What is an image?

An image is a two-dimensional function f(x,y), where x and y are the spatial (plane) coordinates, and the amplitude of f at any pair of coordinates (x,y) is called the intensity of the image at that level.

What is a digital image?

If x,y and the amplitude values of f are finite and discrete quantities, we call the image a digital image. A digital image is composed of a finite number of elements called pixels, each of which has a particular location and value.

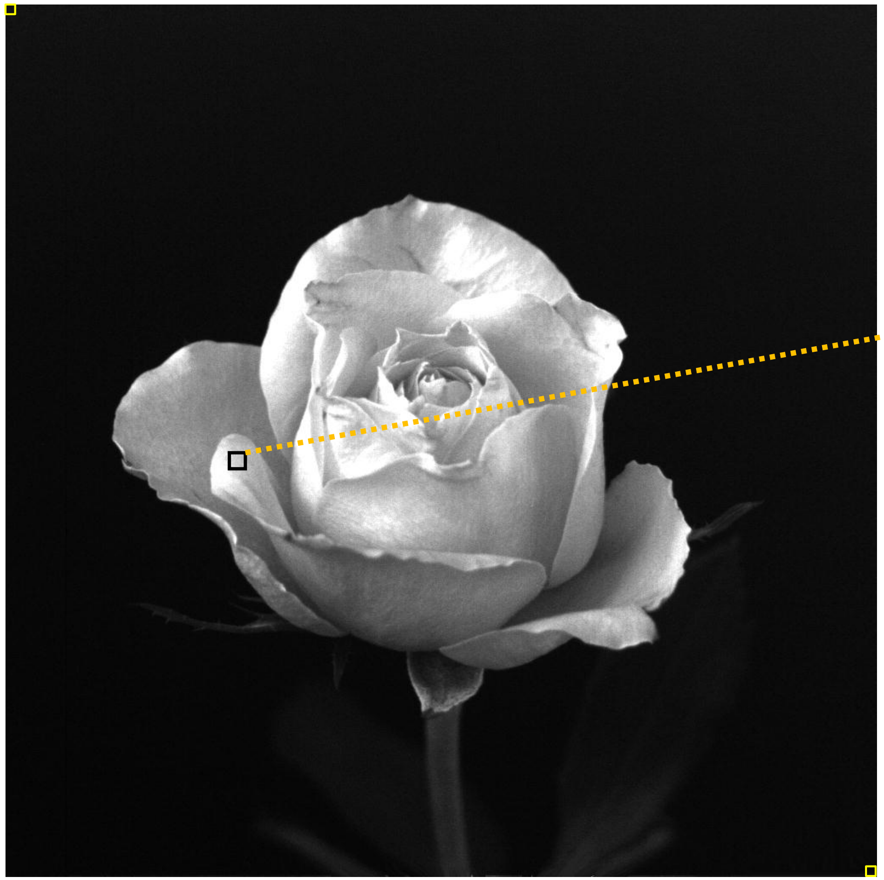
First Digital Photograph Ever: Russell Kirsch in 1957 made a 176×176 pixel digital image by scanning a photograph of his three-month-old son.

*Consider the following image (1024 x1024 pixels) to be 2D function or a **matrix** with **rows** and **columns***

Pixel location

Pixel intensity value

$f(\underbrace{1,1}) = 21$



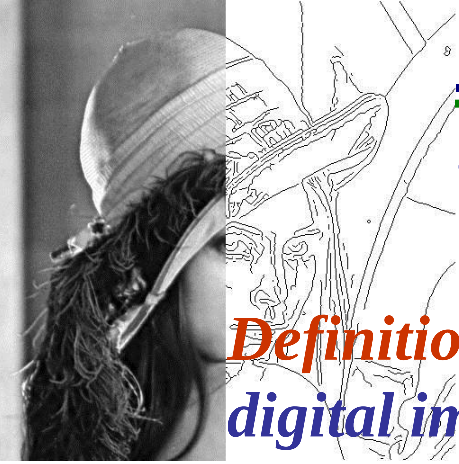
$f(1024,1024) = 15$

In 8-bit representation Pixel intensity values change between <u>0 (Black)</u> and <u>255 (White)</u>

rows columns

$$f(\underbrace{520:525}_{\text{rows}},\underbrace{375:380}_{\text{columns}}) =$$

$$\begin{matrix} 152 & 148 & 144 & 152 & 181 & 203 \\ 144 & 138 & 156 & 152 & 184 & 208 \\ 141 & 141 & 138 & 156 & 181 & 203 \\ 136 & 138 & 144 & 158 & 177 & 196 \\ 144 & 138 & 148 & 154 & 177 & 208 \\ 149 & 138 & 152 & 160 & 188 & 205 \end{matrix}$$



What is Digital Image Processing?

Definition: ***Digital image processing refers to processing of digital images by using digital computers.***

Sources of Digital Images

- ***The principal source for the images is the electromagnetic (EM) energy spectrum.***
- ***The spectral bands are grouped according to energy per photon ranging form the gamma rays (highest energy) to the radio waves (lowest energy).***

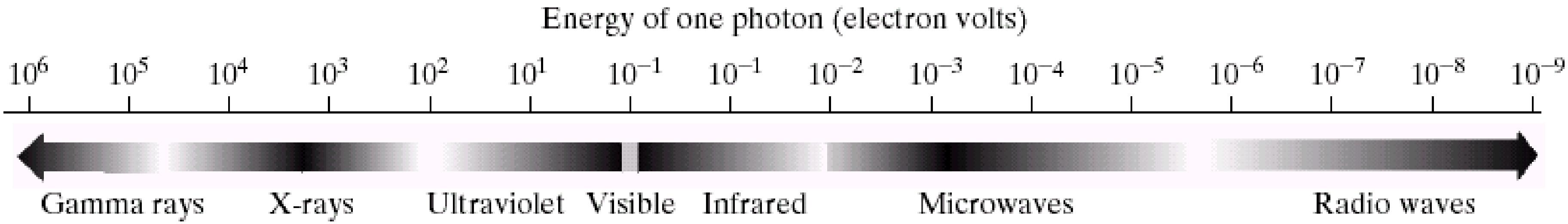


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

The Electromagnetic Spectrum

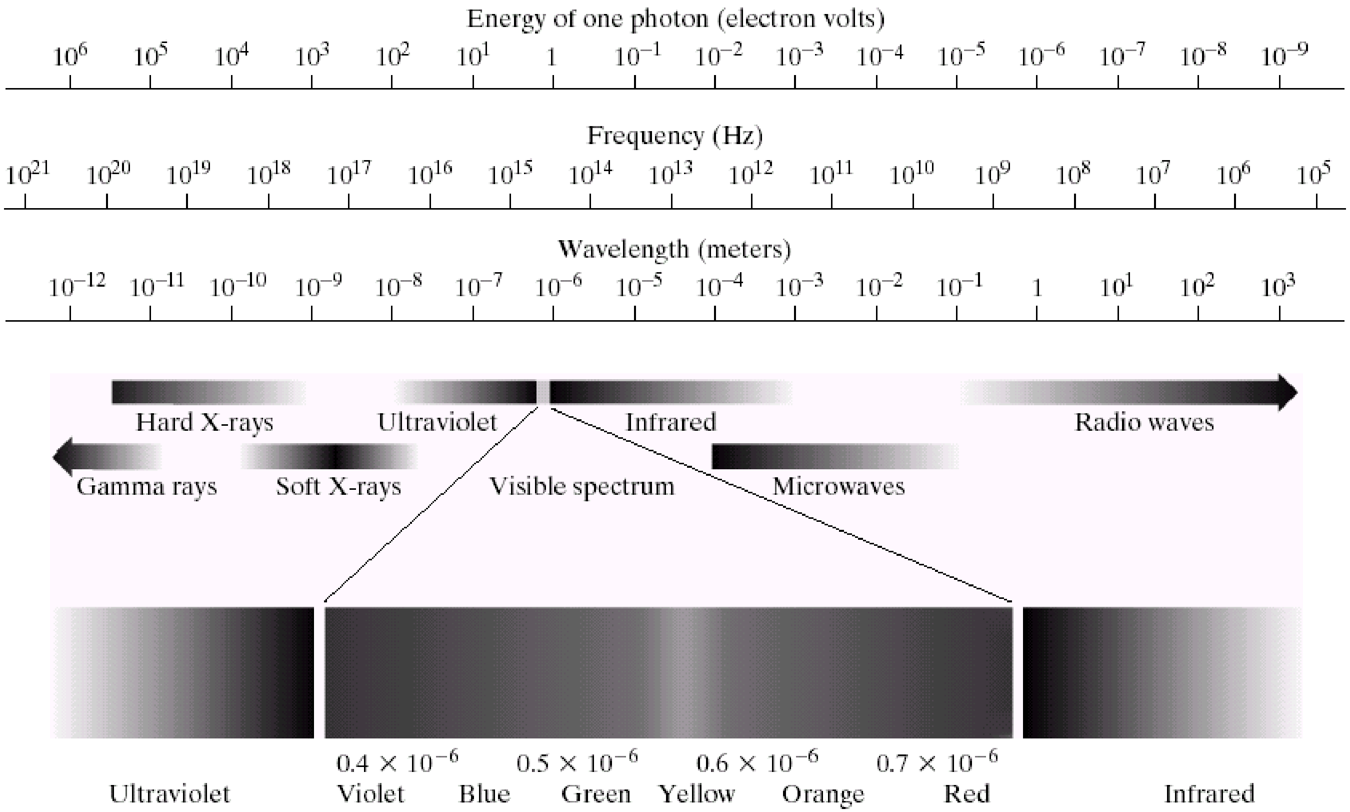
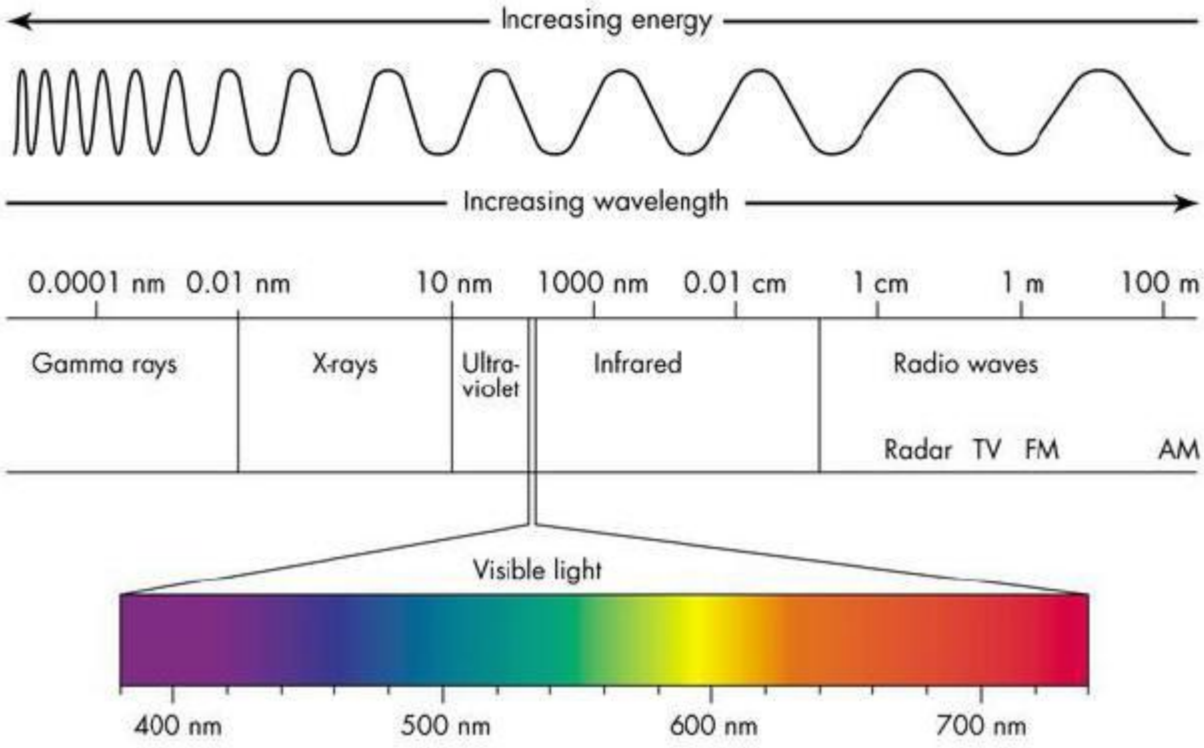


FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

The Electromagnetic Spectrum

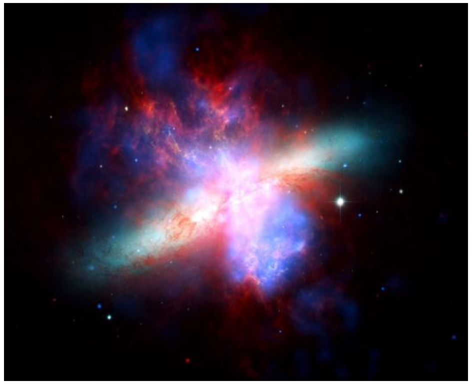


Digital Images based on the EM Spectrum

***Gamma Ray Imaging**: Used in nuclear medicine and astronomical observations.*

Gamma-Ray Imaging
İn nuclear medicine

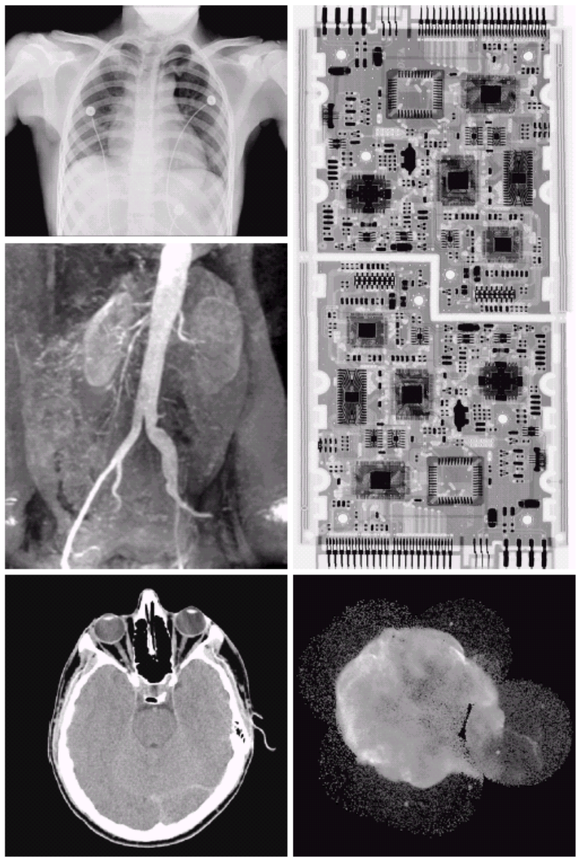
Gamma-Ray Imaging
Cherenkov Telescope



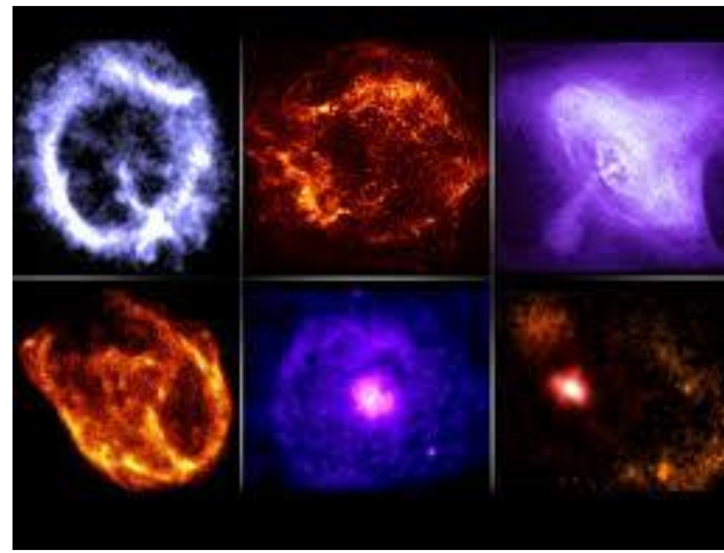
Gamma-Ray imaging of
A starburst galaxy about 12 million light-years away

Digital Images based on the EM Spectrum

***X-ray Imaging**: Used in medical diagnostic, industrial applications and astronomy.*



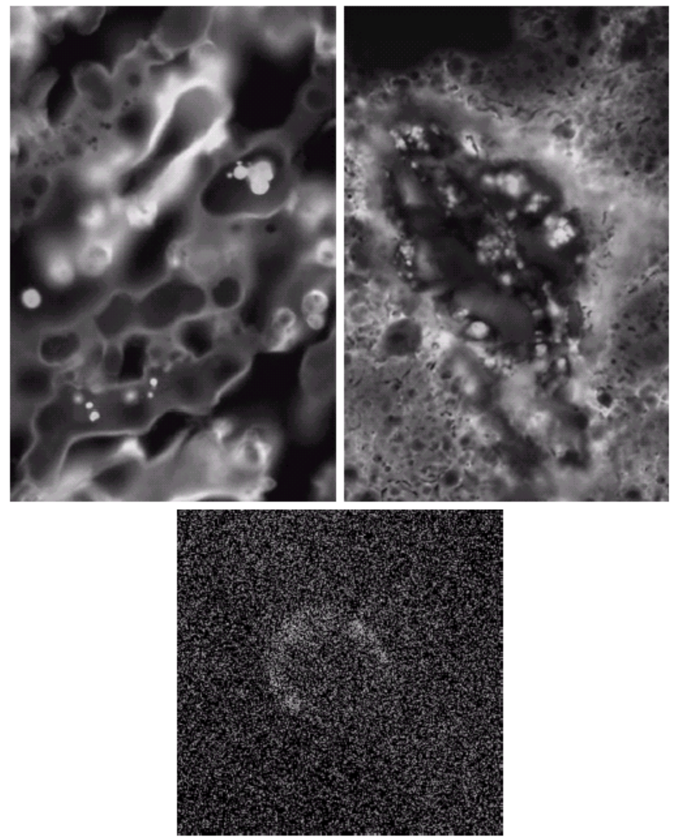
a b c d e **FIGURE 1.7** Examples of X-ray imaging. (a) Chest X-ray. (b) Aortic angiogram. (c) Head CT. (d) Circuit boards. (e) Cygnus Loop. (Images courtesy of (a) and (c) Dr. David R. Pickens, Dept. of Radiology & Radiological Sciences, Vanderbilt University Medical Center, (b) Dr. Thomas R. Gest,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



X-ray images from the space
The Chandra X-Ray Observatory

Digital Images based on the EM Spectrum

***Ultraviolet Band Imaging**: Applications of ultraviolet light includes microscopy, lasers, biological imaging and astronomy.*



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.)

Digital Images based on the EM Spectrum

Visible Light and Infrared Band Imaging: Applications include all the images acquired by our cameras, electron microscope, and monitoring environmental conditions.

Binary image

(1-bit)

Grayscale (Monochrome) image

(8-bit)

Color image

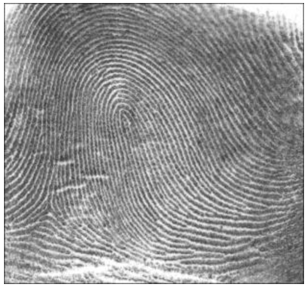
(24-bit)

R

G

B

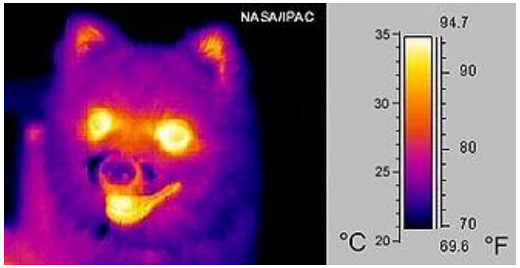
Respective RGB components of a color image.



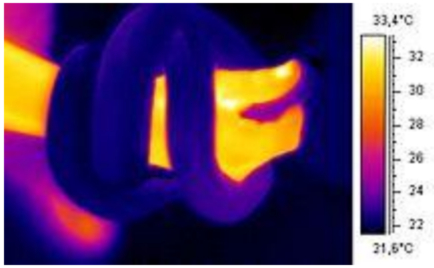
Some visible light image examples

Digital Images based on the EM Spectrum

Visible Light and __Infrared Band Imaging__: Applications include all the images acquired by our cameras, electron microscope, and monitoring environmental conditions.

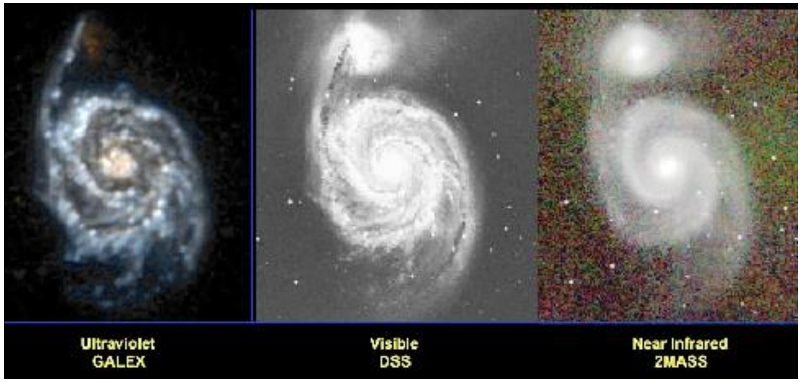


infrared ("thermal") image



Snake around the arm.

A soldier with a rifle.



Messier 51 in ultraviolet (GALEX), visible (DSS), and near infrared (2MASS).
Courtesy of James Fanson.

