Digital Image Fundamentals

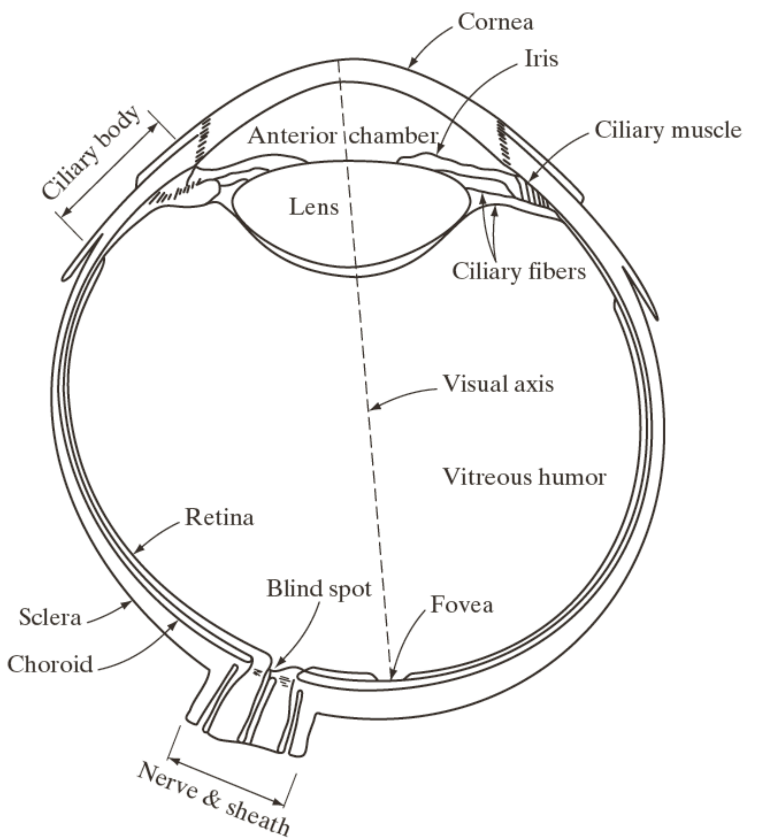


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

Image Formation

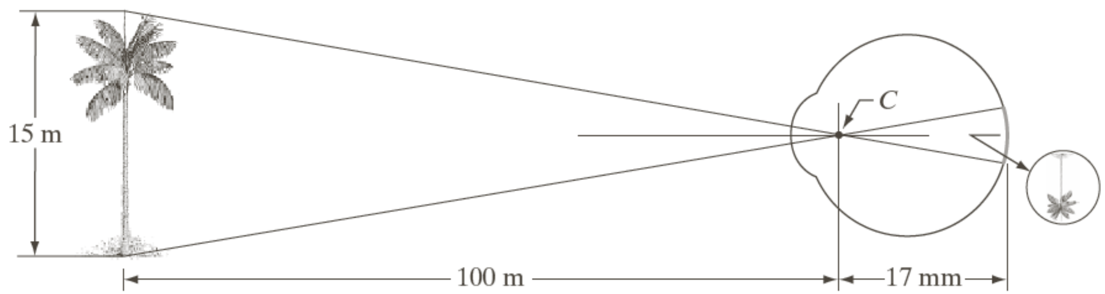


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point C is the optical center of the lens.

