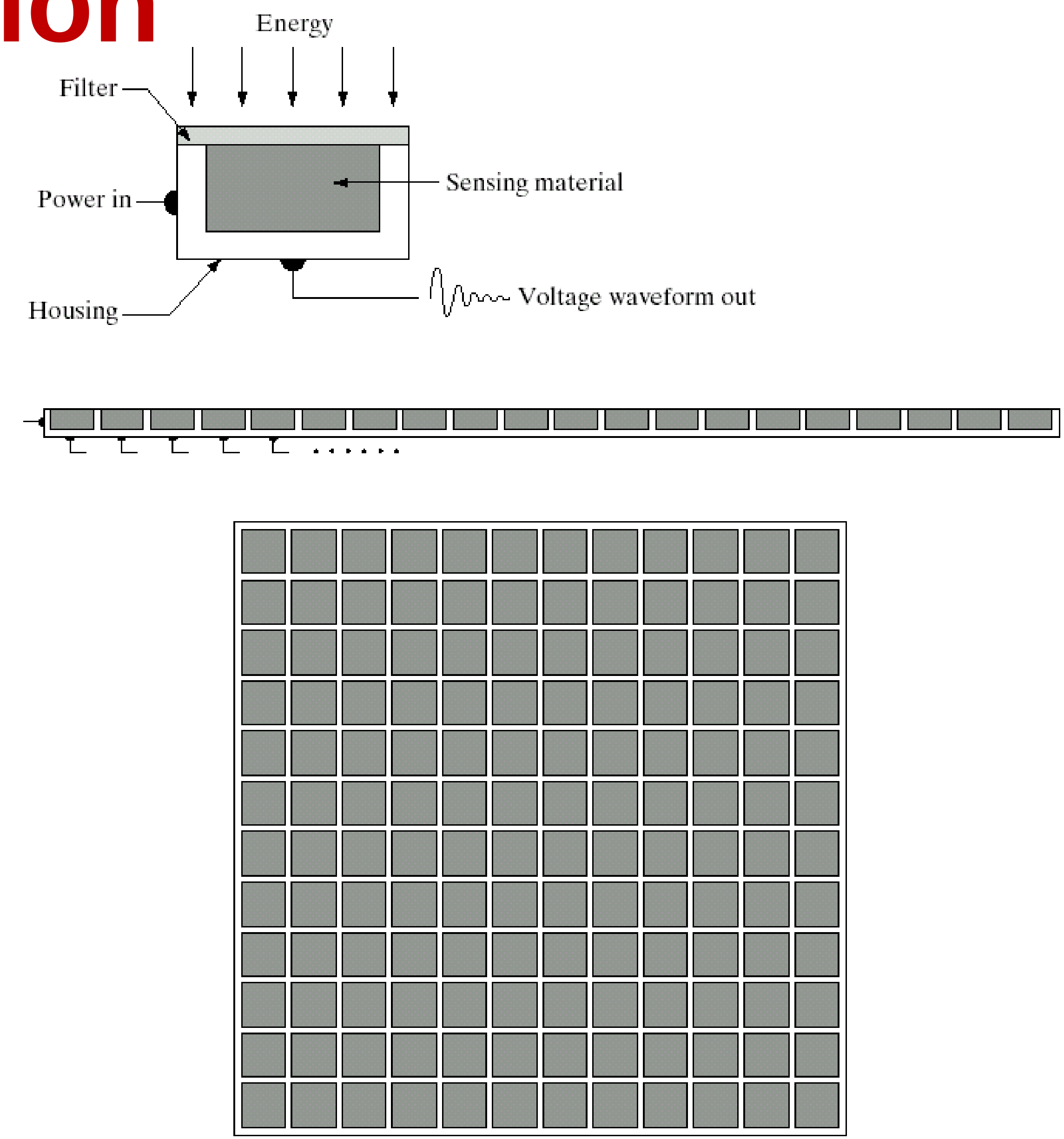
Digital Image Processing

Contents

Light and EM spectrum

- Monochromatic light
  - **Intensity** is the only attribute, from black to white
  - Monochromatic images are referred to as **gray-scale** images
- Chromatic light bands: 0.43 to 0.79 um
  - The quality of a chromatic light source:
    - **Radiance (W)**
    - **Luminance (lm)**
    - **Brightness**

Acquisition



a
b
c

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

Acquisition

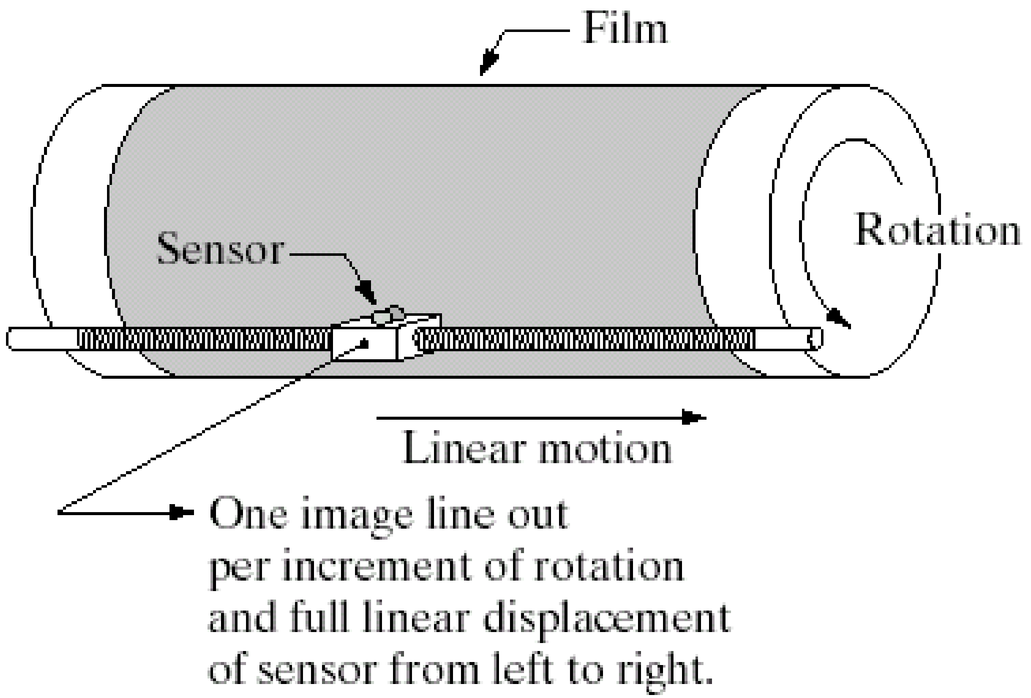


FIGURE 2.13 Combining a single sensor with motion to generate a 2-D image.

Acquisition

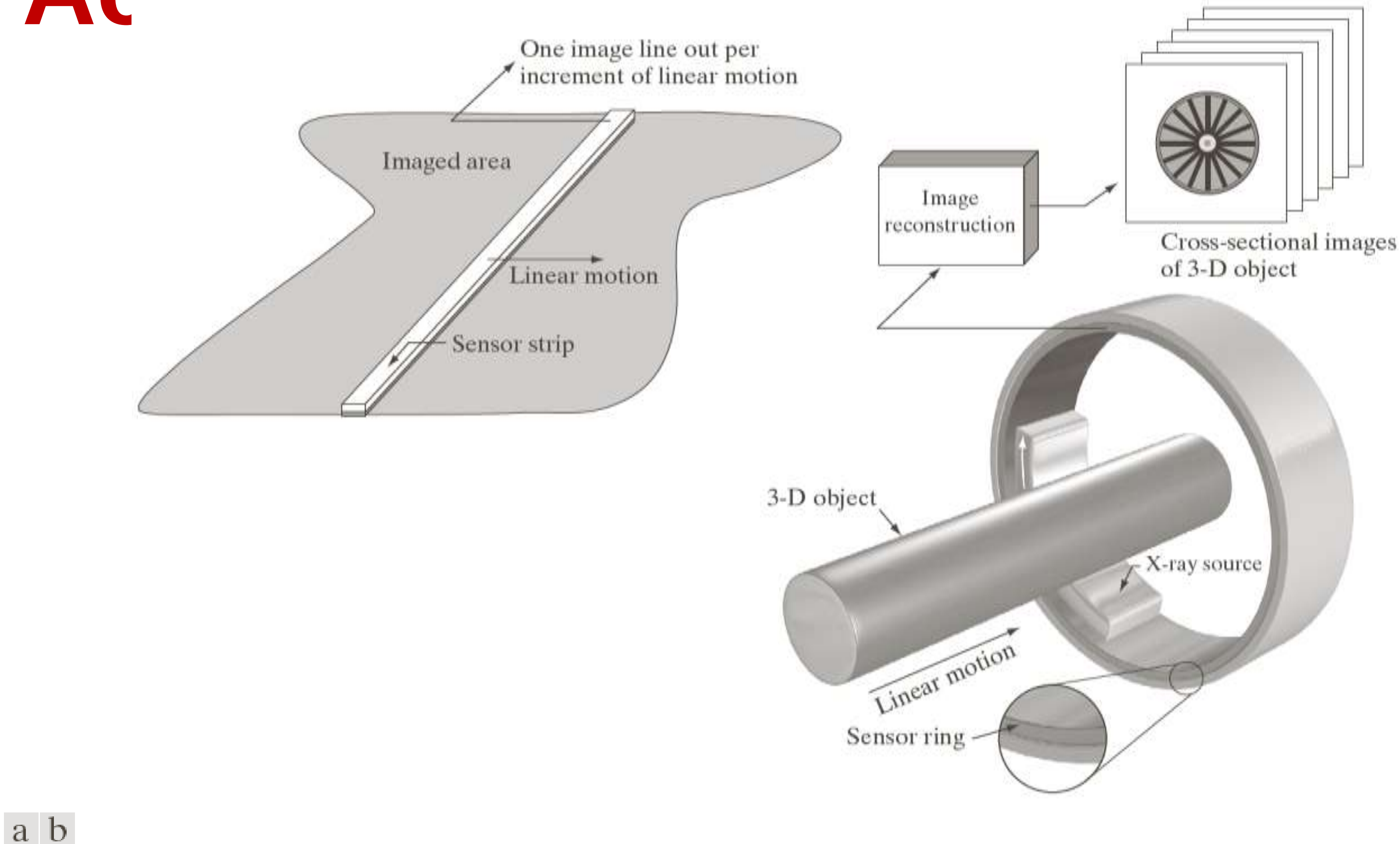


FIGURE 2.14 (a) Image acquisition using a linear sensor strip. (b) Image acquisition using a circular sensor strip.

