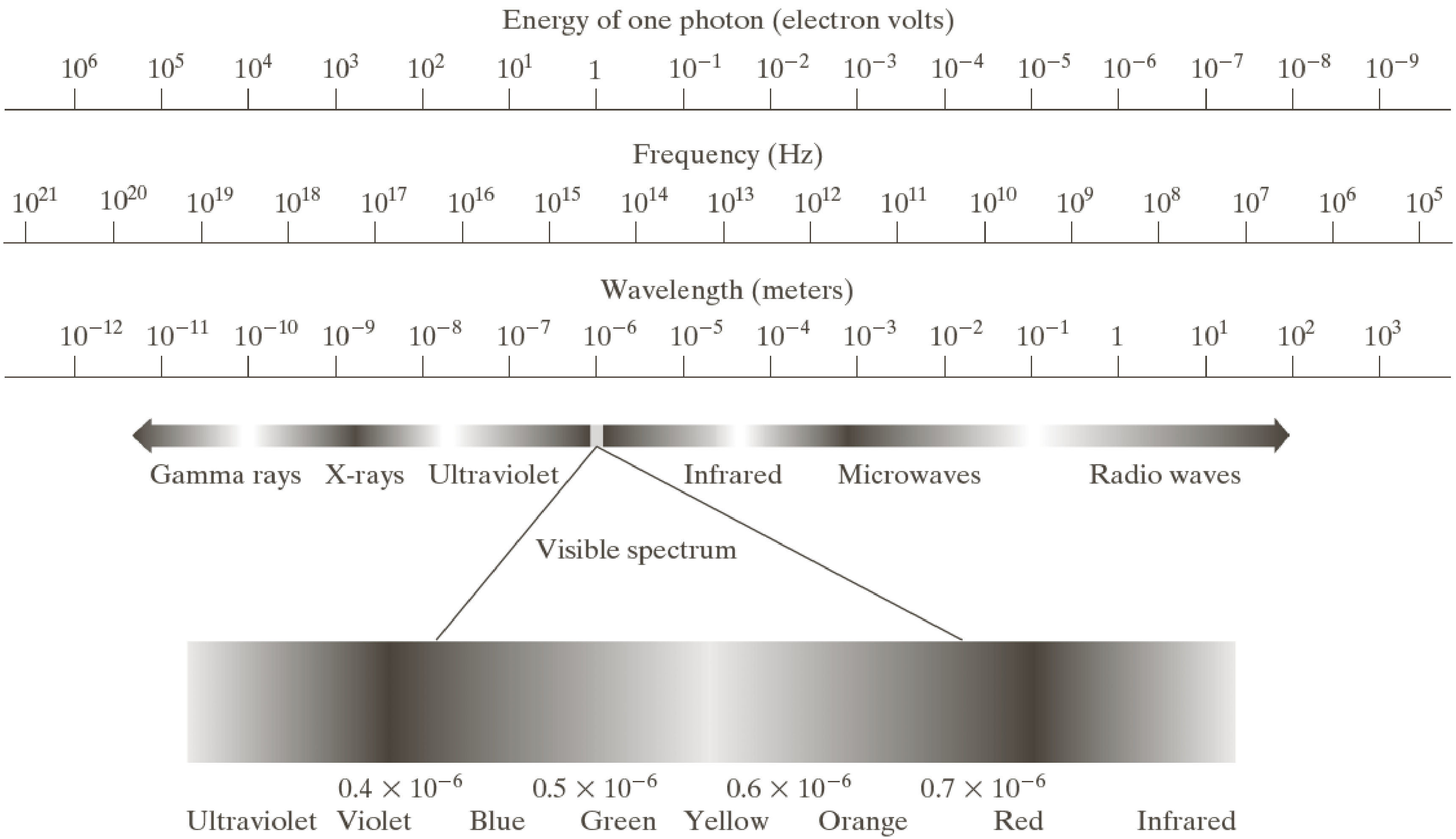
SYDE 575: Introduction to Image Processing