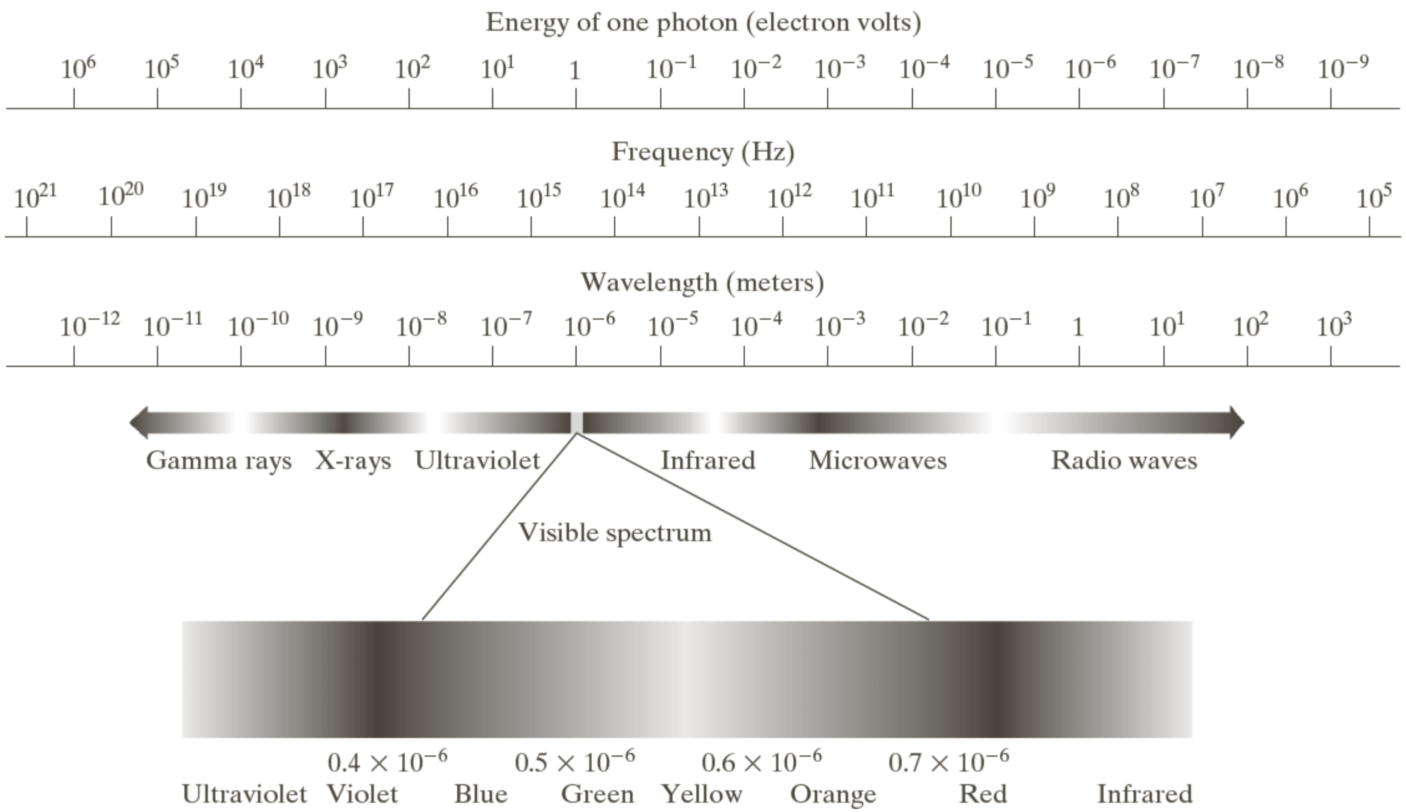
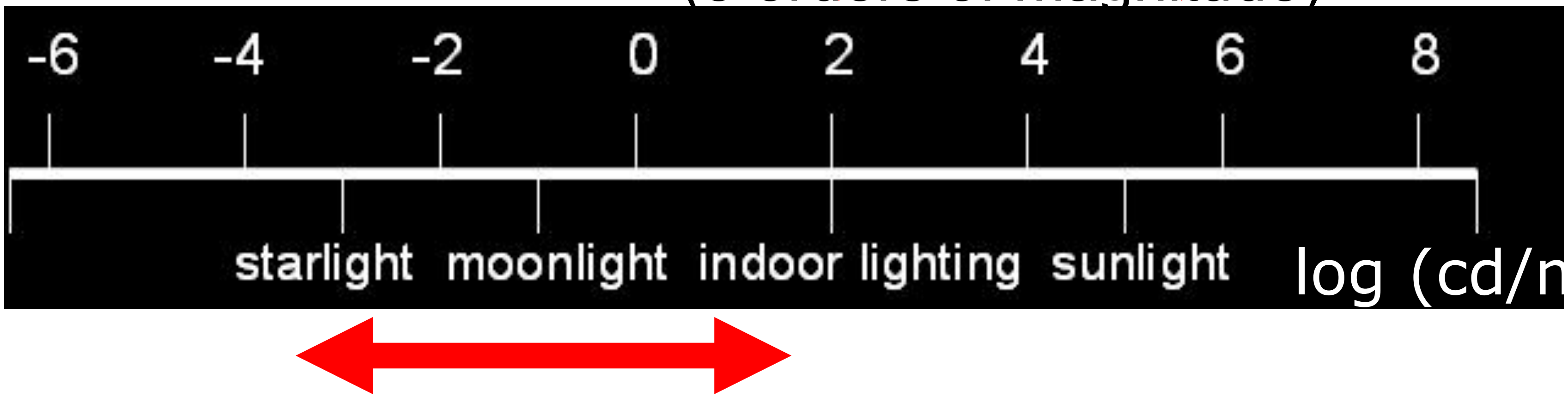


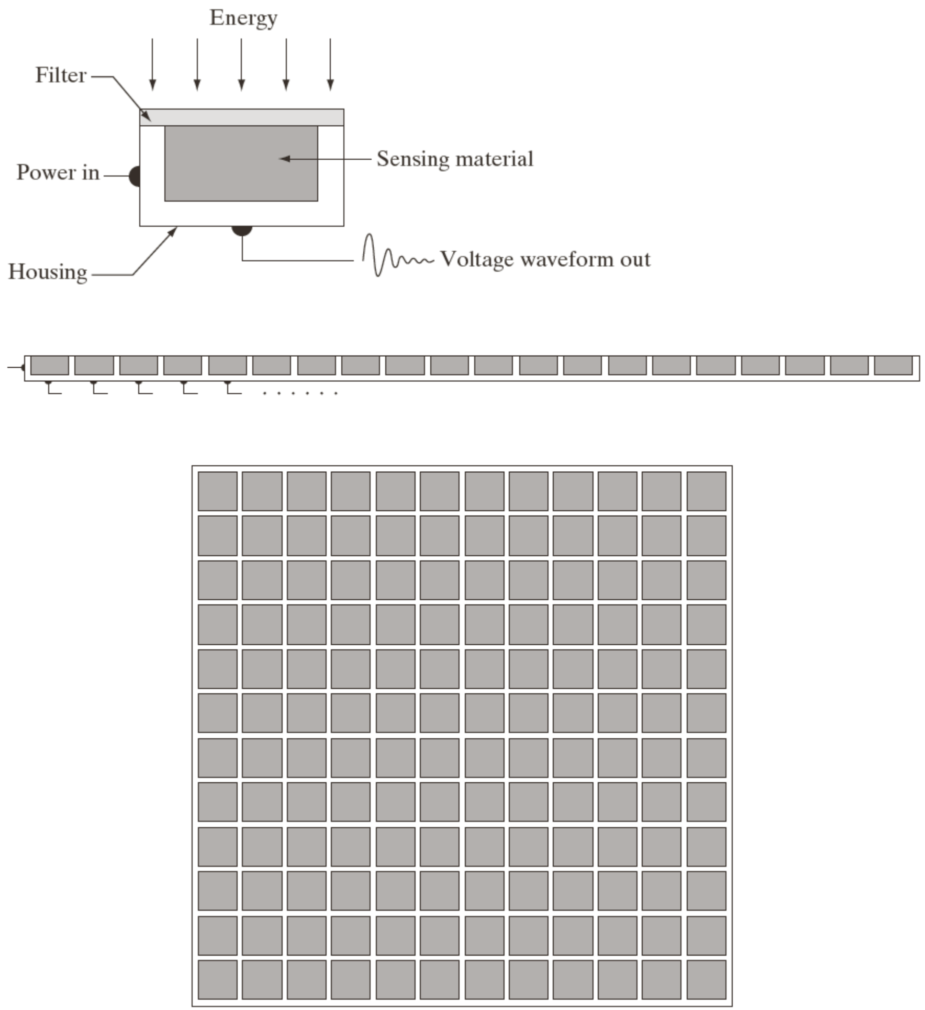
FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