Acquisition

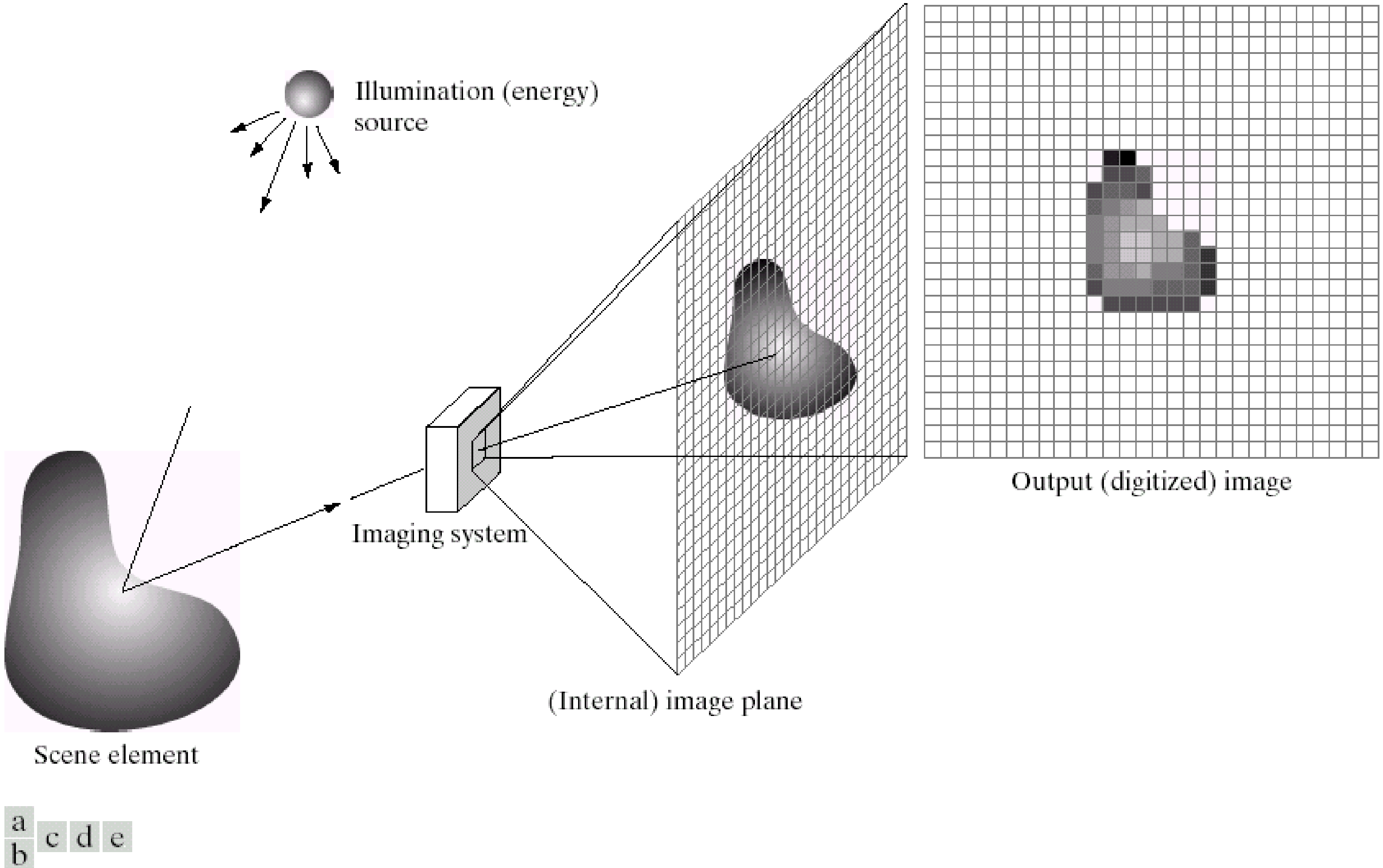


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

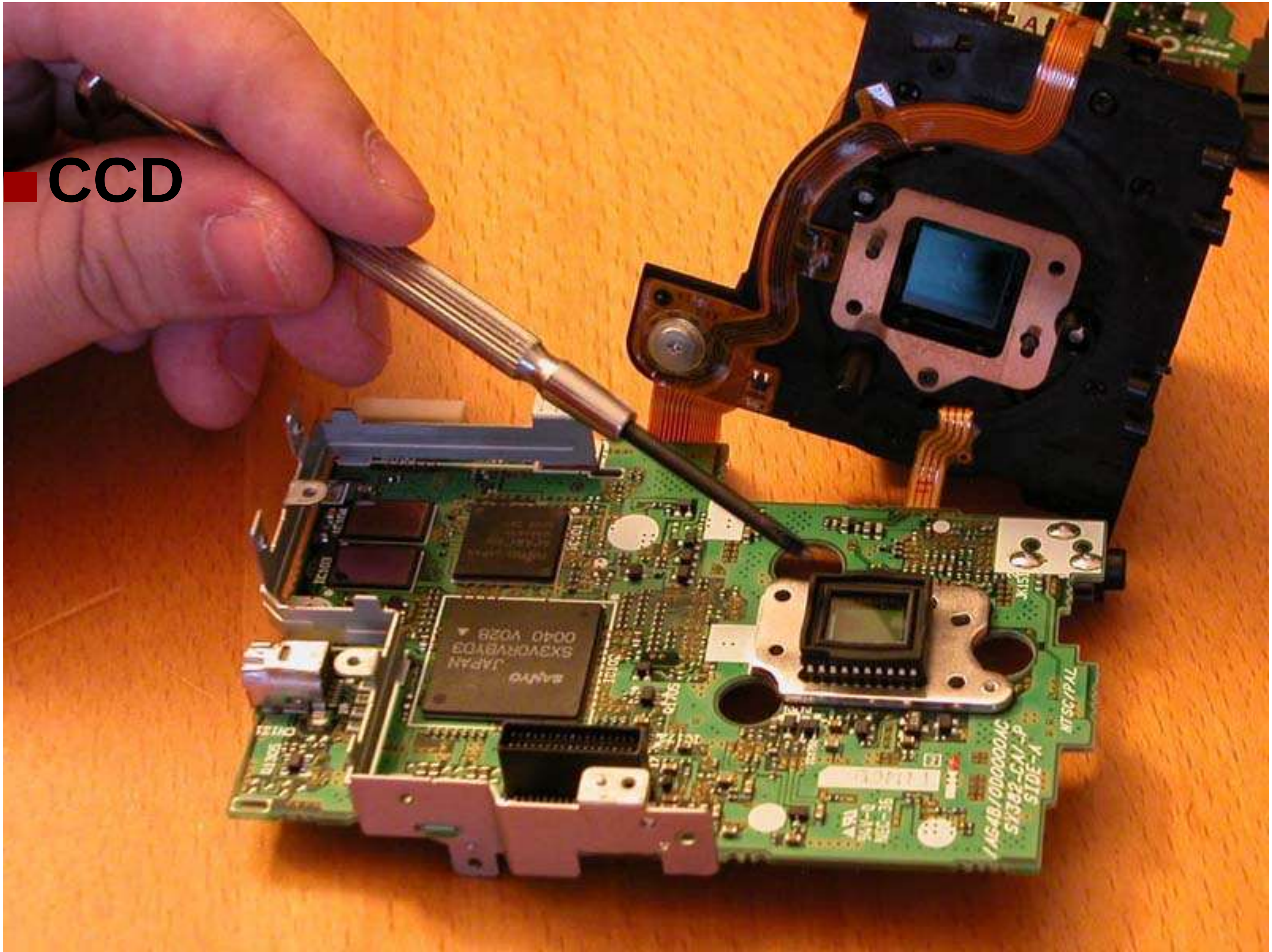
Acquisition using Sensor Arrays

- **CCD Array (Charge Couple Devices)**
  - **Use in digital cameras**

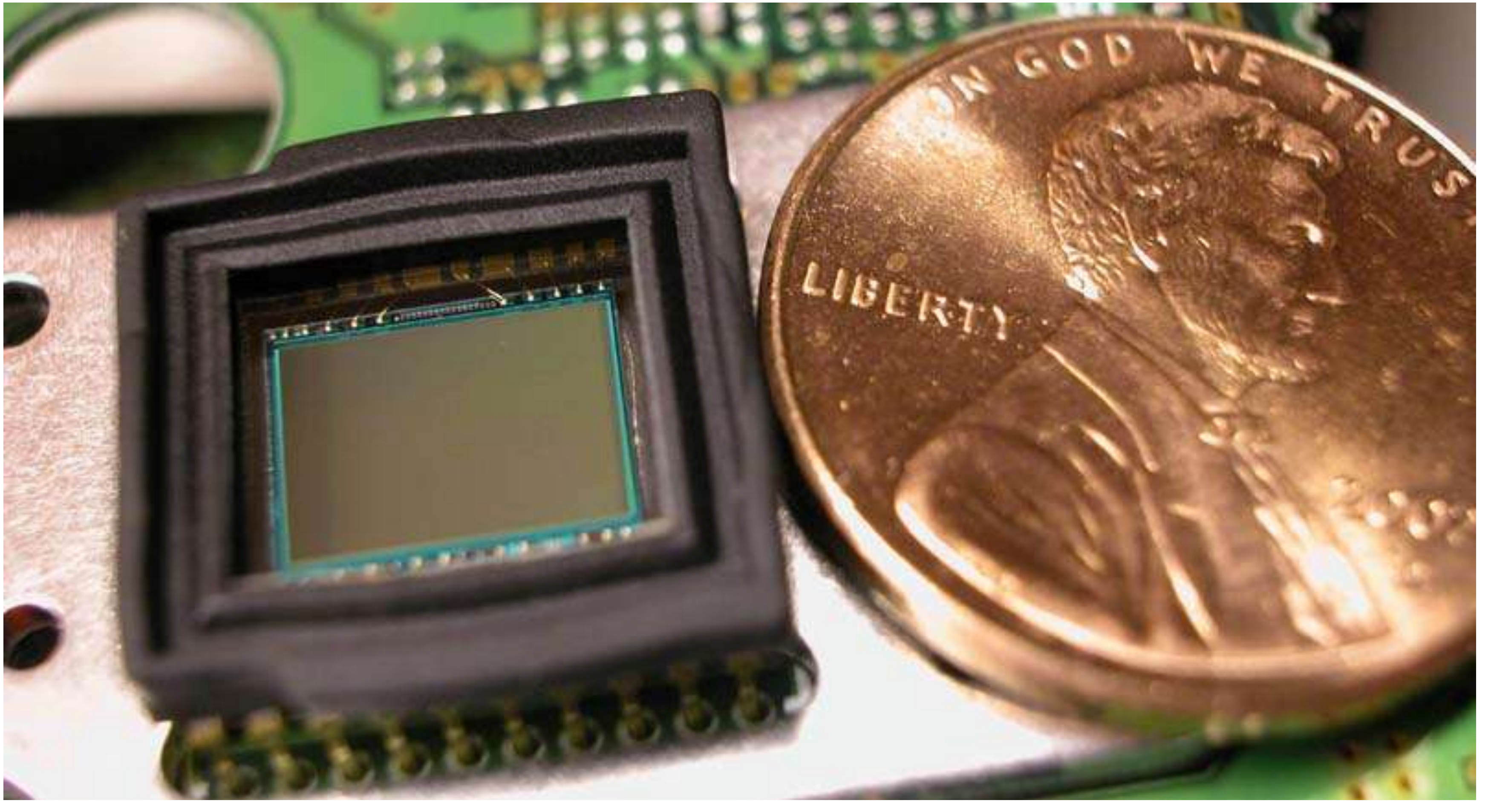
  - Can be packaged in rugged arrays of 4000x4000

- **CCD**

CCD



CCD: 3.2 million pixels !



