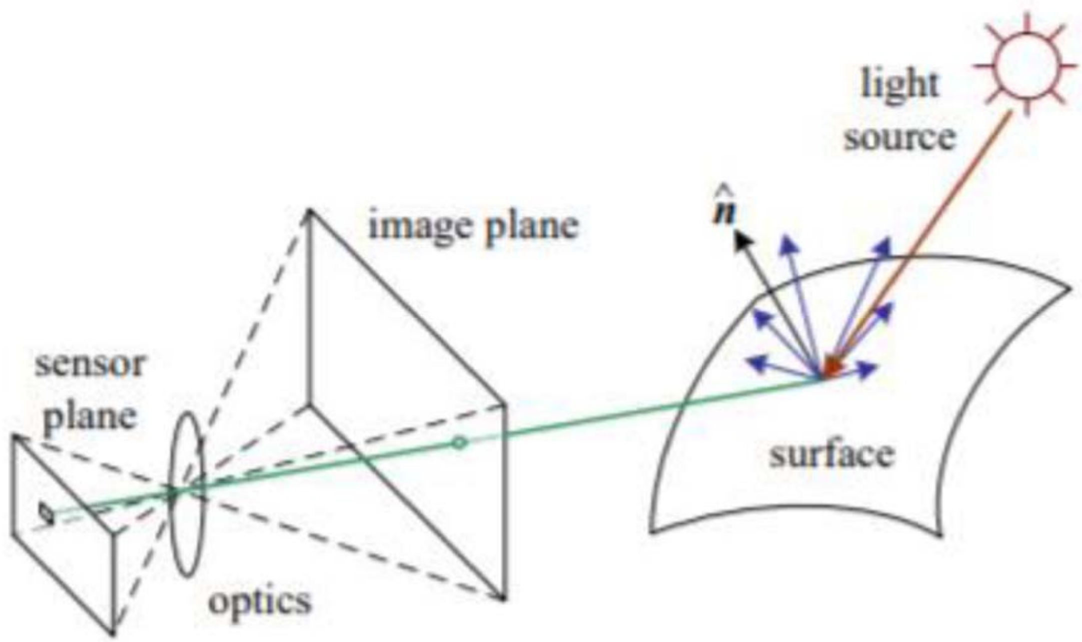
Image Formation



(Credit: Szeliski, Computer Vision: Algorithms and Applications)

The light from a source is reflected on a particular surface. A part of that reflected light goes through an image plane that reaches a sensor plane via optics.

Image Formation: Factors

- Light source strength and direction
- Surface geometry, material and nearby surfaces
- Sensor capture properties
- Image representation and colour