Human simultaneous luminance vision range
(5 orders of magnitude)

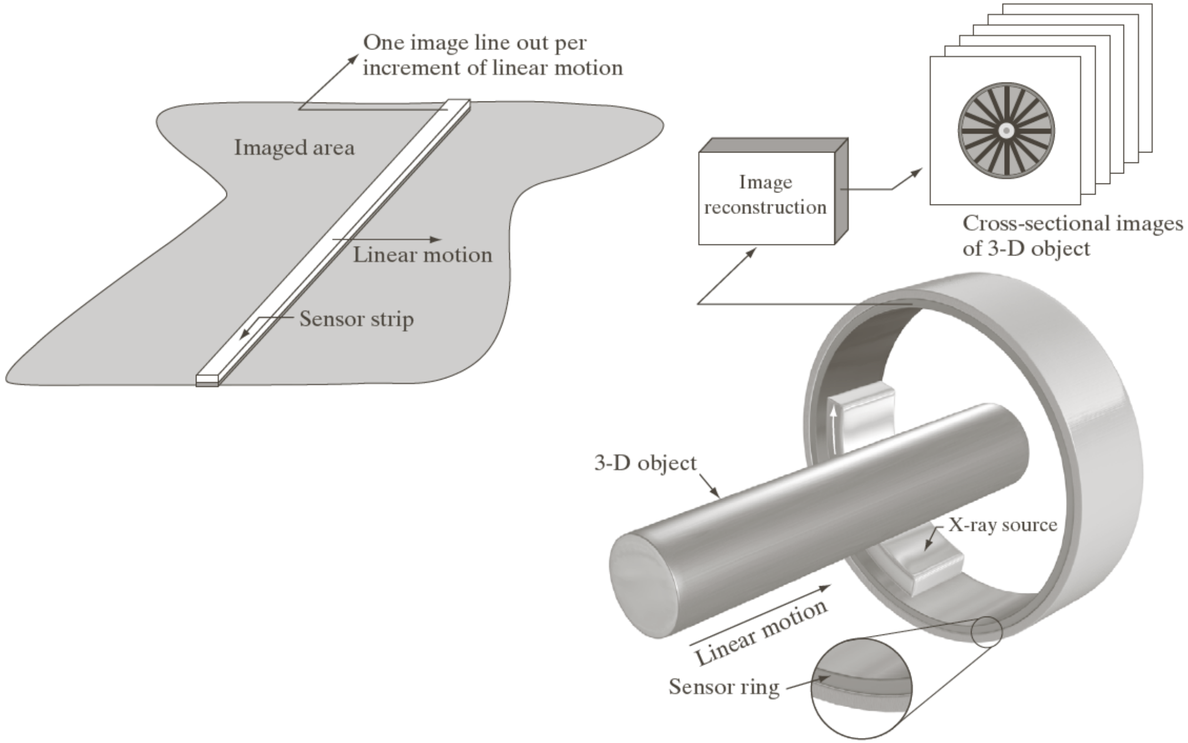


Digital Image Sensing



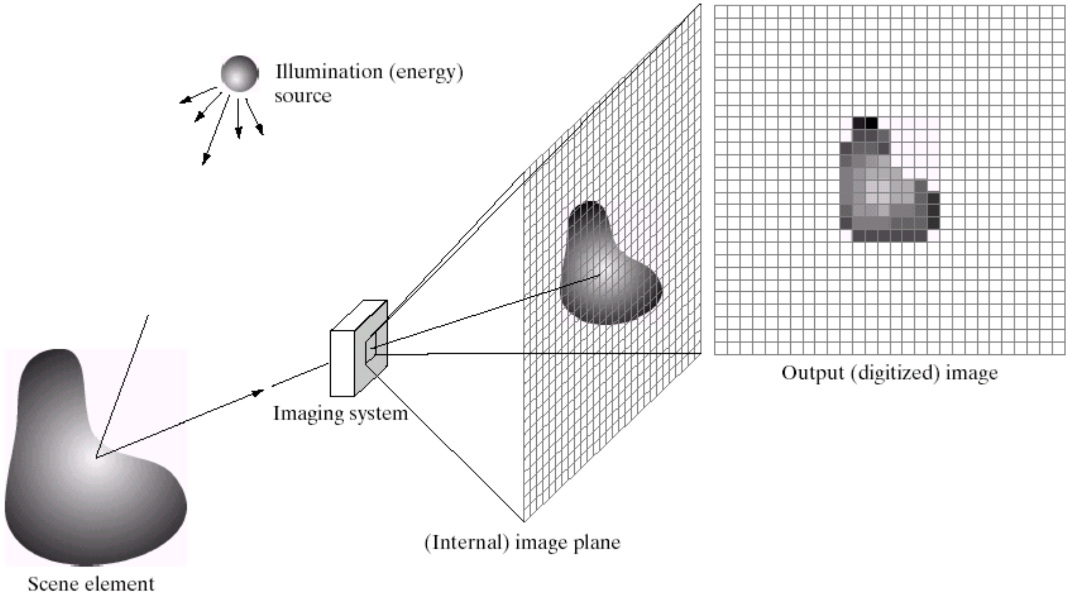
a
b
c

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



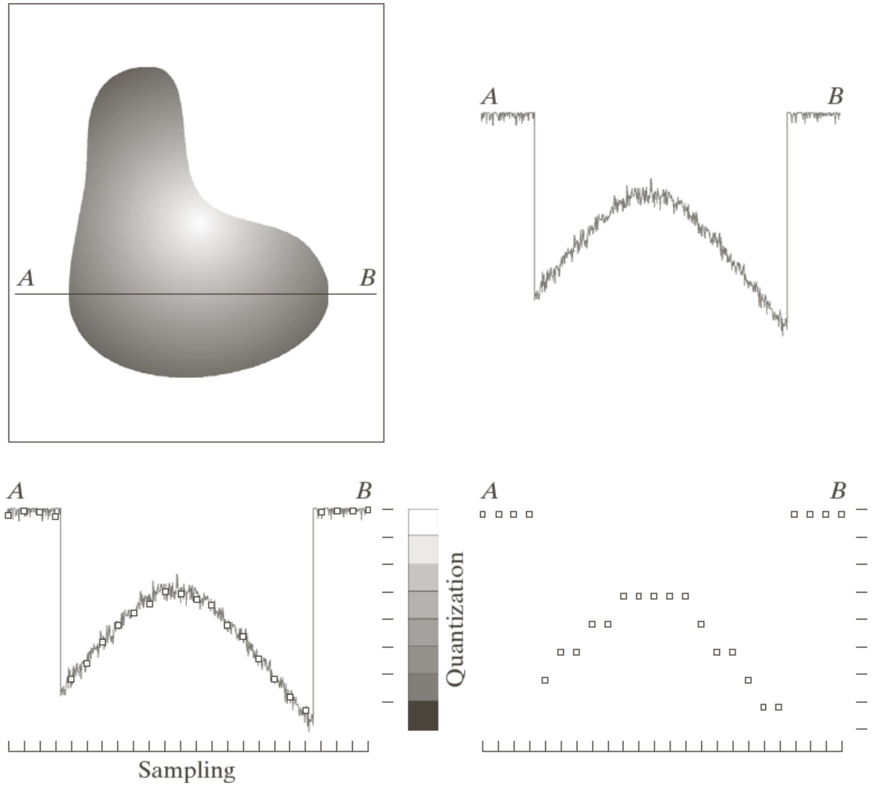
a b

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