A Simple Image Formation Model

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

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

where

$$0 < i(x, y) < \infty$$

and

$$0 < r(x, y) < 1$$

$f(x, y)$: intensity at the point (x, y)

$i(x, y)$: illumination at the point (x, y)

(the amount of source illumination incident on the scene)

$r(x, y)$: reflectance/transmissivity at the point (x, y)

(the amount of illumination reflected/transmitted by the object)

Some Typical Ranges of illumination

- Illumination

  Lumen — A unit of light flow or luminous flux

  Lumen per square meter (lm/m^2) — The metric unit of measure for illuminance of a surface

  - On a clear day, the sun may produce in excess of 90,000 lm/m^2 of illumination on the surface of the Earth
  - On a cloudy day, the sun may produce less than 10,000 lm/m^2 of illumination on the surface of the Earth
  - On a clear evening, the moon yields about 0.1 lm/m^2 of illumination
  - The typical illumination level in a commercial office is about 1000 lm/m^2

Some Typical Ranges of Reflectance

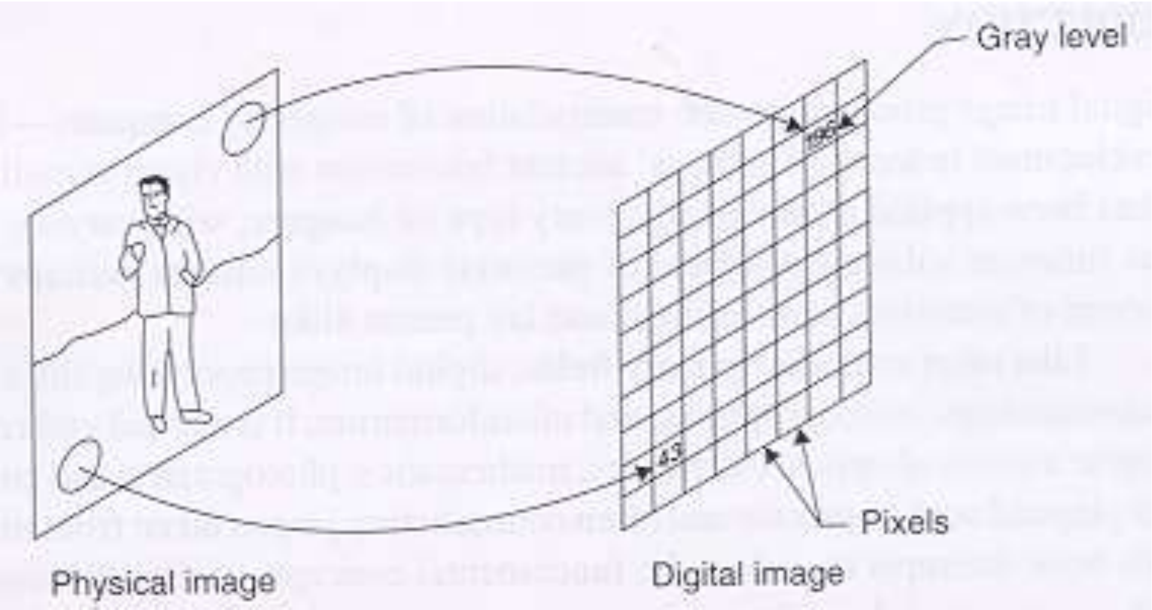
- Reflectance
  - 0.01 for black velvet
  - 0.65 for stainless steel
  - 0.80 for flat-white wall paint
  - 0.90 for silver-plated metal
  - 0.93 for snow

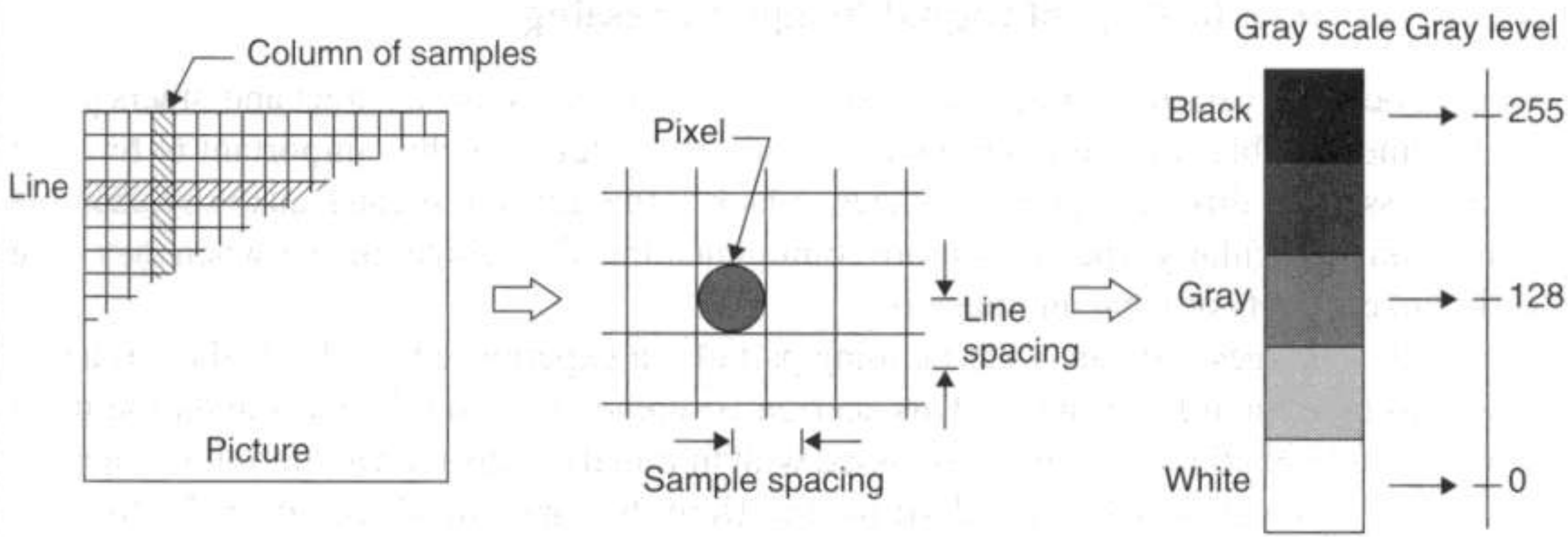
Digital vs. Analog Images

- **Analog:**
  - **Function $v = f(x,y)$: v,x,y are REAL**

- **Digital:**
  - **Function $v = f(x,y)$: v,x,y are INTEGER**

- **Sampling** means measuring the value of an image at a finite number of points.
- **Quantization** is the representation of the measured value at the sampled point by an integer.




Column of samples
Line
Picture
Pixel
Line spacing
Sample spacing
Gray scale Gray level
Black
Gray
White
255
128
0

