“One picture is worth more than ten thousand words”-Anonymous

Digital Image Processing - *Basics*

FCV (CSE: 3172)

Images

- Images are two-dimensional functions

$$f(x, y)$$

  - *x, y* are the spatial coordinates
  - *f* is the intensity/amplitude at (*x, y*)

(0,0) $\longrightarrow$ *y*

$x \downarrow$

f(x, y)

Digital video

- Sequence of 2D images
- *f(x, y, t)*
    - *x* , *y* are the spatial coordinates and *t* is the time.

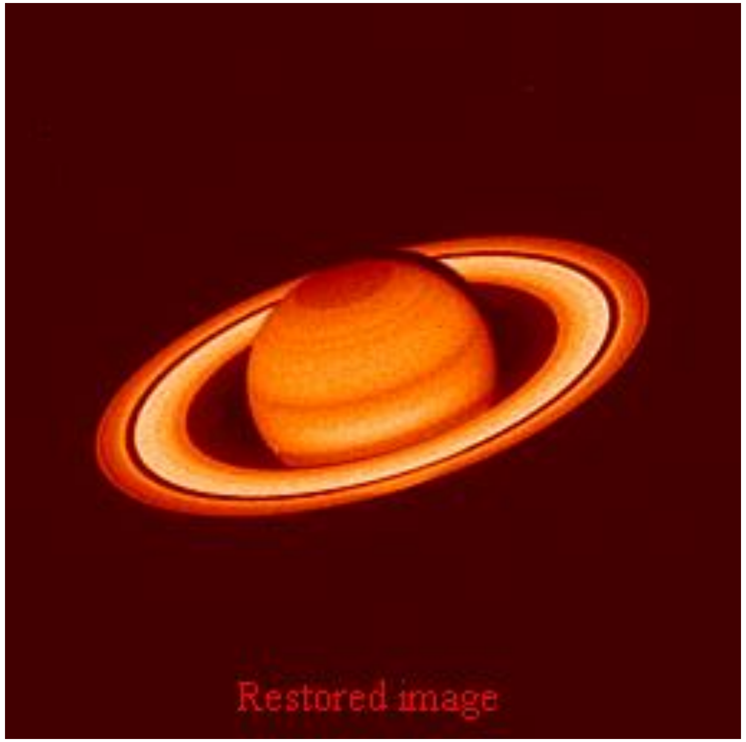
time

What is the purpose of image processing?

- Enhance the picture for be for better clarity
  - Images in –Images out
- Extract information from images
  - Images in –Image attributes out
- Picture storage and transmission
  - Encoder: Images in –Image attributes out
  - Decoder: Image attributes in –Images out

Image processing examples

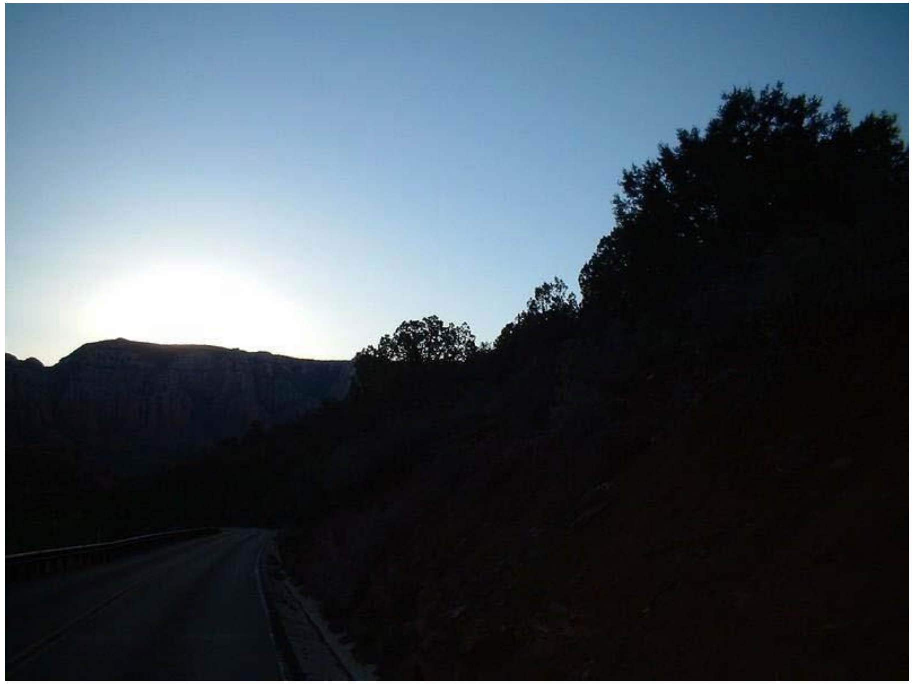
- Restoration of images from Hubble Space Telescope



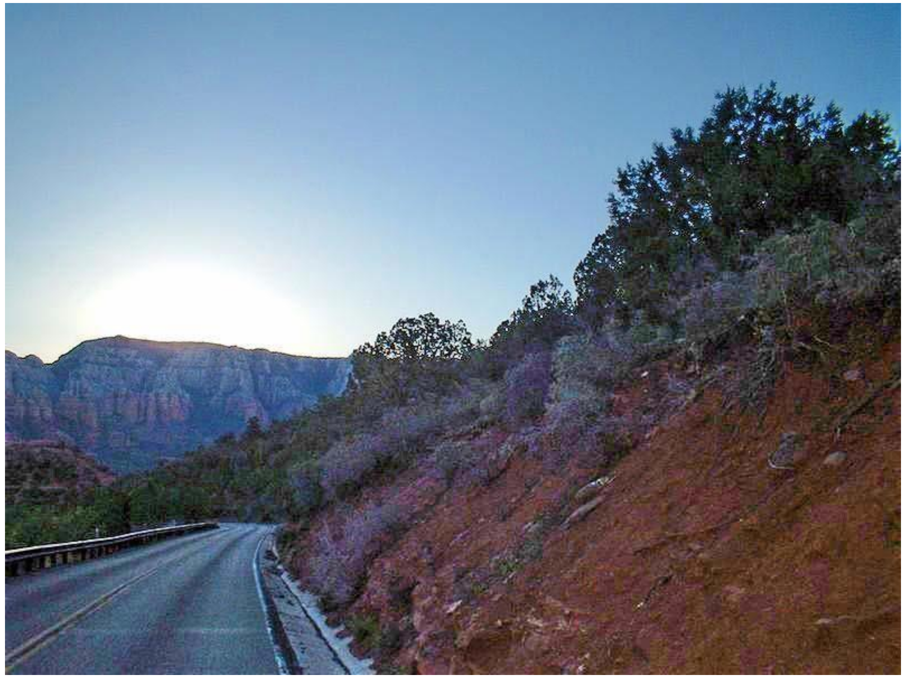
- http://hubblesite.org/sci.d.tech/nuts_.and._bolts/optics/costar/index.shtml

Image processing examples

- Image enhancement



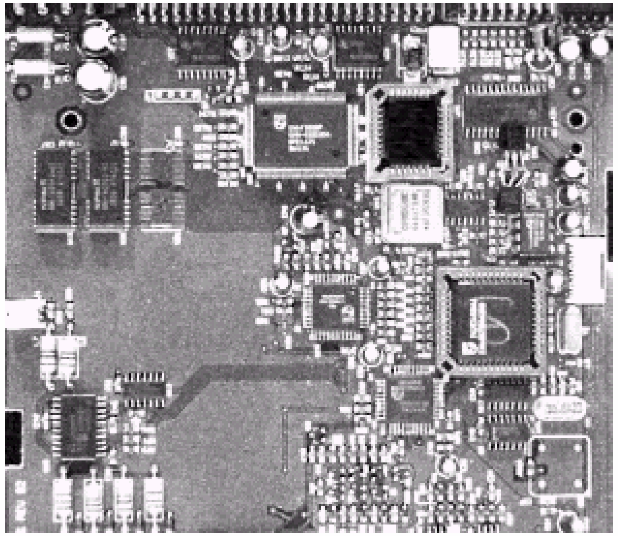
Before



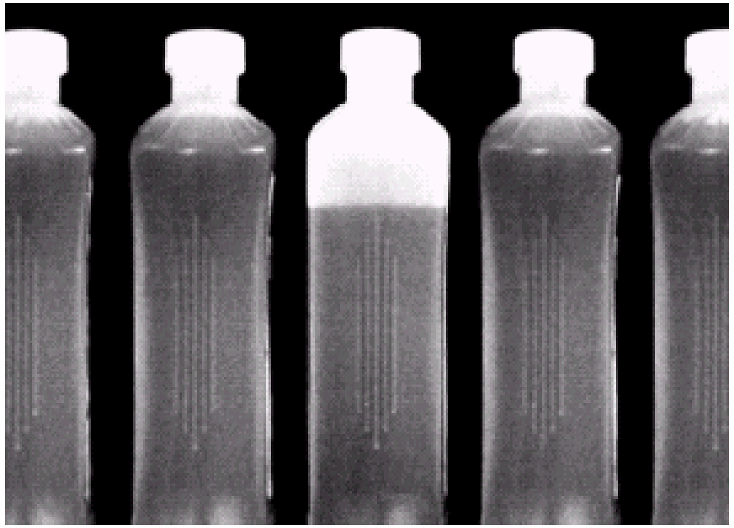
After

Image processing examples

- Quality control in industrial environment



PCB



Bottles

Cornflakes

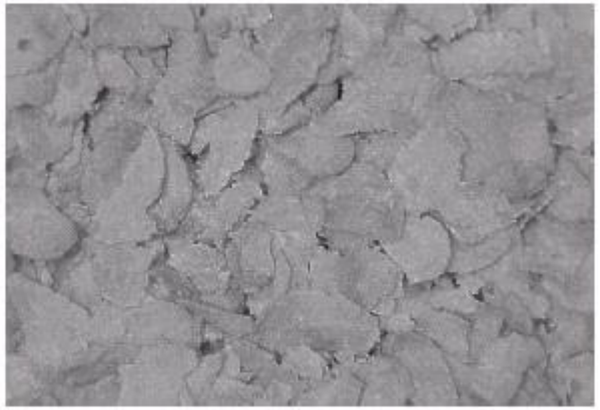


Image processing examples

- Image compression for storage and transmission
  - Store 8X-10X more pictures in memory in digital cameras
  - Take less time to transmit pictures from Mars to Earth

Original -532 kB JPEG -66 kB(1:8 compression)