Light and the Electromagnetic Spectrum

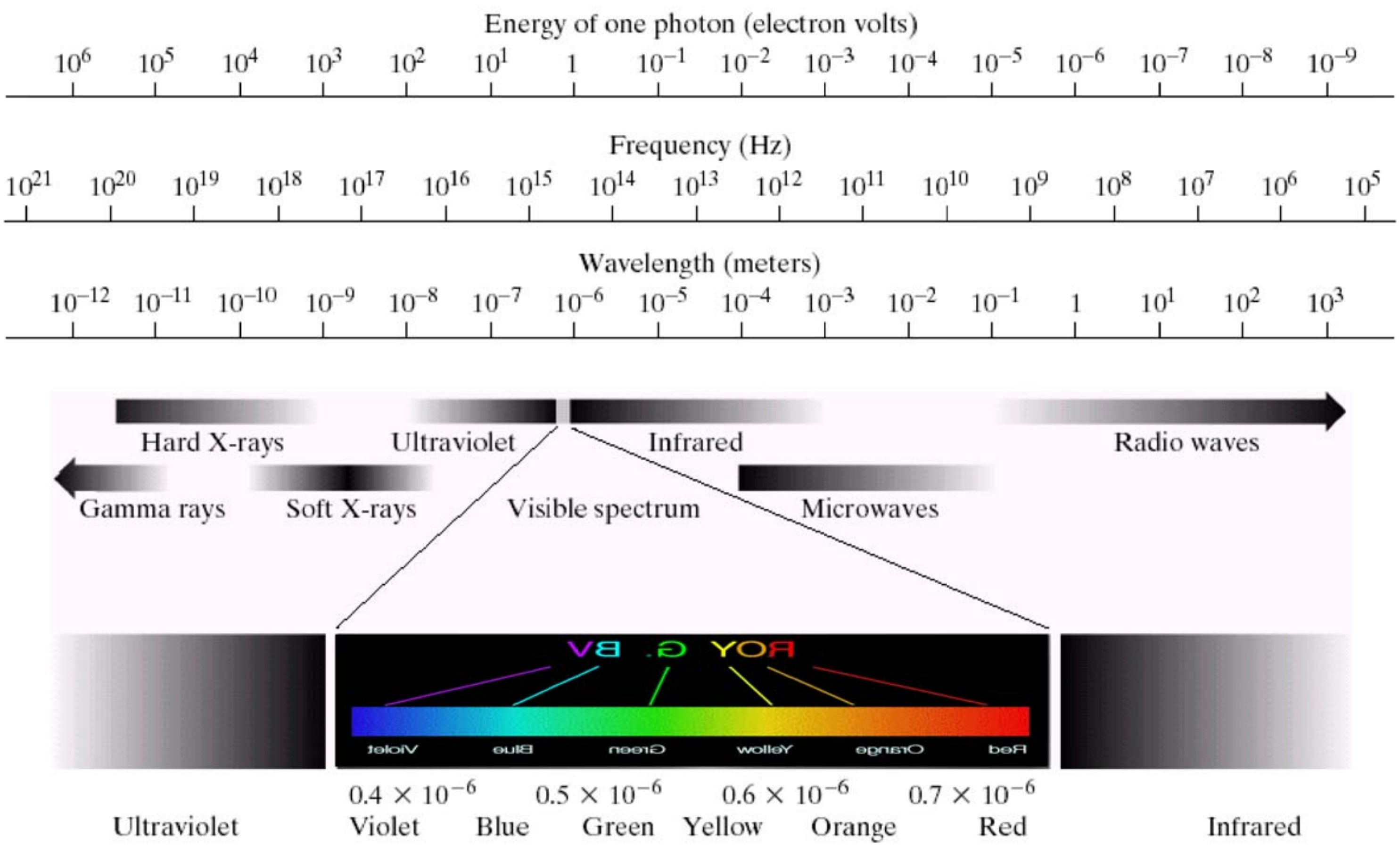


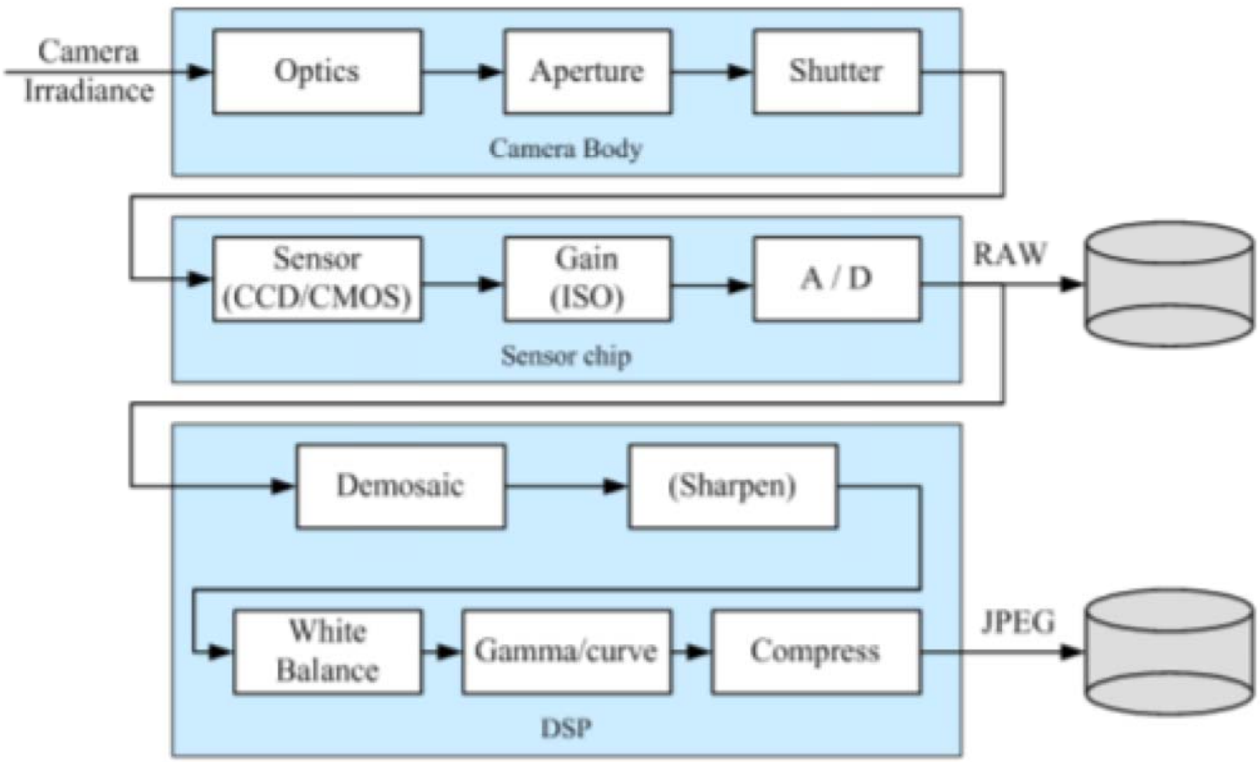
FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

Light and the Electromagnetic Spectrum

- Three basic quantities described the quality of a chromatic light source:
  - Radiance: the total amount energy that flow from the light source (can be measured)
  - Luminance: the amount of energy an observer perceives from a light source (can be measured)
  - Brightness: a subjective descriptor of light perception; perceived quantity of light emitted (cannot be measured)

Image Sensing Pipeline in a Camera

- The light originates from multiple light sources, gets reflected on multiple surfaces, and finally enters the camera where the photons are converted into the (R, G, B) values that we see while looking at a digital image.



(Credit: *Szeliski, Computer Vision: Algorithms and Applications 2010*)

Image Sensing and Acquisition

- Nowadays most visible and near IR electromagnetic imaging is done with 2-dimensional charged-coupled devices (CCDs).