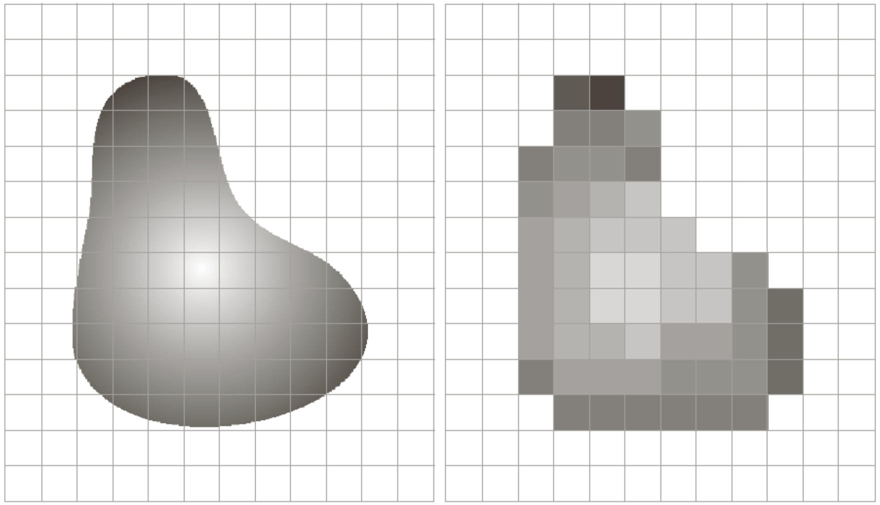
a
b c d e

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 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.



a b

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

Sampling and Quantization

How many samples to take?

- Number of pixels (samples) in the image
- Nyquist rate

How many gray-levels to store?

