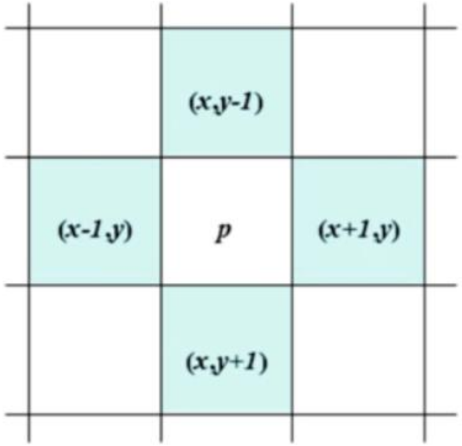
  (x-1, y), (x+1, y), (x,y-1), and (x, y+1).

- **4 diagonal neighbors of p**, denoted by $\mathbf{N_D(p)}$:

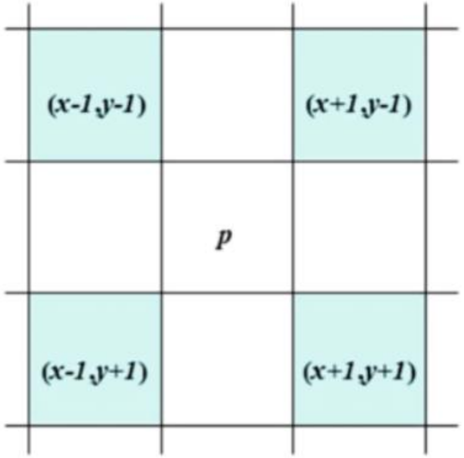
  (x-1, y-1), (x+1, y+1), (x+1,y-1), and (x-1, y+1).

- **8 neighbors of p**, denoted $\mathbf{N_8(p)}$

  $N_8(p) = N_4(p) \cup N_D(p)$

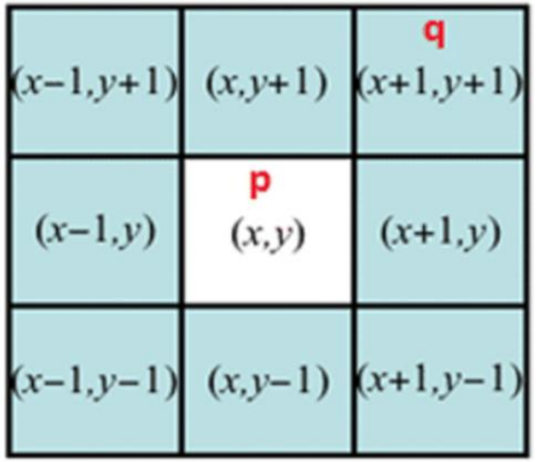


$N_4(p)$



$N_D(p)$

$N_8(p)$



Basic relationship between pixels

Adjacency

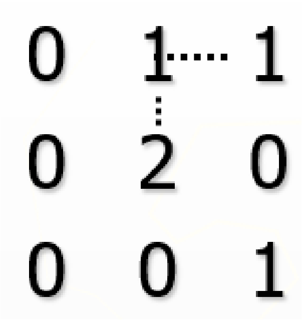
Let V be the set of intensity values

- **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 m-adjacent if

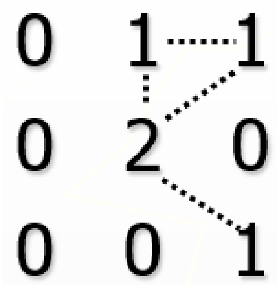
i. q is in the set $N_4(p)$, or

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

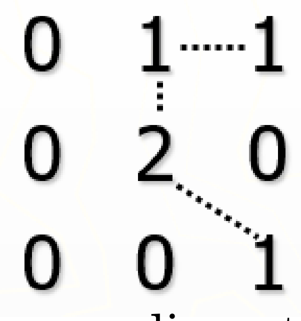
$V = \{1, 2\}$



4-adjacent



8-adjacent



m-adjacent

Basic relationship between pixels

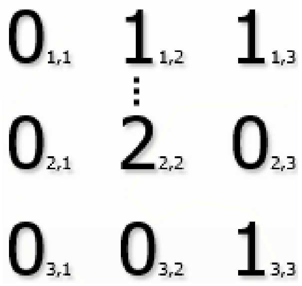
Path

A (digital) path (or curve) from pixel p with coordinates (x_0, y_0) to pixel q with coordinates (x_n, y_n) is a sequence of distinct pixels with coordinates