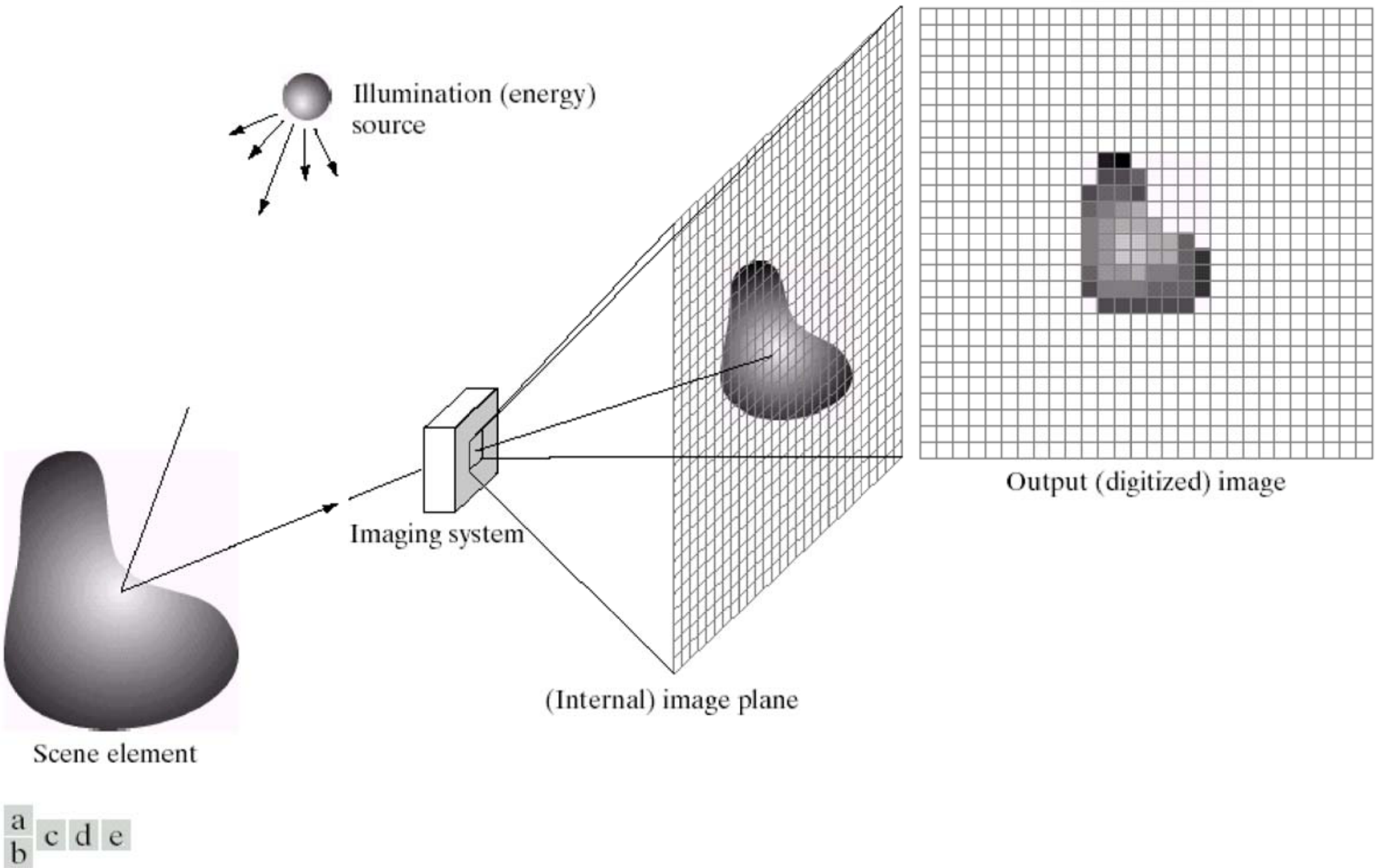


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

A Simple Image Formation Model

Let $f(x,y)$ be an image function, then

$$\boldsymbol{f(x,y) = i(x,y)\, r(x,y)}$$

where $i(x,y)$: the illumination function (amount of source illumination incident on the scene being viewed)

$r(x,y)$: the reflection function (amount of illumination reflected by the objects in the scene)

Note: $0 < i(x,y) < \infty$ and $0 < r(x,y) < 1$.

Reflectance is bounded by 0 (total absorption) and 1 (total reflectance)

A Simple Image Formation Model