Stepping down from REALity to INTEGER coordinates x,y: Sampling

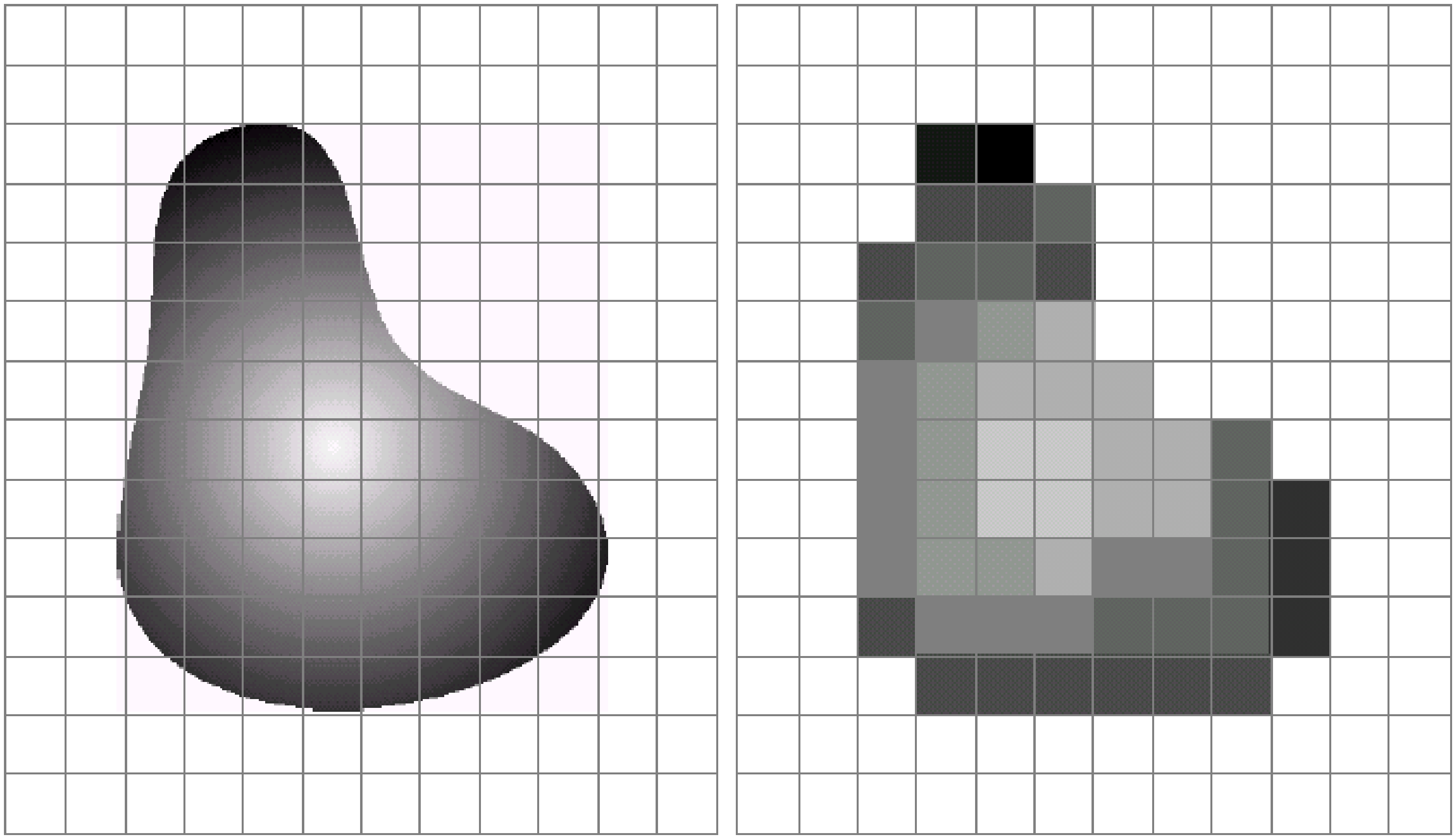
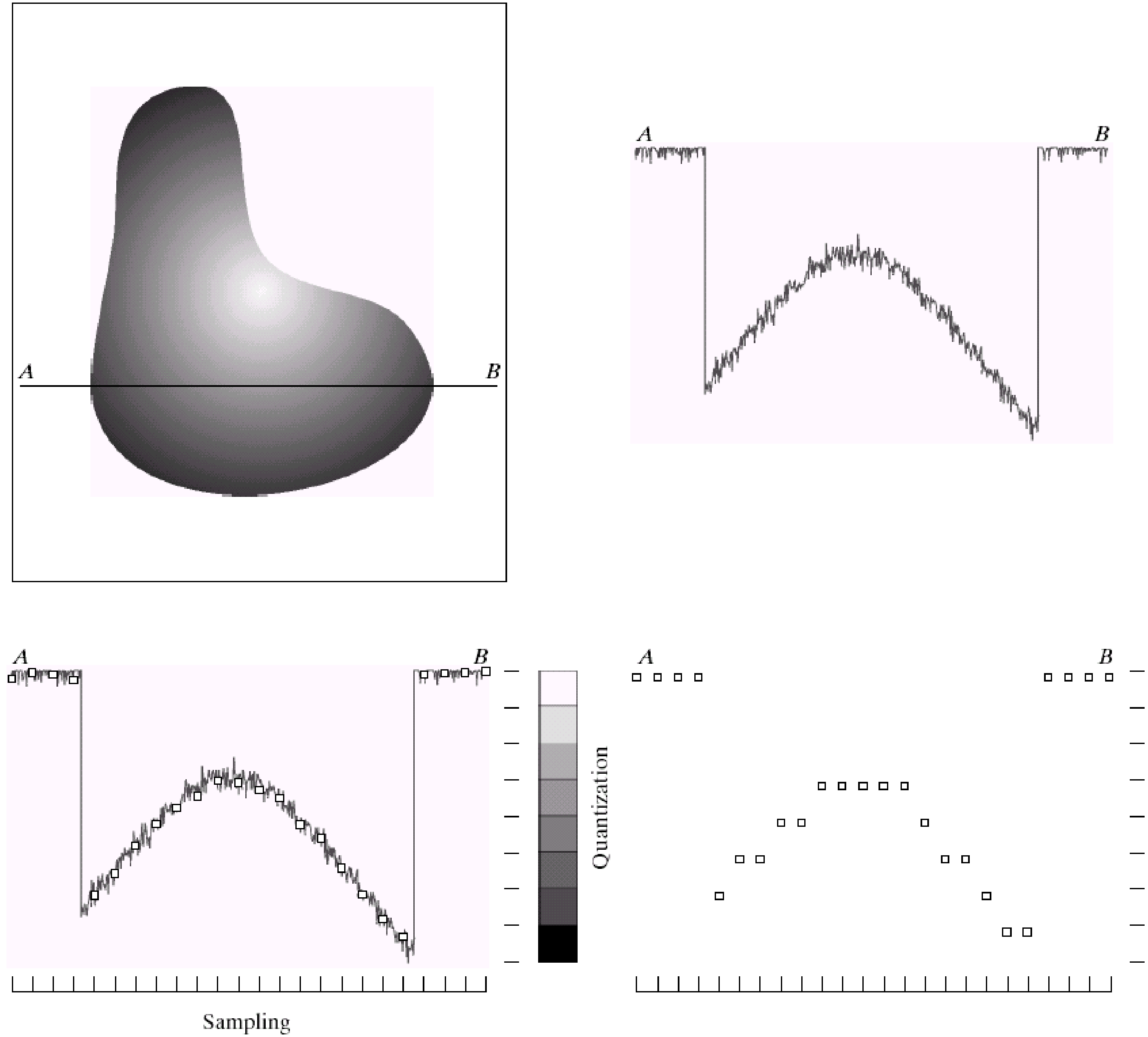


FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

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.

Image quantization(example)

- 256 gray levels (8bits/pixel)

32 gray levels (5 bits/pixel)

16 gray levels (4 bits/pixel)

- 8 gray levels (3 bits/pixel)

4 gray levels (2 bits/pixel)

2 gray levels (1 bit/pixel)

Image sampling (example)

original image

sampled by a factor of 2

sampled by a factor of 4

sampled by a factor of 8

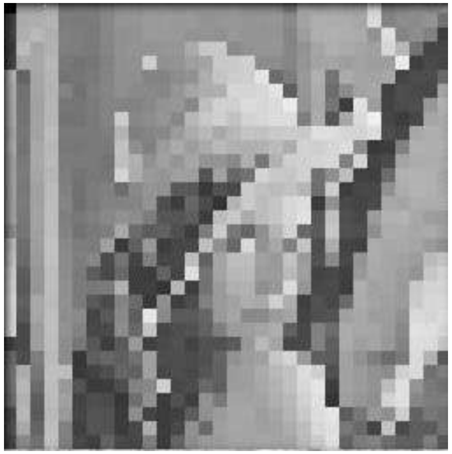
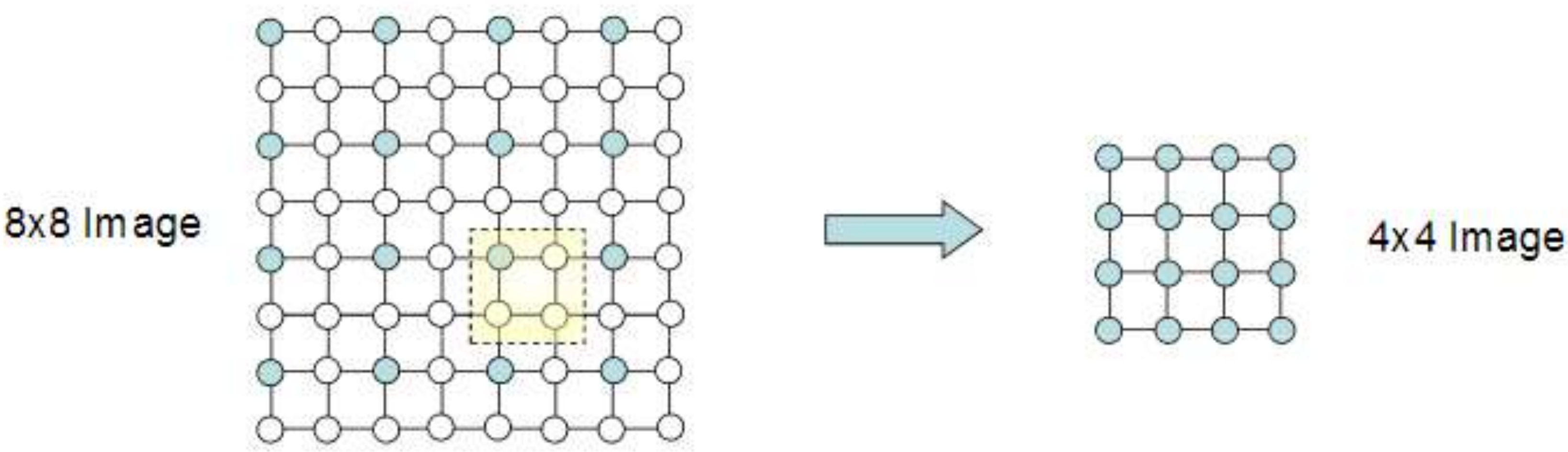
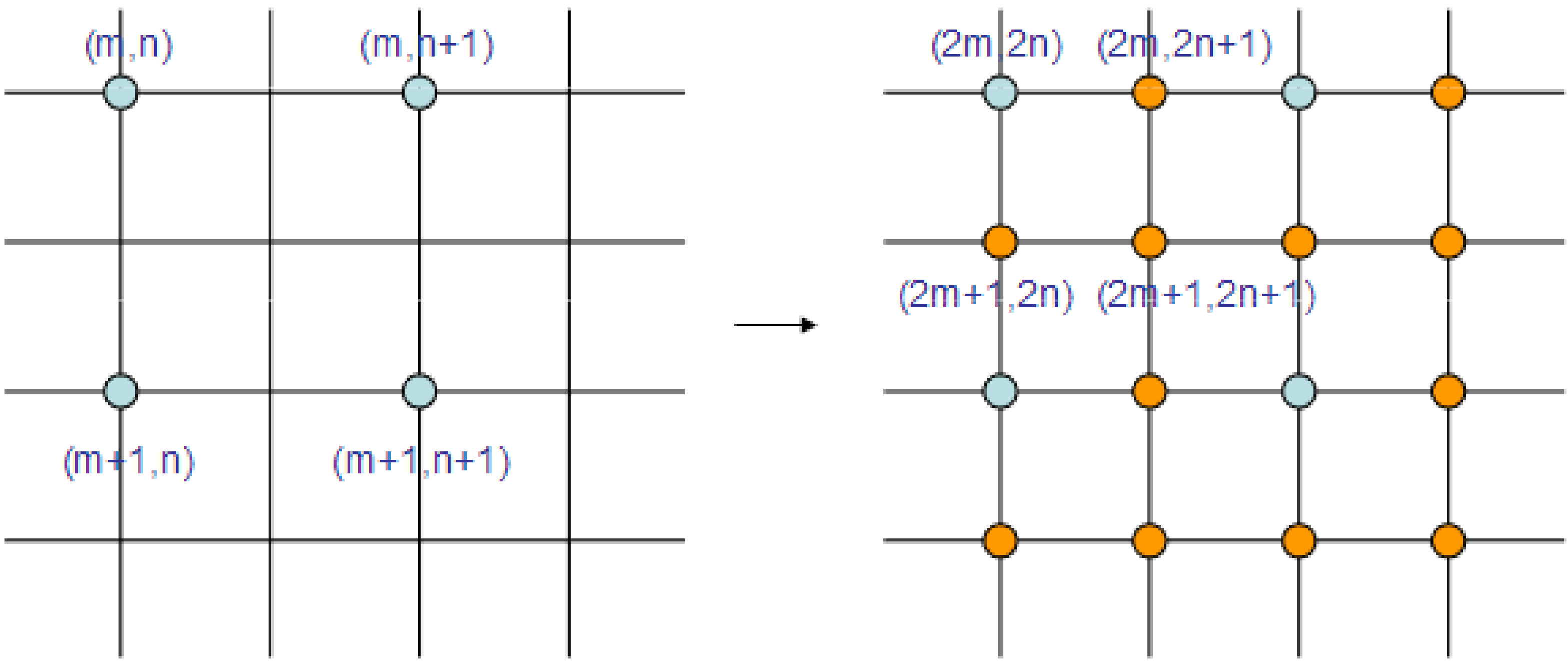