- At a pixel position (sample), number of levels of color/intensity to be represented

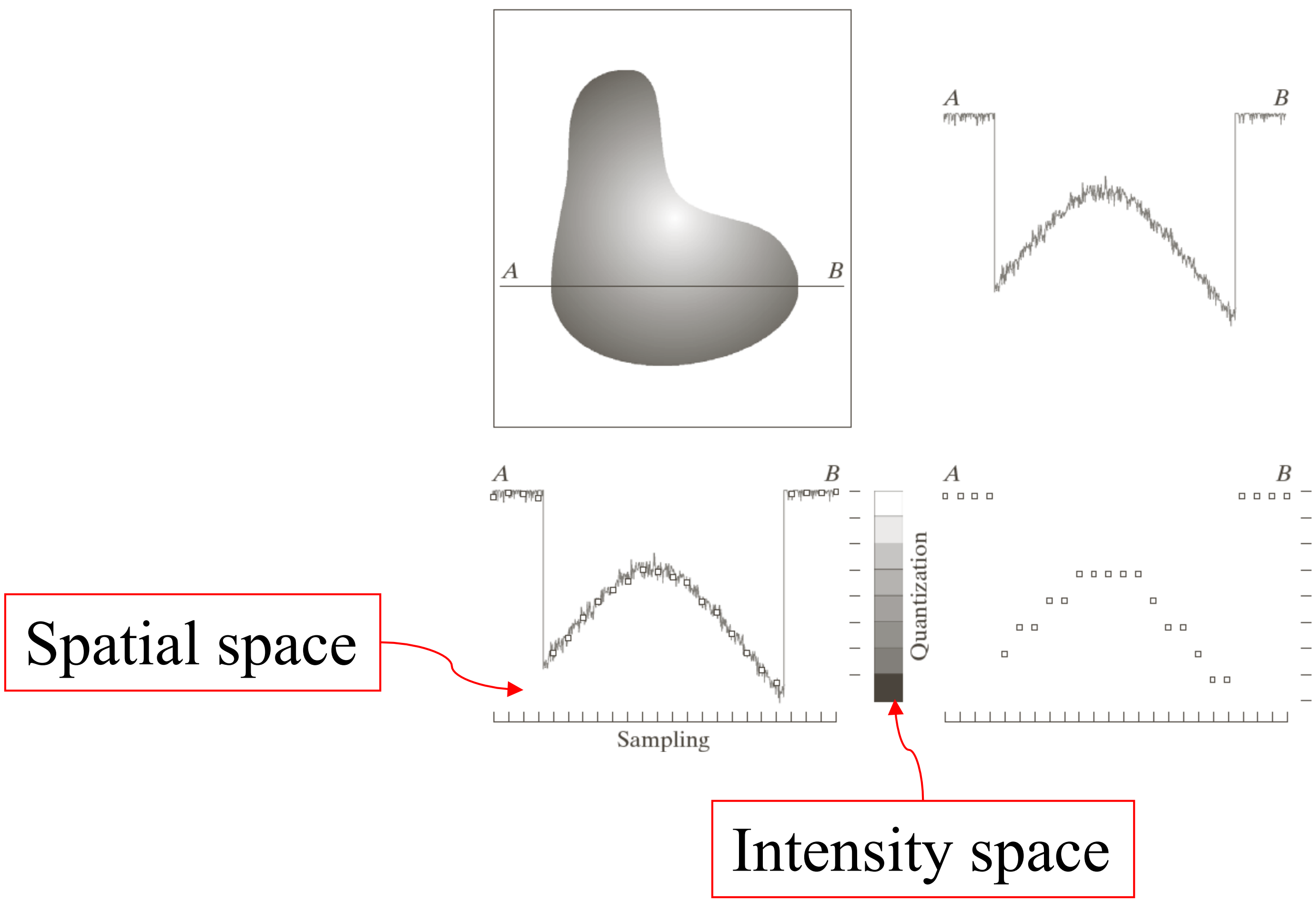


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Digital image in computer

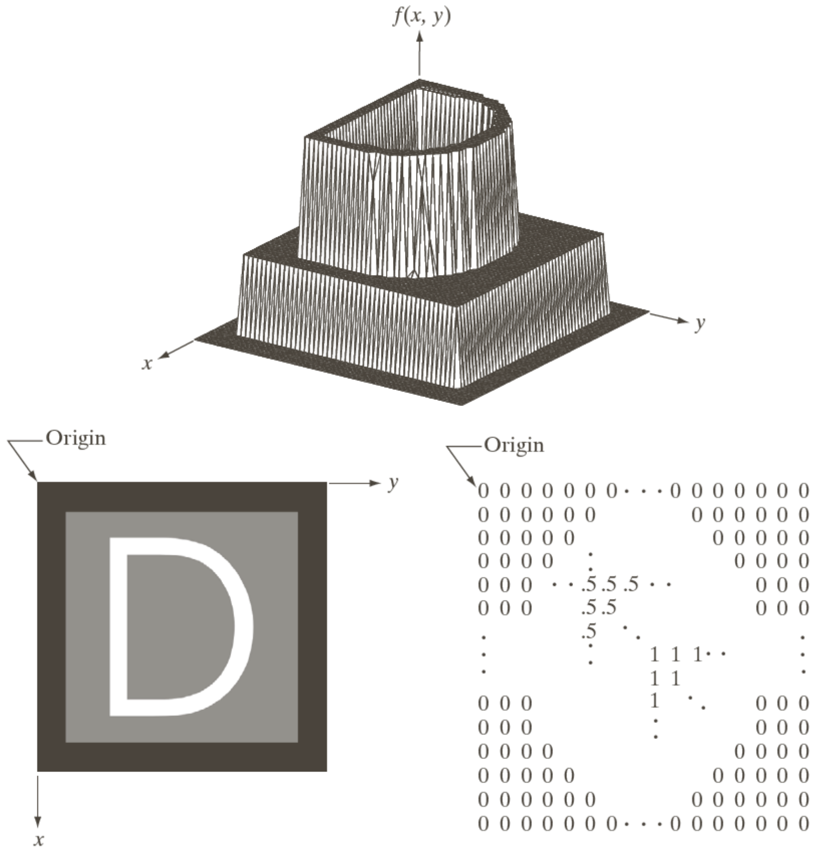
The representation of an gray image is a M×N numerical array as