- For digital images the minimum gray level is usually 0, but the maximum depends on number of quantization levels used to digitize an image. The most common is 256 levels, so that the maximum level is 255.
- $L=2^k$ (k-bits)
- **Dynamic range** of an image: 0 to $L-1$ levels (also can be normalized to [0, 1])
- **Image contrast** is associated with dynamic range and can be defined as the difference in intensity between highest and lowest intensity levels in an image
- High dynamic range => High contrast
- Image size: MxN, k-bits per pixel => No. of bits required= M*N*k

Image Sampling and Quantization

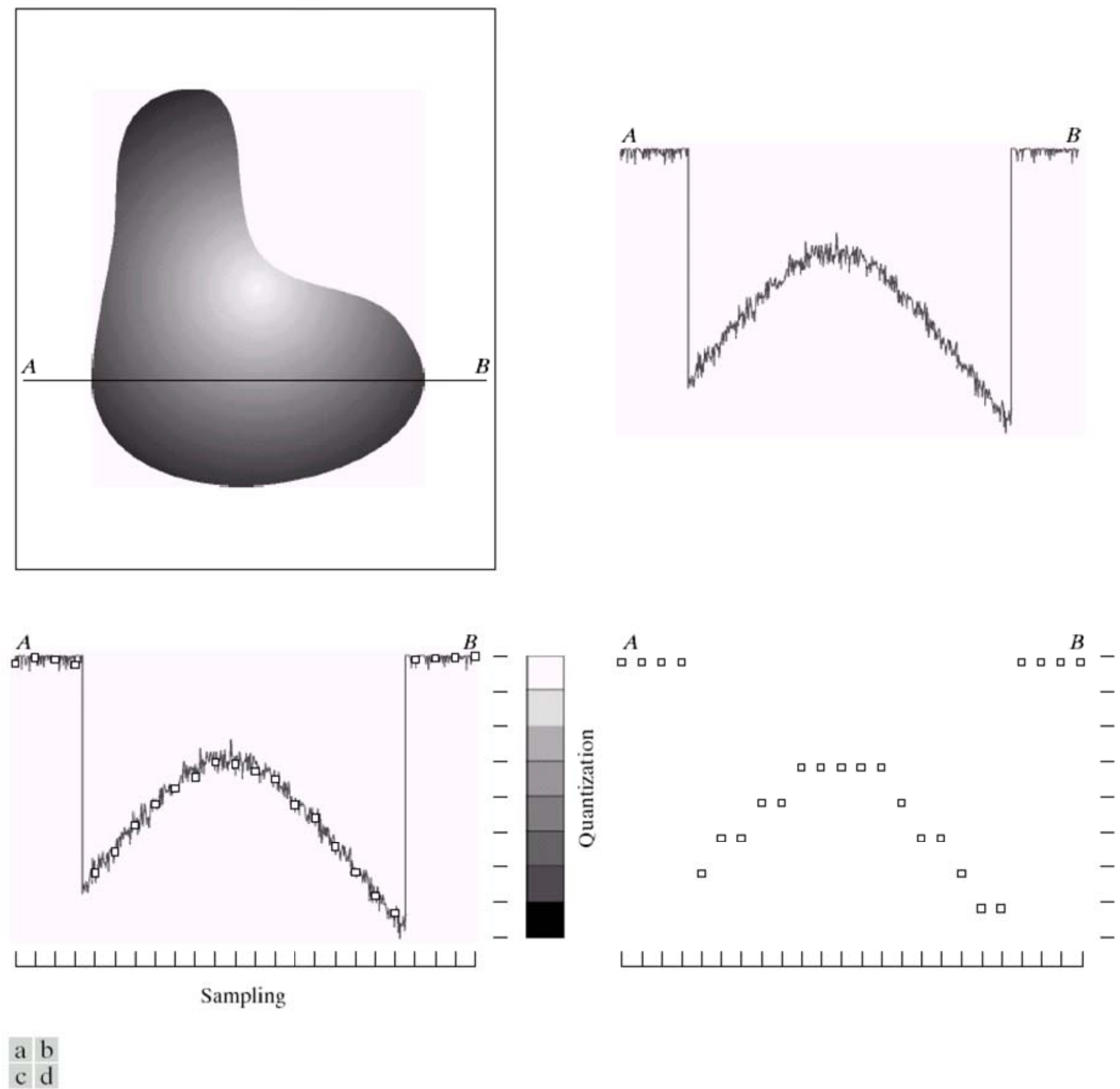
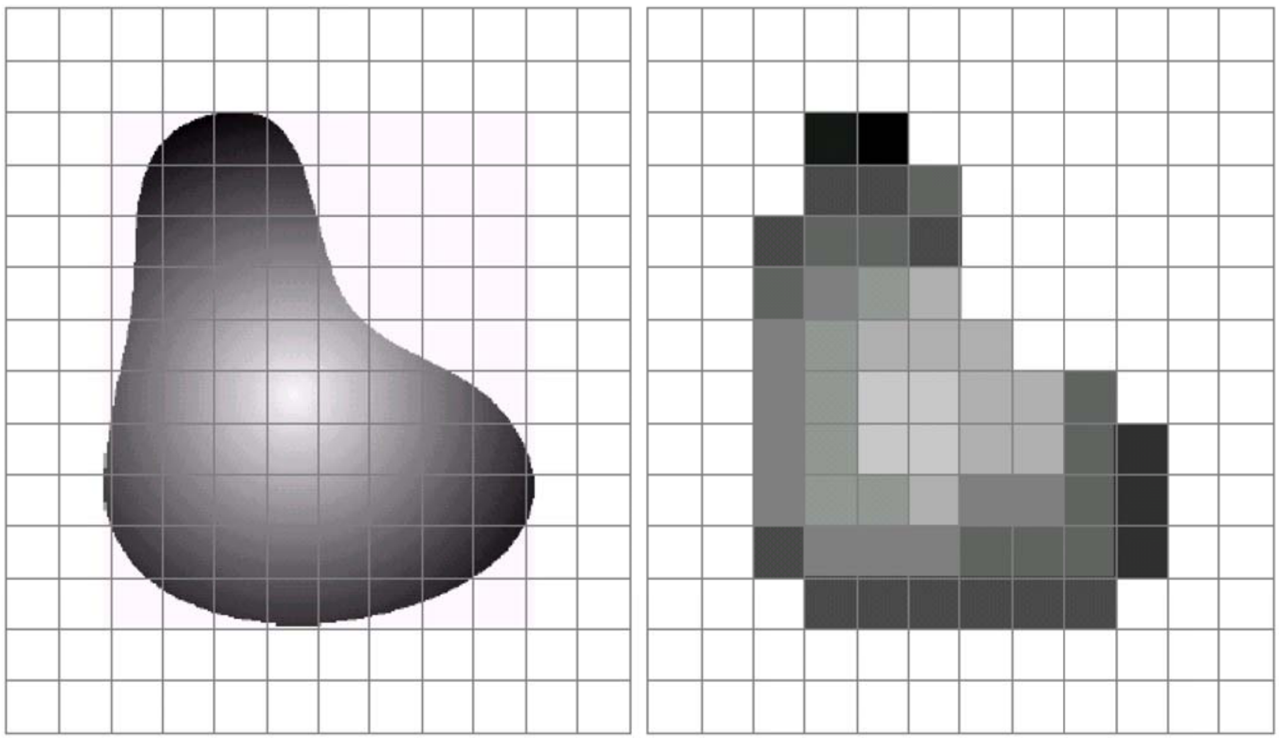