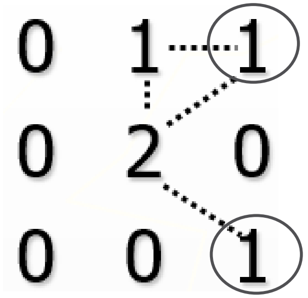
$$(x_0, y_0), (x_1, y_1), \ldots, (x_n, y_n)$$

- Where (x_i, y_i) and (x_{i-1}, y_{i-1}) are adjacent for $1 \leq i \leq n$.
- Here n is the *length* of the path.
- If $(x_0, y_0) = (x_n, y_n)$, the path is ***closed*** path.
- We can define 4-, 8-, and m-paths based on the type of adjacency used.

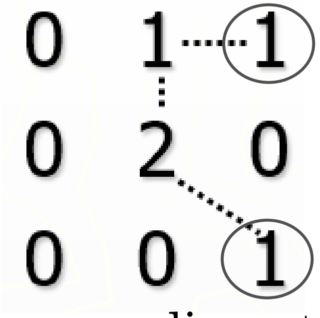
V = {1, 2}



4-adjacent



8-adjacent



m-adjacent

The 8-path from (1,3) to (3,3):
(i) (1,3), (1,2), (2,2), (3,3)
(ii) (1,3), (2,2), (3,3)

The m-path from (1,3) to (3,3):
(1,3), (1,2), (2,2), (3,3)

Basic relationship between pixels

Connectivity between pixels:

- An important concept used in establishing boundaries of objects and components of regions

Two pixels p and q are connected if

- They are adjacent in some sense
- Both pixels **p** and **q** have values in the same set **V**

V: Set of gray level values used to define the criterion of similarity

4-connectivity: If gray-level p , q $\in V$, and q is 4-adjacent

8-connectivity: If gray-level p , q $\in V$, and q is 8-adjacent

m-connectivity: Gray-level p , q $\in V$, and q is m-adjacent

V = {1}

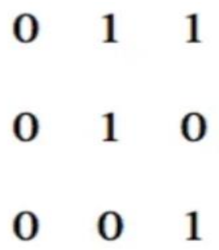


Fig: An arrangement of pixels

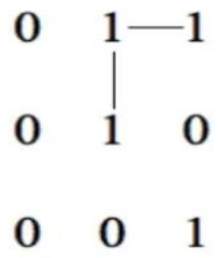


Fig: 4-connectivity of pixels

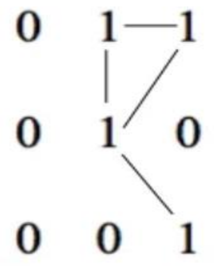


Fig: 8-connectivity of pixels

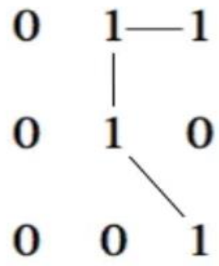


Fig: m-connectivity of pixels

Basic relationship between pixels

Regions

- A set of pixels in an image where all component pixels are connected

Boundary of a region

- A set of pixels of a region R that have one of more neighbors that are not in R

Distance Measures

Given coordinates of pixels p, q, and z: (x,y), (s,t), and (u,v)

Euclidean distance between p and q:

- $D_e(p,q) = \sqrt{(x-s)^2 + (y-t)^2}$

- *The pixels with D_e distance $\leq r$ from (x,y) define a disk of radius* r *centered at* (x,y)

	2.2	2	2.2	
2.2	1.4	1	1.4	2.2
2	1	0	1	2
2.2	1.4	1	1.4	2.2
	2.2	2	2.2	

City-block distance between p and q:

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

- *The pixels with D_4 distance $\leq r$ from (x,y) form a diamond centered at (x,y)*
- *the pixels with D_4=1 are the 4-neighbors of (x,y)*

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

Chessboard distance between p and q:

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

- *The pixels with D_4 distance $\leq r$ from (x,y) form a square centered at (x,y)*
- *The pixels with D_4=1 are the 8-neighbors of (x,y)*

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

Thank You