Digital Images based on the EM Spectrum

Visible Light and Infrared Band Imaging

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

Visible and Infrared Bands used in Satellite imaging

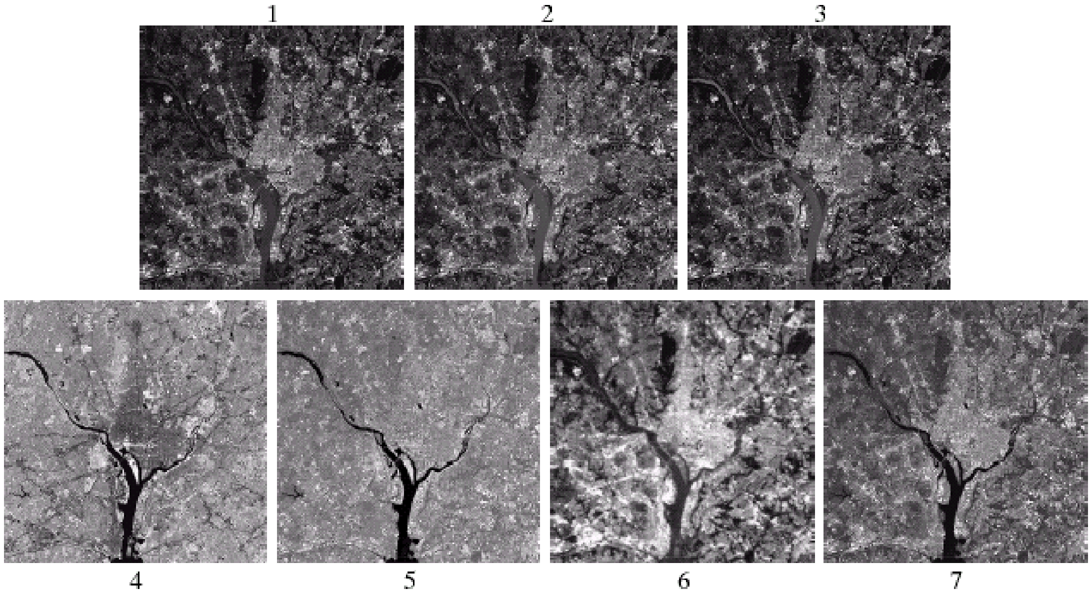
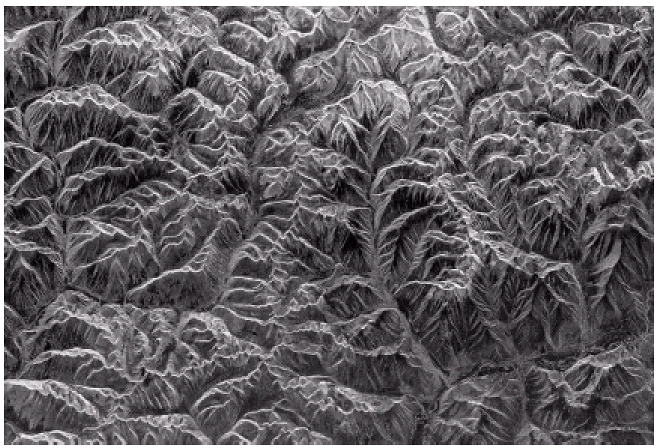


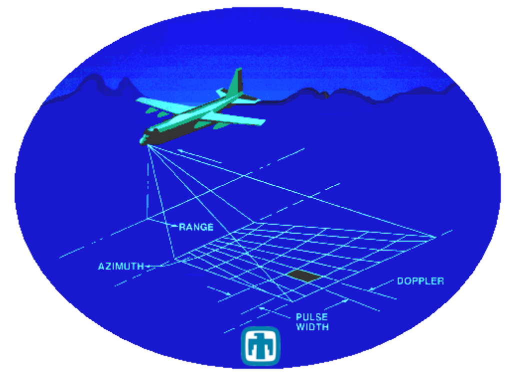
FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

Digital Images based on the EM Spectrum

Microwave Band Imaging *: Applications include all the radar applications including military applications and environmental applications.*

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

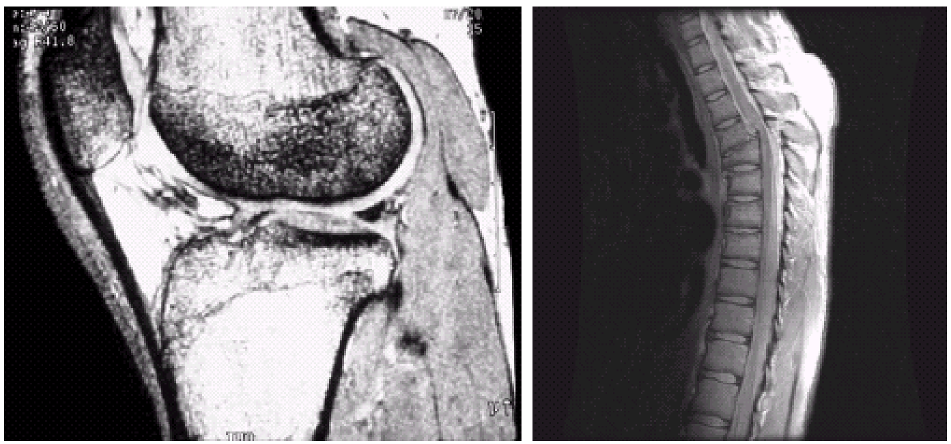




Synthetic Aperture Radar System

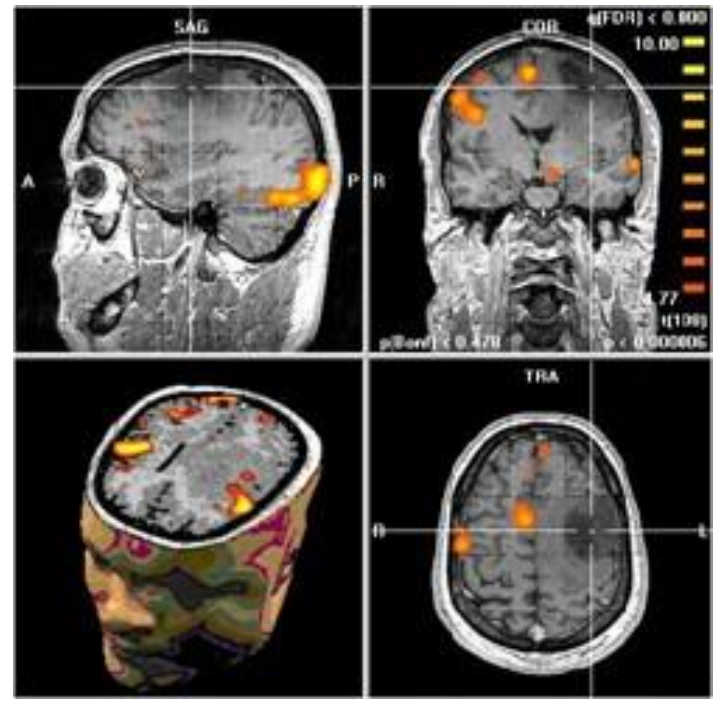
Digital Images based on the EM Spectrum

Radio Band Imaging *: Applications include medical imaging (i.e. Magnetic Resonance Imaging- MRI) and astronomy.*



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.)



MRI image slices from the brain

Digital Images based on the EM Spectrum

An example showing Imaging in all of the bands

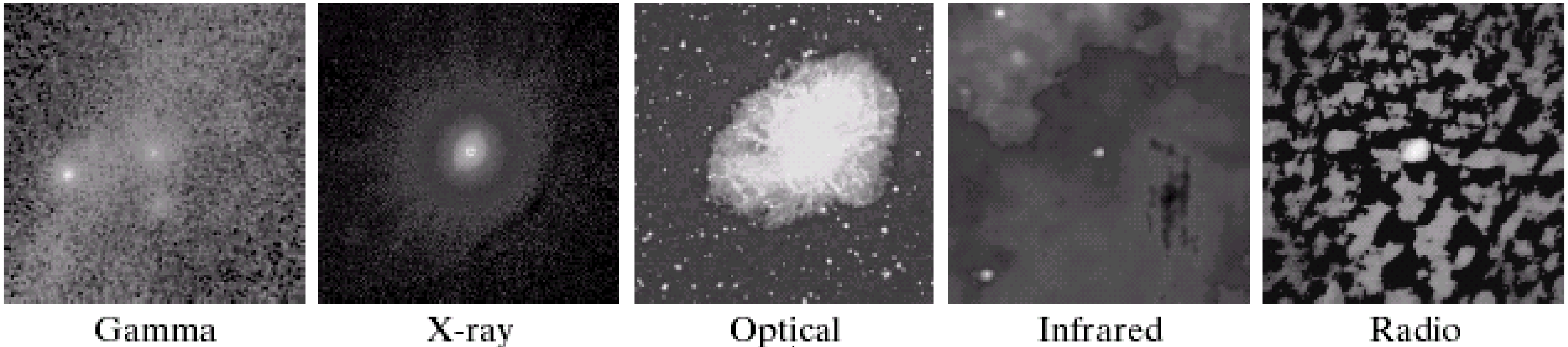
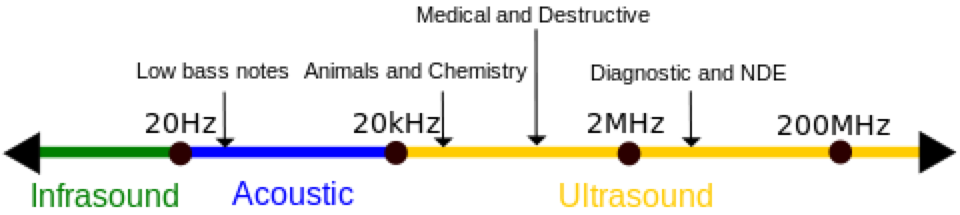


FIGURE 1.18 Images of the Crab Pulsar (in the center of images) covering the electromagnetic spectrum. (Courtesy of NASA.)

Visible light

Digital Images based on the Ultrasound

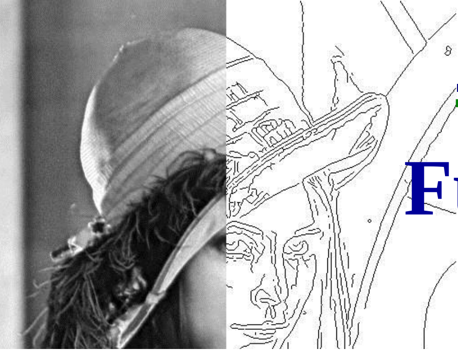
Ultrasound Imaging: *Ultrasound is a cyclic sound pressure wave with a frequency greater than the upper limit of human hearing. The most well-known application of ultrasound is its use in sonography to produce pictures of fetuses in the human womb.*