Image downsampling by factor of 2

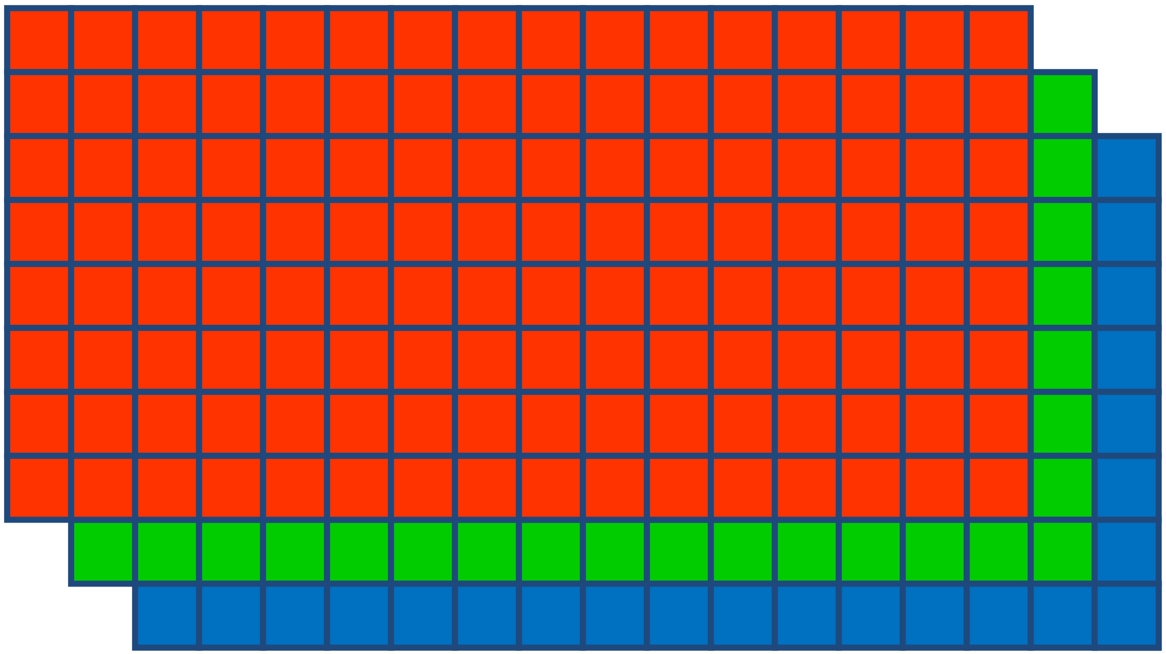


Factor of 2 Up-Sampling



Green samples are retained in the interpolated image;
Orange samples are estimated from surrounding green samples.

- **Color images can be represented by 3D Arrays (e.g. 320 x 240 x 3)**



- But for the time being we'll handle 2D grayvalue images

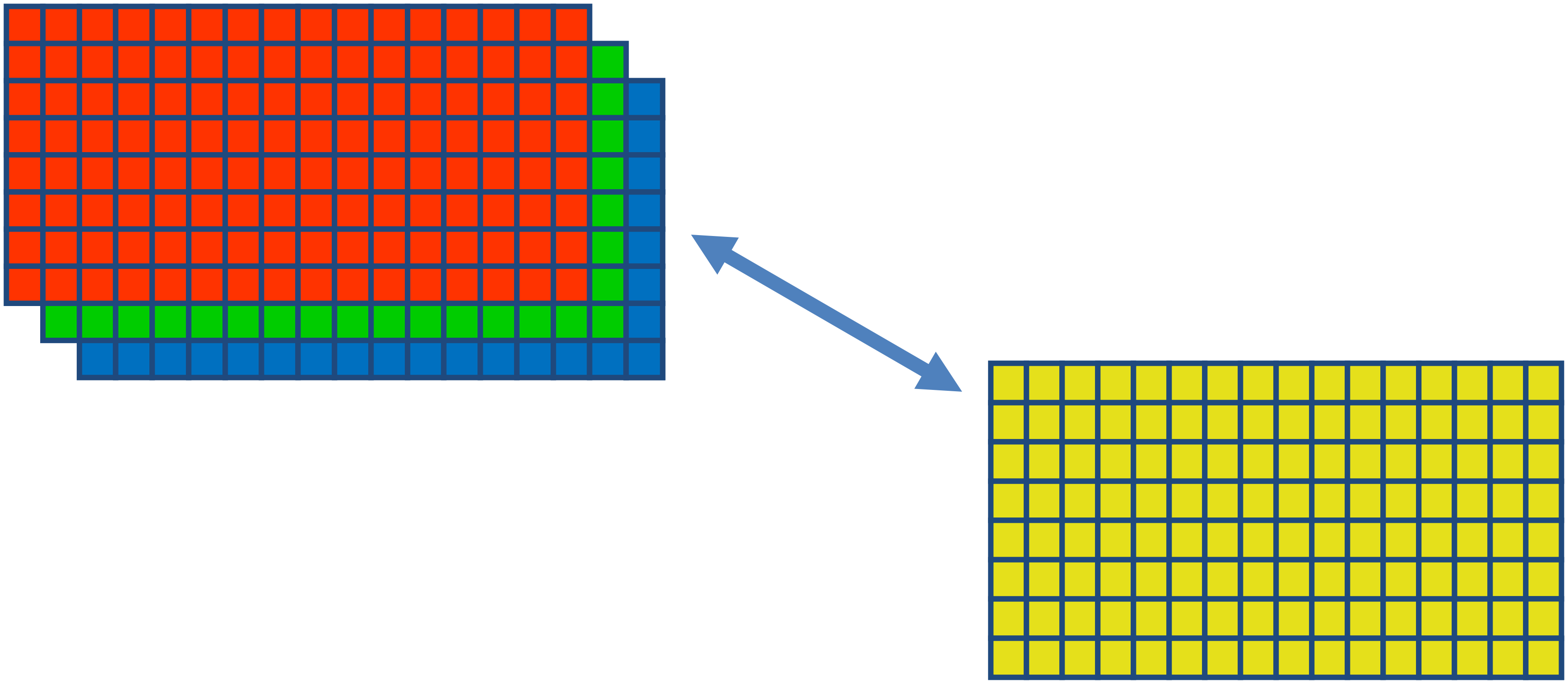


Image Interpolation

- **Interpolation** — Process of using known data to estimate unknown values

  e.g., zooming, shrinking, rotating, and geometric correction

- **Interpolation** (sometimes called ***resampling***) — an imaging method to increase (or decrease) the number of pixels in a digital image.

  Some digital cameras use interpolation to produce a larger image than the sensor captured or to create digital zoom

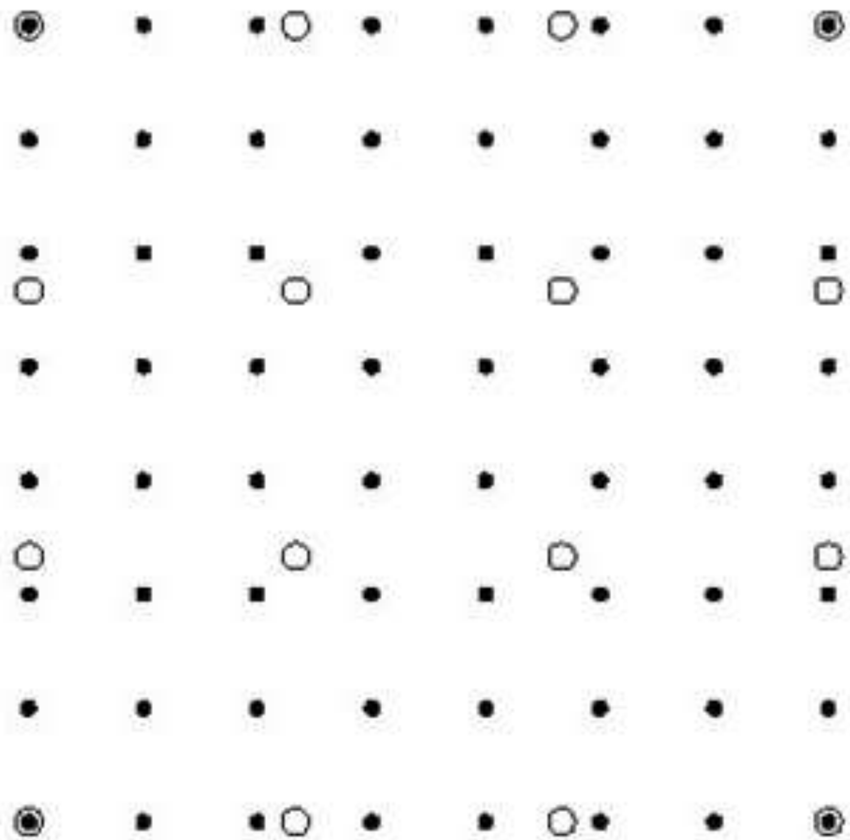
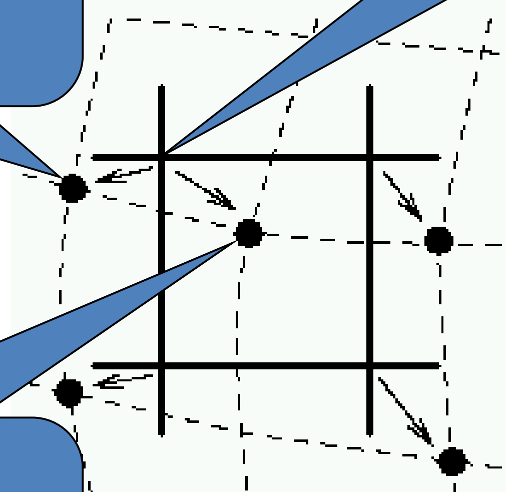


Image Interpolation:

Nearest Neighbor Interpolation

$f_1(x_2,y_2) =$
$f(\text{round}(x_2), \text{round}(y_2))$
$=f(x_1,y_1)$

$f(x_1,y_1)$



$f_1(x_3,y_3) =$
$f(\text{round}(x_3), \text{round}(y_3))$
$=f(x_1,y_1)$

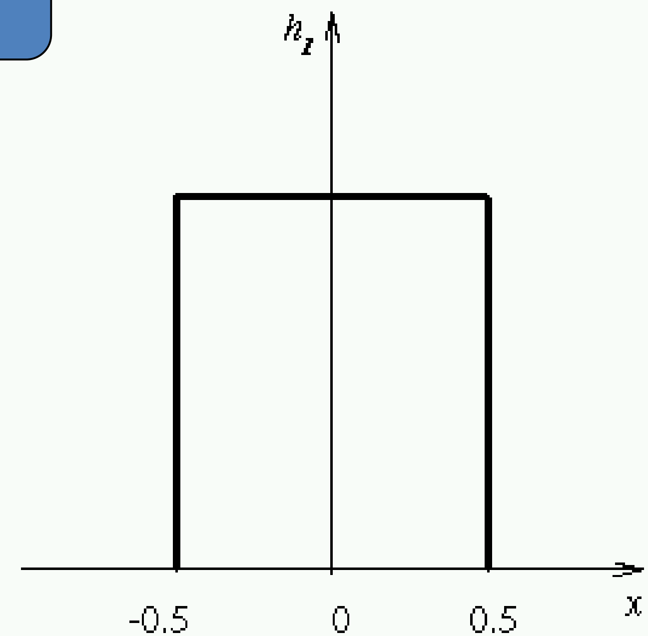
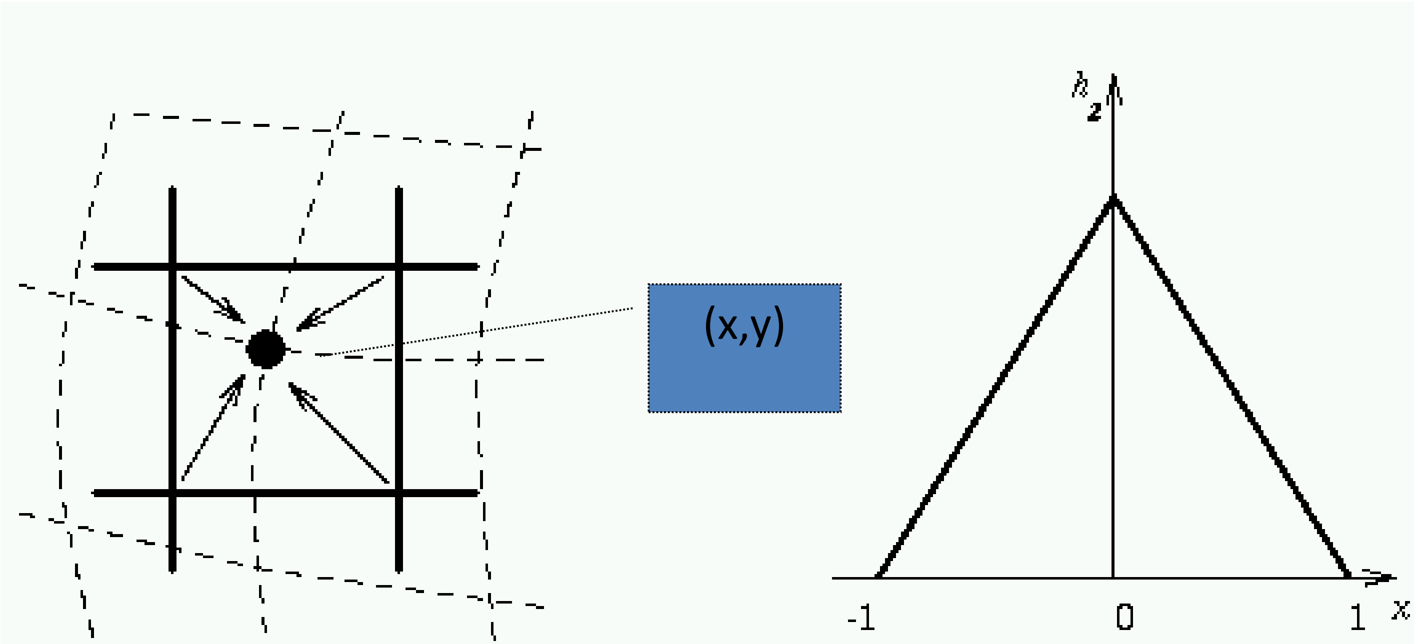


Image Interpolation:

Bilinear Interpolation



The output pixel value is a weighted average of pixels in the nearest 2-by-2 neighborhood

Considers the closest 2x2 neighborhood of known pixel values surrounding the unknown pixel

It then takes a weighted average of these 4 pixels to arrive at its final interpolated value

This results in much smoother looking images than nearest neighbor

Image Interpolation:

Bilinear Interpolation

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

Image Interpolation:

Bicubic Interpolation

- The intensity value assigned to point (x,y) is obtained by the following equation

$$f_3(x, y) = \sum_{i=0}^{3} \sum_{j=0}^{3} a_{ij} x^i y^j$$

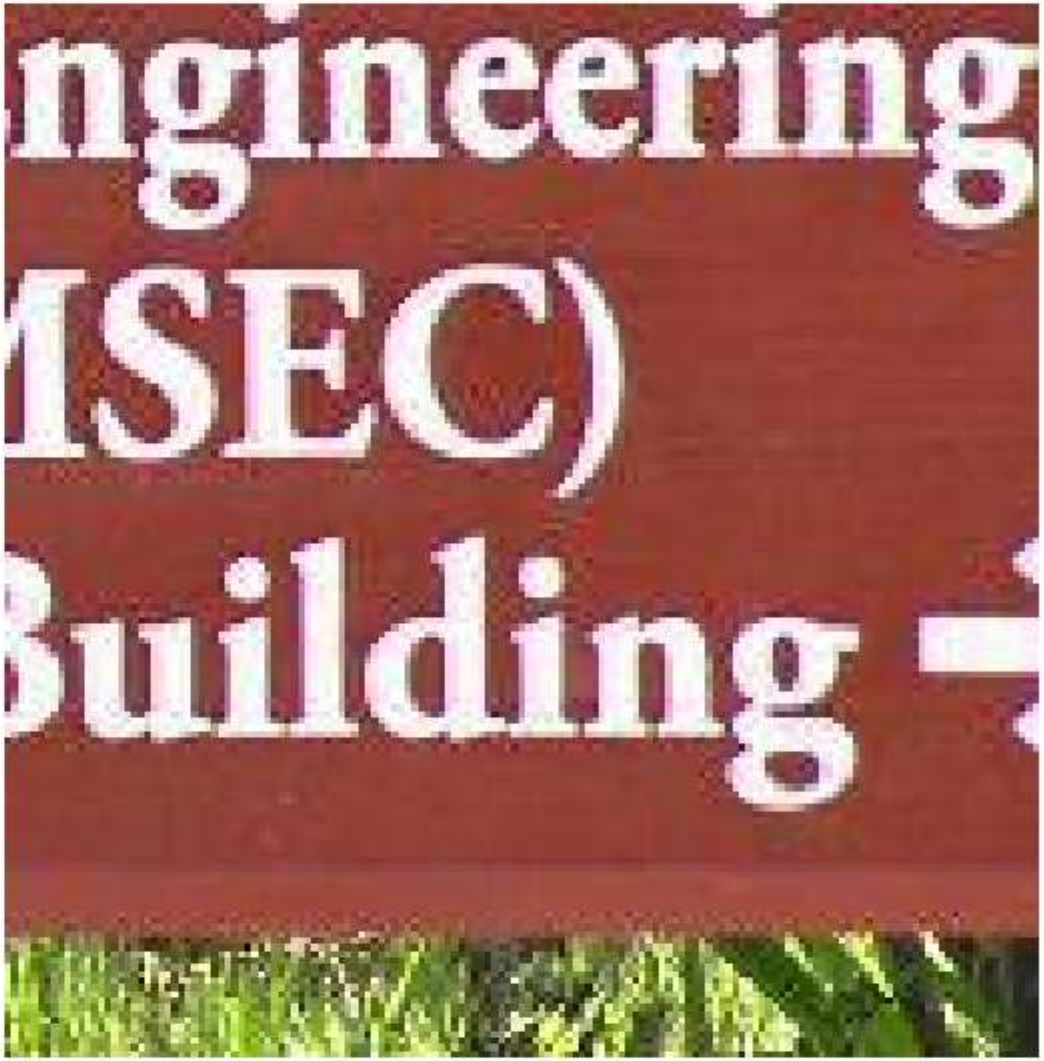
- The sixteen coefficients are determined by using the sixteen nearest neighbors.