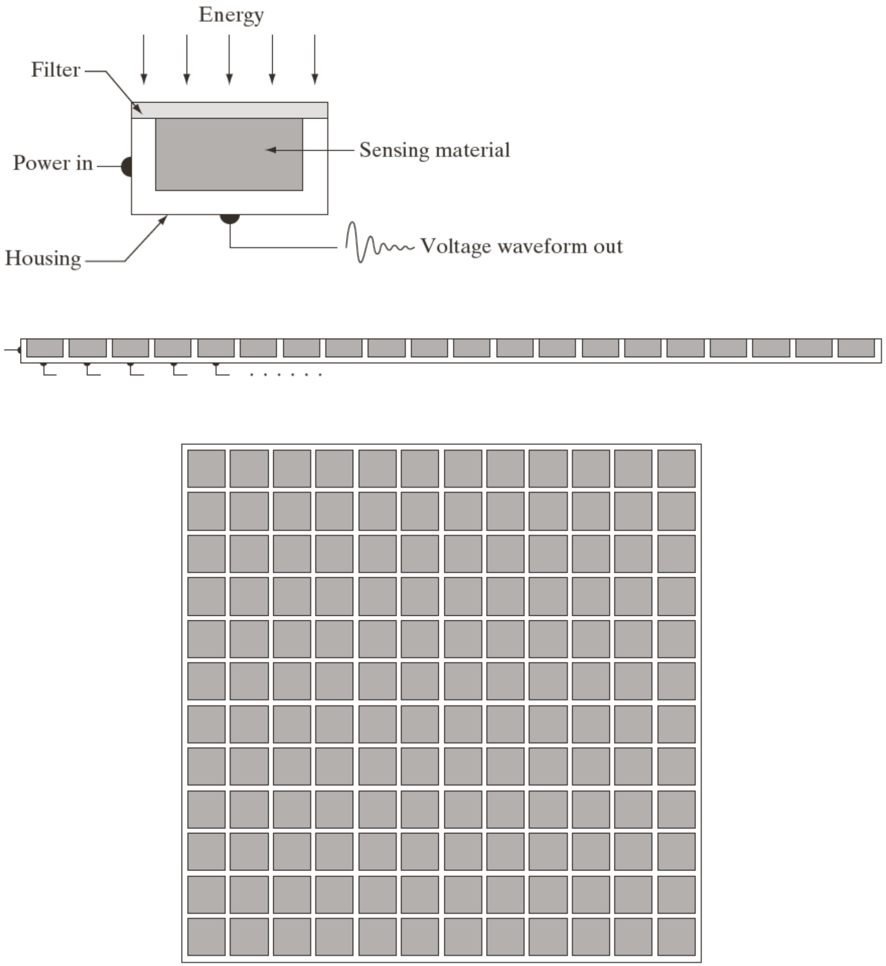
Digital Image Processing Fundamentals

Electromagnetic Spectrum



Source: Gonzalez and Woods

Image Sensing



a
b
c

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

Source: Gonzalez and Woods

Digital Image Acquisition Example

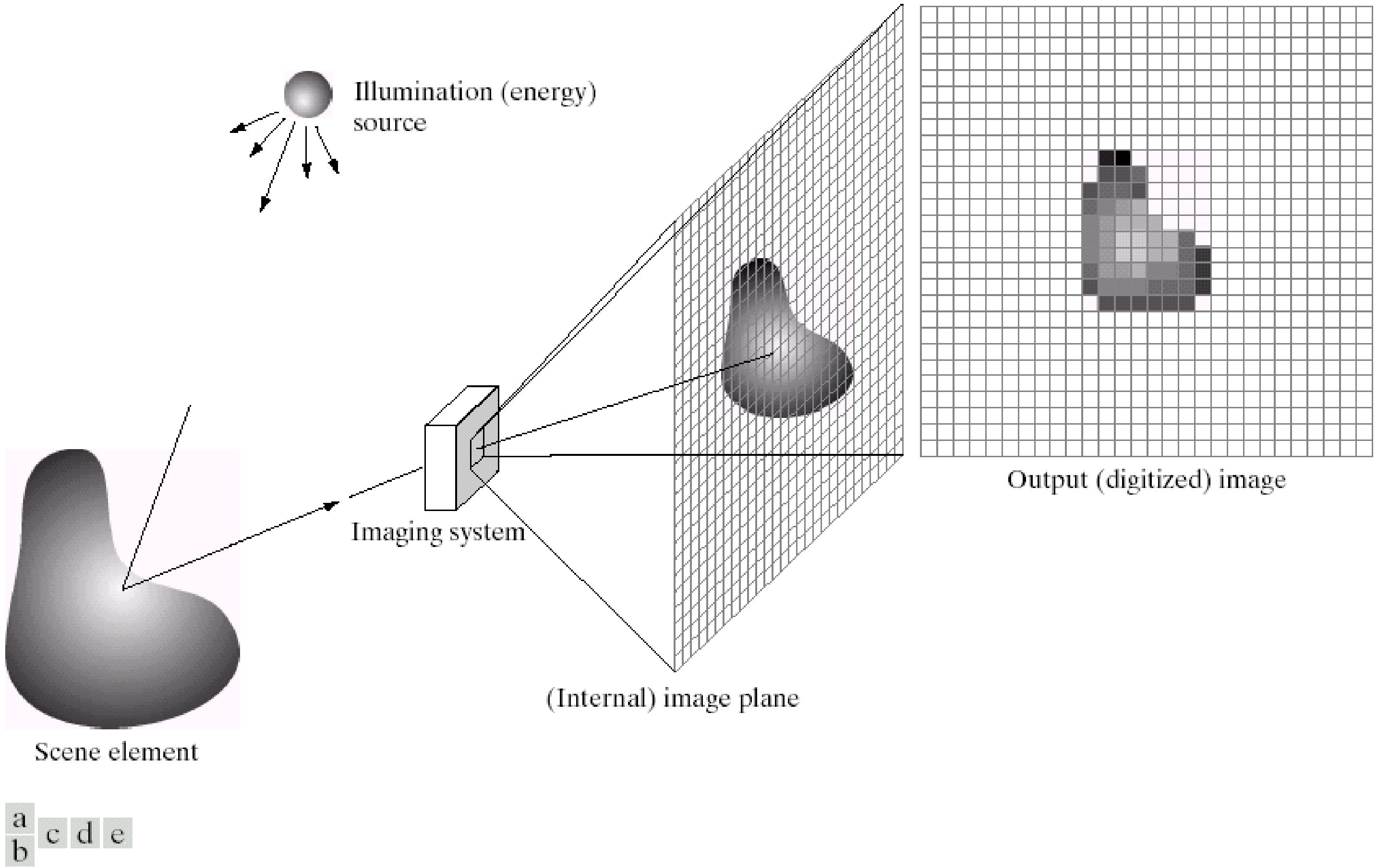