Ultrasonic spectrum

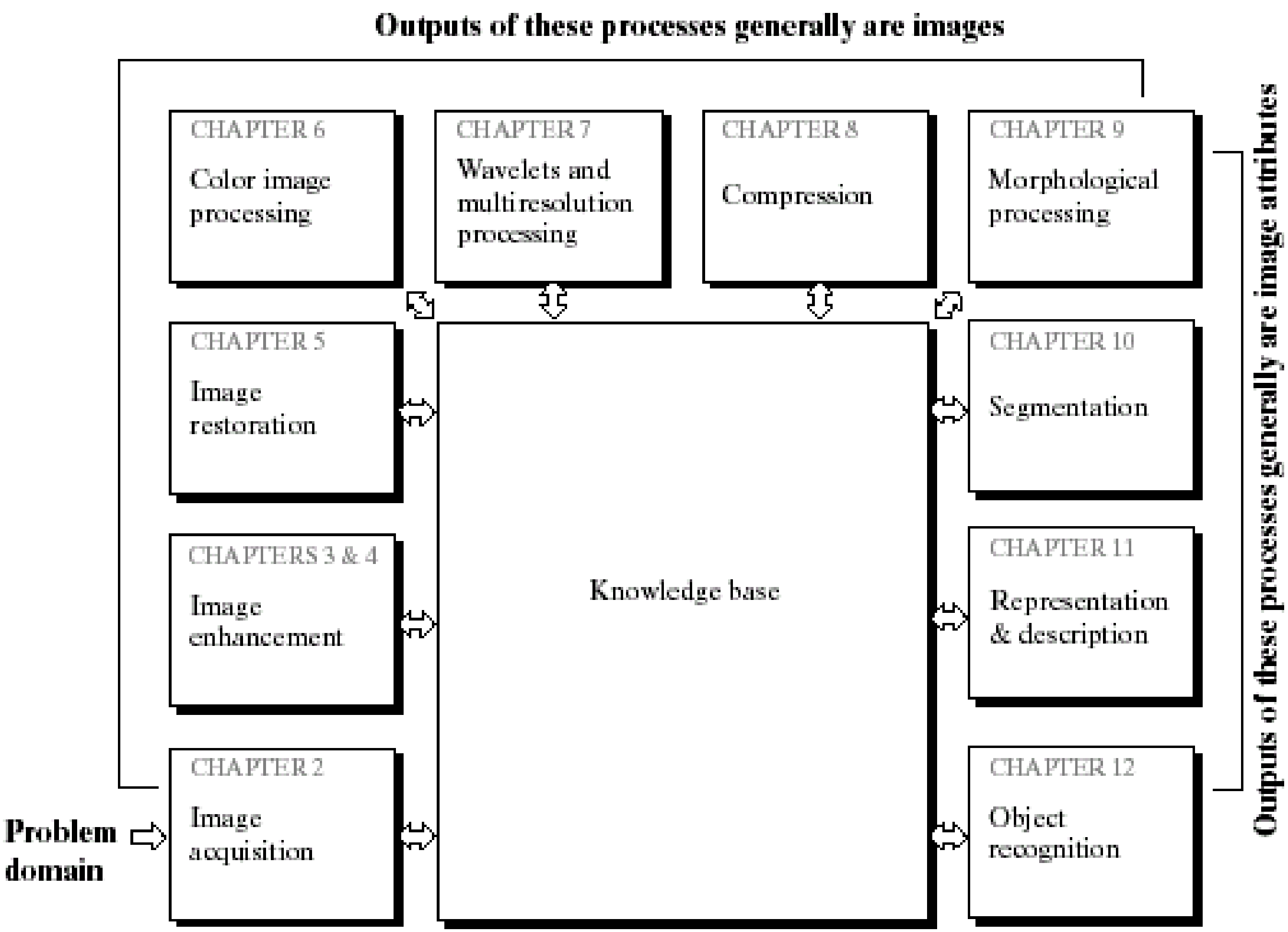
Ultrasound image acquisition device

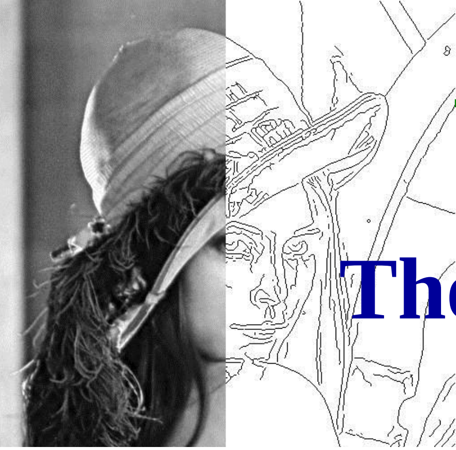
Ultrasonic Baby image during pragnancy



Fundamental Steps in Image Processing

FIGURE 1.23 Fundamental steps in digital image processing.





The Human Eye & Image Formation

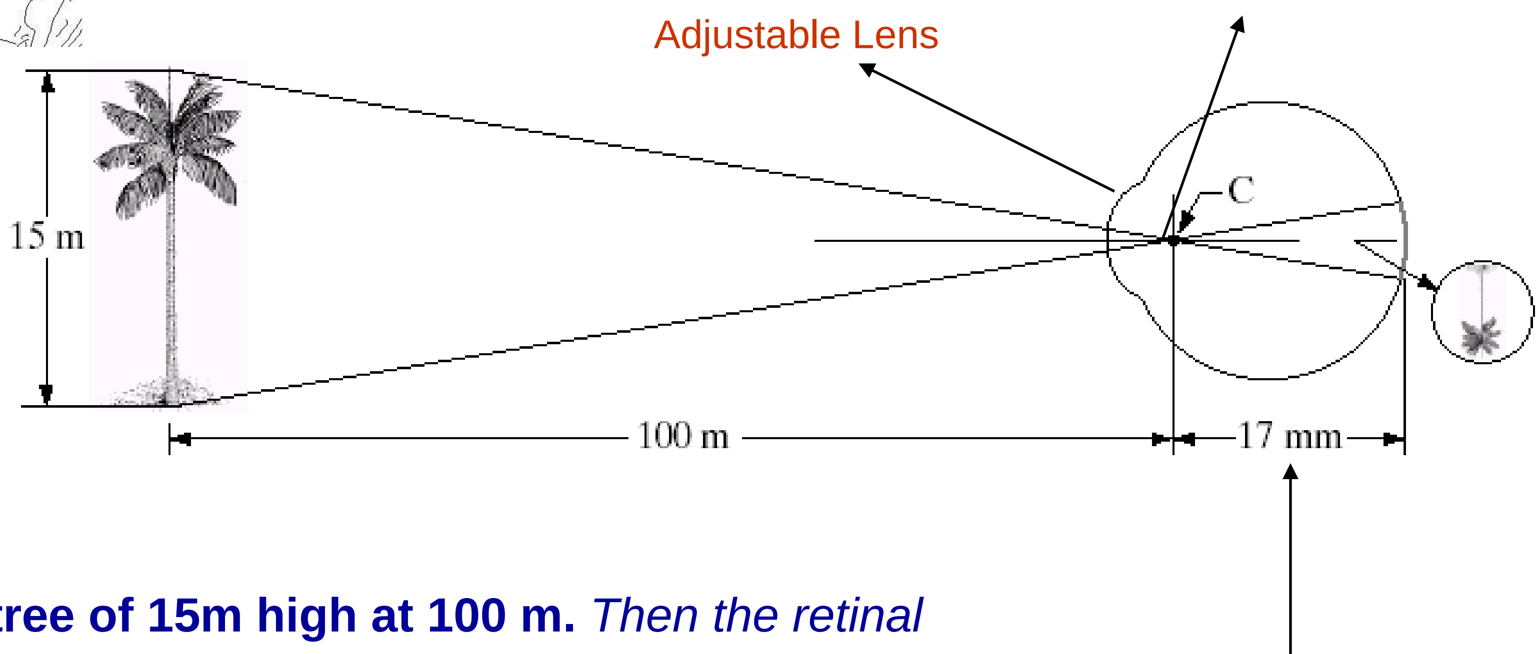


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point *C* is the optical center of the lens.

Consider a tree of 15m high at 100 m. *Then the retinal image height can be calculated by:*

$$\boxed{\frac{15}{100} = \frac{h}{17} \quad \Rightarrow \quad h = 2.55mm}$$

Acquisition of Images.

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.

***Imaging sensors* are used to transform the *illumination energy* into digital images.**

Each *sensor* transforms the incoming energy into *voltage* by the combination of the input electrical power and the sensor material that is responsive to the particular type of energy being detected.

Types of Image Sensors

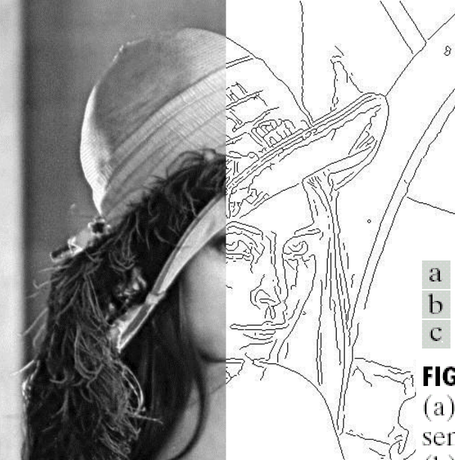
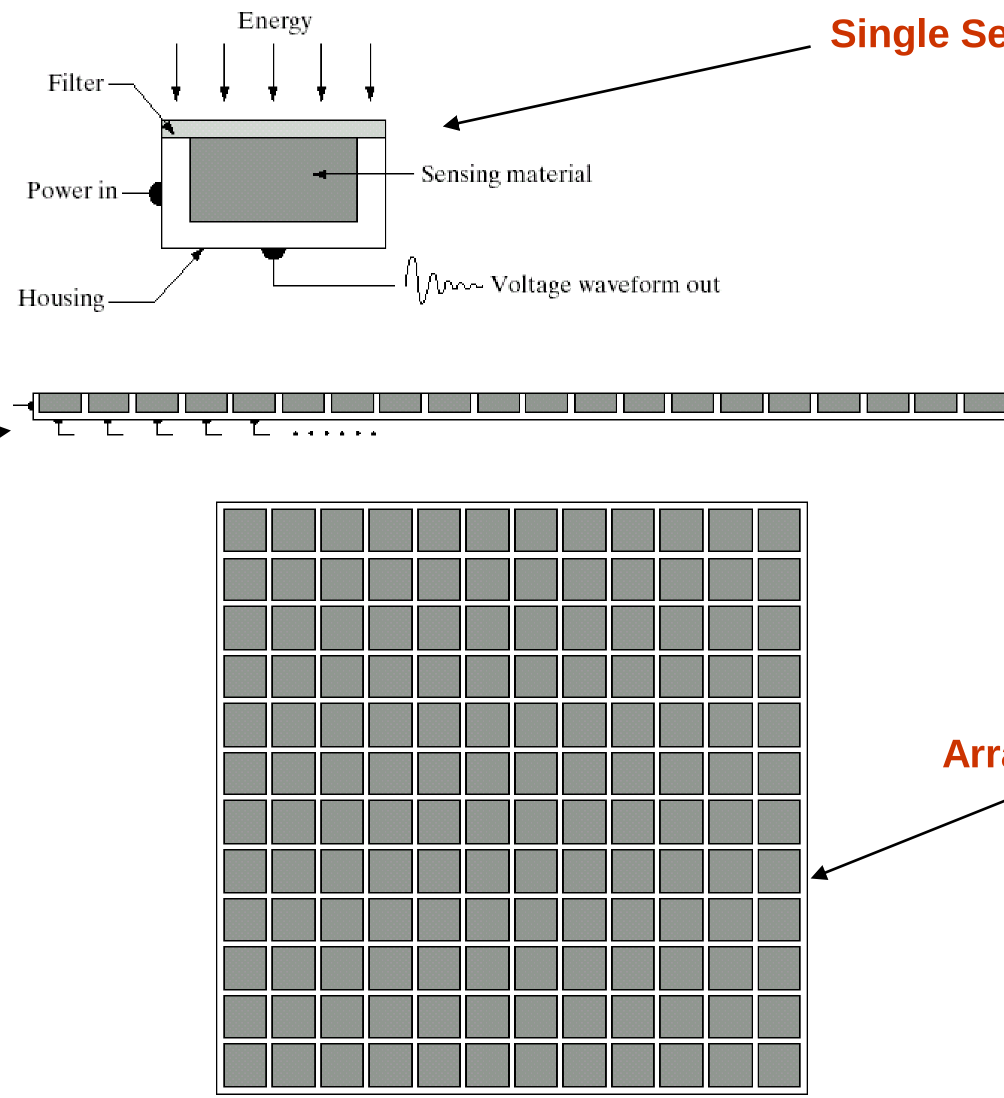


FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.