Types of Images

Radiation from EM spectrum

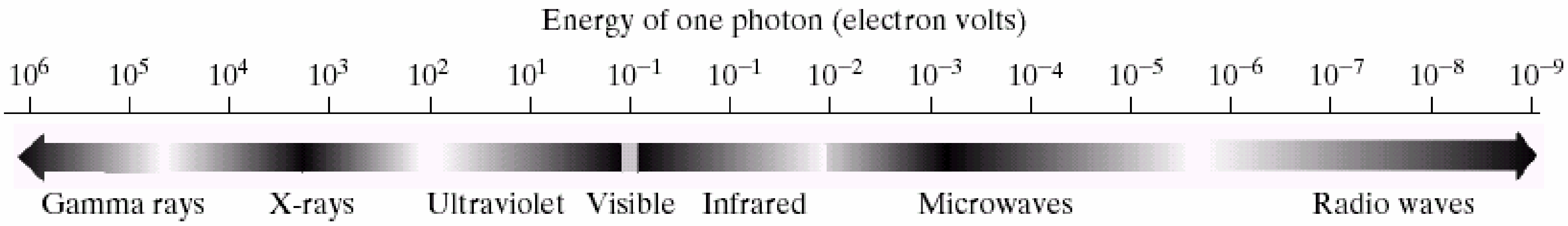


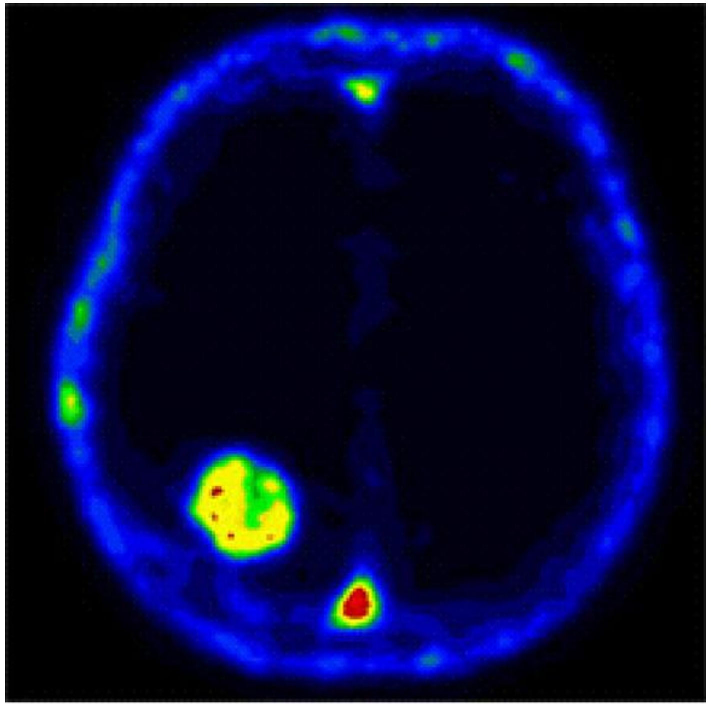
FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

- EM waves = a stream of massless (photon) particles, each traveling in a wavelike pattern and moving at the speed of light.

- Spectral bands are grouped by energy per photon
  - Gamma rays, X-rays, Ultraviolet, Visible, Infrared, Microwaves, Radio waves

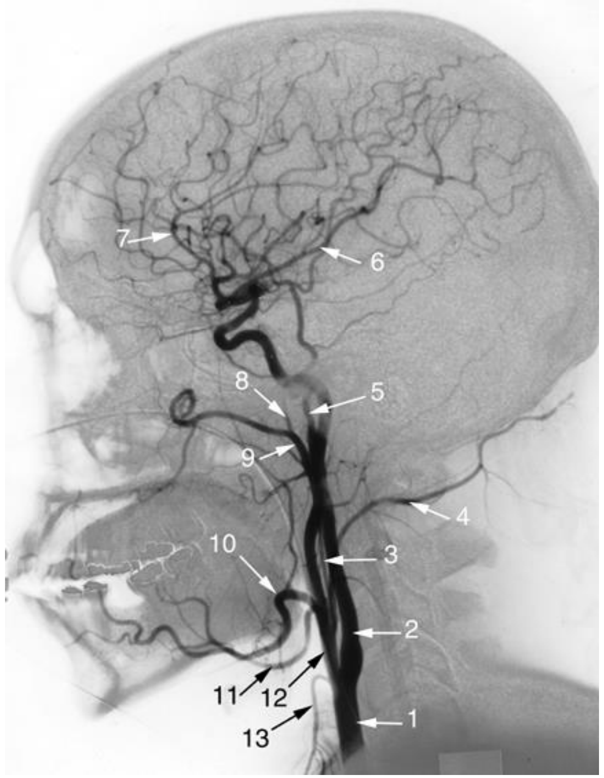
Gamma-ray imaging

- Positron emission tomography



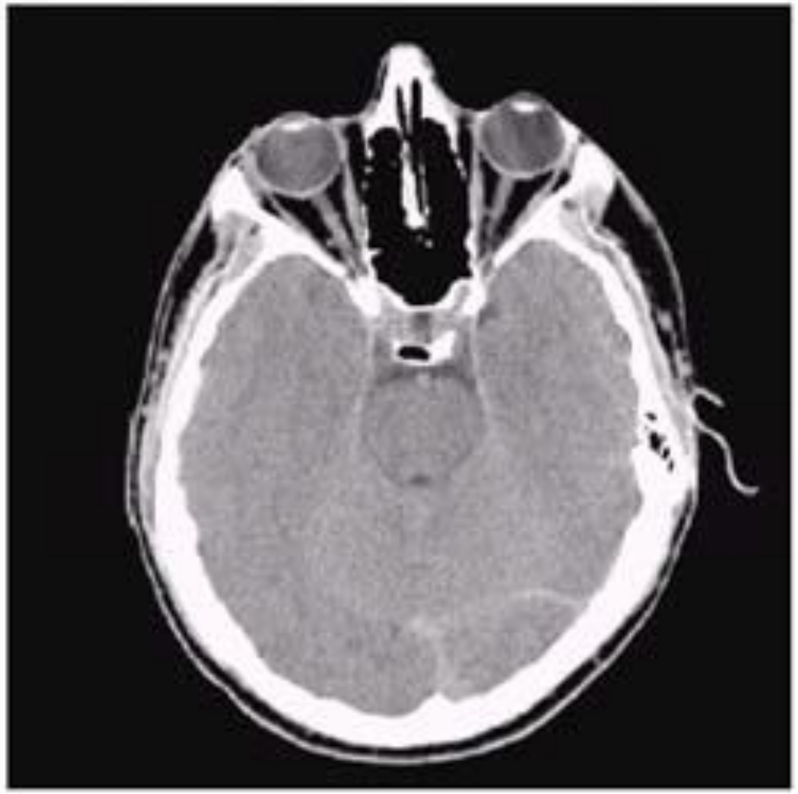
X-ray imaging

- X-rays discovered in 1895
- Nobel Prize for Physics awarded to W. C. Rontgen(1901)

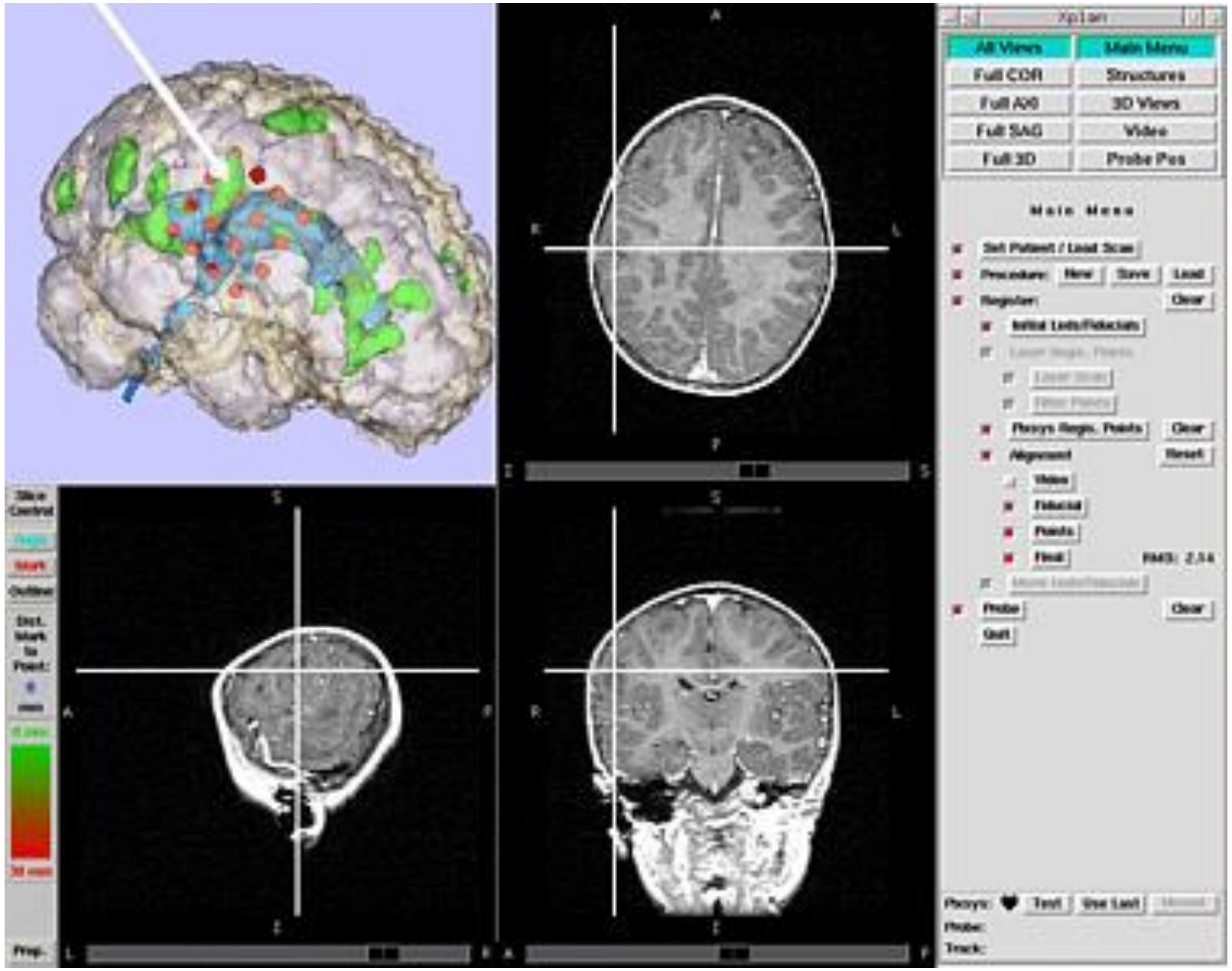


X-ray imaging –CT scans

- Computed tomography (CT)
- First system built in 1971
- Nobel Prize for Medicine awarded to
  G. Hounsfieldand A. Cormack(1979)