$$A = \begin{bmatrix} a_{0,0} & a_{0,1} & \cdots & a_{0,N-1} \\ a_{1,0} & a_{1,1} & \cdots & a_{1,N-1} \\ \cdots & \cdots & \cdots & \cdots \\ a_{M-1,0} & a_{M-1,1} & \cdots & a_{M-1,N-1} \end{bmatrix}$$

Each $a_{i,j}$ is called a pixel

The magnitude of $a_{i,j}$ is represented digitally with a fixed number of bits - quantization

Digital image in computer



a
b c

FIGURE 2.18 (a) Image plotted as a surface. (b) Image displayed as a visual intensity array. (c) Image shown as a 2-D numerical array (0, .5, and 1 represent black, gray, and white, respectively).

Spatial and Intensity Resolution

Spatial resolution

— A measure of the smallest discernible detail in an image

— stated with *line pairs per unit distance, dots (pixels) per unit distance, dots per inch (dpi)*

$$\mathbf{A} \in \mathcal{R}^{M \times N}$$

Intensity resolution

— The smallest discernible change in intensity level

— stated with *8 bits, 12 bits, 16 bits, etc.*

$$a_{i,j} \in (0, 255) \quad a_{ij} \in (0, 2^{12} - 1) \quad a_{ij} \in (0, 2^{16} - 1)$$

TABLE 2.1
Number of storage bits for various values of N and k.

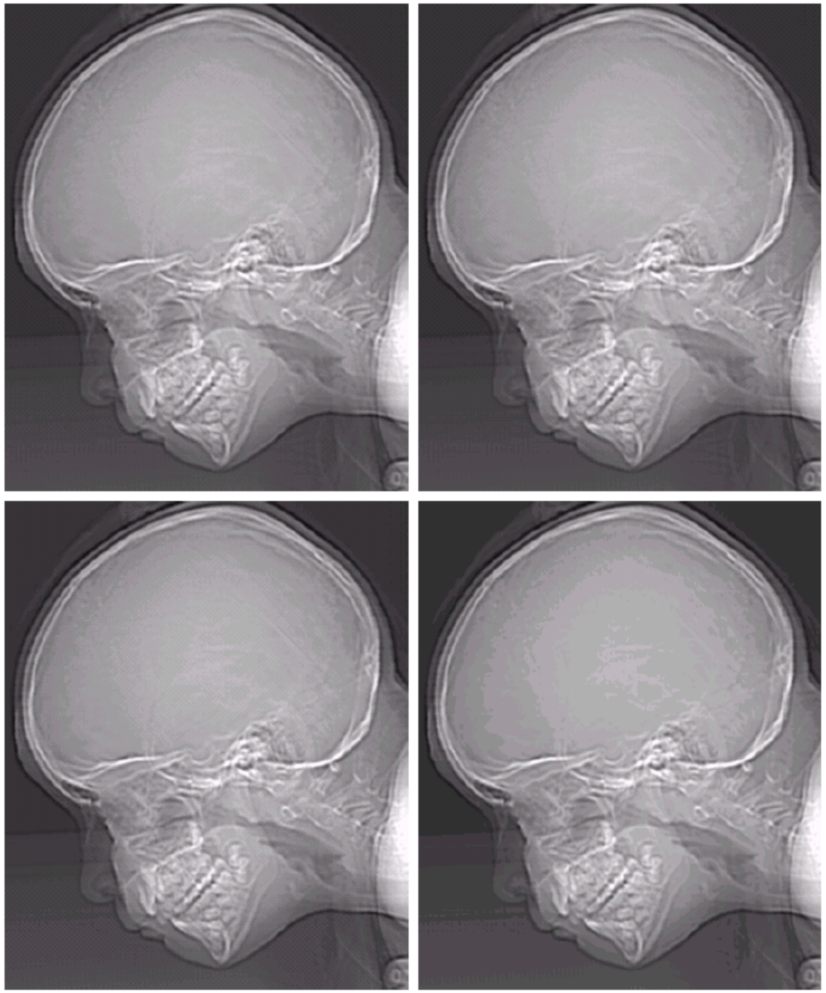
N/k	**1 (L = 2)**	**2 (L = 4)**	**3 (L = 8)**	**4 (L = 16)**	**5 (L = 32)**	**6 (L = 64)**	**7 (L = 128)**	**8 (L = 256)**
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	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

Spatial resolution

a b
c d

FIGURE 2.20 Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.

Intensity resolution



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.