Examples: Interpolation

Original Image

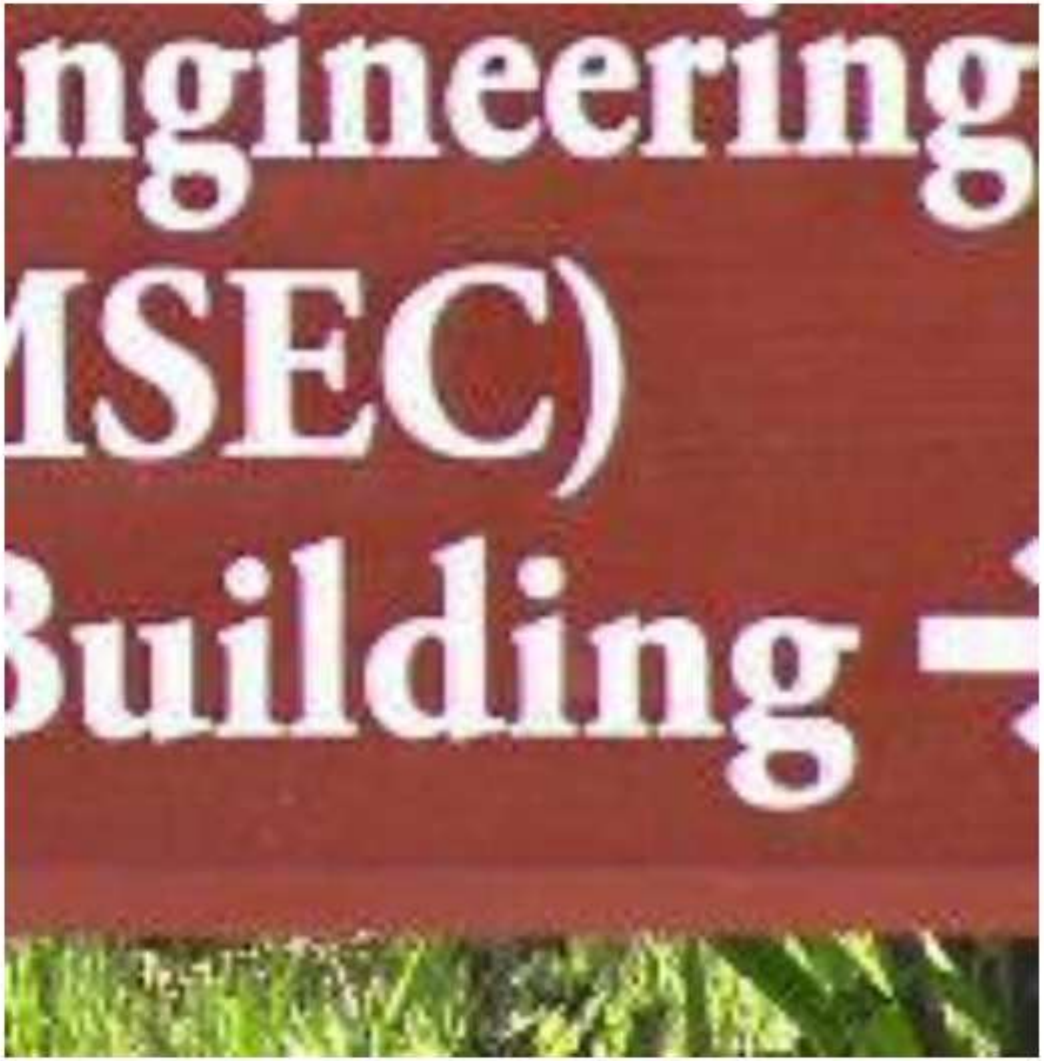
Examples: Interpolation

Nearest Neighbor Interpolation



Examples: Interpolation

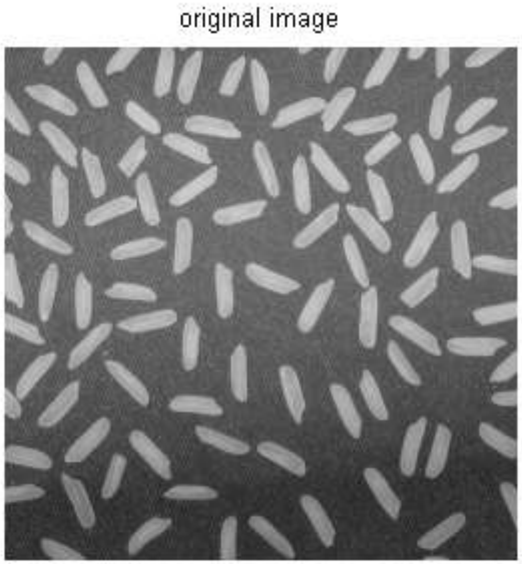
Bilinear Interpolation



Examples: Interpolation

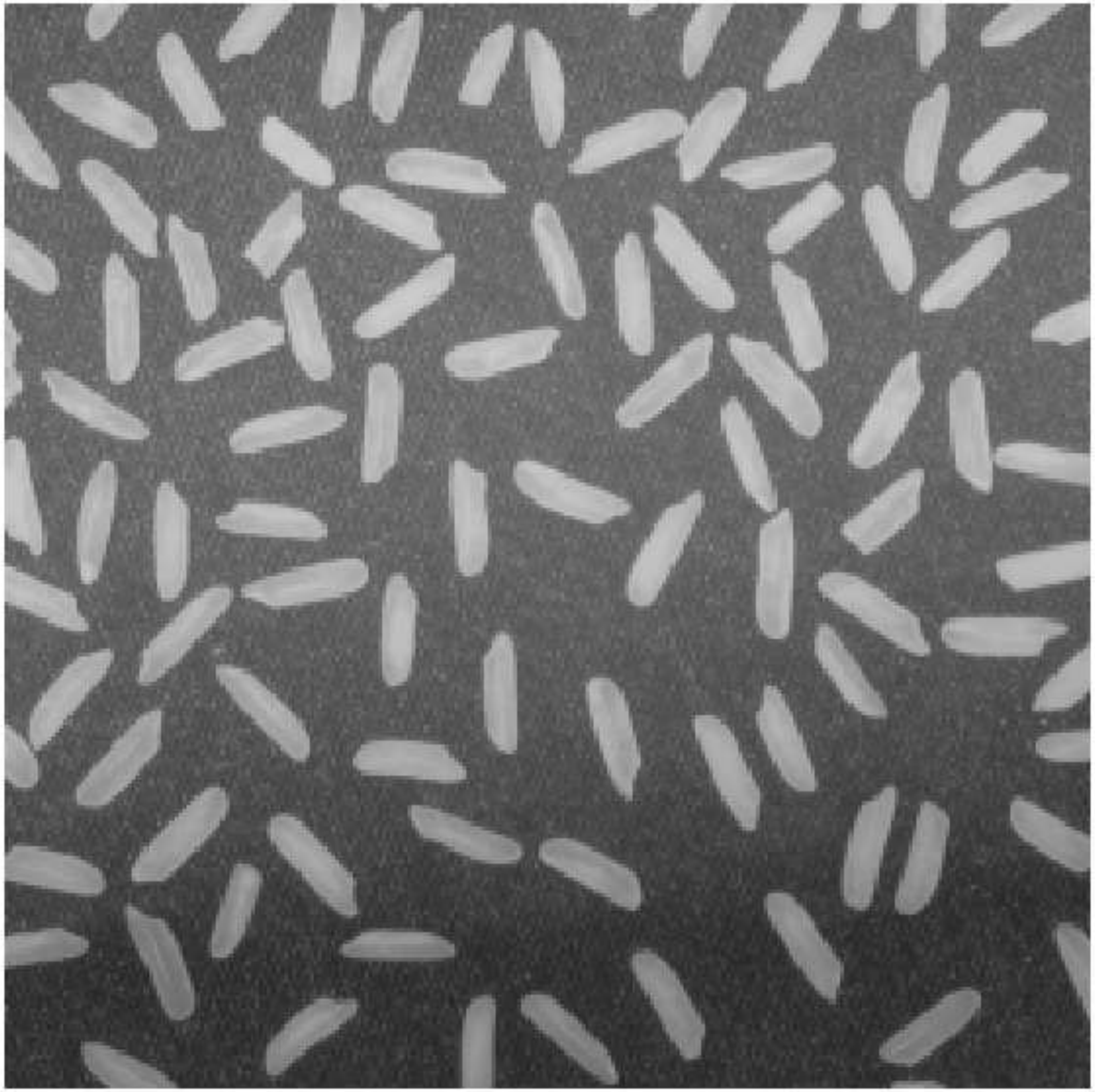
Bicubic Interpolation

Examples: Interpolation



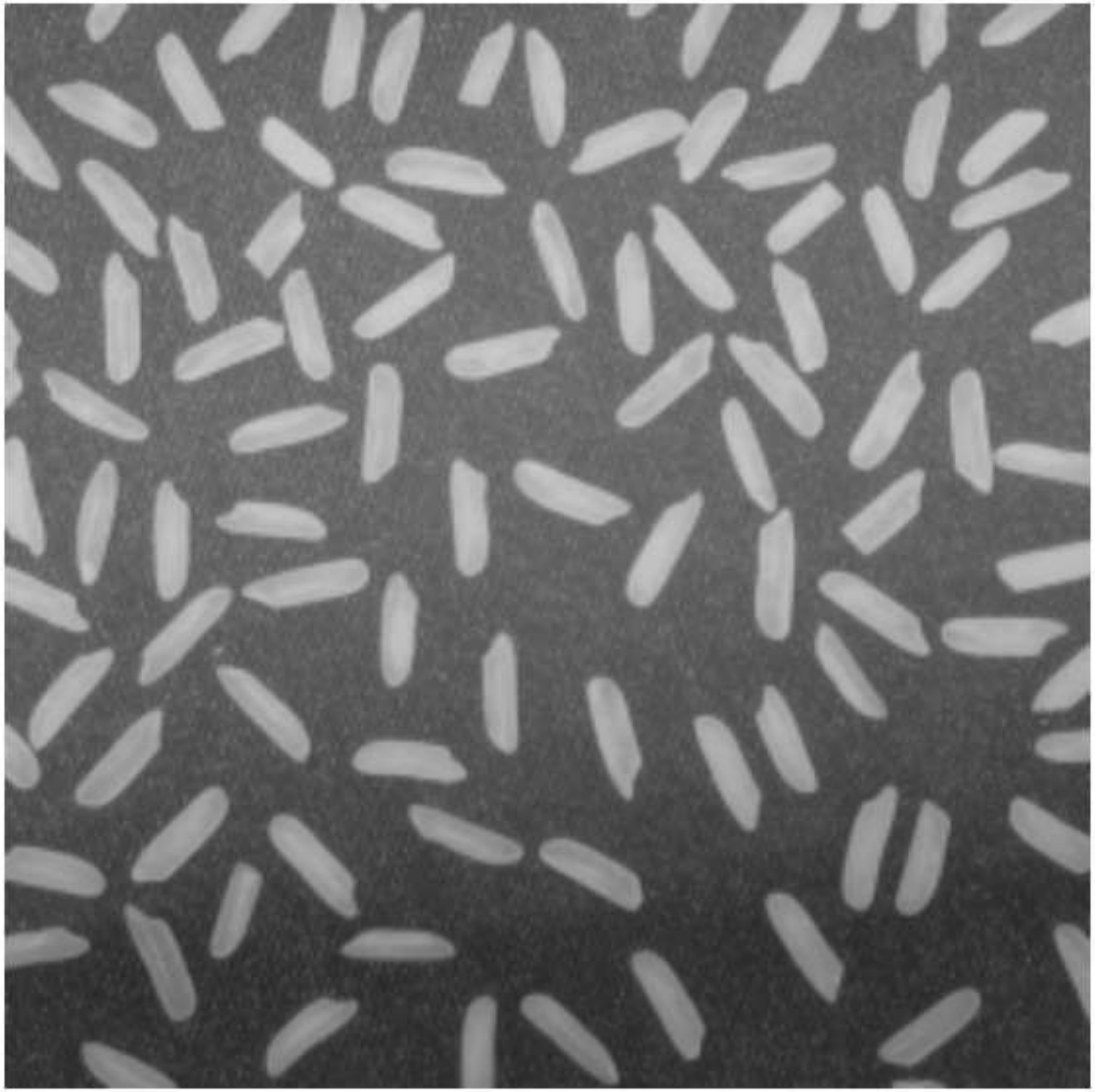
Examples: Interpolation

nearest

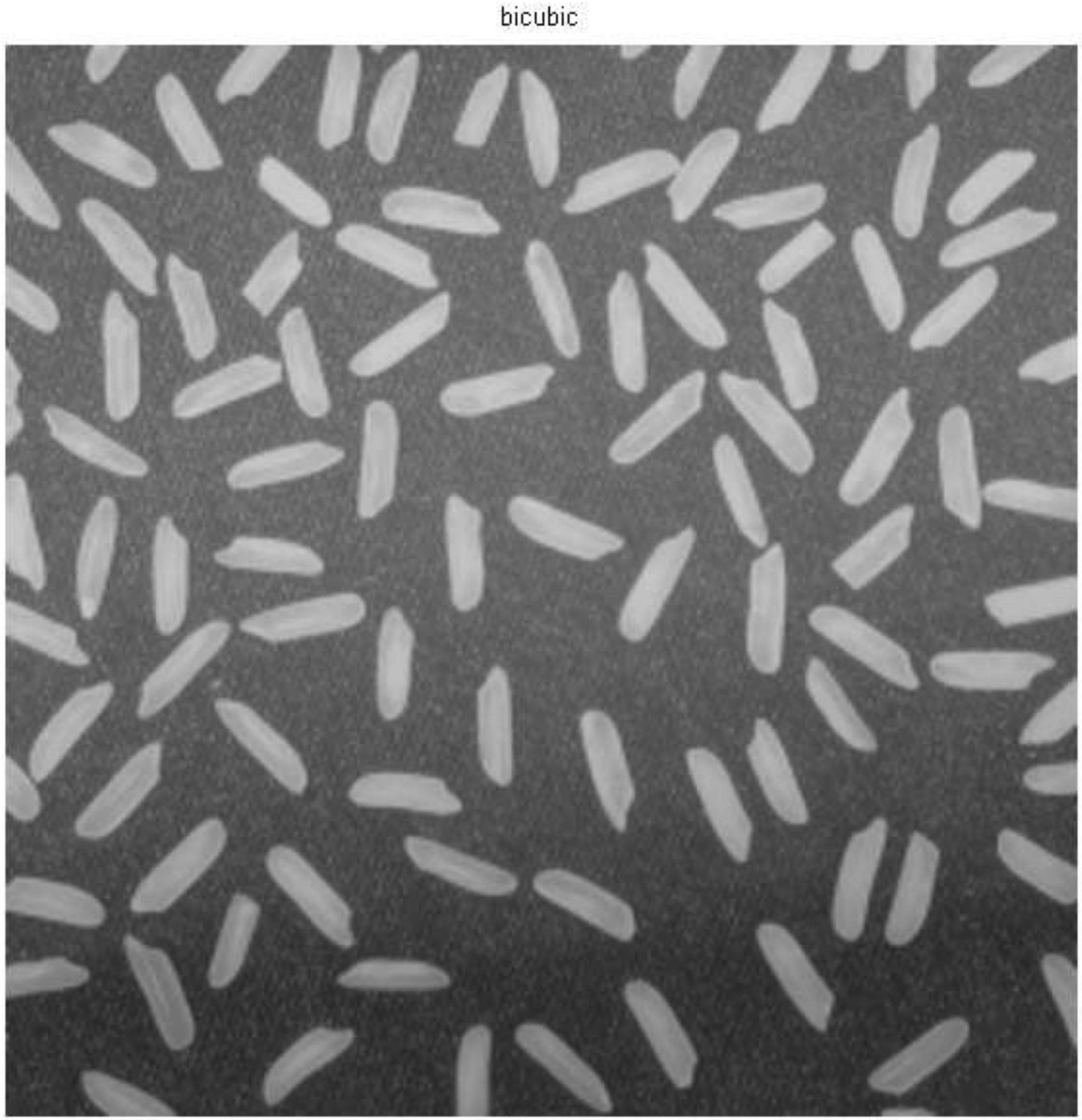


Examples: Interpolation

bilinear



Examples: Interpolation



Homework

Consider the following 4x4 image. Construct the 8x8 image using nearest neighbor and bilinear interpolation techniques.

9	8	7	6
8	8	4	6
1	1	4	6
0	9	2	3

Basic Relationships Between Pixels

- Neighborhood
- Adjacency
- Connectivity
- Paths
- Regions and boundaries

Basic Relationships Between Pixels

- **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 $\mathbf{N_8(p)}$
  $N_8(p) = N_4(p) \cup N_D(p)$

Basic Relationships 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 $N_8(p)$.

Basic Relationships Between Pixels

- **Adjacency**

  Let V be the set of intensity values

- **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.

Basic Relationships 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 $1 \le i \le n$.

- 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.

Examples: Adjacency and Path

V = {1, 2}

$$\begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix} \qquad \begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix} \qquad \begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix}$$

Examples: Adjacency and Path

V = {1, 2}

$$\begin{array}{ccc} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{array} \qquad \begin{array}{ccc} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{array} \qquad \begin{array}{ccc} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{array}$$

8-adjacent

Examples: Adjacency and Path

V = {1, 2}

$$\begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix} \qquad \begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix} \qquad \begin{matrix} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{matrix}$$

8-adjacent **m-adjacent**

Examples: Adjacency and Path

V = {1, 2}

$$\begin{array}{ccc} 0_{1,1} & 1_{1,2} & 1_{1,3} \\ 0_{2,1} & 2_{2,2} & 0_{2,3} \\ 0_{3,1} & 0_{3,2} & 1_{3,3} \end{array} \qquad \begin{array}{ccc} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{array} \qquad \begin{array}{ccc} 0 & 1 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{array}$$

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 Relationships Between Pixels

- **Connected in S**

  Let S represent a subset of pixels in an image. Two pixels p with coordinates (x_0, y_0) and q with coordinates (x_n, y_n) are said to be **connected in S** if there exists a path

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

  Where $\forall i, 0 \le i \le n, (x_i, y_i) \in S$

Basic Relationships Between Pixels

Let S represent a subset of pixels in an image

- For every pixel *p* in S, the set of pixels in S that are connected to *p* is called a ***connected component*** of S.
- If S has only one connected component, then S is called ***Connected Set*.**
- We call R a **region** of the image if R is a connected set
- Two regions, R_i and R_j are said to be ***adjacent*** if their union forms a connected set.