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Source: Gonzalez and Woods

Simple Image Formation Model

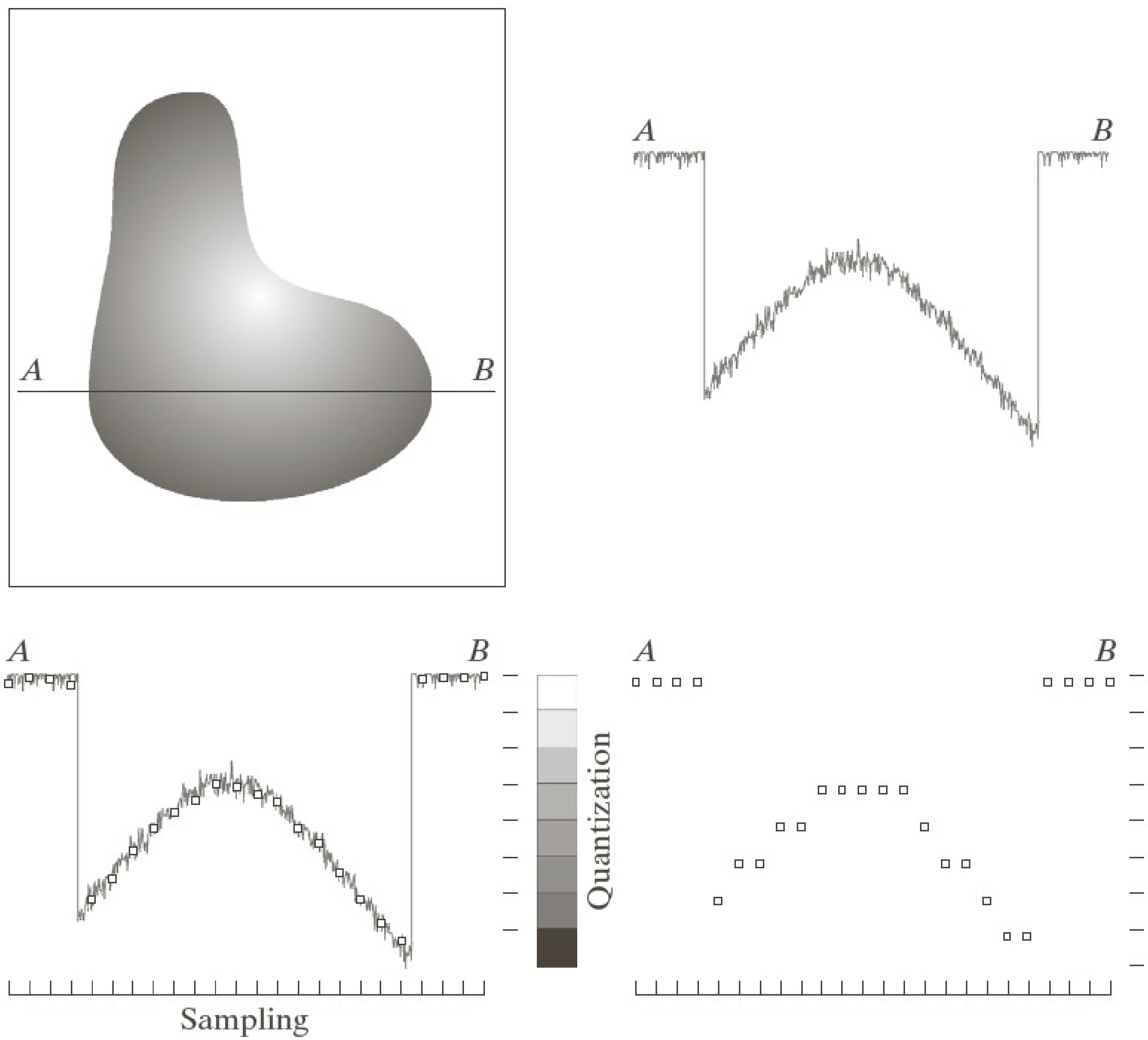
- Image may be characterized by:
  - Amount of source illumination incident on scene
  - Amount of illumination reflected by objects in scene (r=0 for total absorption, and r=1 for total reflectance)