Intensity resolution

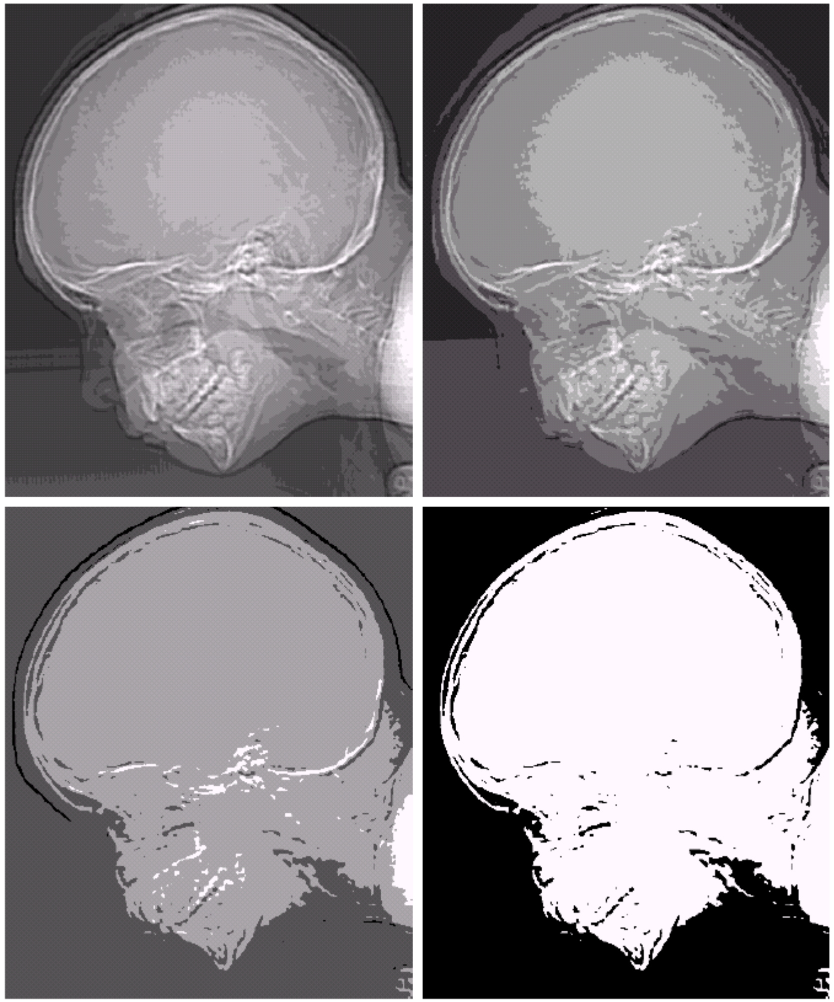
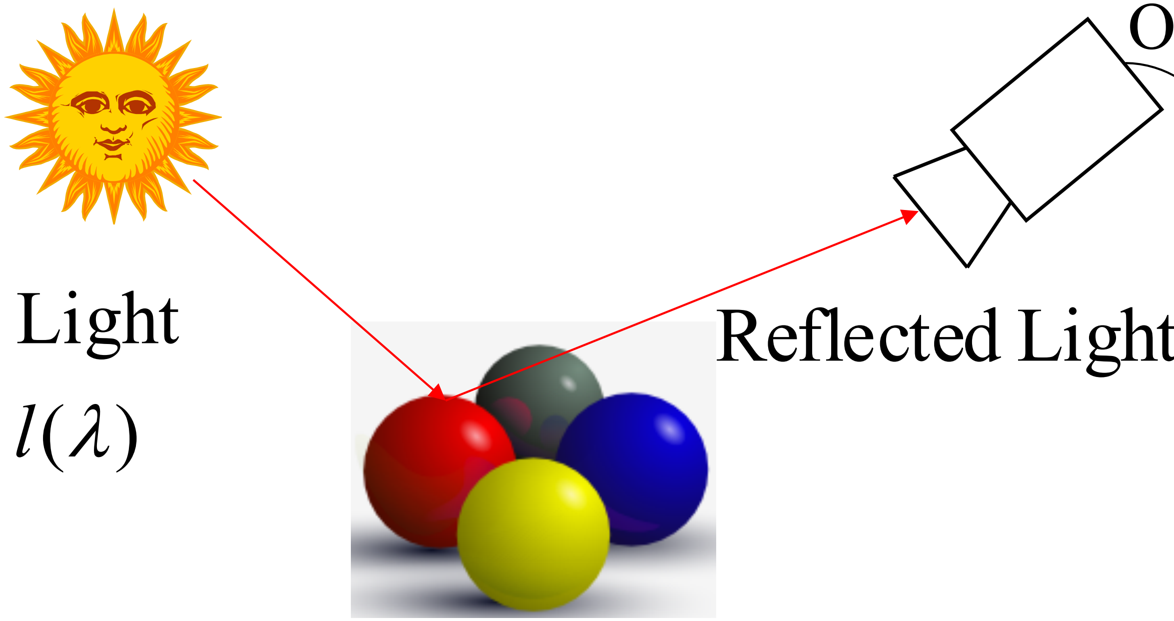


FIGURE 2.21 *(Continued)* (e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)

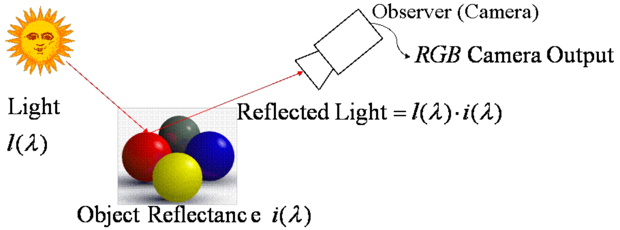
Color Imaging

Color image formation (acquisition)