3D Reconstruction



- http://www.ai.mit.edu/people/leventon/Research/9810-MICCAI-Ped/node1.html

Imaging in visible and infrared bands

- Color images
  - "multispectral" image

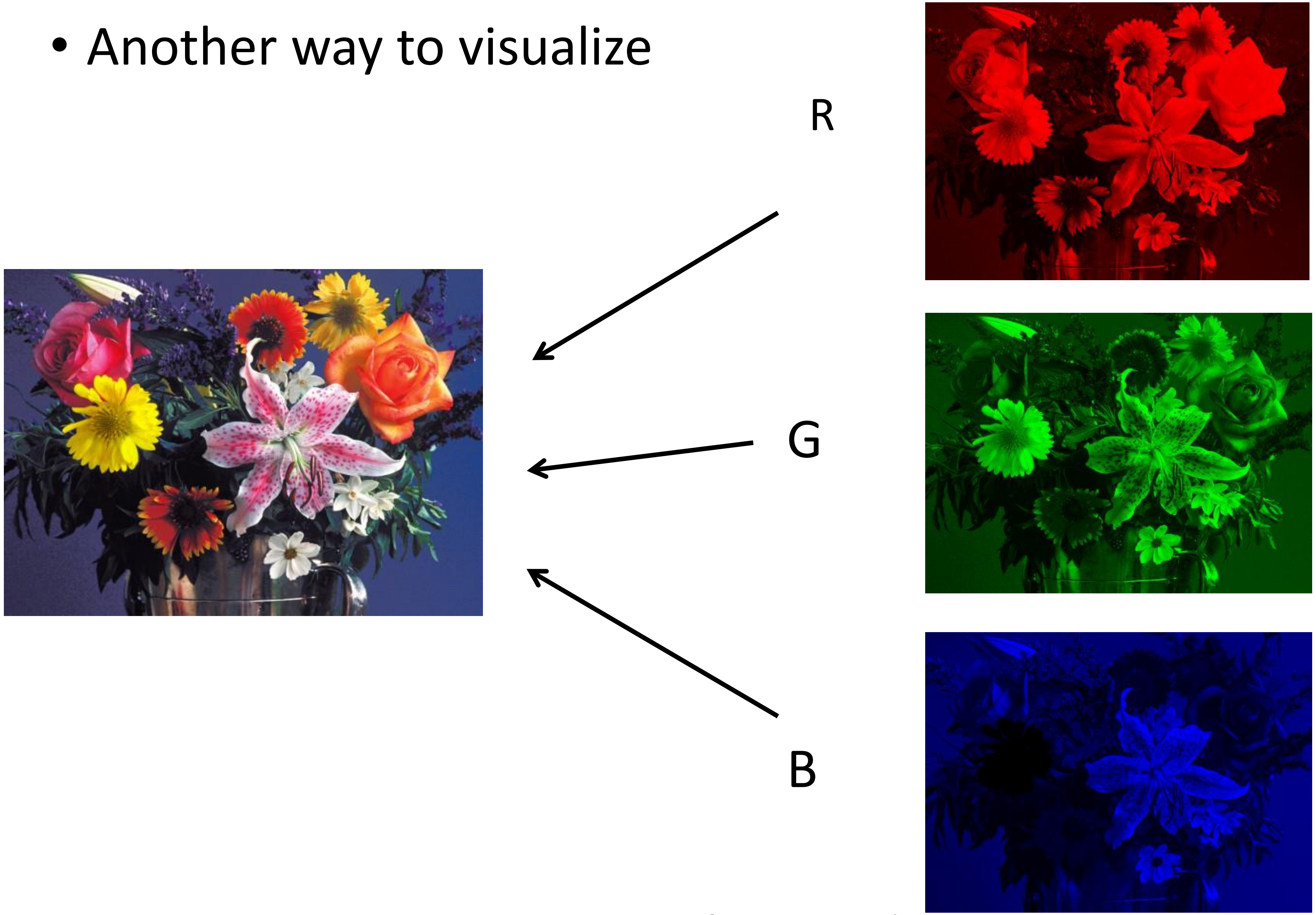
R

G

B

Imaging in visible and infrared bands

- Another way to visualize



Imaging in visible and infrared bands

- Multispectral imaging

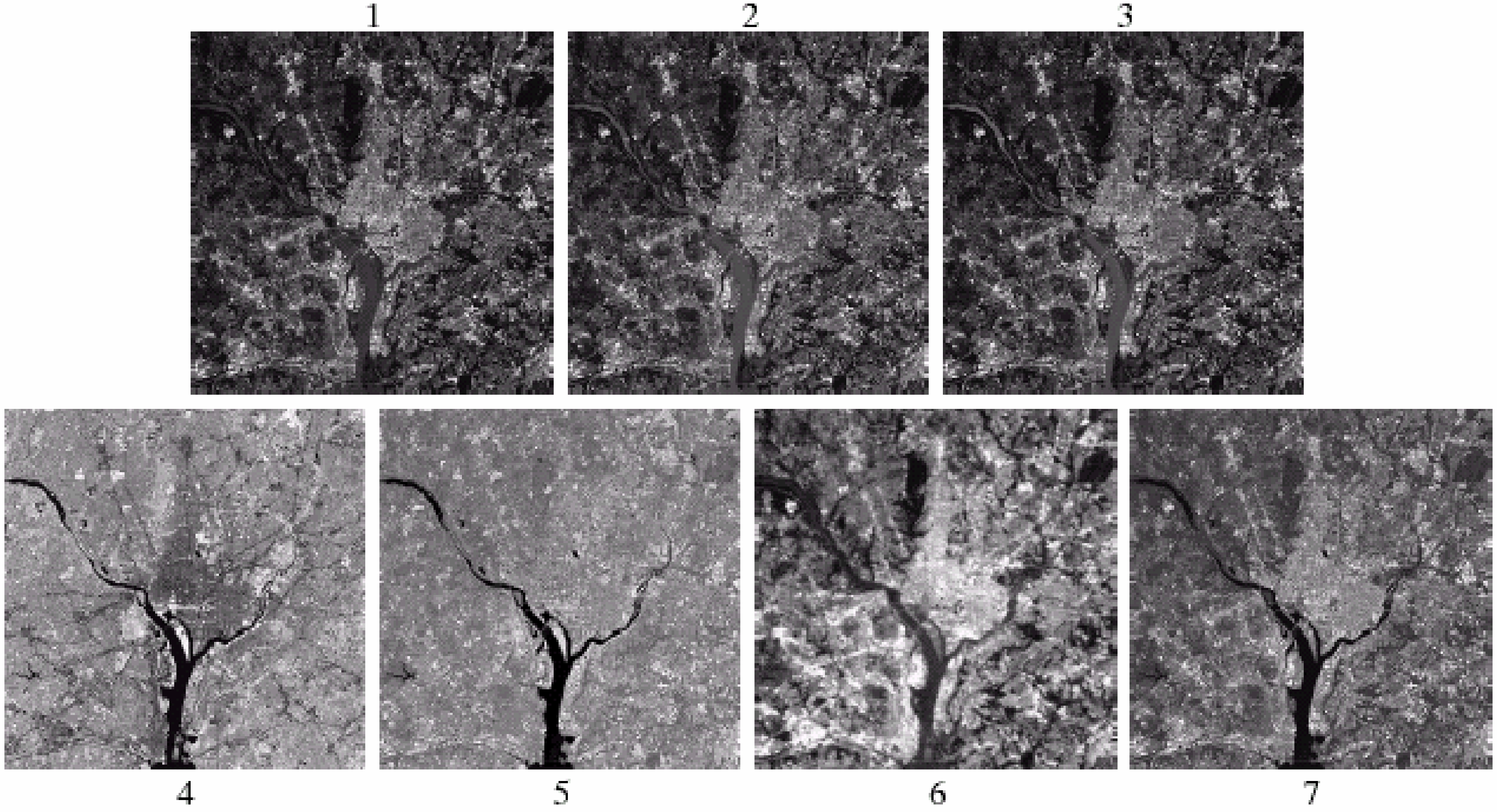
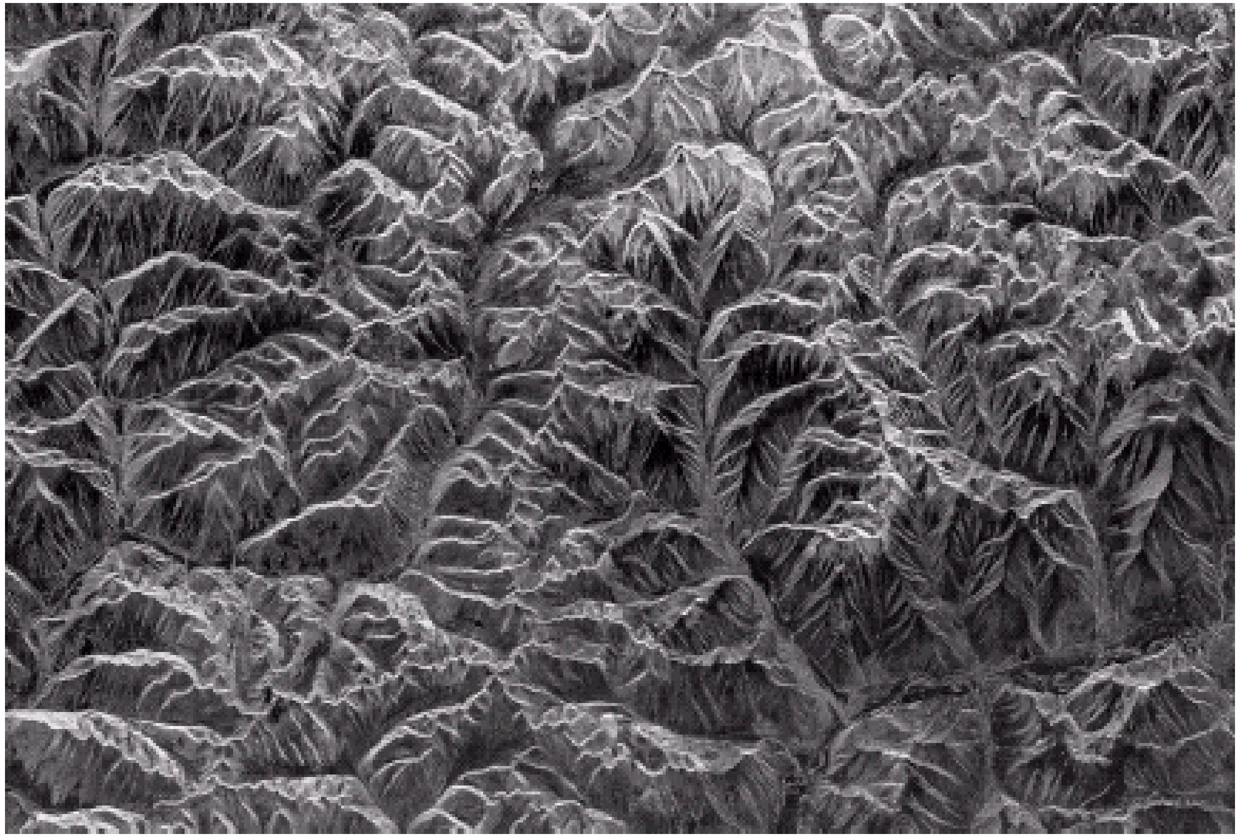


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

Imaging in Microwave band

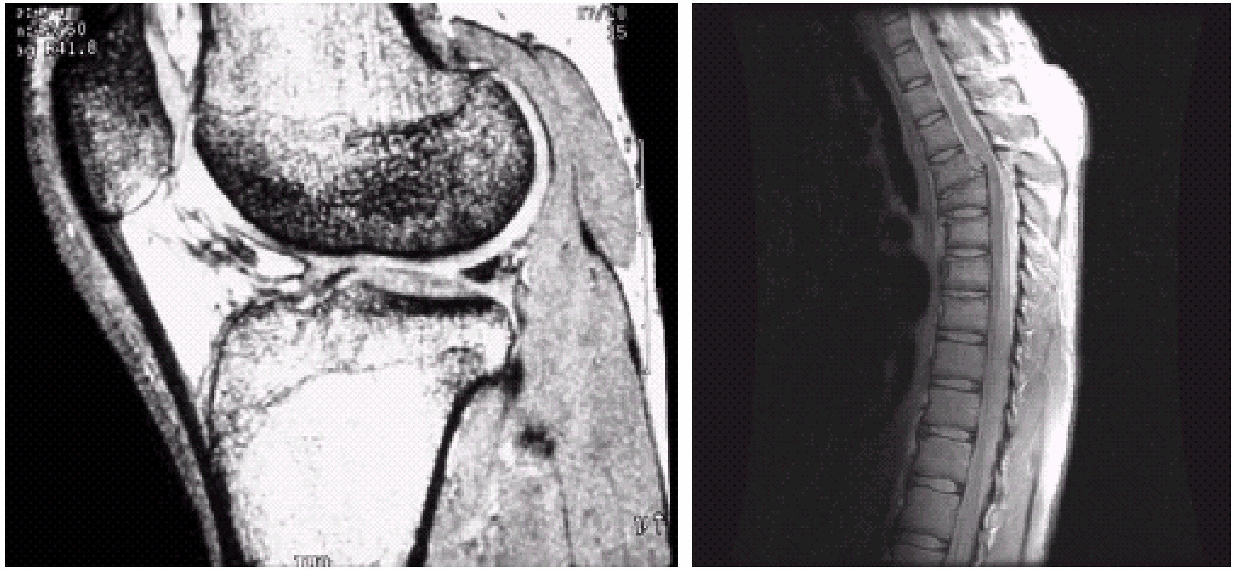
- Radar imaging
  - all-weather, day-or-night capability