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Image Sampling and Quantization

- Sampling: digitizing the 2-dimensional spatial coordinate values
- Quantization: digitizing the amplitude values (brightness level)



a b

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

Representing Digital Images

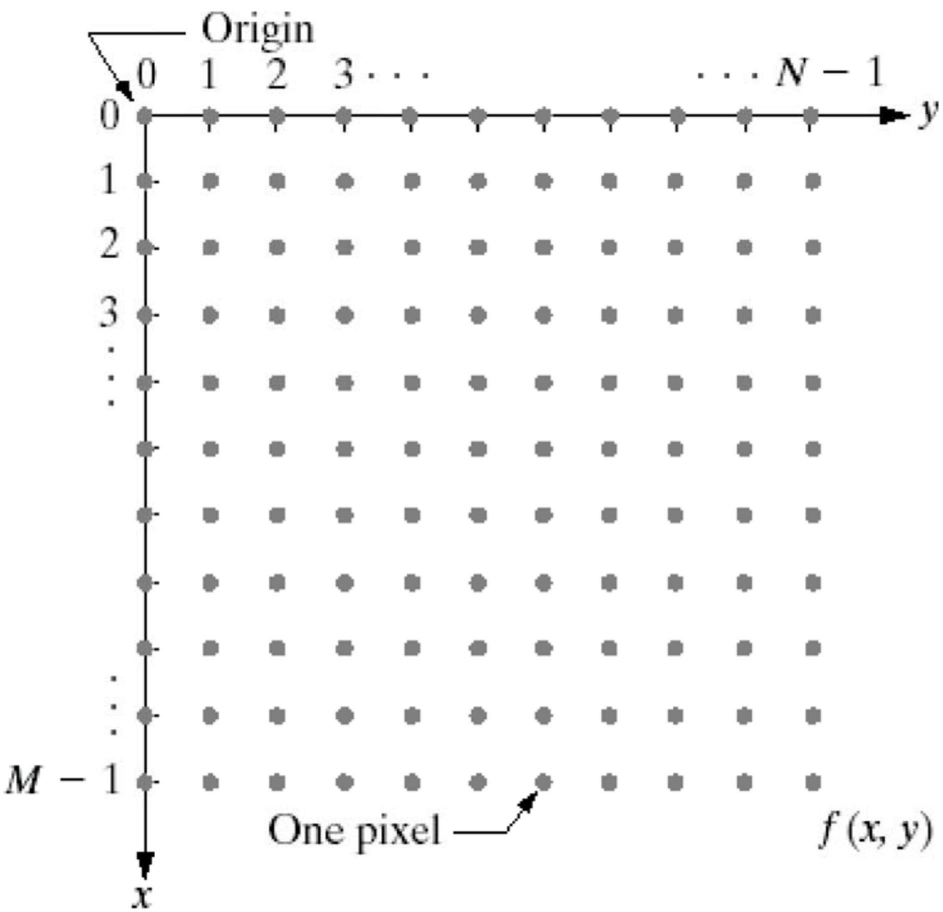
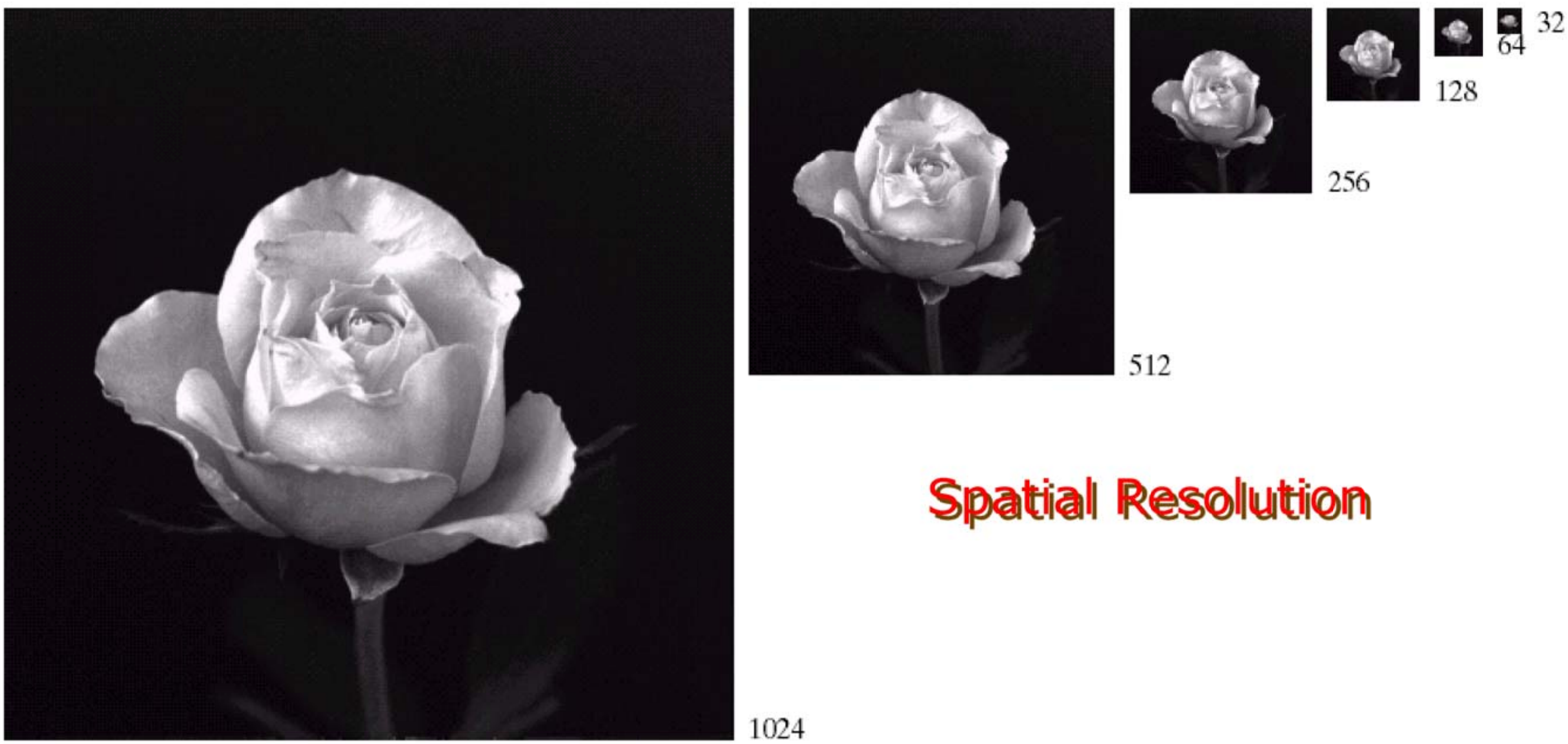


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

Spatial and Gray-Level Resolution

- **Spatial Resolution:** smallest discernible detail in an image (dots or pixels per unit distance)
- **Gray-level Resolution:** This refers to the smallest discernible change in gray level.
- Lower resolution images are smaller than the original image