- Regions that are not to be adjacent are said to be ***disjoint.***

Basic Relationships Between Pixels

- **Boundary (or border)**

➢ The ***boundary*** of the region R is the set of pixels in the region that have one or more neighbors that are not in R.

➢ If R happens to be an entire image, then its boundary is defined as the set of pixels in the first and last rows and columns of the image.

- **Foreground and background**

➢ An image contains K disjoint regions, R_k, k = 1, 2, …, K. Let R_u denote the union of all the K regions, and let $(R_u)^c$ denote its complement.

All the points in R_u is called **foreground**;

All the points in $(R_u)^c$ is called **background**.

Question

- **In the following arrangement of pixels, are the two regions (of 1s) adjacent? (if 8-adjacency is used)**

1	1	1
1	0	1
0	1	0
0	0	1
1	1	1
1	1	1

Region 1

Region 2

Question

- **In the following arrangement of pixels, are the two parts (of 1s) adjacent? (if 4-adjacency is used)**

1	1	1
1	0	1
0	1	0
0	0	1
1	1	1
1	1	1

Part 1

Part 2

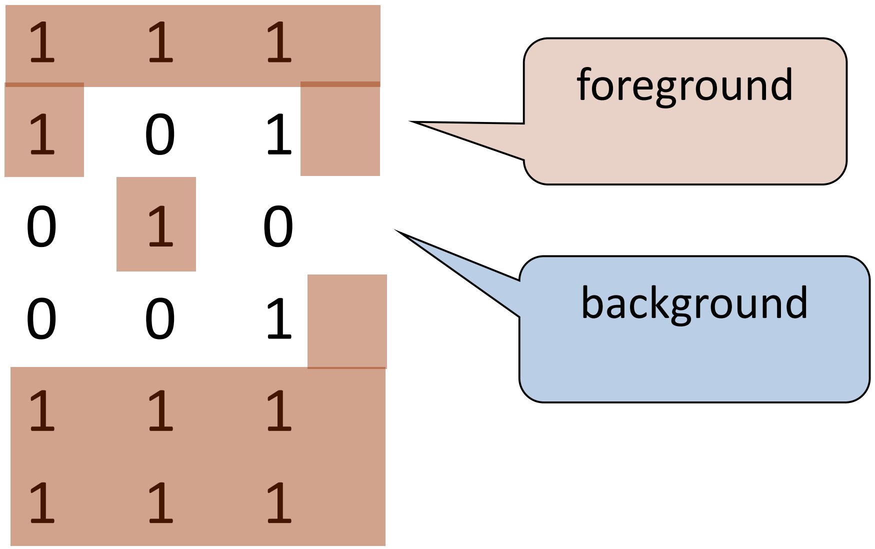
- **In the following arrangement of pixels, the two regions (of 1s) are disjoint (if 4-adjacency is used)**

1	1	1
1	0	1
0	1	0
0	0	1
1	1	1
1	1	1

Region 1

Region 2

- **In the following arrangement of pixels, the two regions (of 1s) are disjoint (if 4-adjacency is used)**



Question

- **In the following arrangement of pixels, the circled point is part of the boundary of the 1-valued pixels if 8-adjacency is used, true or false?**

0	0	0	0	0
0	1	1	0	0
0	1	1	0	0
0	1	1	1	0
0	1	1	1	0
0	0	0	0	0

Homework: Question 1

- **In the following arrangement of pixels, the circled point is part of the boundary of the 1-valued pixels if 4-adjacency is used, true or false?**

0	0	0	0	0
0	1	1	0	0
0	1	1	0	0
0	1	1	1	0
0	1	1	1	0
0	0	0	0	0

Distance Measures

- Given pixels *p, q* and *z* with coordinates (x, y), (s, t), (u, v) respectively, the distance function D has following properties:

a. $D(p, q) \geq 0$ [$D(p, q) = 0$, iff $p = q$]

b. $D(p, q) = D(q, p)$

c. $D(p, z) \leq D(p, q) + D(q, z)$

Distance Measures

The following are the different Distance measures:

a. Euclidean Distance :

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

b. City Block Distance:

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

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

c. Chess Board Distance:

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

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

Question

- **In the following arrangement of pixels, what's the value of the chessboard distance between the circled two points?**

0	0	0	0	0
0	0	1	1	0
0	1	1	0	0
0	1	0	0	0
0	0	0	0	0
0	0	0	0	0

Homework: Question 2

- **In the following arrangement of pixels, what's the value of the city-block distance between the circled two points?**

0	0	0	0	0
0	0	1	1	0
0	1	1	0	0
0	1	0	0	0
0	0	0	0	0
0	0	0	0	0

Homework: Question 3

- **In the following arrangement of pixels, what's the value of the length of the m-path between the circled two points?**

0	0	0	0	0
0	0	1	1	0
0	1	1	0	0
0	1	0	0	0
0	0	0	0	0
0	0	0	0	0

Homework: Question 4

- **In the following arrangement of pixels, what's the value of the length of the m-path between the circled two points?**

0	0	0	0	0
0	0	1	1	0
0	0	1	0	0
0	1	0	0	0
0	0	0	0	0
0	0	0	0	0