Single Sensor

Line Sensor

Array Sensor

Dr. Hasan Demirel, PhD

Image Acquisition using Single Sensor

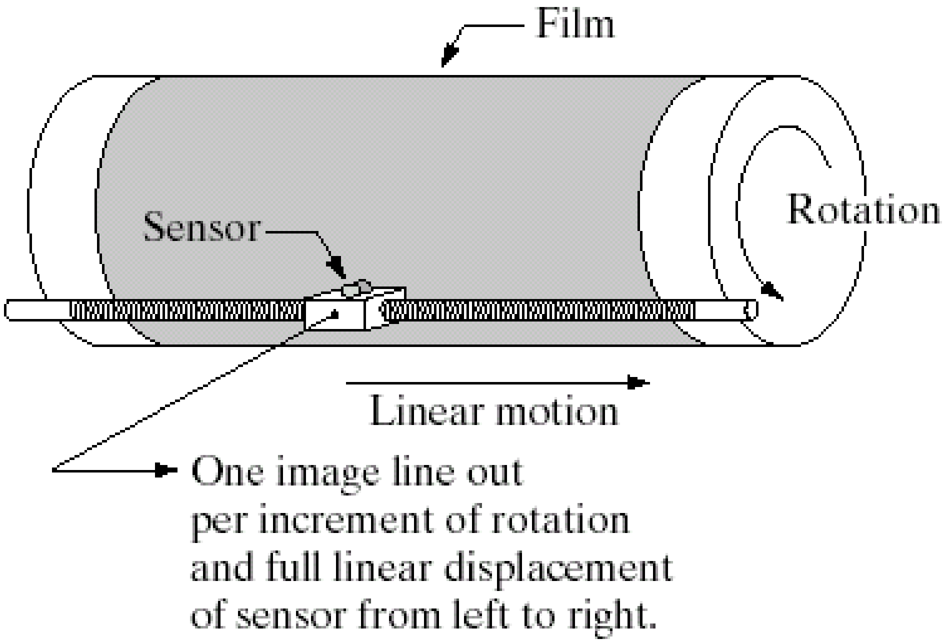


FIGURE 2.13 Combining a single sensor with motion to generate a 2-D image.

Image Acquisition using Line Sensor

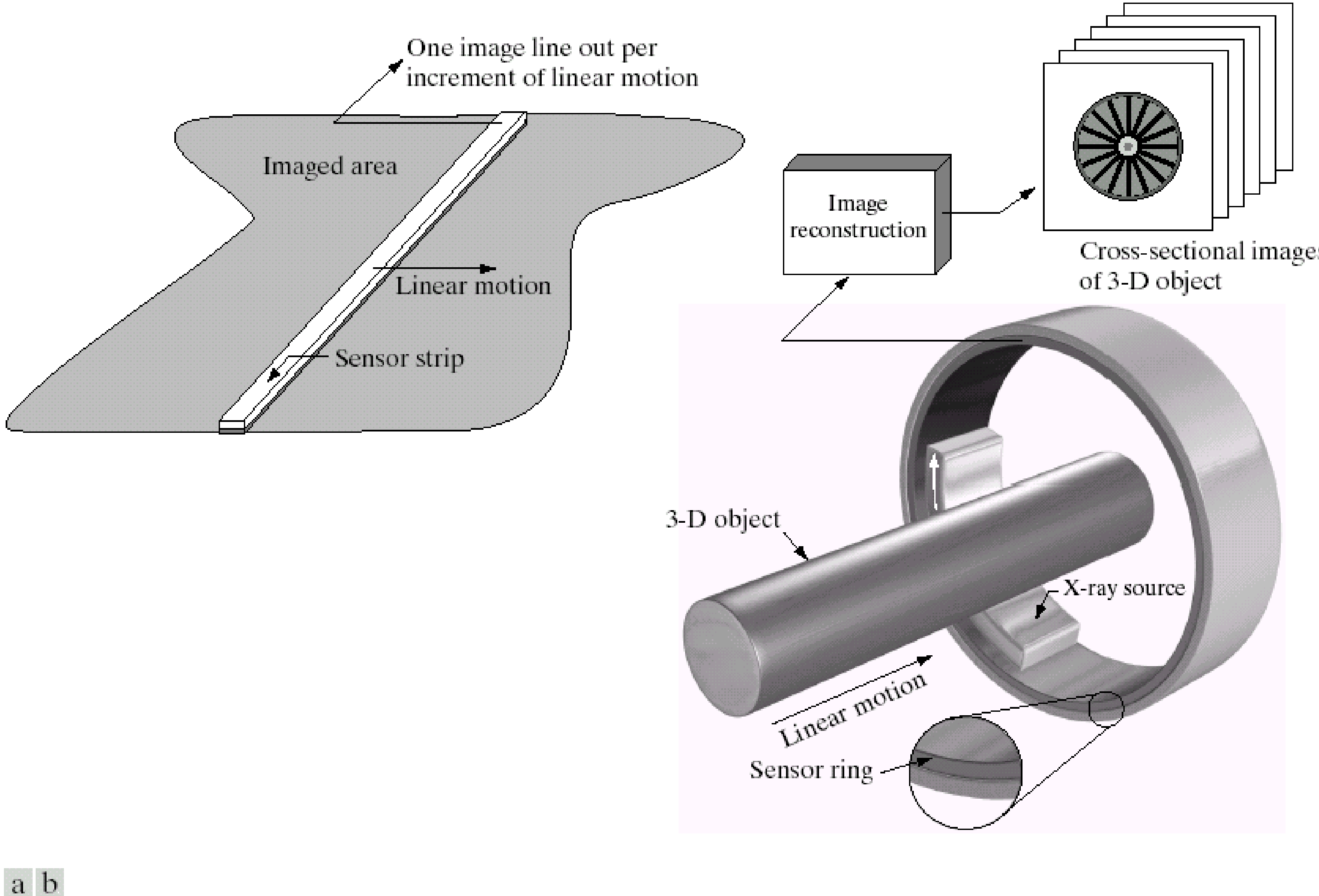


FIGURE 2.14 (a) Image acquisition using a linear sensor strip. (b) Image acquisition using a circular sensor strip.

Image Acquisition using Sensor Array

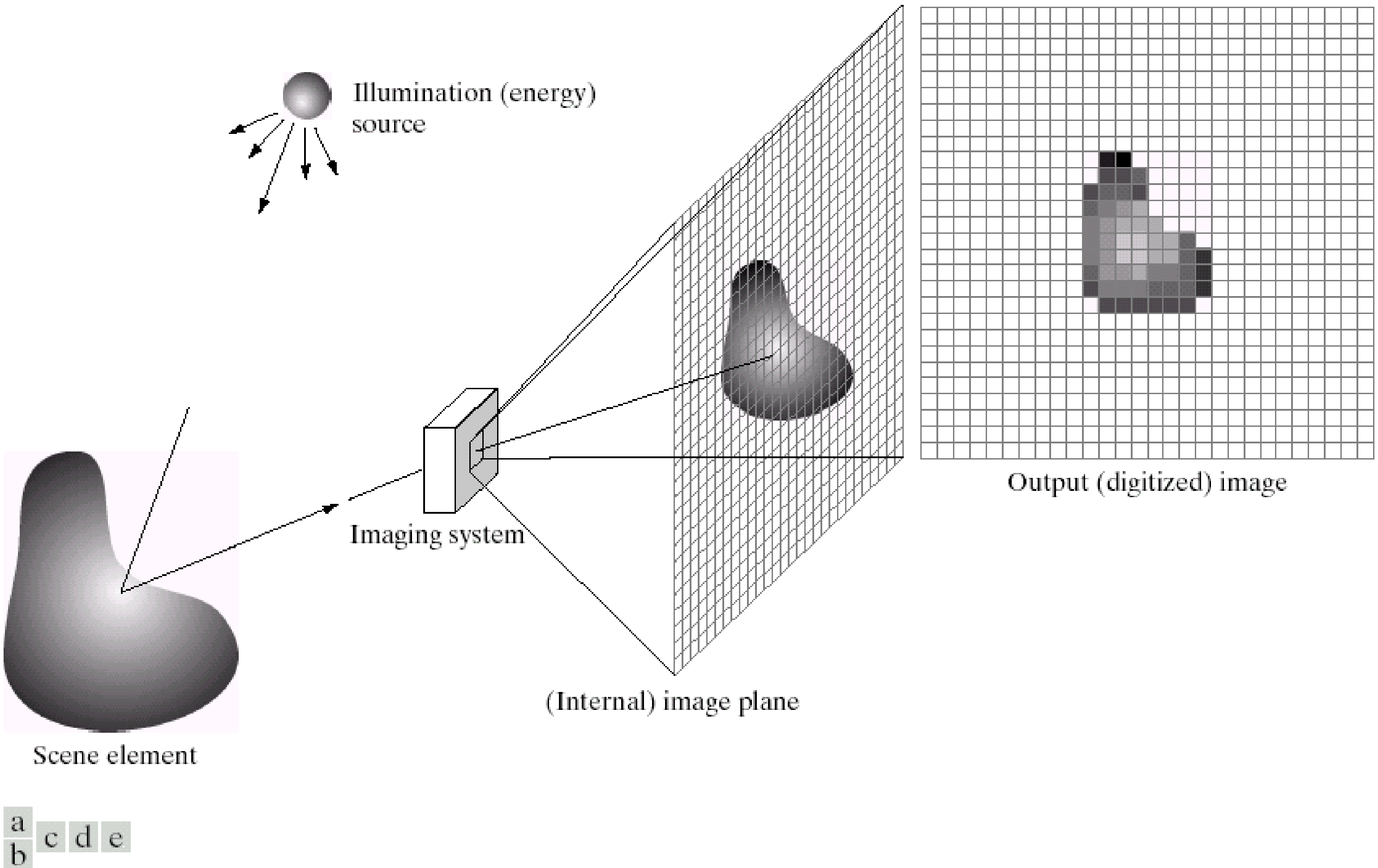


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Image Sampling and Quantization

A digital image can be obtained by converting a continuous/ analog image in a digital form by:

Sampling and
Quantization.

Given a continuous image, f(x,y), digitizing the coordinate values is called sampling and digitizing the amplitude (intensity) values is called quantization.