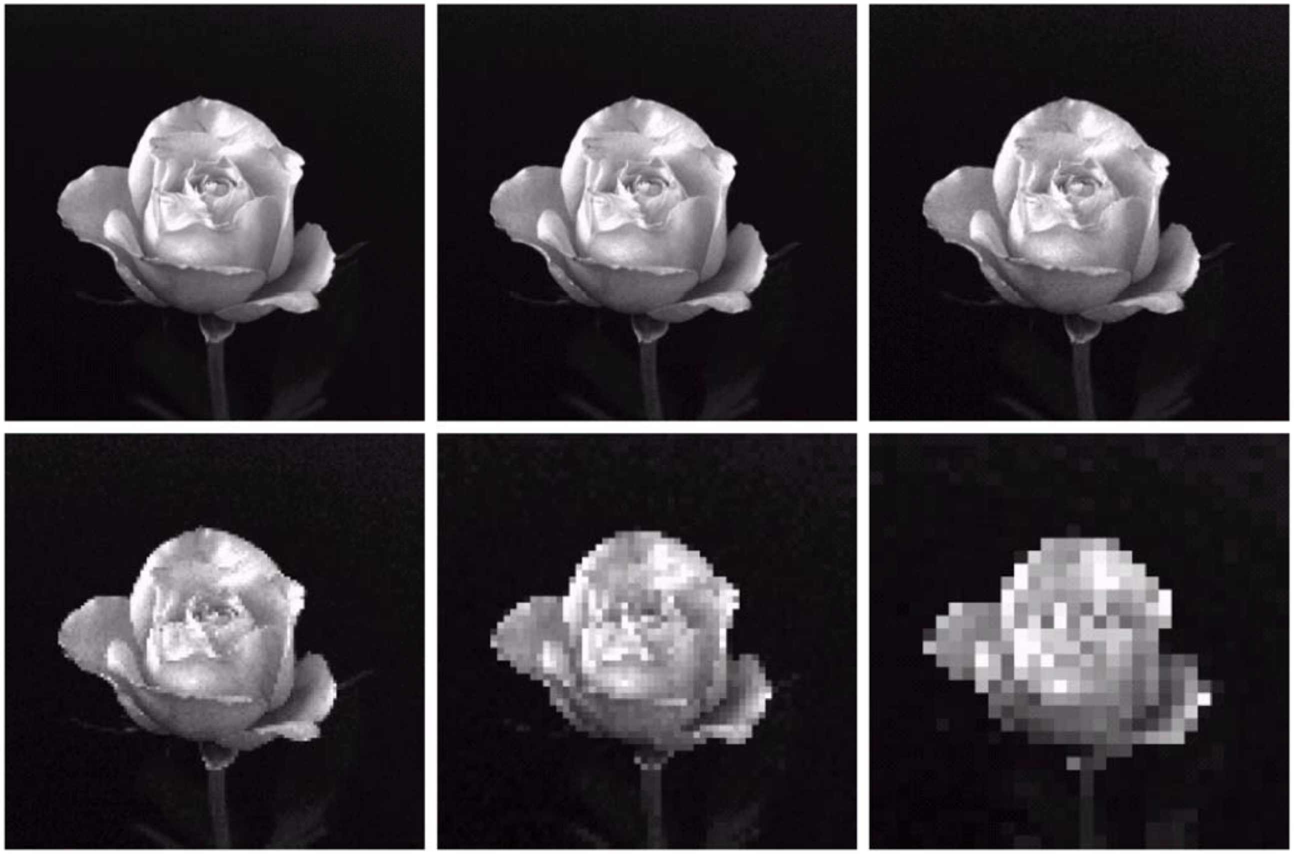
Spatial Resolution

FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

Spatial Resolution by Re-sampling

Effect of reducing spatial resolution

- Lower resolution images are smaller than the original image
- All smaller images are zoomed back to original size
- **Checker-board effect**



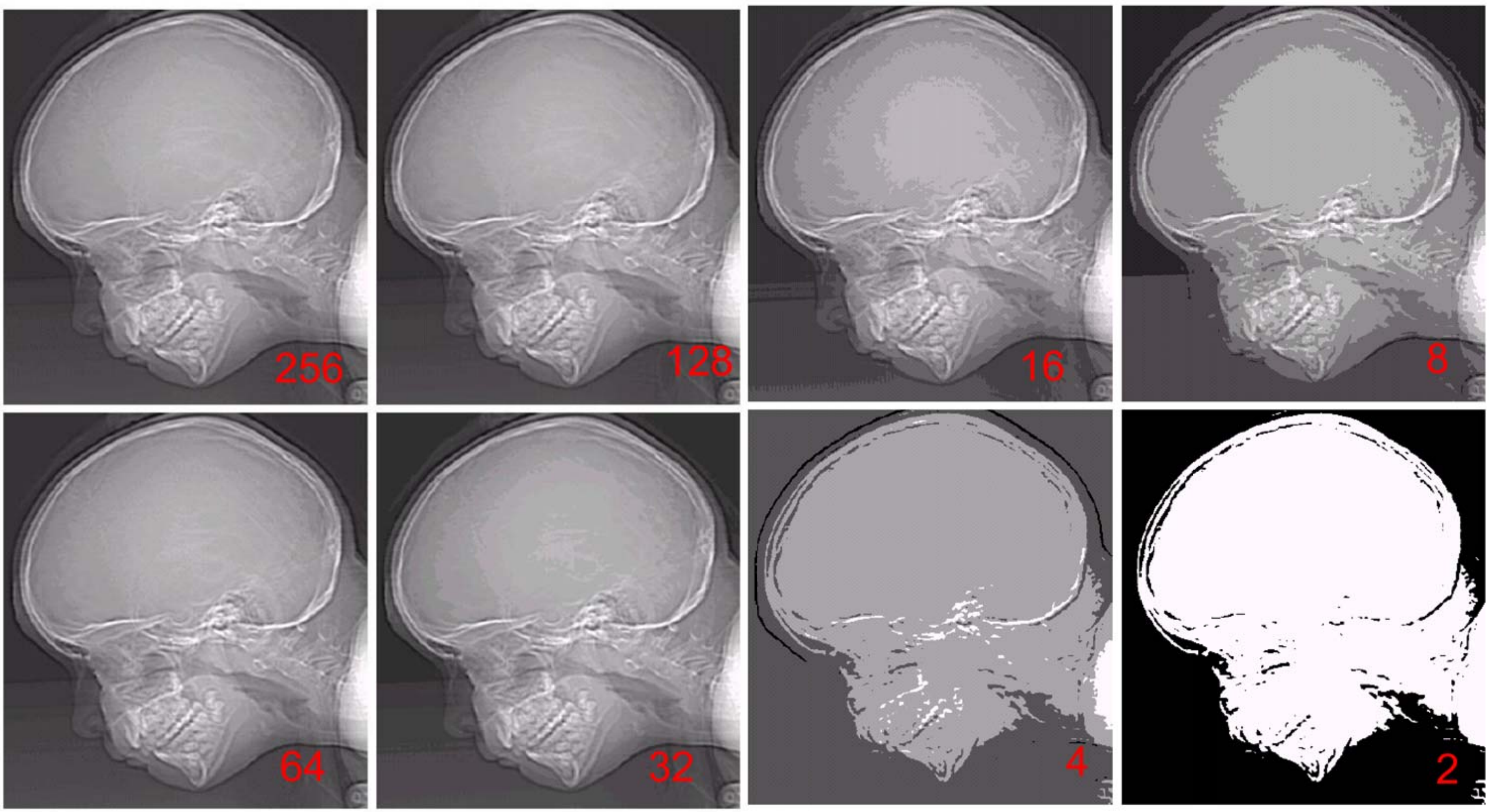
a b c
d e f

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.

Gray-Level Resolution

Effect of varying number of intensity levels in an image

- **False contouring effect**(often observed in images with 16 or less intensity levels)



How to Decide Spatial and Gray-Level Resolution?

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 2.22 (a): The woman's face; Image with low level of detail.
- Figure 2.22 (b): The cameraman; Image with medium level of detail.
- Figure 2.22 (c): The crowd picture; Image with a relatively large amount of detail.