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

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

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

Image Sampling and Quantization



Source: Gonzalez and Woods

Example

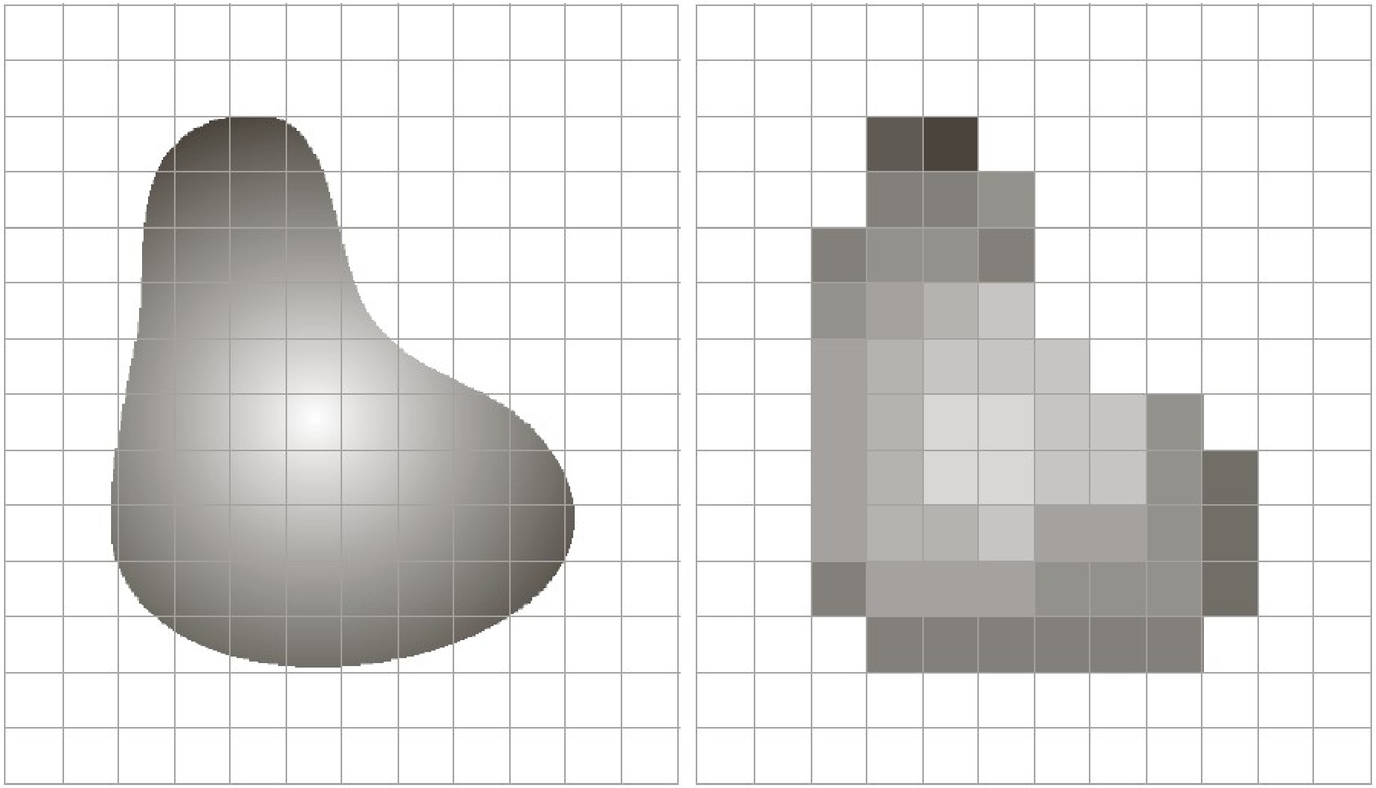
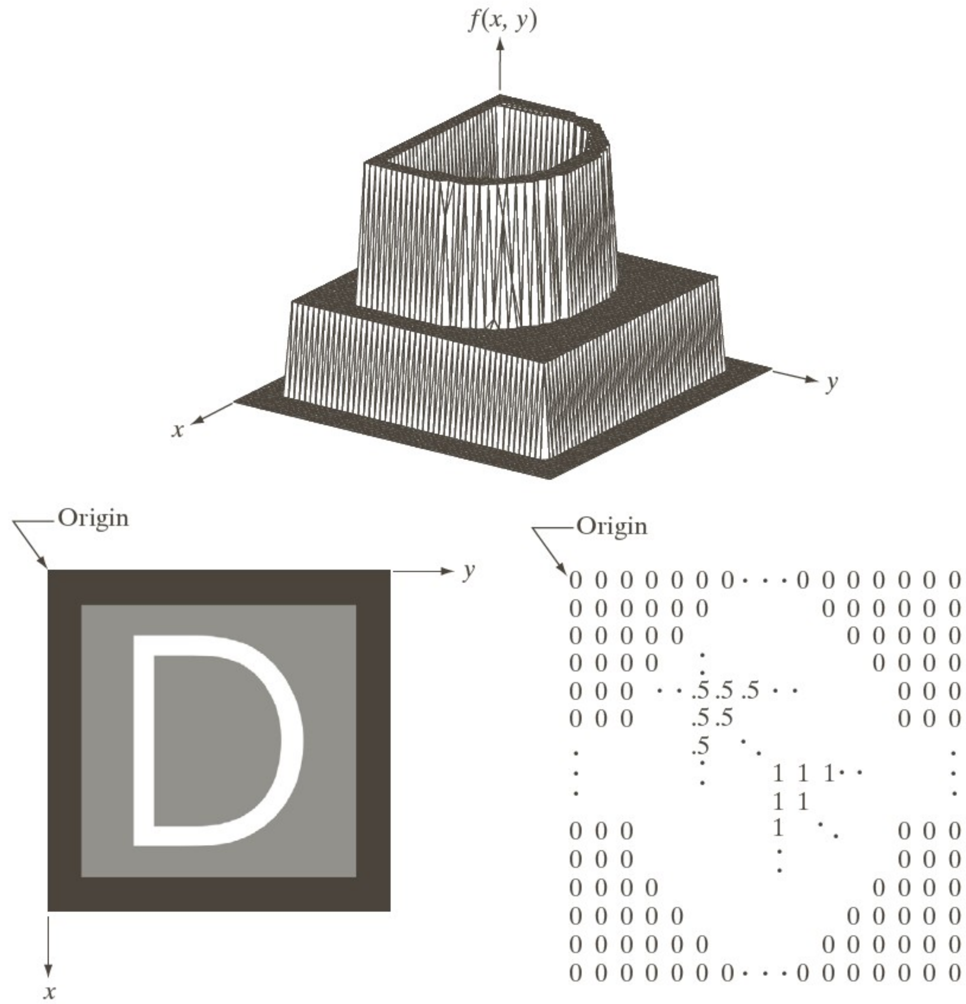


FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Source: Gonzalez and Woods

Digital Image Representation



Source: Gonzalez and Woods

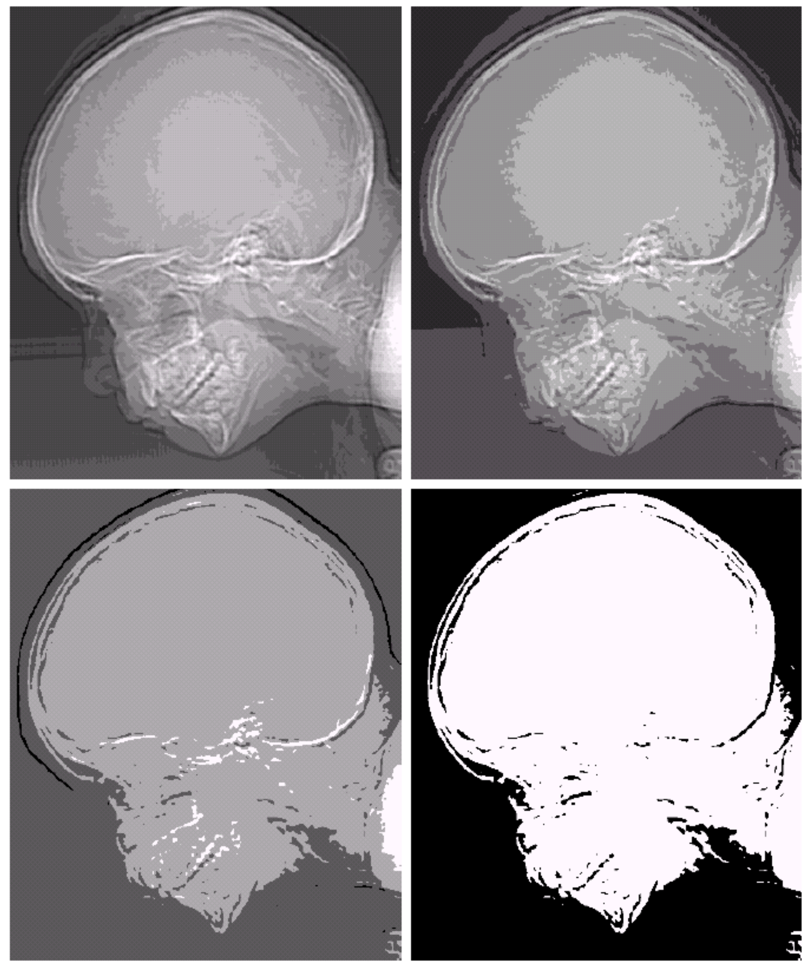
Spatial Resolution

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.

Source: Gonzalez and Woods

Gray-level Resolution



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.)

Source: Gonzalez and Woods

Digital Zooming

- Nearest neighbor interpolation
  - Look for closest pixel in original image
  - Fast but causes undesirable checkerboard effect
- Bilinear interpolation
  - Determines pixel value based on four nearest neighbors
    - Do linear interpolation in x direction
    - Do linear interpolation in y direction based on results of interpolation from x direction
  - Does not suffer from checkerboard effect but can result in a blurred appearance

Digital Zooming

- Bicubic Interpolation
  - Determines pixel value based on sixteen nearest neighbors
    - Do cubic spline interpolation in x direction
    - Do cubic spline interpolation in y direction based on results of interpolation from x direction
  - Does not suffer from checkerboard effect like nearest neighbor interpolation and preserves fine details better than bilinear interpolation