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



Imaging in Radio band

- Magnetic resonance imaging (MRI)
- Magnetic resonance imaging discovered in 1973.
- Nobel Prize for Medicine awarded to P. C. Lauterburand P. Manseld, 2003

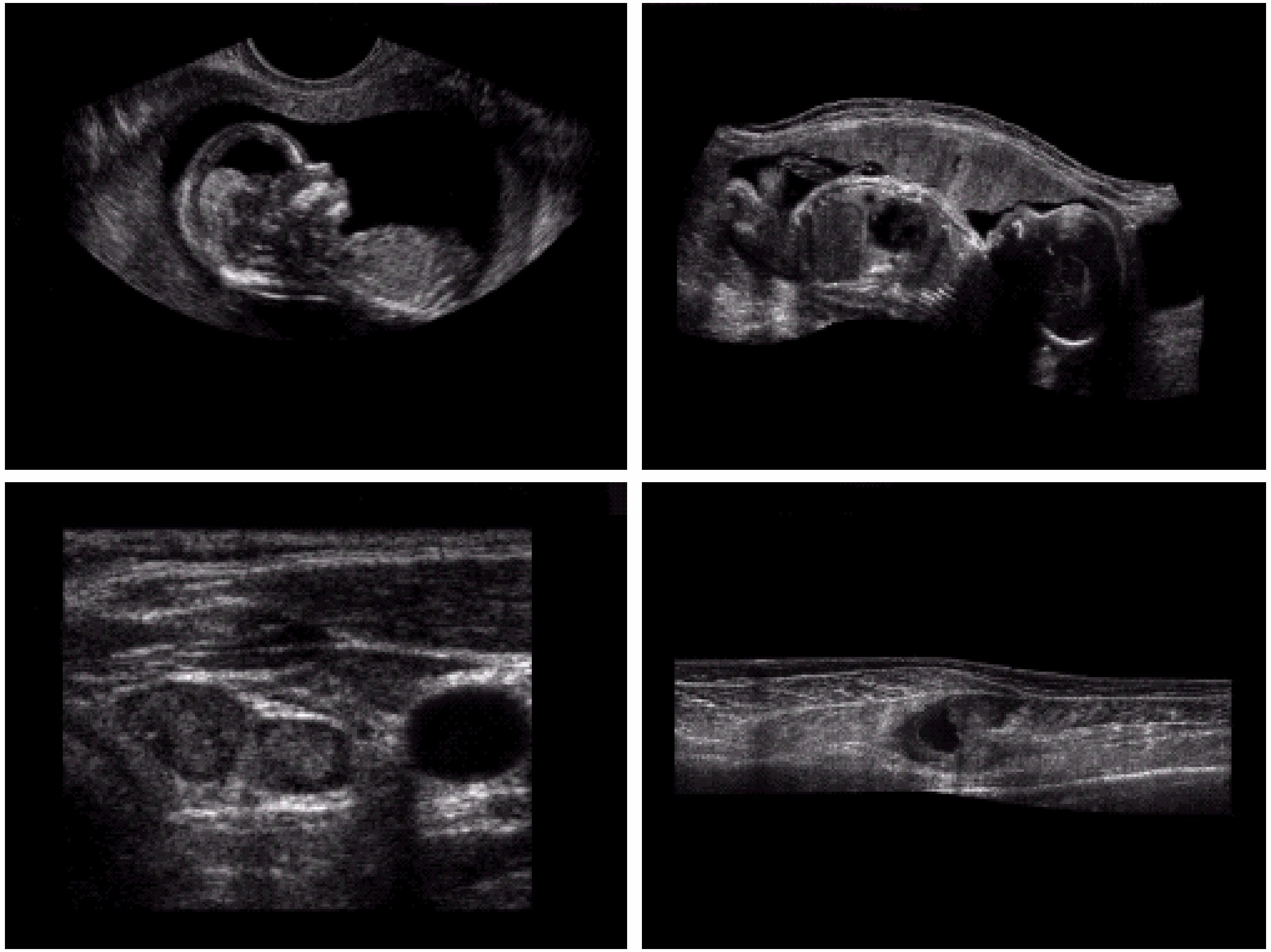


a b

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.)

Other imaging modalities

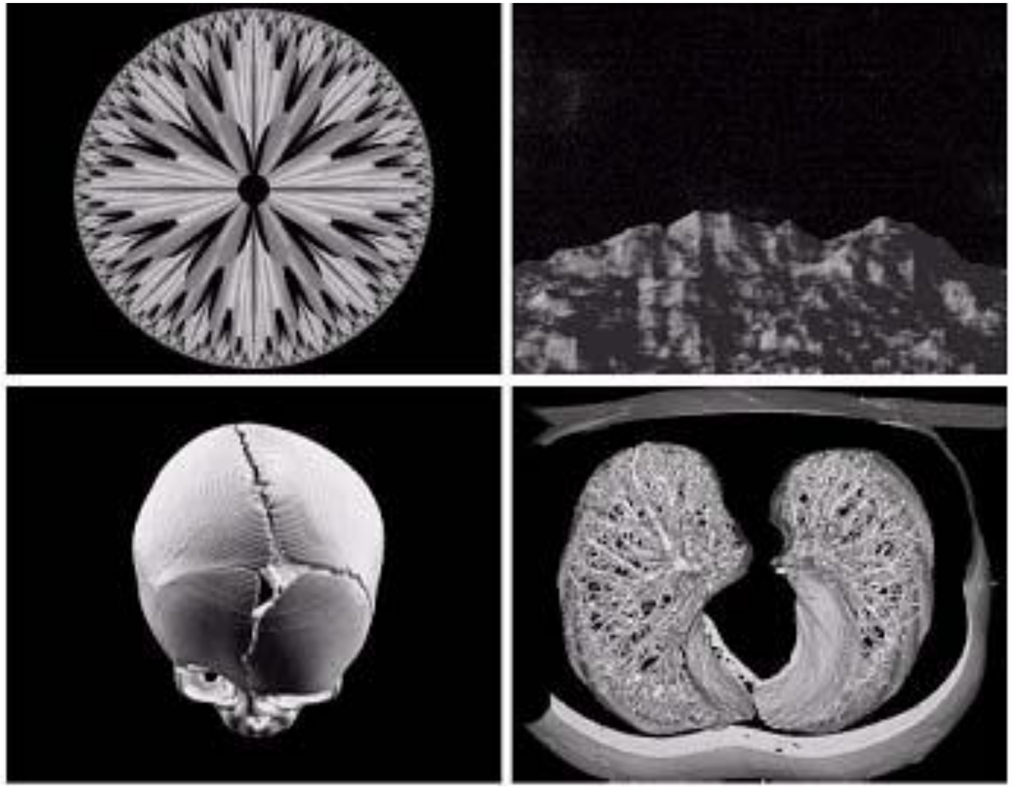
- Ultrasound imaging



a b
c d

FIGURE 1.20 Examples of ultrasound imaging. (a) Baby. (2) Another view of baby. (c) Thyroids. (d) Muscle layers showing lesion. (Courtesy of Siemens Medical Systems, Inc., Ultrasound Group.)

Generated images by computer



- Fractals : an iterative reproduction of a basic pattern according to some mathematical rules

- 3-D computer modeling

The human eye

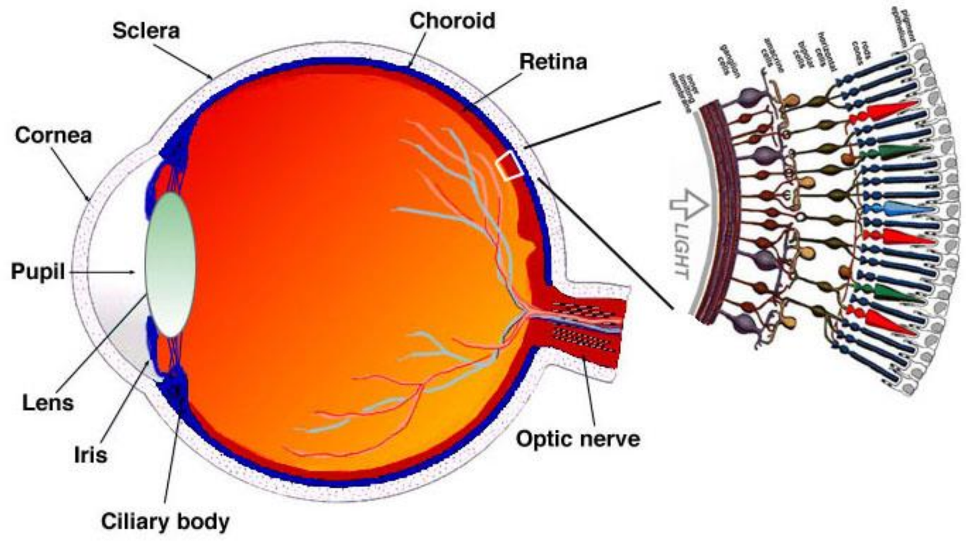
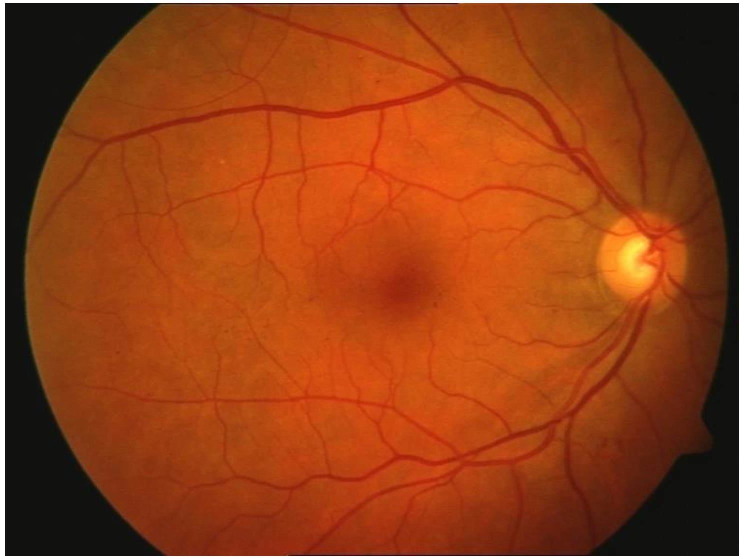


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.