Zooming and Shrinking Digital Images

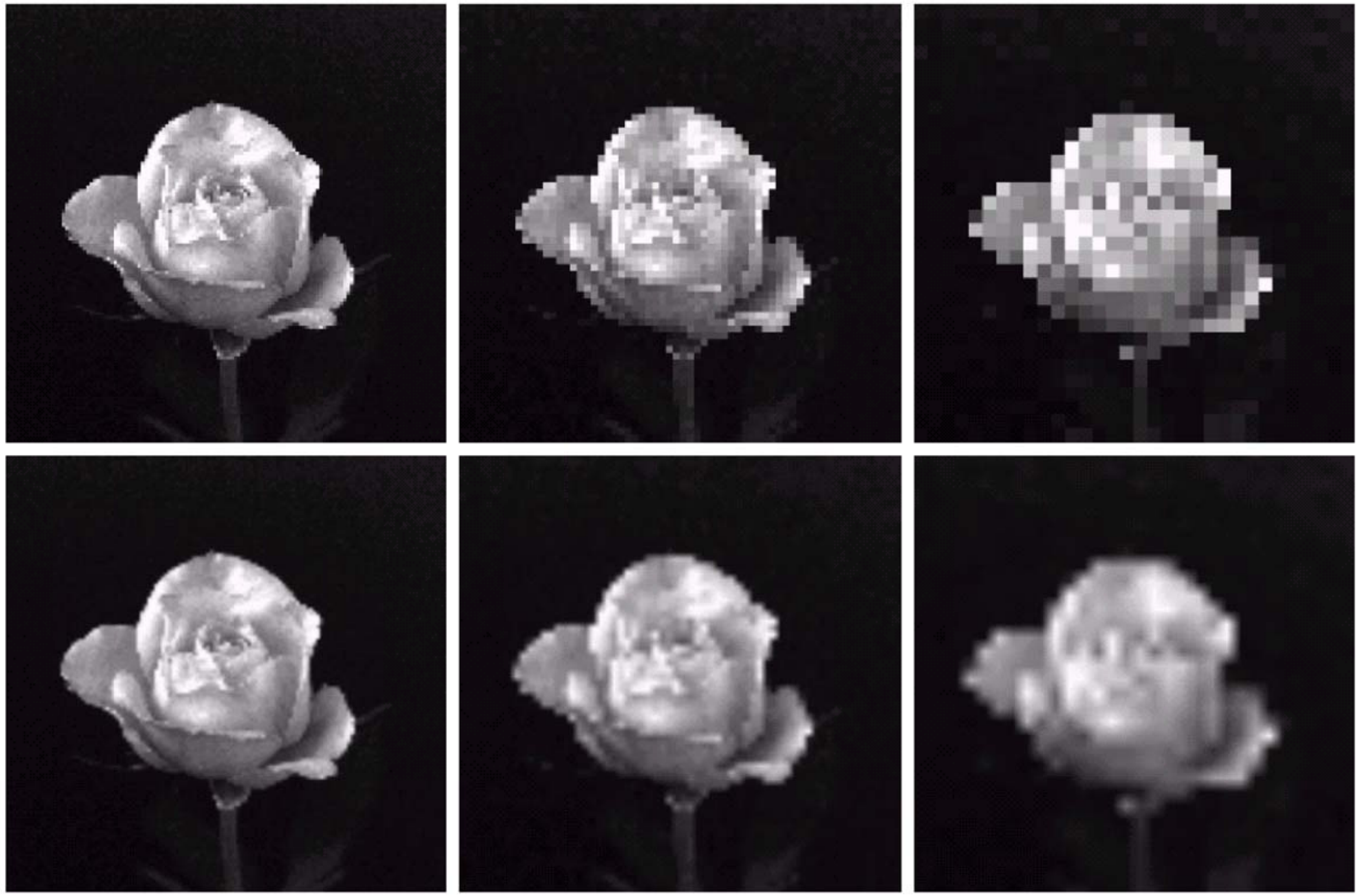
- Zooming: increasing the number of pixels in an image so that the image appears larger
  - Nearest neighbor interpolation
    - For example: pixel replication--to repeat rows and columns of an image
  - Bilinear interpolation
    - Smoother
  - Higher order interpolation

- Image shrinking: subsampling

Zooming and Shrinking Digital Images

Nearest neighbor
Interpolation
(Pixel replication)

Bilinear
interpolation



a b c
d e f

FIGURE 2.25 Top row: images zoomed from 128 × 128, 64 × 64, and 32 × 32 pixels to 1024 × 1024 pixels, using nearest neighbor gray-level interpolation. Bottom row: same sequence, but using bilinear interpolation.

Some Basic Relationships Between Pixels

- Neighbors of a pixel
  - There are three kinds of neighbors of a pixel:
    - ***$N_4(p)$* 4-neighbors:** the set of 2 horizontal and 2 vertical neighbors
    - *$N_D(p)$* diagonal neighbors: the set of 4 diagonal neighbors
    - *$N_8(p)$* 8-neighbors: union of 4-neighbors and diagonal neighbors

Each of these neighbors is at a unit distance from the central pixel (p). If p is a boundary pixel then it will have less number of neighbors.

	(x-1,y)	
(x,y-1)	p (x,y)	(x,y+1)
	(x+1,y)	

Some Basic Relationships Between Pixels

- Neighbors of a pixel
  - There are three kinds of neighbors of a pixel:
    - $N_4(p)$ 4-neighbors: the set of horizontal and vertical neighbors
    - **$N_D(p)$ diagonal neighbors:** the set of 4 diagonal neighbors
    - **$N_8(p)$ 8-neighbors:** union of 4-neighbors and diagonal neighbors

(x-1,y-1)		(x-1,y+1)
	p (x,y)	
(x+1,y-1)		(x+1,y+1)

(x-1,y-1)	(x-1,y)	(x-1,y+1)
(x,y-1)	p (x,y)	(x,y+1)
(x+1,y-1)	(x+1,y)	(x+1,y+1)