Color Imaging

Color image formation (acquisition)



$$R(x,y)=\int l(\lambda)\cdot i(x,y,\lambda)\cdot F_R(\lambda)d\lambda$$

$$G(x,y)=\int l(\lambda)\cdot i(x,y,\lambda)\cdot F_G(\lambda)d\lambda$$

$$B(x,y)=\int l(\lambda)\cdot i(x,y,\lambda)\cdot F_B(\lambda)d\lambda$$

Color filters
Of the sensor

Color Imaging

The RGB Color Model

- R, G, B at 3 axis ranging in [0 1] each
- Gray scale along the diagonal
- If each component is quantized into 256 levels [0:255], the total number of different colors that can be produced is $(2^8)^3 = 2^{24}$ =16,777,216 colors.

Color Imaging

The RGB Color Model

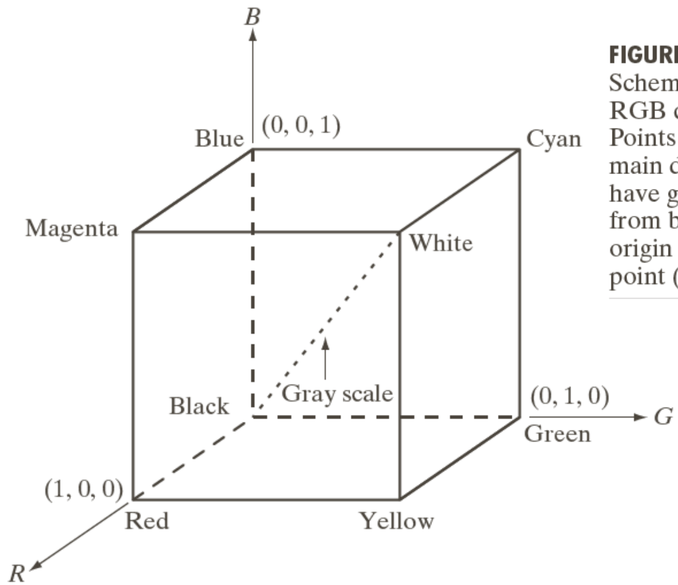


FIGURE 6.7 Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

FIGURE 6.8 RGB 24-bit color cube.

Color Imaging

The YIQ Color Model

- Video (NTSC) standard
- Y encodes luminance; I and Q encode chrominance (“color”)
- Black and white TV shows only the Y channel
- Backward compatibility; efficiency

$$\begin{cases} Y &= 0.299 \times R + 0.587 \times G + 0.114 \times B \\ I &= 0.596 \times R - 0.274 \times G - 0.322 \times B \\ Q &= 0.212 \times R - 0.523 \times G + 0.311 \times B \end{cases}$$

Color Imaging

Color Models, YCbCr

$$\left\{ \begin{array}{lcl} Y & = & 0.2989 \times R + 0.5866 \times G + 0.1145 \times B \\ Cb & = & -0.1688 \times R - 0.3312 \times G + 0.5000 \times B \\ Cr & = & 0.5000 \times R - 0.4184 \times G - 0.0816 \times B \end{array} \right.$$

Color Imaging

More Color Models, see e.g.,

Color Imaging

Color image representation (in RGB space)

=

Red

Green

Blue

Color Imaging

Color image representation (in RGB space)

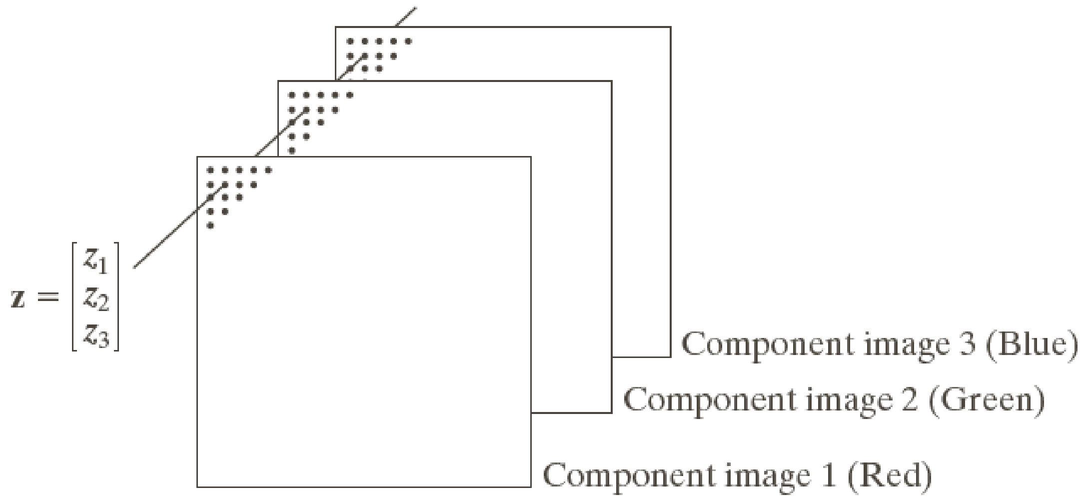


FIGURE 2.38 Formation of a vector from corresponding pixel values in three RGB component images.