Digital Colour Retinal Image
(576×768 pixels, 24 bit RGB with JPEG compression)

- http://webvision.med.utah.edu/sretina.html

Image Acquisition Process

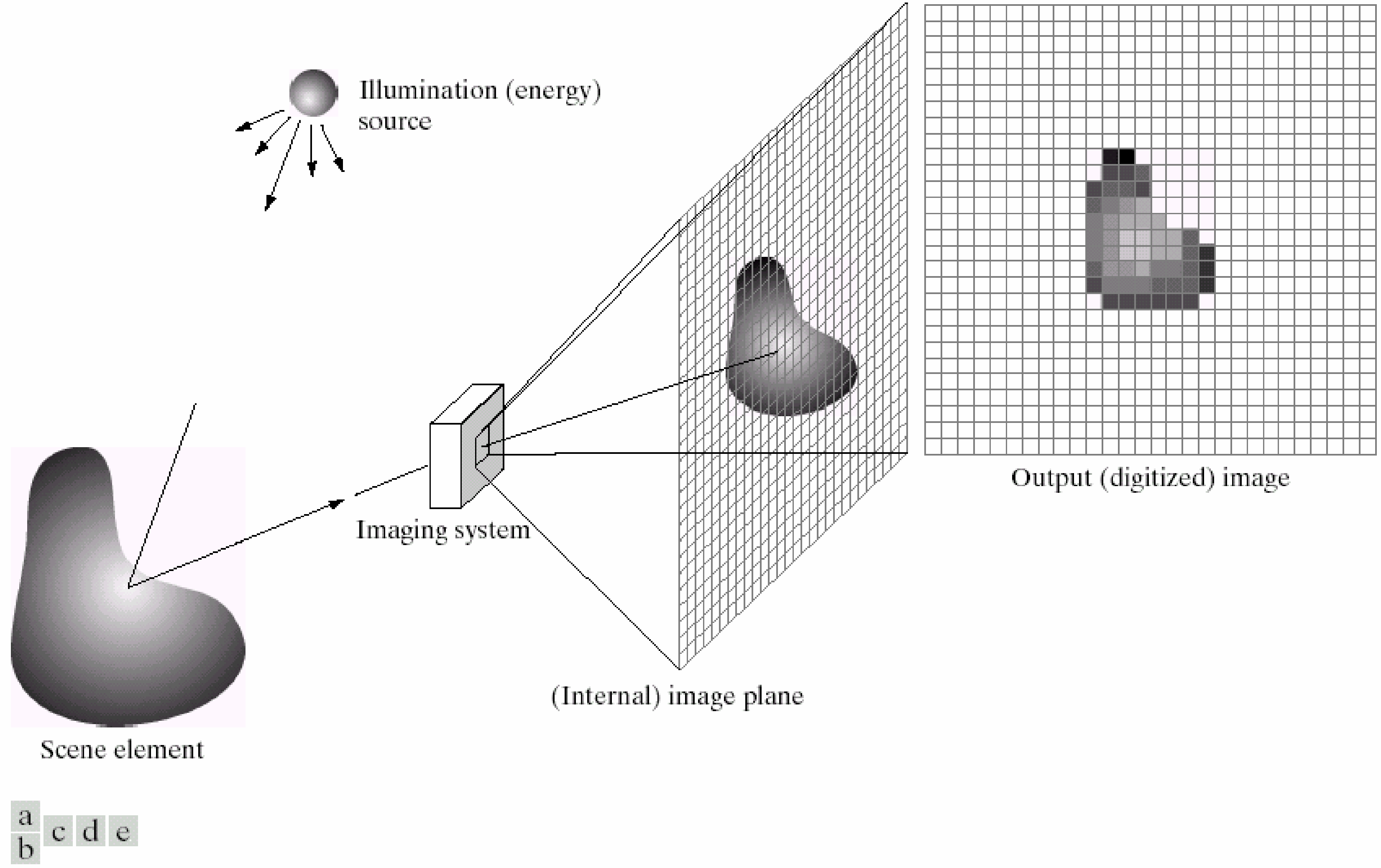


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Intensity function

- Image refers to a 2D light-intensity function, ***f(x,y)***
- Amplitude of ***f*** at spatial coordinates ***(x,y)*** gives the intensity (brightness) of the image at that point.
- Light is a form of energy thus ***f(x,y)*** must be nonzero and finite.

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

but its not

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

Image Sampling and Quantization

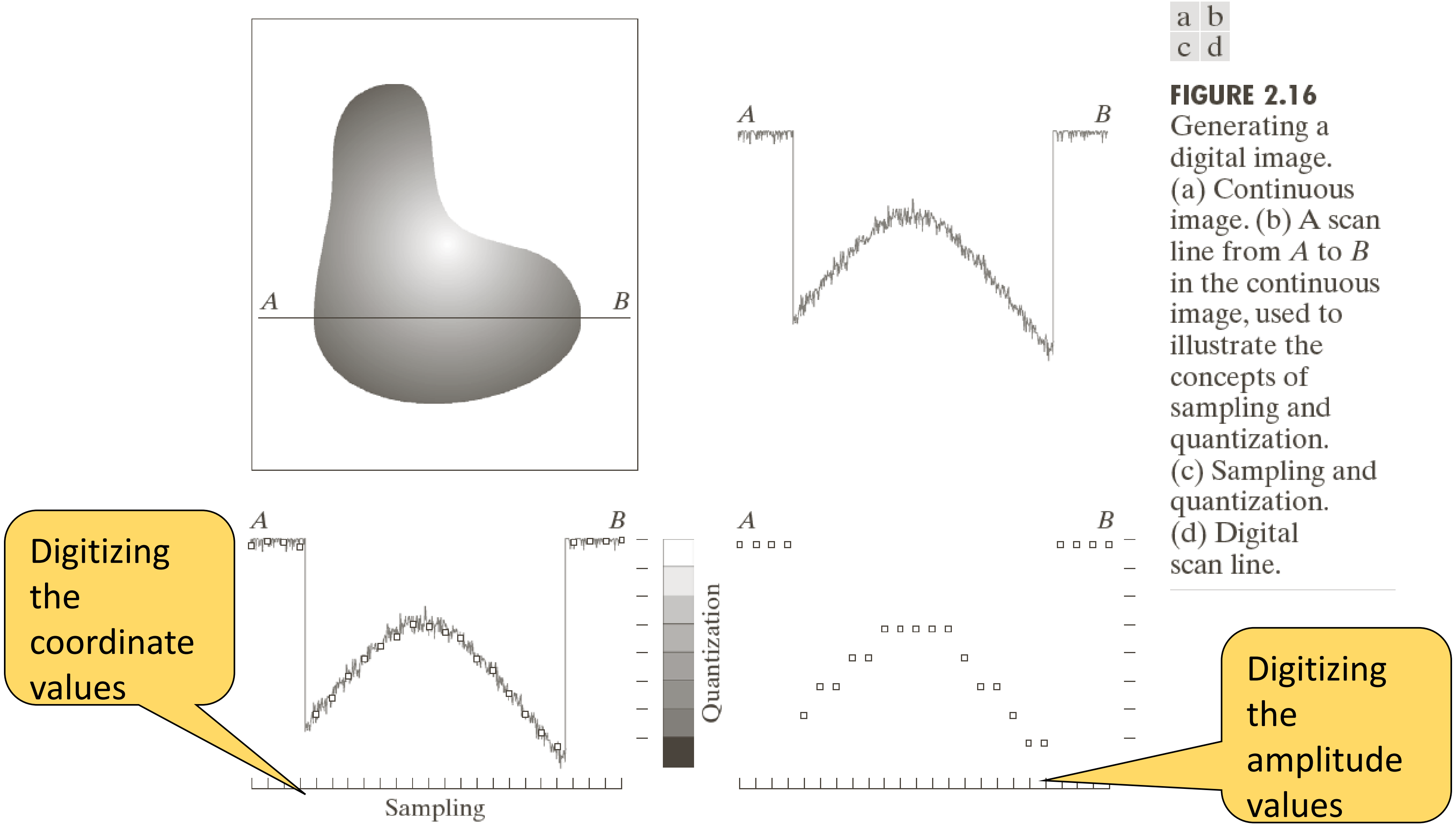
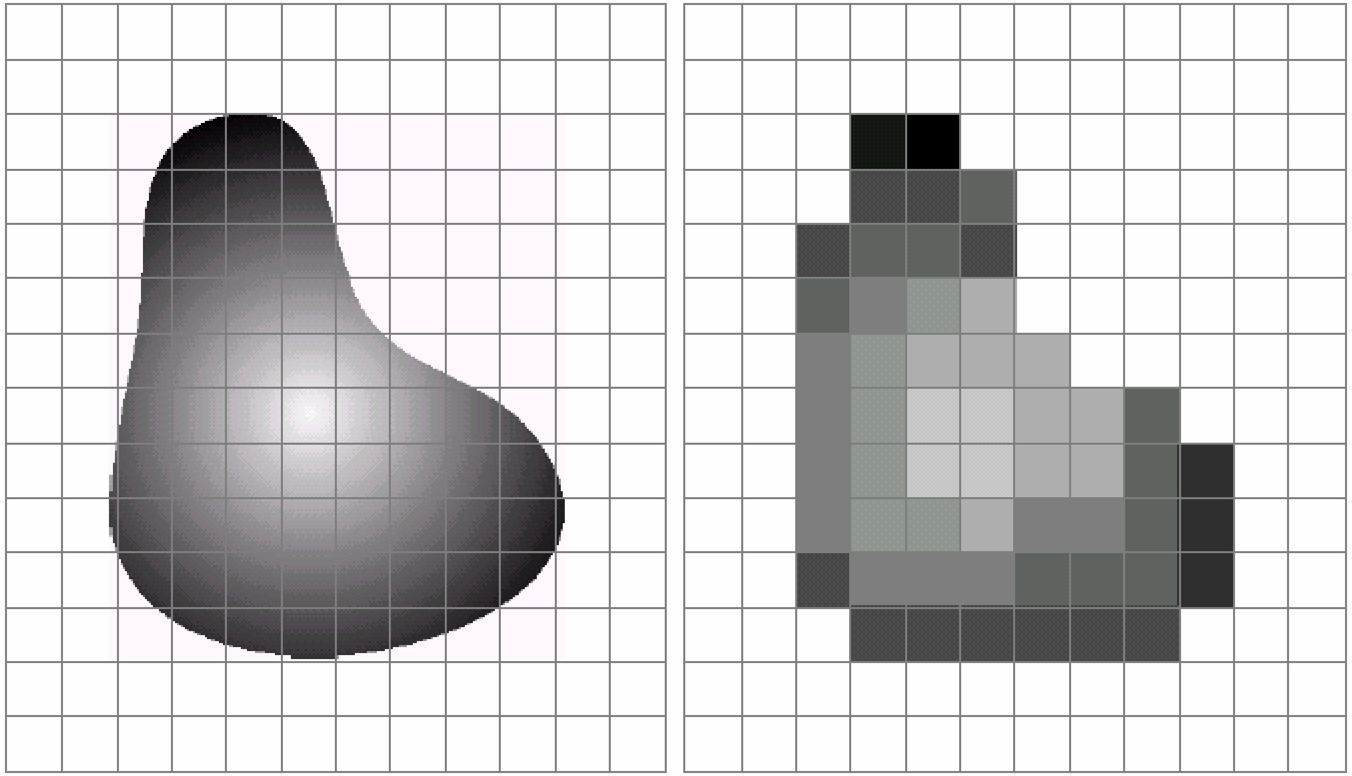


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Digital images – Sampling and quantization



a b

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

Digital images

$f(x, y)$ y

x \ y	0	1	2	3	4	5	6	7	8	9	10	11
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	22	0	0	0	0	0	0	0	0
3	0	0	0	71	78	95	0	0	0	0	0	0
4	0	0	78	98	102	71	0	0	0	0	0	0
5	0	0	95	126	150	175	0	0	0	0	0	0
6	0	0	126	150	175	175	175	0	0	0	0	0
7	0	0	126	150	199	199	175	175	95	0	0	0
8	0	0	126	150	199	199	175	715	95	47	0	0
9	0	0	126	150	150	175	126	126	85	47	0	0
10	0	0	71	126	126	126	95	95	95	47	0	0
11	0	0	0	71	71	71	71	71	71	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0