Image Sampling and Quantization

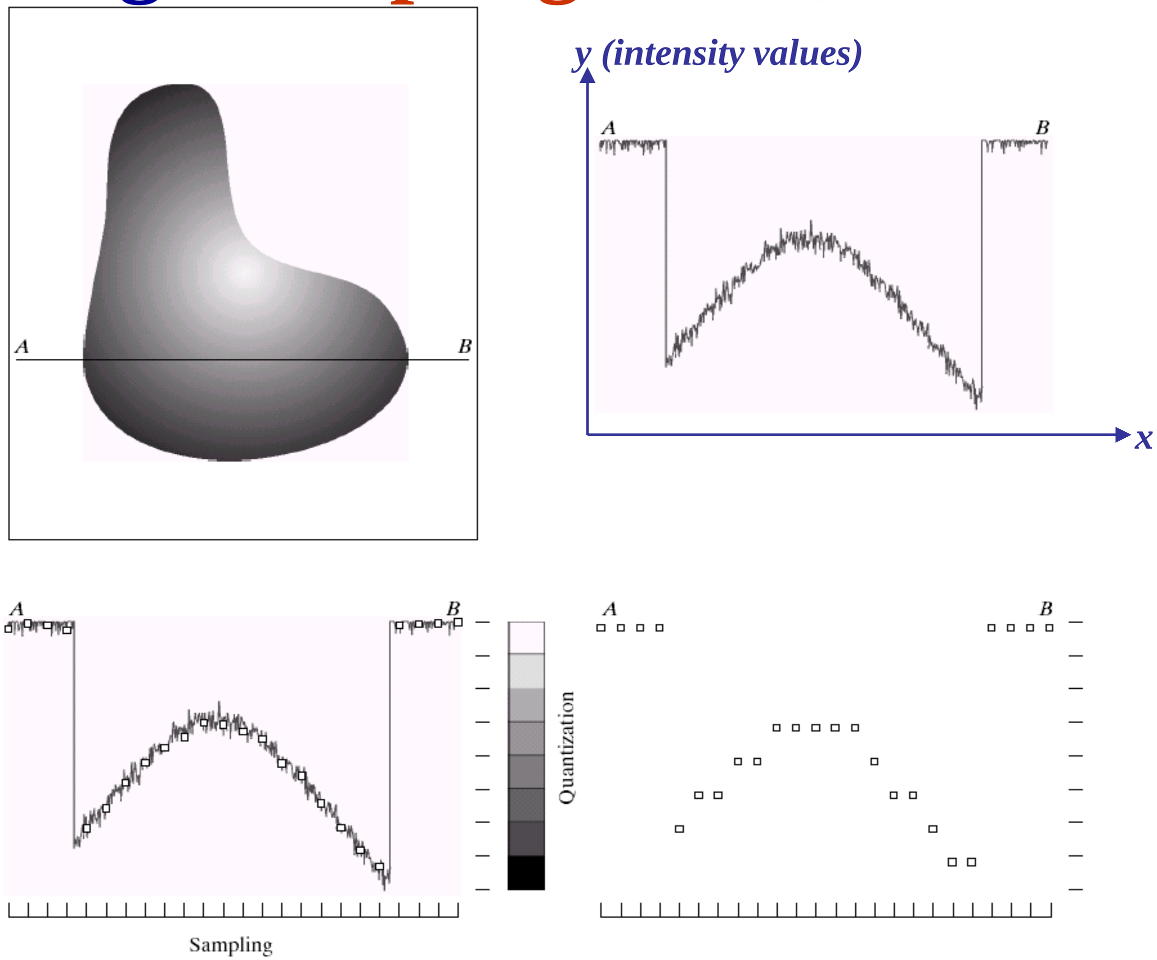
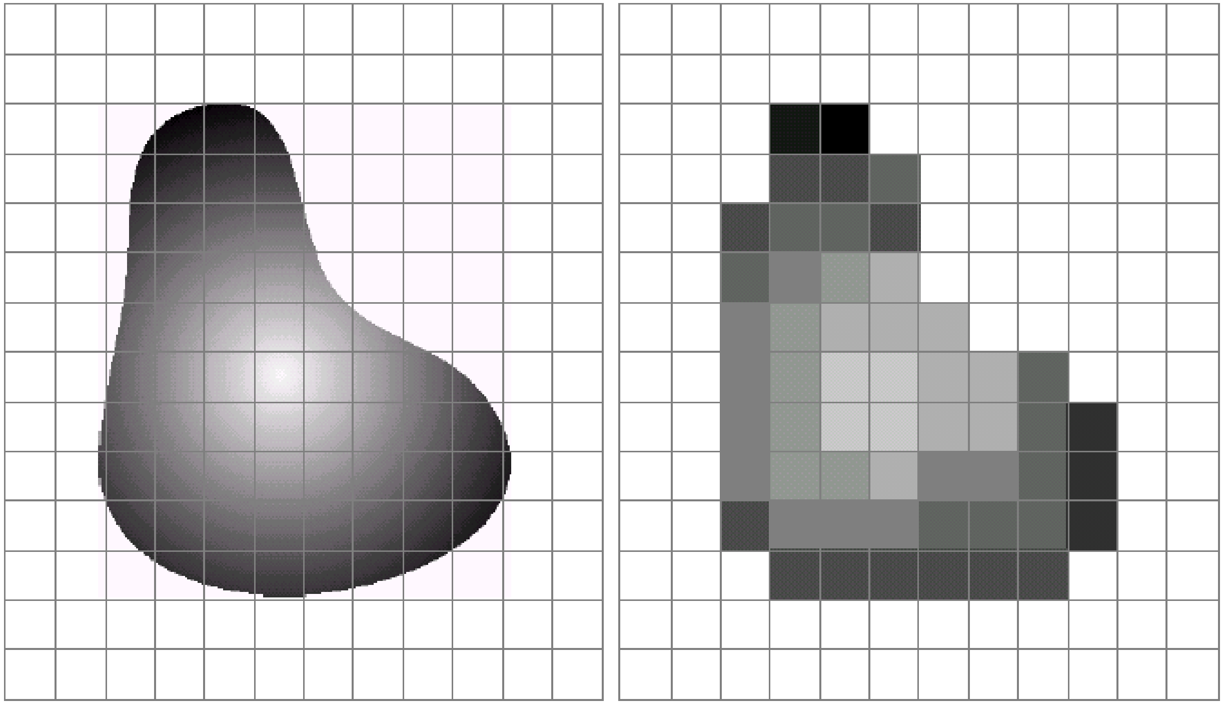


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Image Sampling and Quantization



a b

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

Matrix Representation of Images

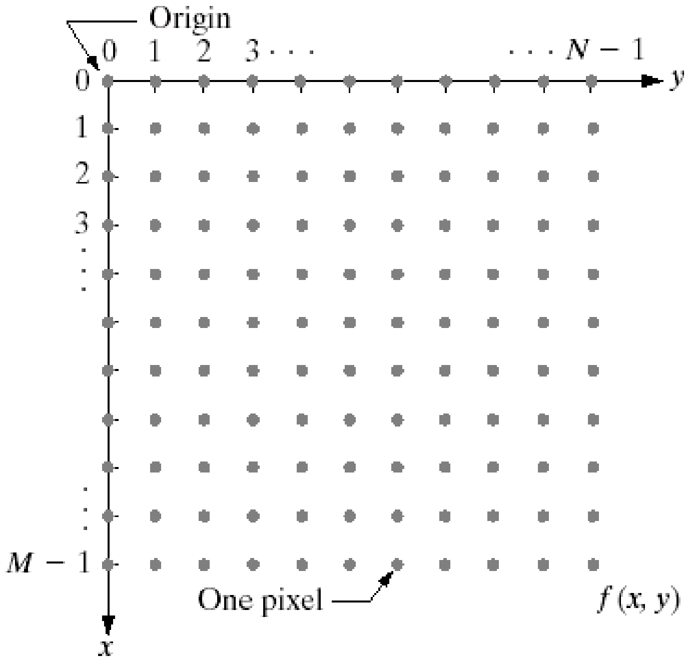


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

A matrix representing an *N* x *M* image.

- ***M* and *N* can be any positive integers.**
- **The number of gray levels, *L*, is an integer power of 2.**

$$L=2^k \quad \text{(}k\text{ is \# of bits per pixel)}$$

- **Number of bits required to store a digitized image:**

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

Number of bits used to represent an image

Assume that $M=N$. *Therefore* $b=N^2 k$

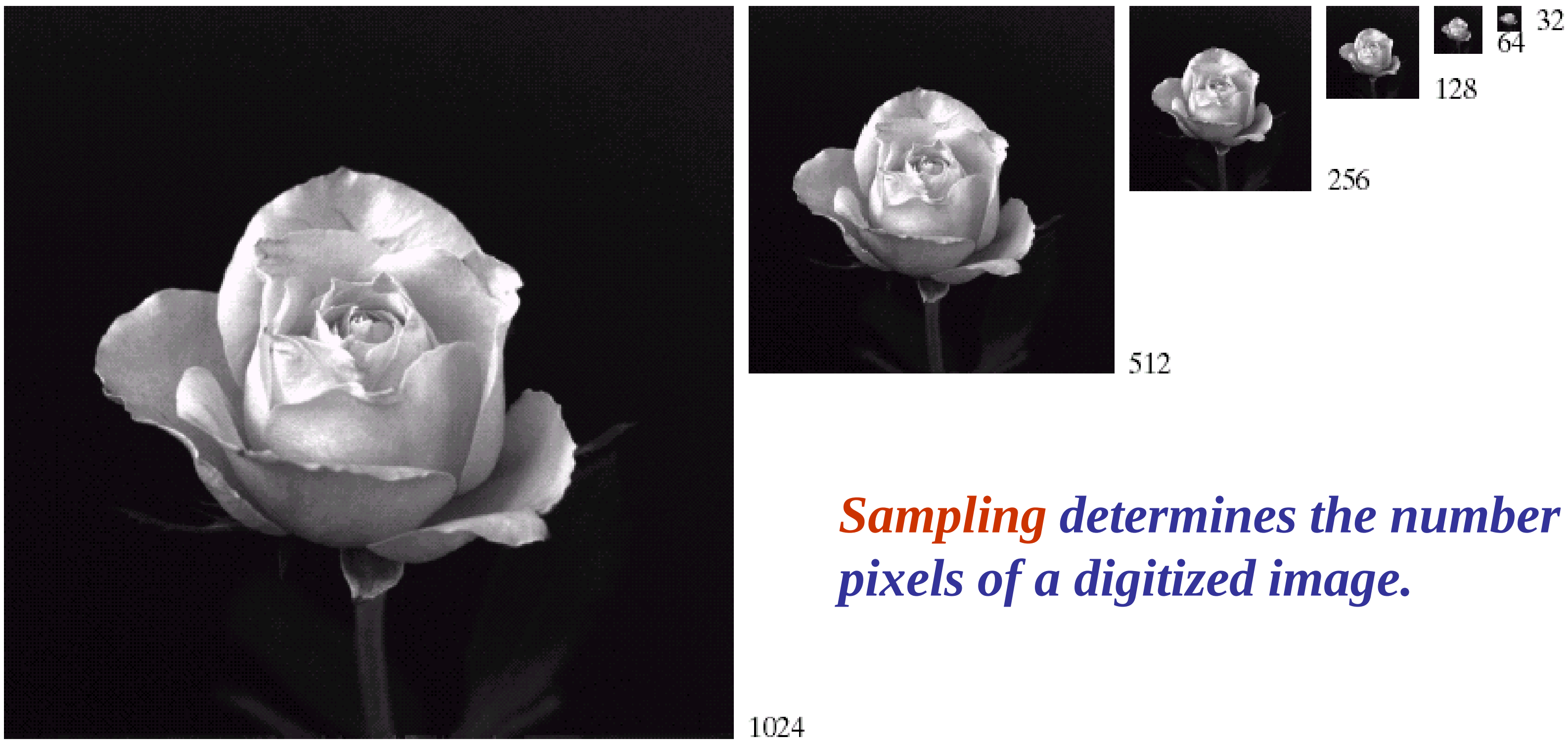
TABLE 2.1

Number of storage bits for various values of N and k.