Zooming Results

Nearest Neighbor

Bilinear Interpolation

Bicubic Interpolation

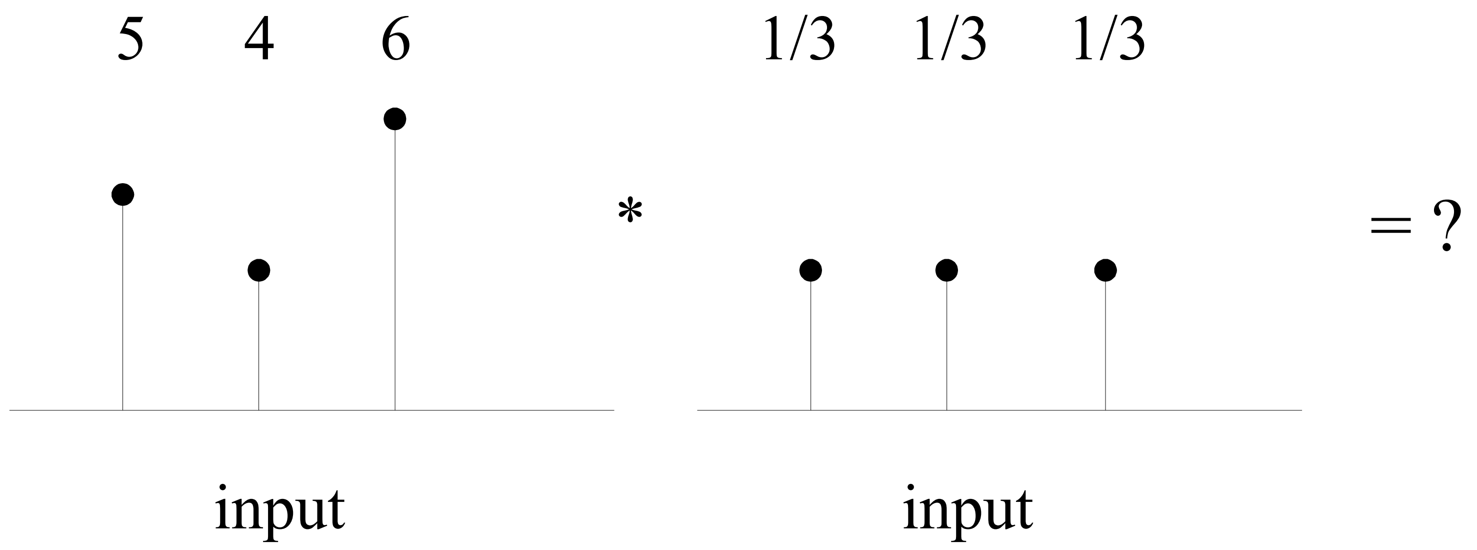
Source: Gonzalez and Woods

Discrete Convolution

$$g[n] = f[n] * h[n] = \sum_{k=-\infty}^{\infty} f[k] \cdot h[n-k]$$

output   input   impulse function

Discrete Convolution Example



Discrete Convolution in 2D

$$g[m,n] = f[m,n] * h[m,n] = \sum_{j=-\infty}^{\infty} \sum_{i=-\infty}^{\infty} f[i,j] \cdot h[m-i, n-j]$$

output

input

impulse function

Discrete Fourier Transform

- A signal can be expressed as a weighted sum of sines and cosines

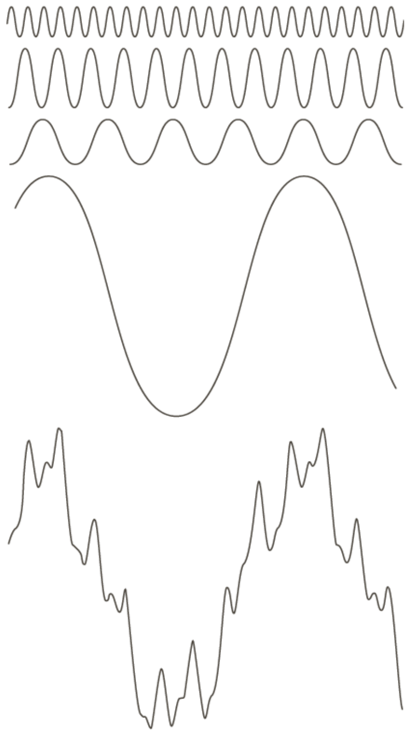


FIGURE 4.1 The function at the bottom is the sum of the four functions above it. Fourier's idea in 1807 that periodic functions could be represented as a weighted sum of sines and cosines was met with skepticism.

Source: Gonzalez and Woods

Discrete Fourier Transform

- Euler's formula

$$e^{j\theta} = \cos\theta + j\sin\theta$$

- Based on this, summation of sines and cosines can be expressed

$$e^{-j2\pi ux/M} = \underbrace{\cos(2\pi ux/M)}_{\text{cosines}} - j\underbrace{\sin(2\pi ux/M)}_{\text{sines}}$$

Discrete Fourier Transform

$$F(u) = \frac{1}{M}\sum_{x=0}^{M-1} f(x)e^{-j2\pi ux/M} \; for \text{ u=0,1,2,...,M-1}$$

output

input

sinusoids

$$f(x) = \sum_{u=0}^{M-1} F(u)e^{j2\pi ux/M} \; for \text{ x=0,1,2,...,M-1}$$

Discrete Fourier Transform in 2D

- For an MxN image

$$F(u,v) = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)e^{-j2\pi(ux/M+vy/N)}$$

output input sinusoids

$$f(x,y) = \sum_{u=0}^{M-1}\sum_{v=0}^{N-1} F(u,v)e^{j2\pi(ux/M+vy/N)}$$

Fourier Analysis: Spectra

$$\left|F(u,v)\right| = \left[R^2(u,v) + I^2(u,v) \right]^{1/2}$$

$$R = \mathrm{Re}(F(u,v)),\ I = \mathrm{Im}(F(u,v))$$

- Power Spectrum

$$P(u,v) = \left|F(u,v)\right|^2$$

Fourier Spectra Characteristics of Images

- Most energy reside in low frequency components
  - Implies that the original image can be reconstructed with good approximation with the low frequency components
- Low frequency components correspond to coarse details
  - e.g., DC component represents average color of an image
- High frequency components correspond to fine details
  - e.g., edges, noise