Basic Relationships Between Pixels

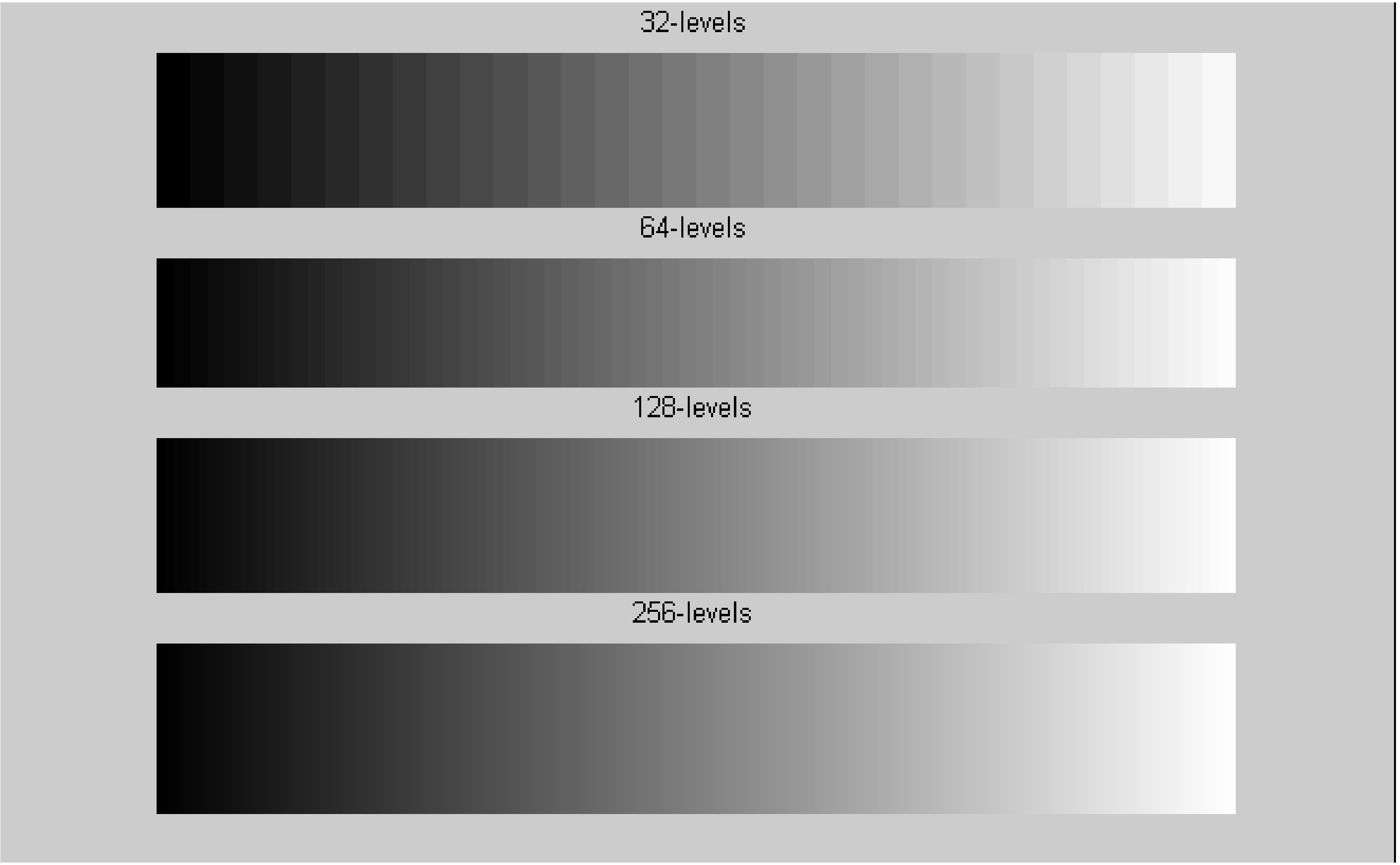
- **Neighbors** of a pixel p at coordinates (x,y)

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

How many levels of gray required?



Majority of image typically quantized to 256 levels

Storage requirements for images

- Image size: $N \times M$
- Number of levels: 2^k
- Number of colors (components): C

$$Size = N \times M \times k \times c$$

- Examples:
- B&W (gray-level, monochorme) images:
  - N=M=512, k = 8, c = 1 –*Size = 2,097,152 bits = 256 kByte*
- Color images:
  - N=M=1024, k = 8, c = 3 –*Size = 31,457,280 bits = 3.75 MByte*

Image size and spatial resolution

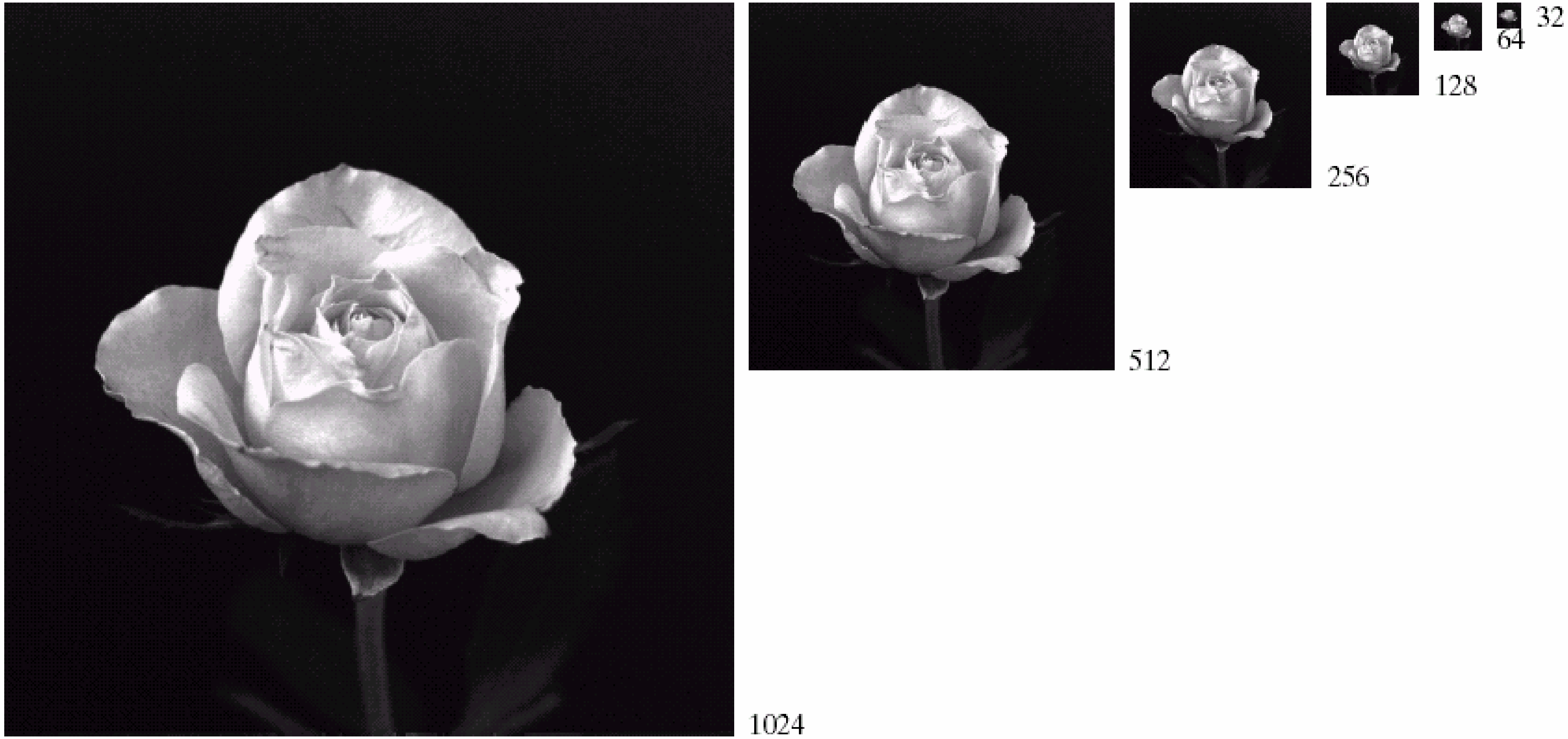


FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

Image size and spatial resolution (cont'd)

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.

Varying the number of gray levels

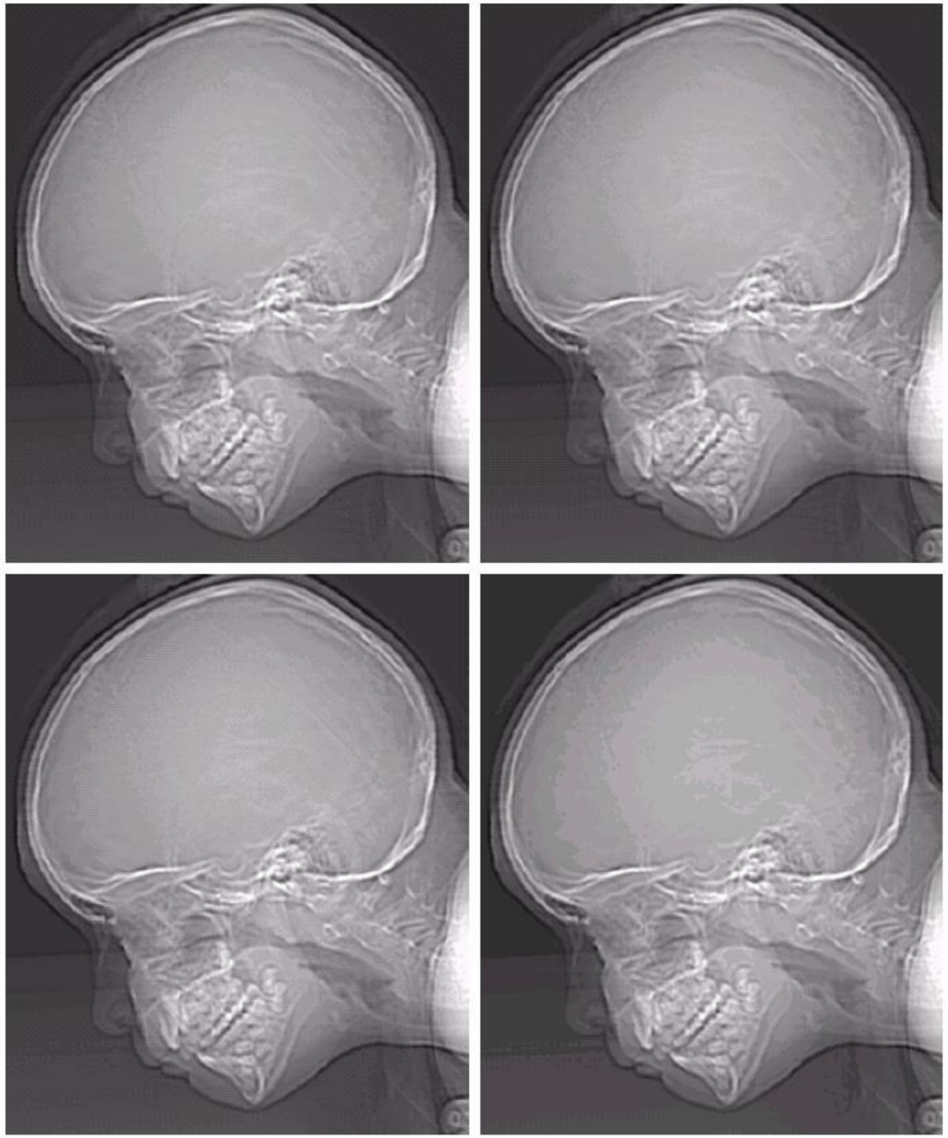
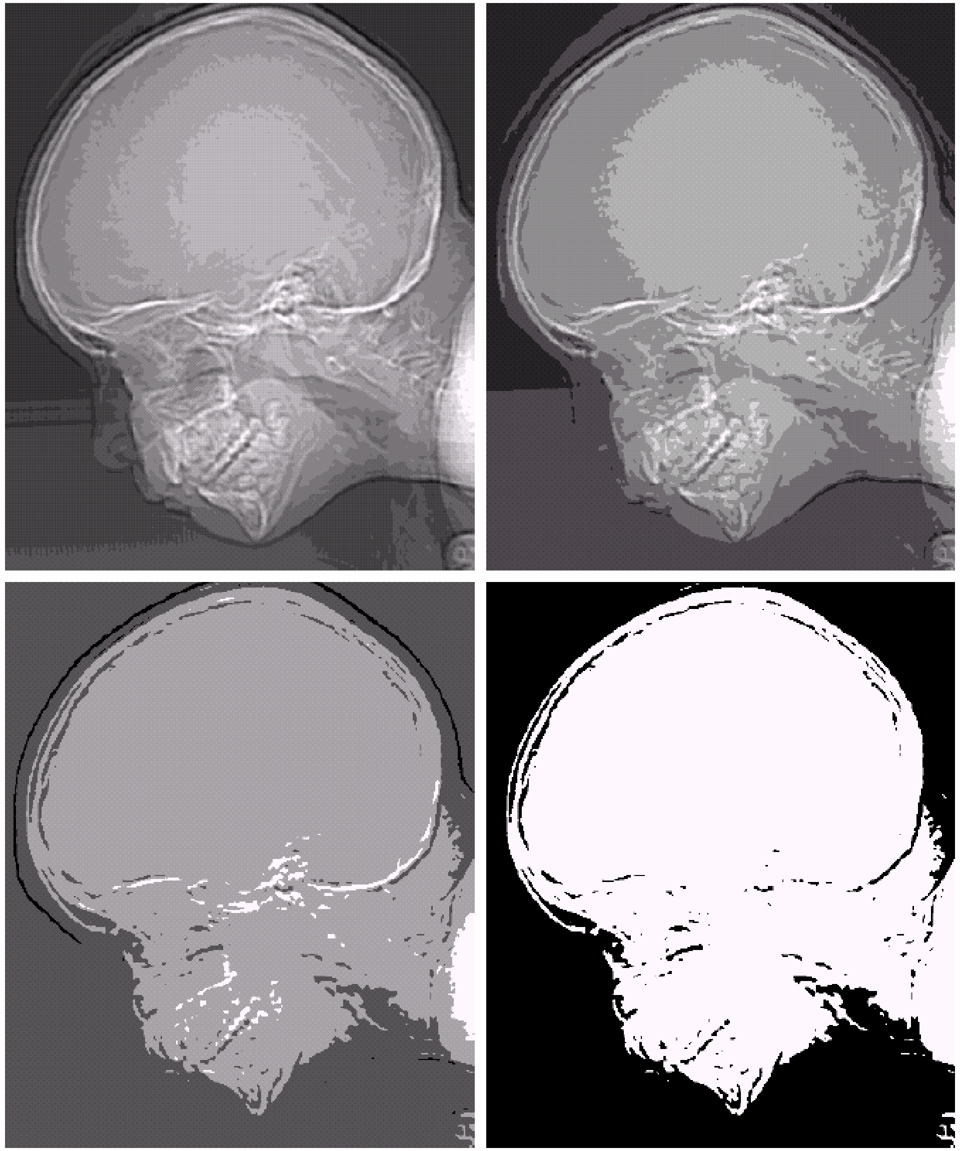