N/k	1 ($L = 2$)	2 ($L = 4$)	3 ($L = 8$)	4 ($L = 16$)	5 ($L = 32$)	6 ($L = 64$)	7 ($L = 128$)	8 ($L = 256$)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

Sampling and Spatial Resolution

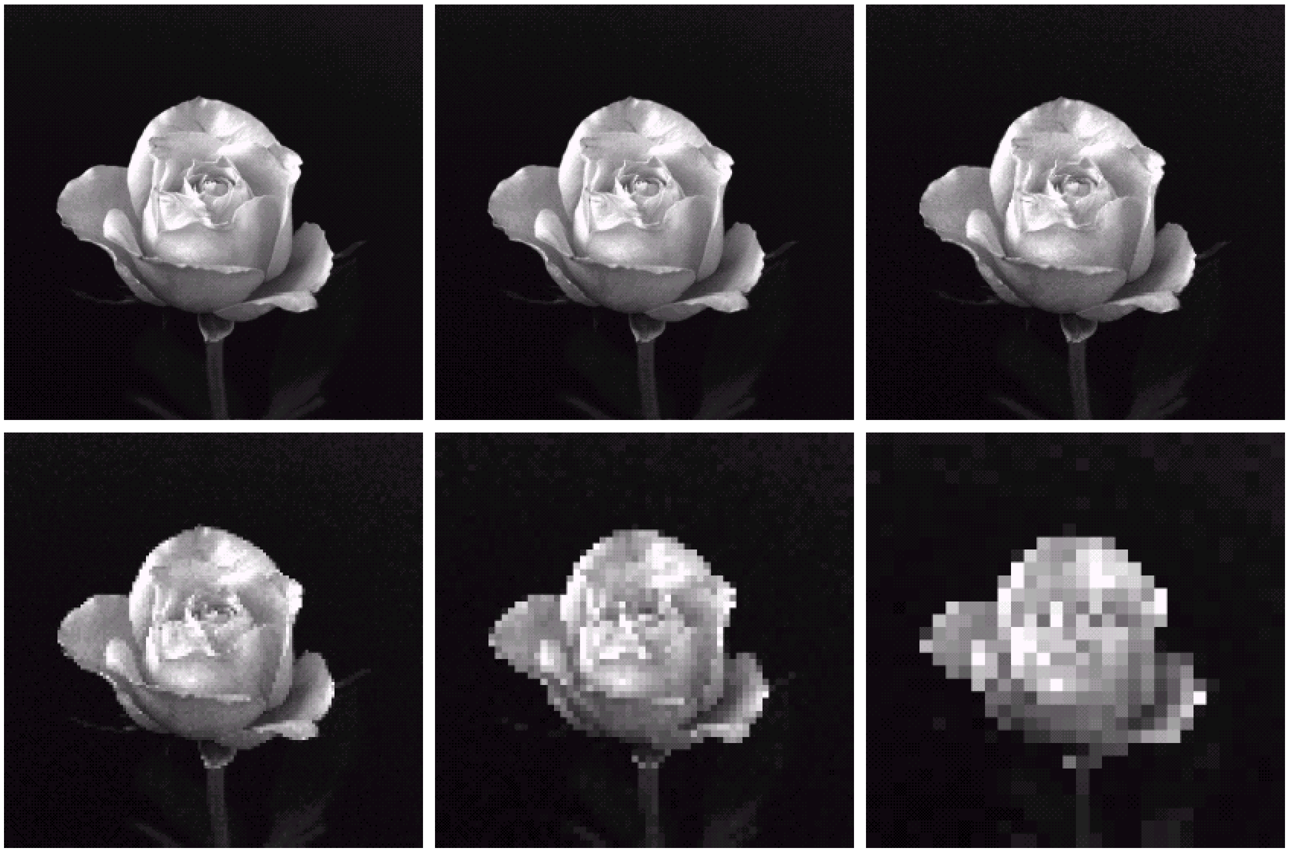
Sampling is the principal factor determining the spatial resolution of an image.



Sampling determines the number of pixels of a digitized image.

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.

Sampling and Spatial Resolution



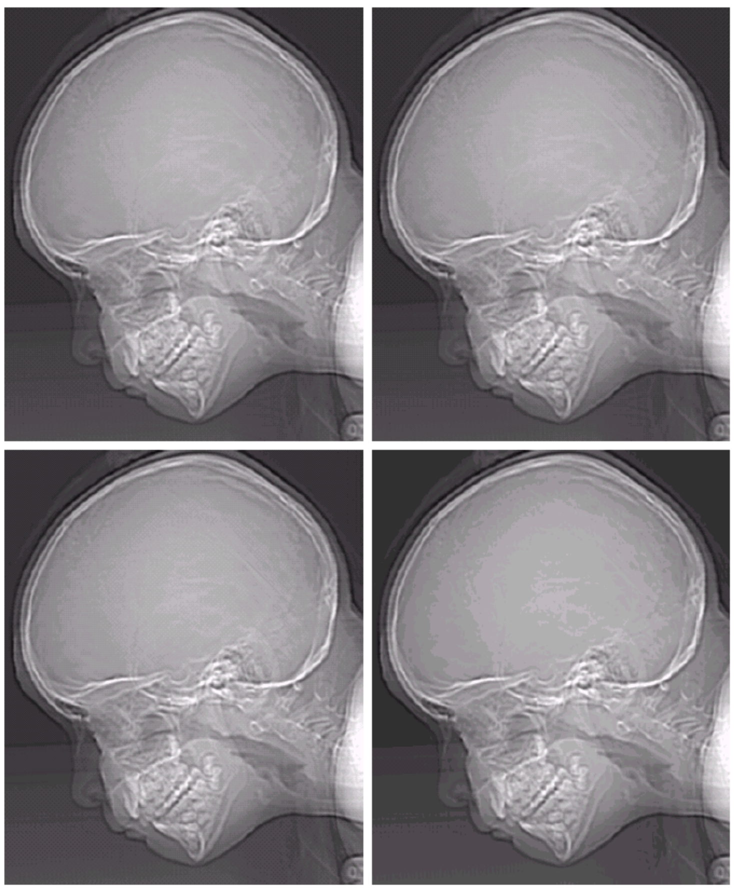
a b c
d e f

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.

Quantization and Gray-level Resolution

Quantization is the most important factor determining the gray-level resolution of an image.

Quantization determines the number of gray levels that each pixel can take.

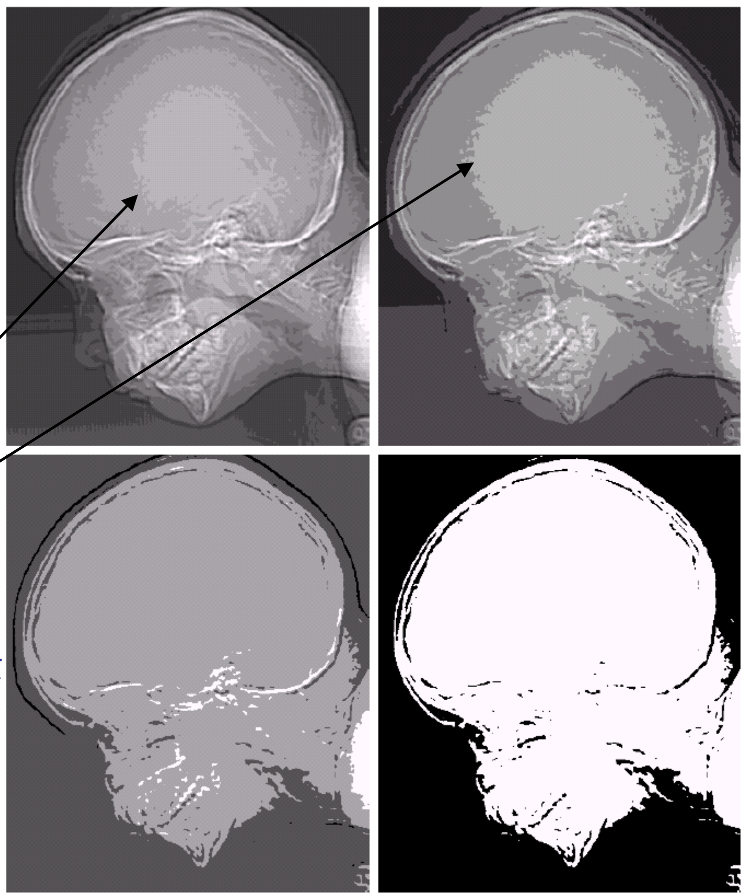


a b
c d

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.)



False contouring effect is visible in 16 and less gray level images.

Resizing Images: Zooming and Shrinking

***Zooming** is a method of increasing the size of a given image.*
*Zooming can be viewed as **oversampling** or **upsampling** of a given image.*
*Zooming requires **2 steps**:*

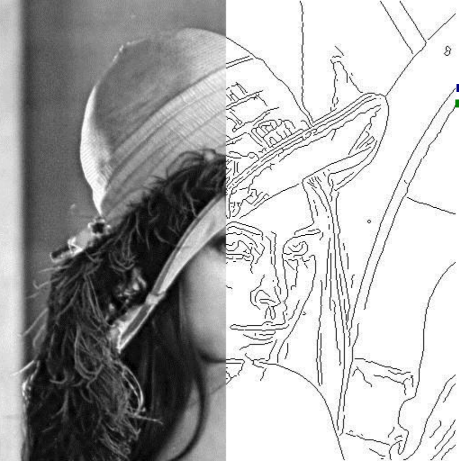
- *Creation of new pixel locations*
- *Assigning new gray-level values to these locations by using **interpolation**.*