Some Basic Relationships Between Pixels

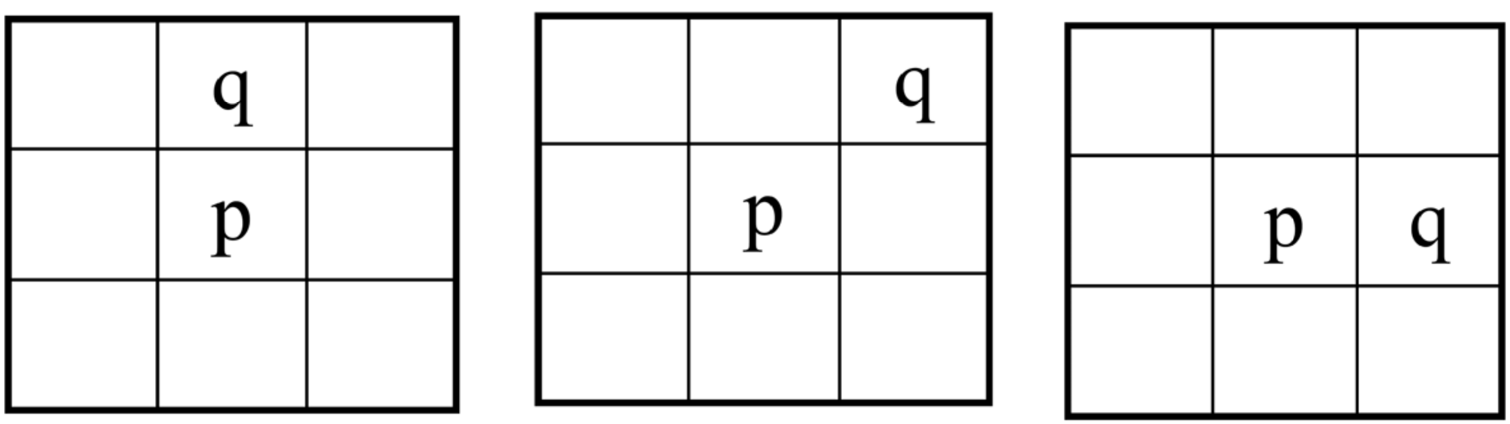
- Connectivity:
  - Connectivity between pixels is a very important concept.
  - It is useful for
    - Establishing object boundaries
    - Defining image components/regions etc.

  Example: Segmentation of multiple objects (after segmentation how would we decide the group of pixels belong to one object, another group of pixels belong to another object, …)

  Solution: Connectivity among pixels (pixels with values 1 and are connected belong to one region; another set of pixels with values 1 but not connected to other set belong to another object)

Some Basic Relationships Between Pixels

- Connectivity:
  - Two pixels are said to be connected if they are adjacent in some sense
    - They are neighbors (N_4, N_D or N_8) and
    - Their intensity values (grey levels) are similar
  - For a binary image B, two points p and q are connected if $q \in N(p)$ or $p \in N(q)$ and $f(p)=f(q)$



Some Basic Relationships Between Pixels

- Connectivity:
  - Let V be the set of grey levels used to define connectivity for two points $f(p), f(q) \in V$, three types of connectivity can be defined
    - 4-connectivity: $f(p), f(q) \in V$ & $p \in N_4(q)$
    - 8-connectivity: $f(p), f(q) \in V$ & $p \in N_8(q)$
    - m-connectivity (mixed): $f(p), f(q) \in V$ are m-connected if

      (i) $q \in N_4(p)$ or

      (ii) $q \in N_D(p)$ & $N_4(p) \cap N_4(q) = \phi$

  - Mixed connectivity is a modification of 8-connectivity. It eliminates the multi-path connections that often arise with 8-conenctivity

Some Basic Relationships Between Pixels

- An example of connectivity: Let V={1}

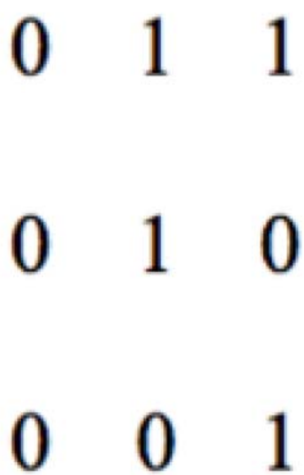


Fig: An arrangement of pixels

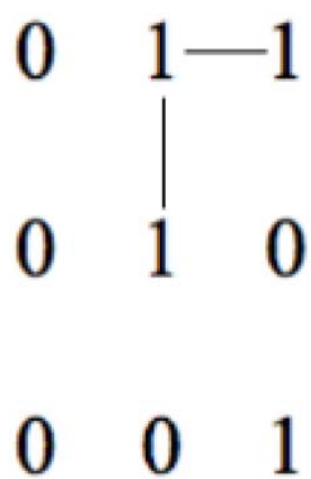


Fig: 4-connectivity of pixels

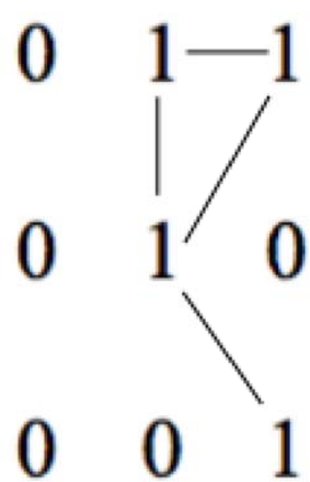


Fig: 8-connectivity of pixels

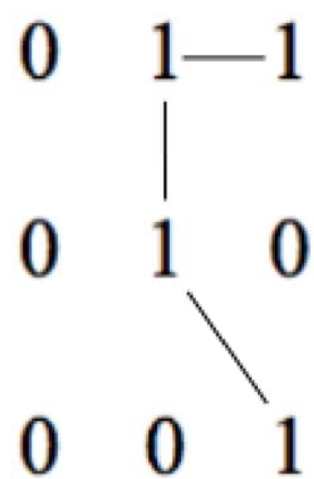


Fig: m-connectivity of pixels

Some Basic Relationships Between Pixels

- Adjacency:
  - Two pixels that are neighbors and have the same grey-level (or some other specified similarity criterion) are adjacent if they are **connected**
  - Pixels can be 4-adjacent, diagonally adjacent, 8-adjacent, or m-adjacent.
- *m*-adjacency (mixed adjacency):
  - Two pixels *p* and *q* of the same value (or specified similarity) are *m*-adjacent if either
    - (i) *q* and *p* are 4-adjacent, or
    - (ii) *p* and *q* are diagonally adjacent and do not have any common 4-adjacent neighbors.
    - They cannot be both (i) and (ii).

Some Basic Relationships Between Pixels

- Path:
  - The length of the path
  - Closed path
- Connectivity in a subset *S* of an image
  - Two pixels are connected if there is a path between them that lies completely within *S*.
- Connected component of *S*:
  - The set of all pixels in *S* that are connected to a given pixel in *S*.
- Region of an image
- Boundary, border or contour of a region
- Edge: a path of one or more pixels that separate two regions of significantly different gray levels.

Distance measures

- Distance function: a function of two points, *p* and *q*, in space that satisfies three criteria

$$(a)\ D(p,q) \geq 0$$

$$(b)\ D(p,q) = D(q,p), \text{ and}$$

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

- The Euclidean distance $D_e(p, q)$

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

- The city-block (Manhattan) distance $D_4(p, q)$

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

- The chessboard distance $D_8(p, q)$

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