FIGURE 2.21 (a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.

Varying the number of gray levels (cont'd)

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.)



Isopreference curves

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.)

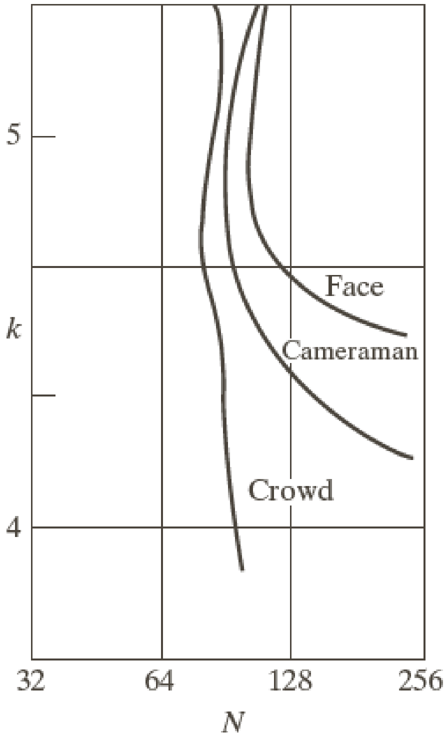


Image Interpolation

- **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 neighborhood interpolation

method assigns the value of the nearest pixel to the unknown pixel

- Bilinear interpolation

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

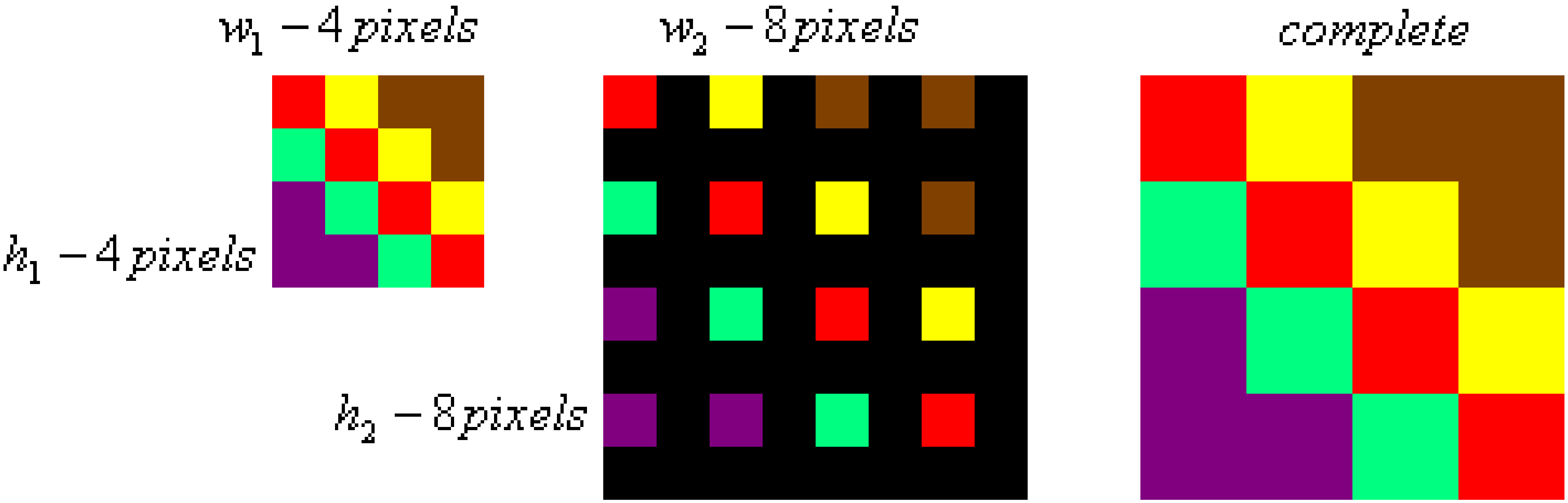
weighted avg of 4 nearest pixels

- Bicubic interpolation

method considers the 16 nearest pixels (a 4x4 grid) and provides even smoother results than bilinear interpolation by fitting a cubic polynomial to the pixel values.

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

Nearest Neighbour Interpolation



Basic Relationships Between Pixels

- Neighborhood
- Connectivity
- Adjacency
- Paths
- Distance measures

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).

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➢ **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 $N_4(p) \cap N_4(q)$ has no pixels whose values are from V.

Examples: Adjacency and Path

V = {1, 2}

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

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.

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

- 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.***

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

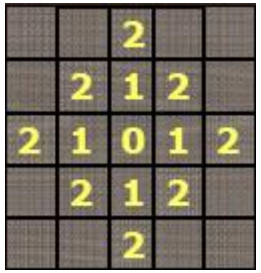
The following are the different Distance measures:

a. Euclidean Distance :

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

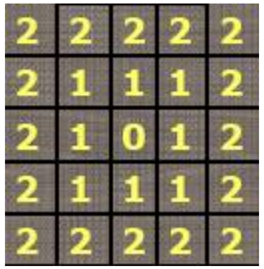
b. City Block Distance:

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



c. Chess Board Distance:

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



Arithmetic Operations

- Arithmetic operations between images are array operations. The four arithmetic operations are denoted as

$$s(x,y) = f(x,y) + g(x,y)$$

$$d(x,y) = f(x,y) - g(x,y)$$

$$p(x,y) = f(x,y) \times g(x,y)$$

$$v(x,y) = f(x,y) \div g(x,y)$$

Example: Addition of Noisy Images for Noise Reduction

Noiseless image: f(x,y)

Noise: n(x,y)

Corrupted image: g(x,y)

$$g(x,y) = f(x,y) + n(x,y)$$

Reducing the noise by adding a set of noisy images, $\{g_i(x,y)\}$

$$\bar{g}(x,y) = \frac{1}{K}\sum_{i=1}^{K} g_i(x,y)$$

By averaging multiple noisy images ({g_i(x,y)}), the random noise tends to cancel out,

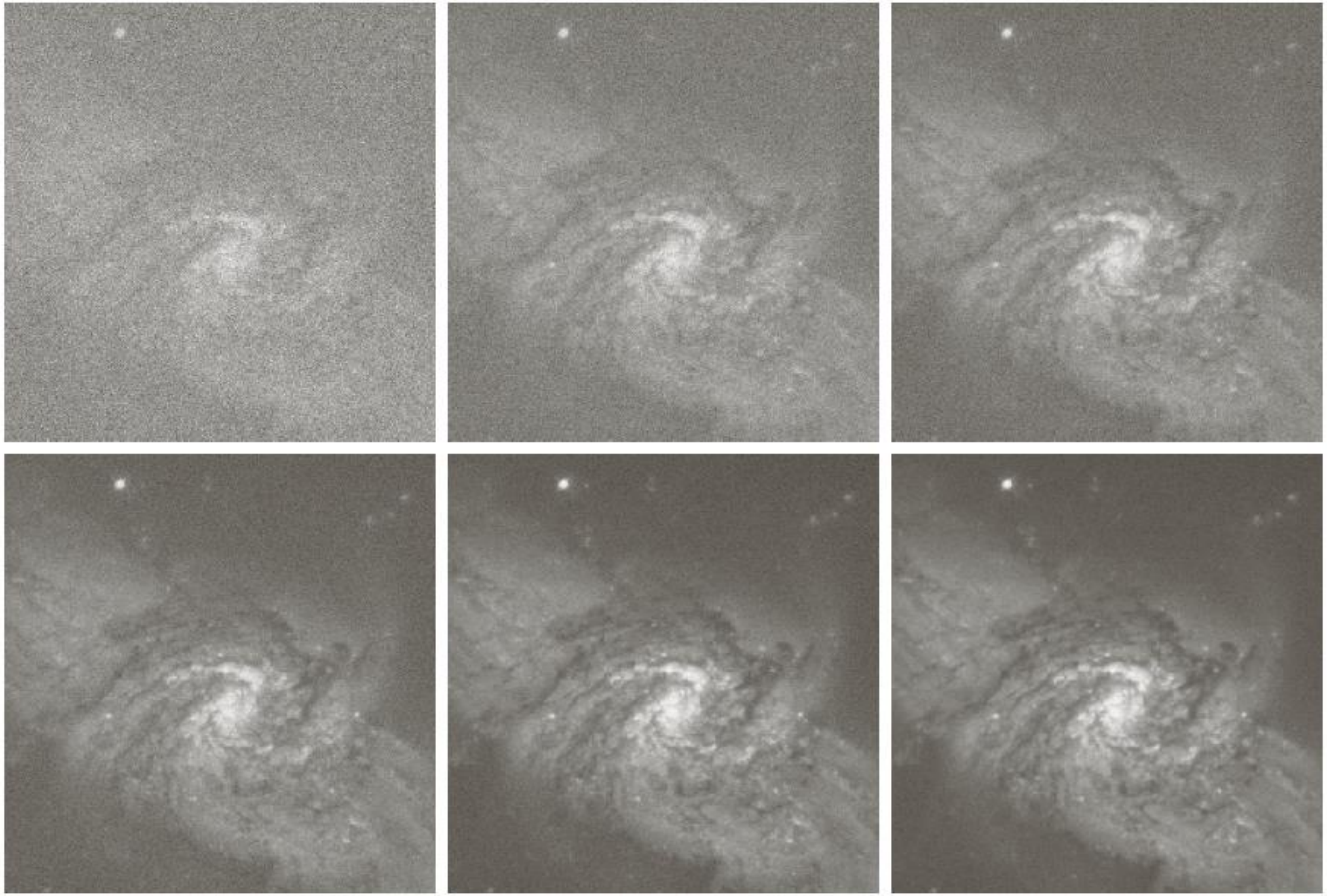


FIGURE 2.26 (a) Image of Galaxy Pair NGC 3314 corrupted by additive Gaussian noise. (b)–(f) Results of averaging 5, 10, 20, 50, and 100 noisy images, respectively. (Original image courtesy of NASA.)