Original image

Resize-zoom

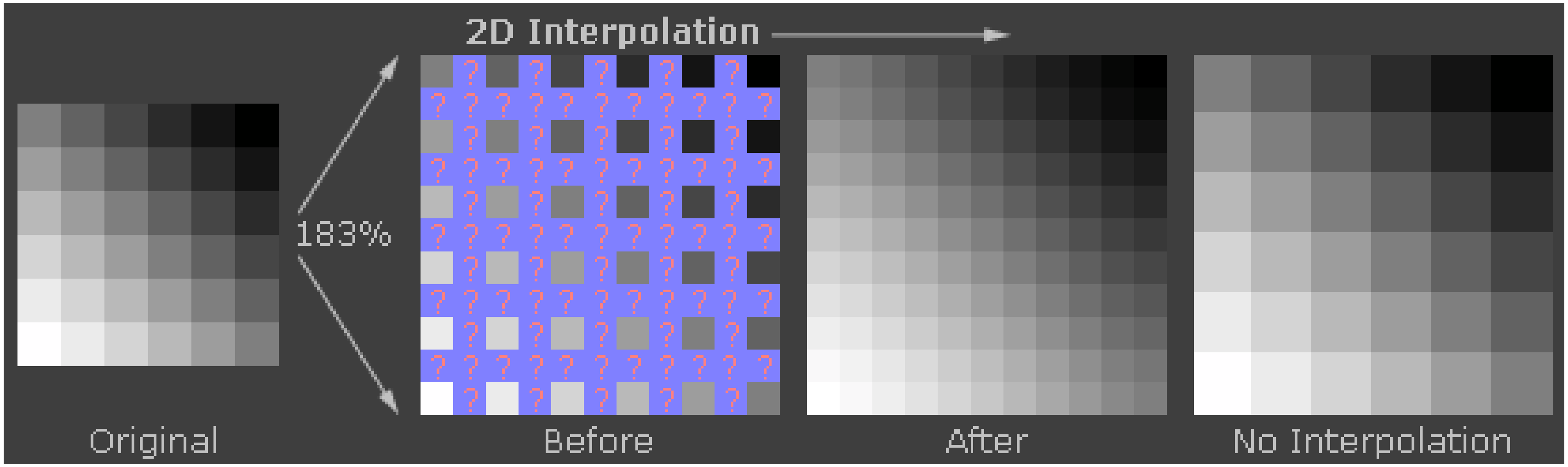
After Interpolation

***Interpolation** is defined to be the estimation of the value of unknown point by using the values of known points.*



Resizing Images: Zooming and Shrinking

2-D Interpolation

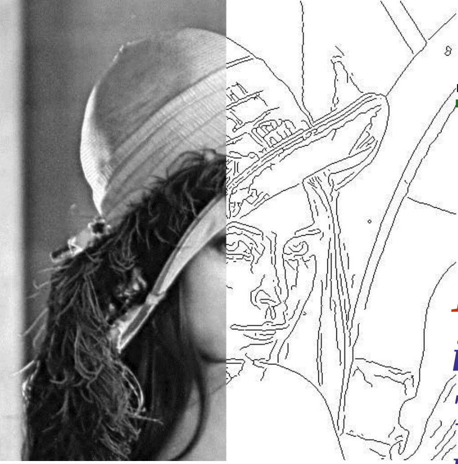


There are 3 main types of 2-D Interpolation techniques for zooming:

- nearest neighbor interpolation

- bilinear interpolation

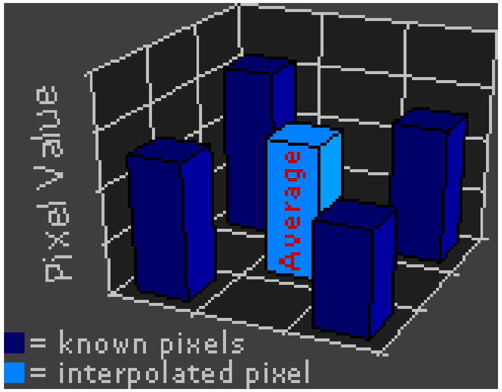
- bicubic interpolation

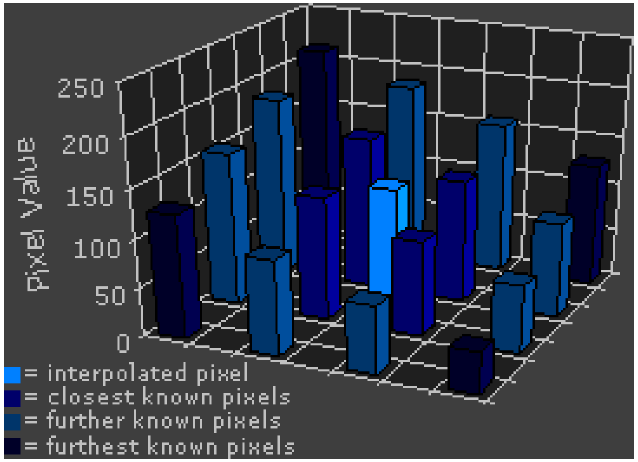


Zooming : Interpolation Techniques

Nearest neighbor interpolation: *Nearest neighbor interpolation is the simplest method and basically makes the pixels bigger. The intensity of a pixel in the new image is the intensity of the nearest pixel of the original image. If you enlarge 200%, one pixel will be enlarged to a 2 x 2 area of 4 pixels with the same color as the original pixel.*

Bilinear interpolation: *Bilinear interpolation 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.*





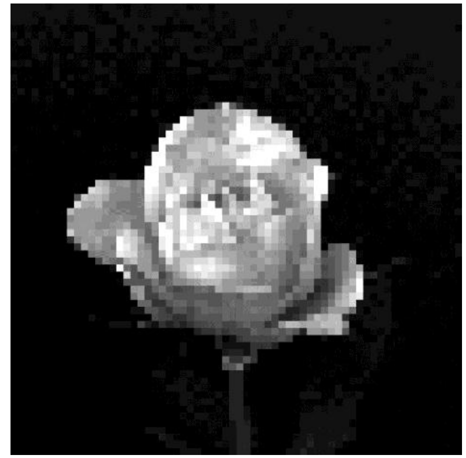
Bicubic interpolation: *Bicubic goes one step beyond bilinear by considering the closest 4x4 neighborhood of known pixels- for a total of 16 pixels. Since these are at various distances from the unknown pixel, closer pixels are given a higher weighting in the calculation. Bicubic interpolation produces noticeably sharper images than the previous two methods, and is perhaps the ideal combination of processing time and output quality.*

Dr. Hasan Demirel, PhD

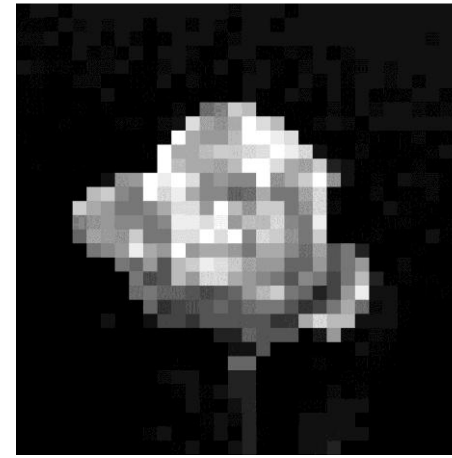
Zooming : Interpolation Techniques

Nearest Neighbour

128x128 ⇨ 1024x1024



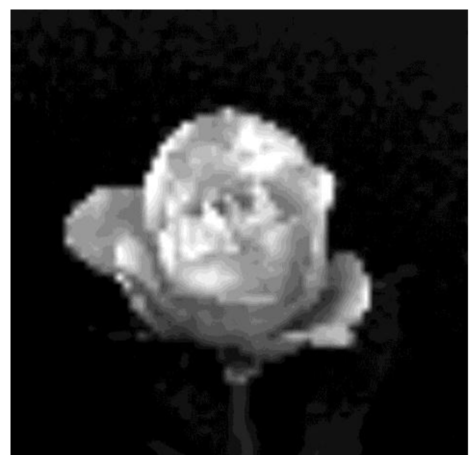
64x64 ⇨ 1024x1024



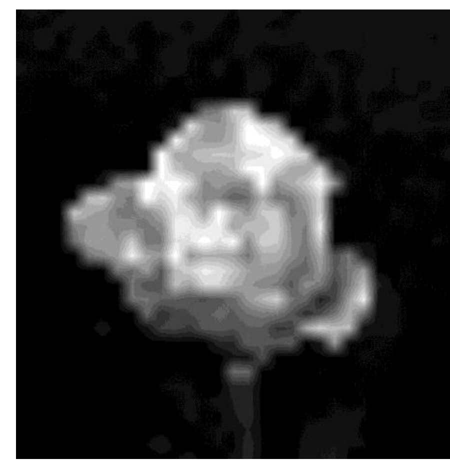
32x32 ⇨ 1024x1024

Bilinear

128x128 ⇨ 1024x1024



64x64 ⇨ 1024x1024



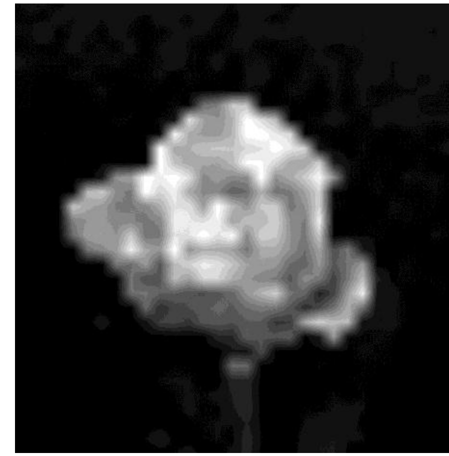
32x32 ⇨ 1024x1024

Zooming : Interpolation Techniques

Bilinear

128x128 ⇨ 1024x1024

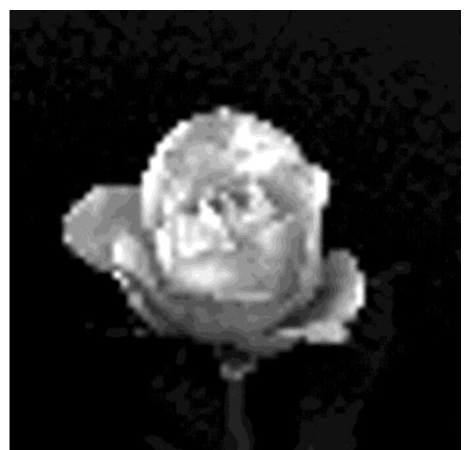
64x64 ⇨ 1024x1024



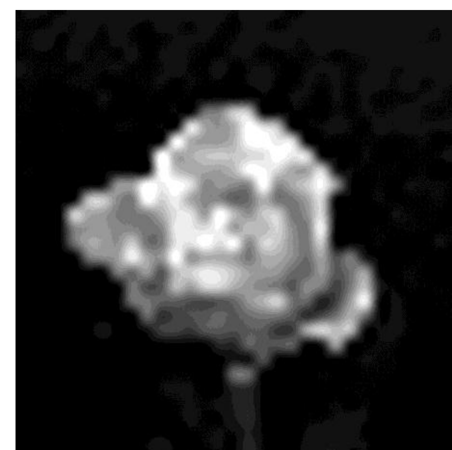
32x32 ⇨ 1024x1024

Bicubic

128x128 ⇨ 1024x1024



64x64 ⇨ 1024x1024



32x32 ⇨ 1024x1024

Zooming : Interpolation Techniques

Nearest neighbor interpolation:

- Fastest Processing
- Produces undesired checkboard/blocking (Aliasing) effect
- May be good for rectangular images
- Not suitable for detailed or photographic images

Bilinear interpolation:

- smoother looking images than nearest neighbor.
- has an anti-aliasing effect, therefore less blocking effect than nearest neighbor.

Bicubic interpolation:

- produces noticeably sharper images than the previous two methods.
- has an anti-aliasing effect (Almost no blocking).
- used as a standard in many image editing programs (i.e. Adobe Photoshop)