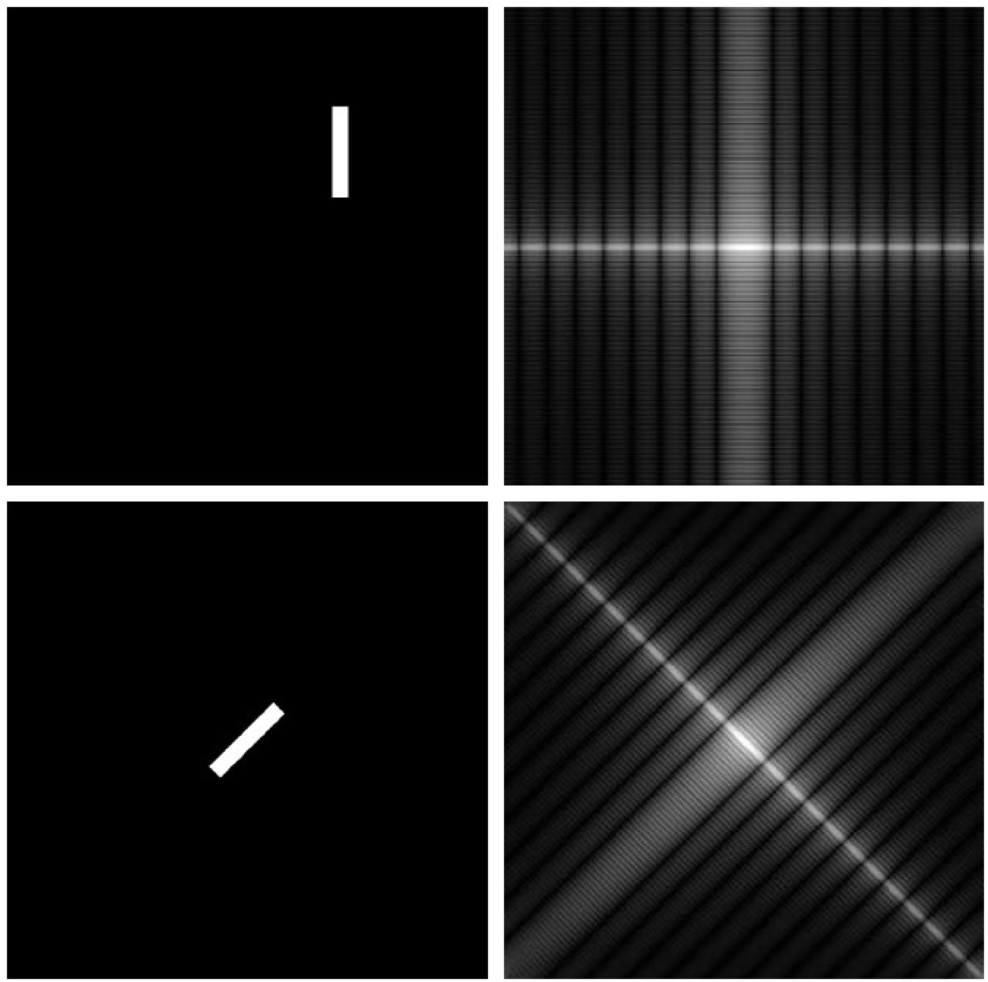
Fourier Analysis: Spectra

- In image coordinates, origin (0,0) refers to top-left corner
- Results in spectra being centered at corner
- Common practice to multiply input image by $(-1)^{x+y}$
  - Why?