An Example of Image Subtraction: Mask Mode Radiography

Mask h(x,y): an X-ray image of a region of a patient's body

Live images f(x,y): X-ray images captured at TV rates after injection of the contrast medium

Enhanced detail g(x,y)

$$g(x,y) = f(x,y) - h(x,y)$$

The procedure gives a movie showing how the contrast medium propagates through the various arteries in the area being observed.

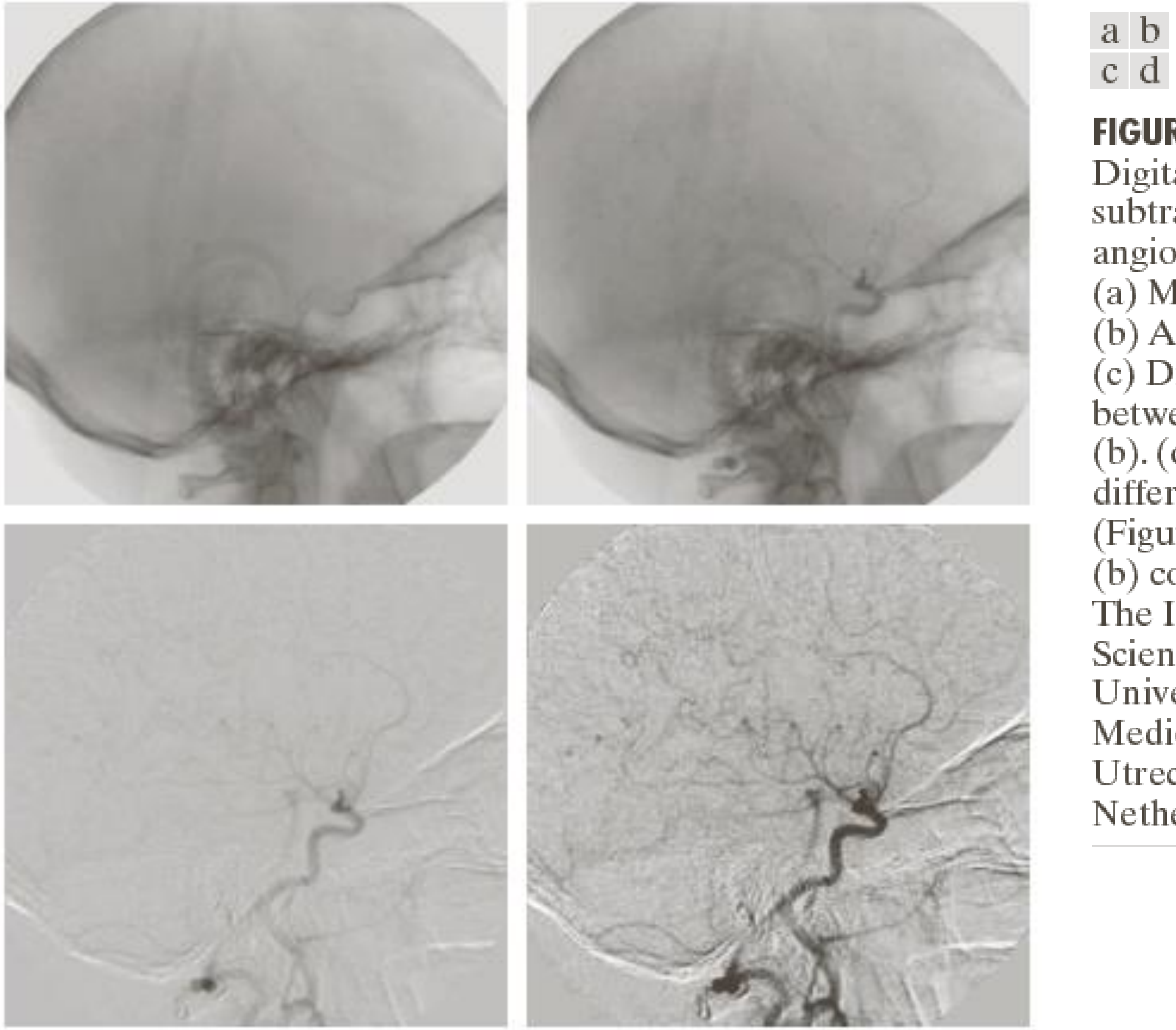


FIGURE 2.28 Digital subtraction angiography. (a) Mask image. (b) A live image. (c) Difference between (a) and (b). (d) Enhanced difference image. (Figures (a) and (b) courtesy of The Image Sciences Institute, University Medical Center, Utrecht, The Netherlands.)

An Example of Image Multiplication and Division

a b c

FIGURE 2.29 Shading correction. (a) Shaded SEM image of a tungsten filament and support, magnified approximately 130 times. (b) The shading pattern. (c) Product of (a) by the reciprocal of (b). (Original image courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene.)

Image Transform

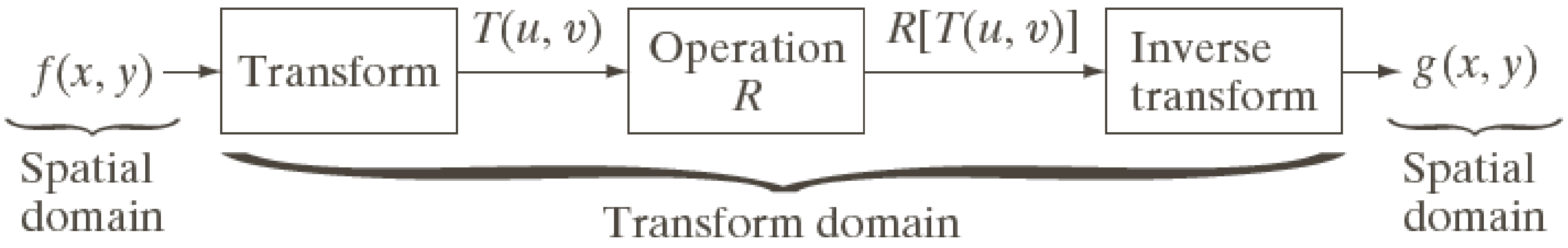


FIGURE 2.39
General approach for operating in the linear transform domain.

Example: Image Denoising

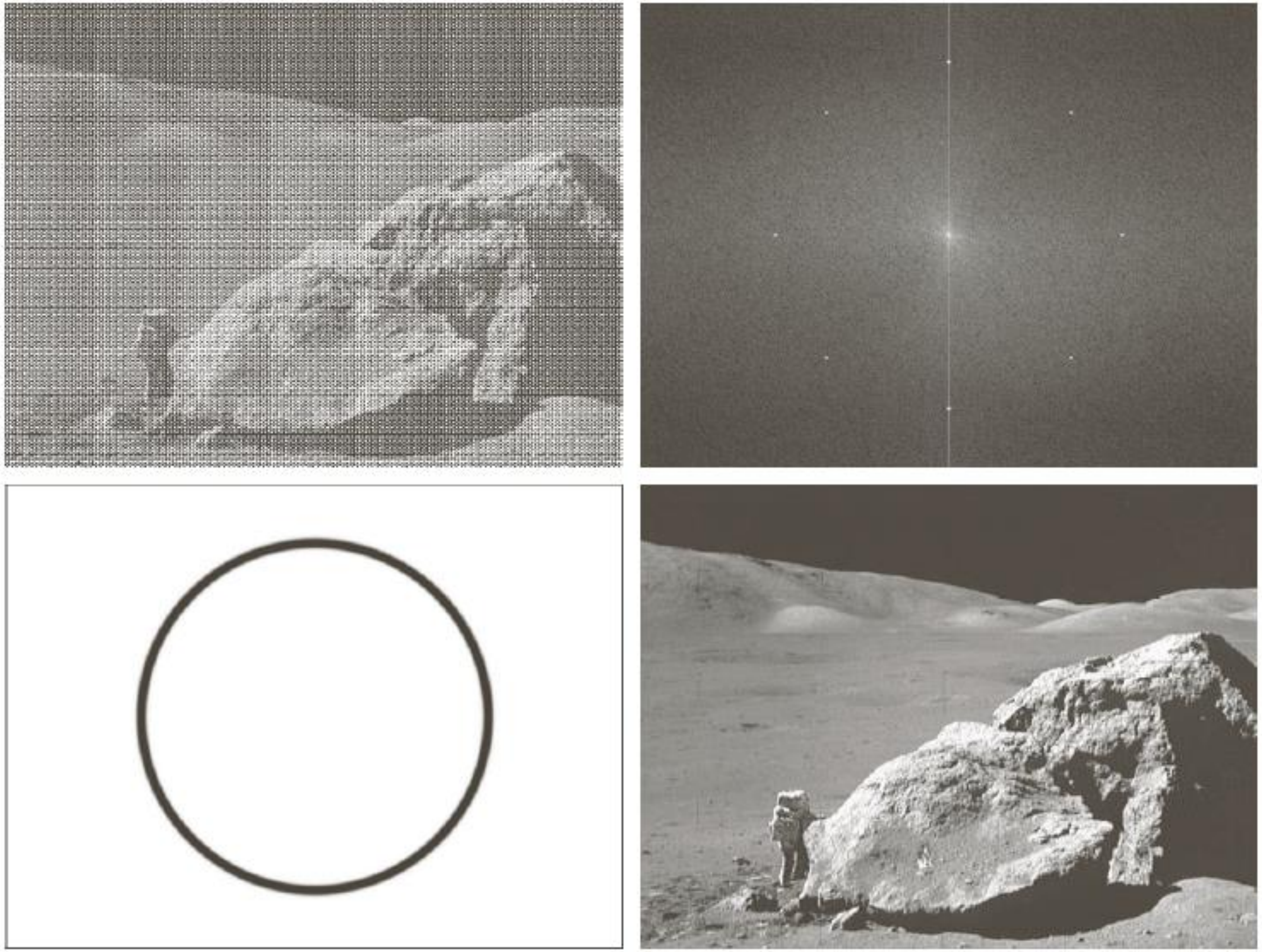


FIGURE 2.40 (a) Image corrupted by sinusoidal interference. (b) Magnitude of the Fourier transform showing the bursts of energy responsible for the interference. (c) Mask used to eliminate the energy bursts. (d) Result of computing the inverse of the modified Fourier transform. (Original image courtesy of NASA.)