$$\Im\left[f(x,y)(-1)^{x+y} \right] = F(u-M/2, v-N/2)$$

- Brings original of spectra to center of image

Fourier Spectra Example

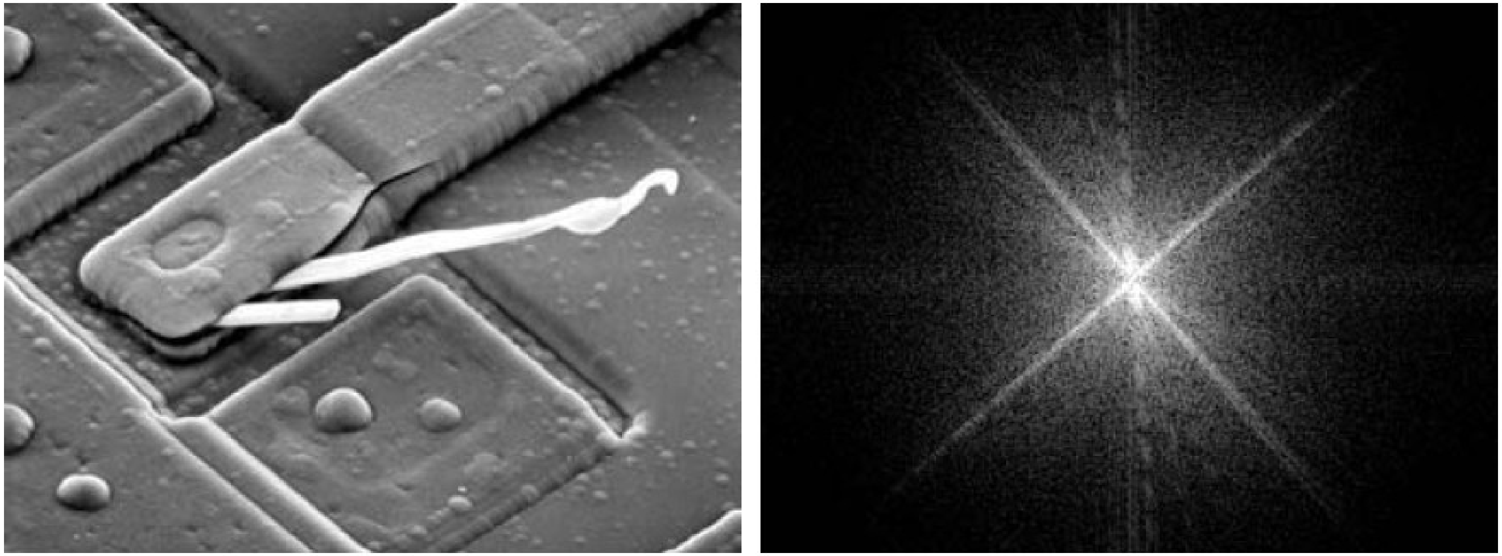


a b
c d

FIGURE 4.25
(a) The rectangle in Fig. 4.24(a) translated, and (b) the corresponding spectrum. (c) Rotated rectangle, and (d) the corresponding spectrum. The spectrum corresponding to the translated rectangle is identical to the spectrum corresponding to the original image in Fig. 4.24(a).

Source: Gonzalez and Woods

Fourier Spectra Example



a b

FIGURE 4.29 (a) SEM image of a damaged integrated circuit. (b) Fourier spectrum of (a). (Original image courtesy of Dr. J. M. Hudak, Brockhouse Institute for Materials Research, McMaster University, Hamilton, Ontario, Canada.)

Source: Gonzalez and Woods

Fourier Analysis: Phase

- Characterizes structural information within an image

$$\phi(u,v) = \tan^{-1}\left[\frac{I(u,v)}{R(u,v)}\right]$$

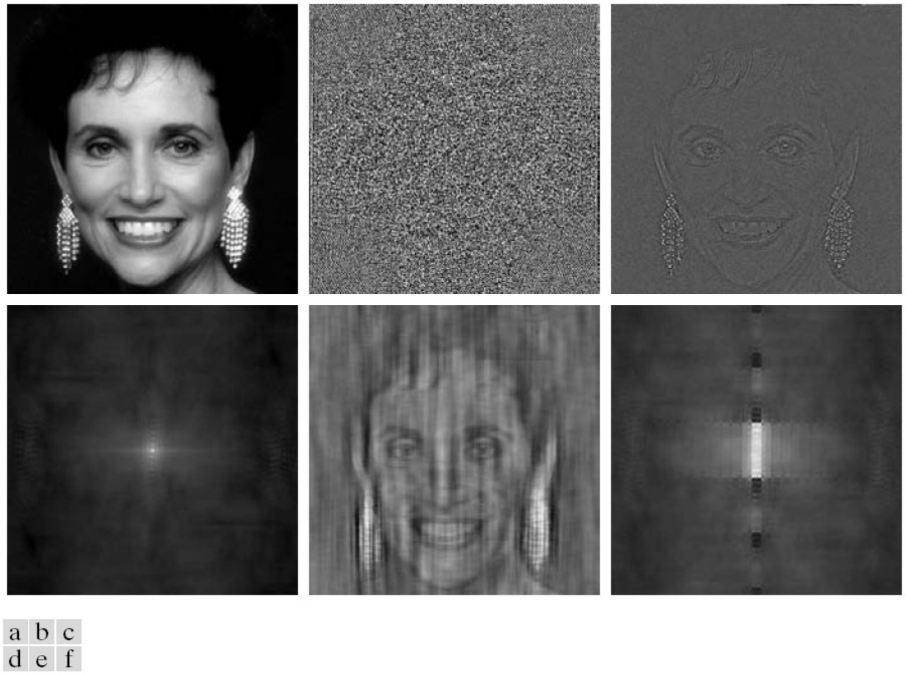


FIGURE 4.27 (a) Woman. (b) Phase angle. (c) Woman reconstructed using only the phase angle. (d) Woman reconstructed using only the spectrum. (e) Reconstruction using the phase angle corresponding to the woman and the spectrum corresponding to the rectangle in Fig. 4.24(a). (f) Reconstruction using the phase of the rectangle and the spectrum of the woman.

Source: Gonzalez and Woods

Transfer Function

$$G(u,v) = F(u,v)H(u,v)$$

output

input

transfer function

Image Quality Measures

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\left\| f(i,j) - g(i,j)\right\|^2$$

$$PSNR = 10\log_{10}\left(\frac{MAX_f^{\,2}}{MSE}\right) = 20\log_{10}\left(\frac{MAX_f}{\sqrt{MSE}}\right)$$