Digital Image Fundamentals

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Imaging process

- Light reaches surfaces in 3D.
- Surfaces reflect.
- Sensor element receives light energy.
- Intensity is important.
- Angles are important.
- Material is important.

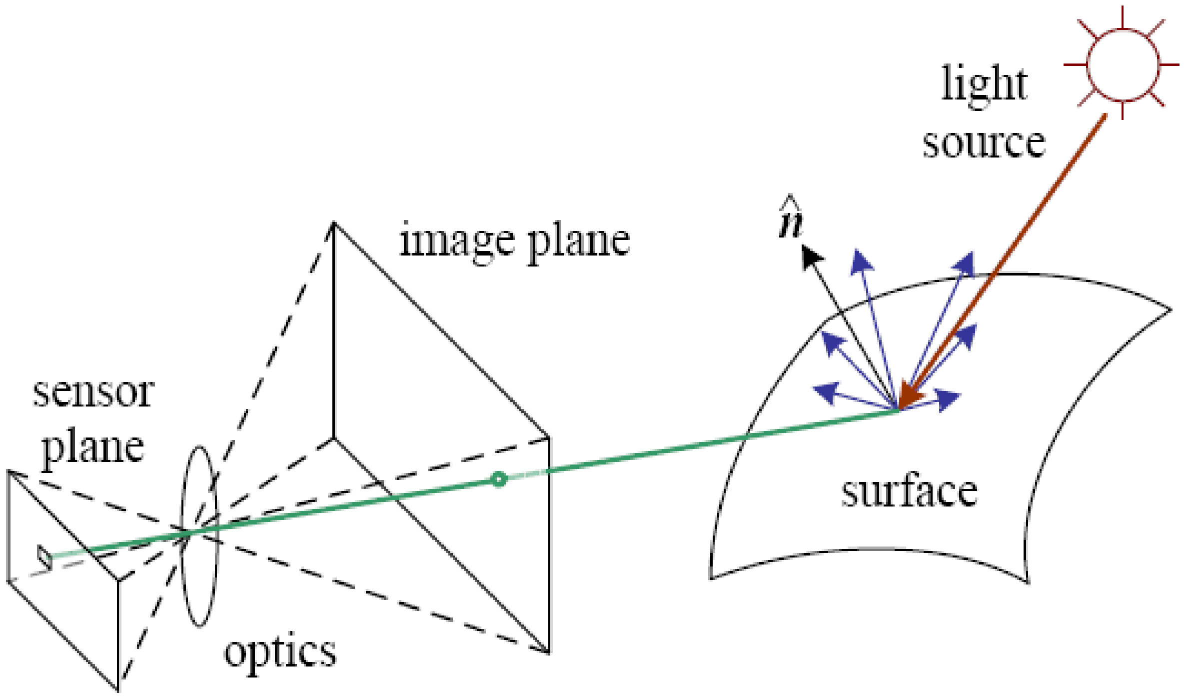


Figure 2.14: *A simplified model of photometric image formation. Light is emitted by one or more light sources, and is then reflected from an object's surface. A portion of this light is directed towards the camera. This simplified model ignores multiple reflections, which often occur in real-world scenes.*

Adapted from Rick Szeliski

Physical parameters

- Geometric
  - Type of projection
  - Camera pose
- Optical
  - Sensor's lens type
  - Focal length, field of view, aperture
- Photometric
  - Type, direction, intensity of light reaching sensor
  - Surfaces' reflectance properties
- Sensor
  - Sampling, etc.

Adapted from Trevor Darrell, UC Berkeley

Image acquisition

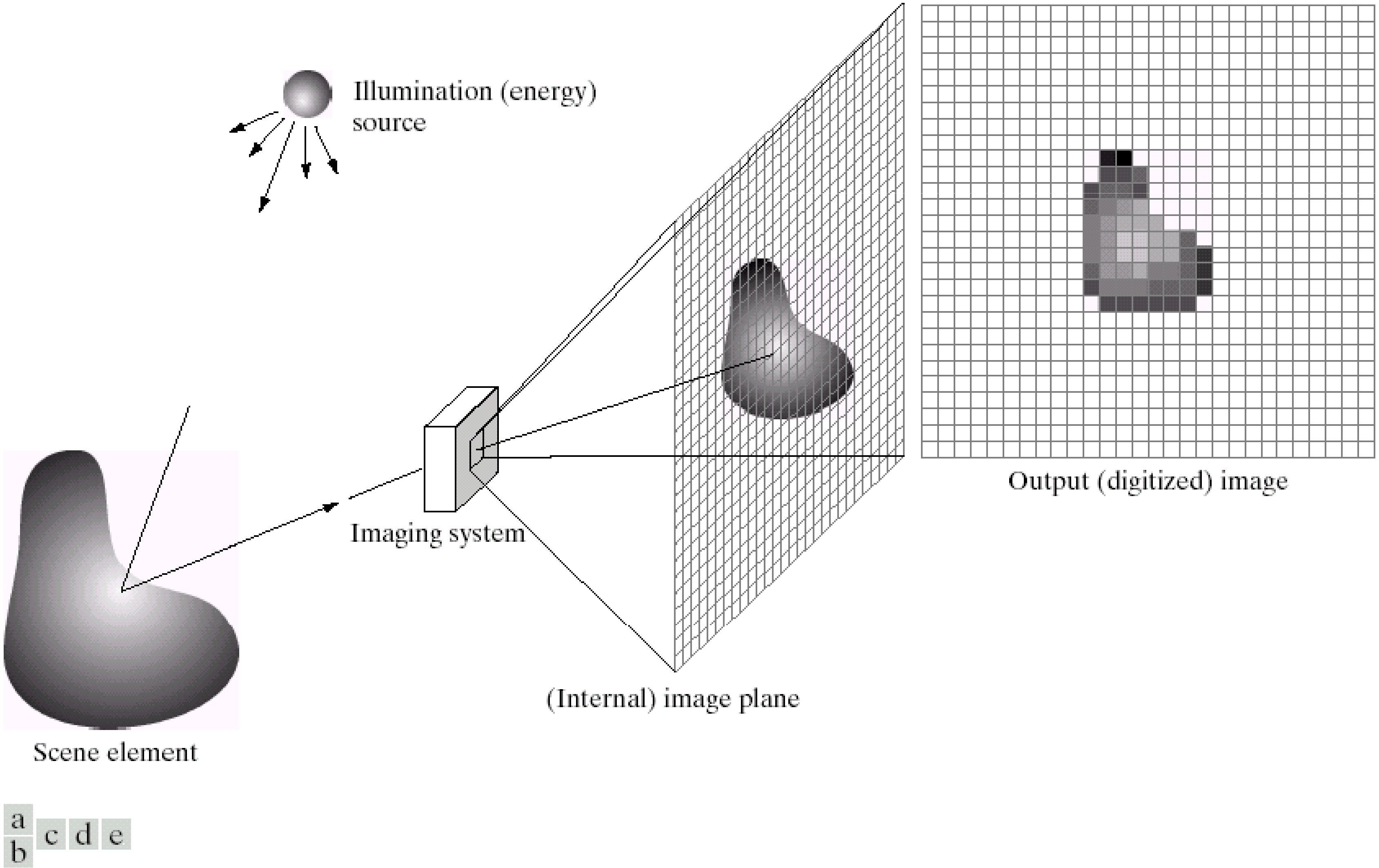


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Adapted from Gonzales and Woods

Image acquisition

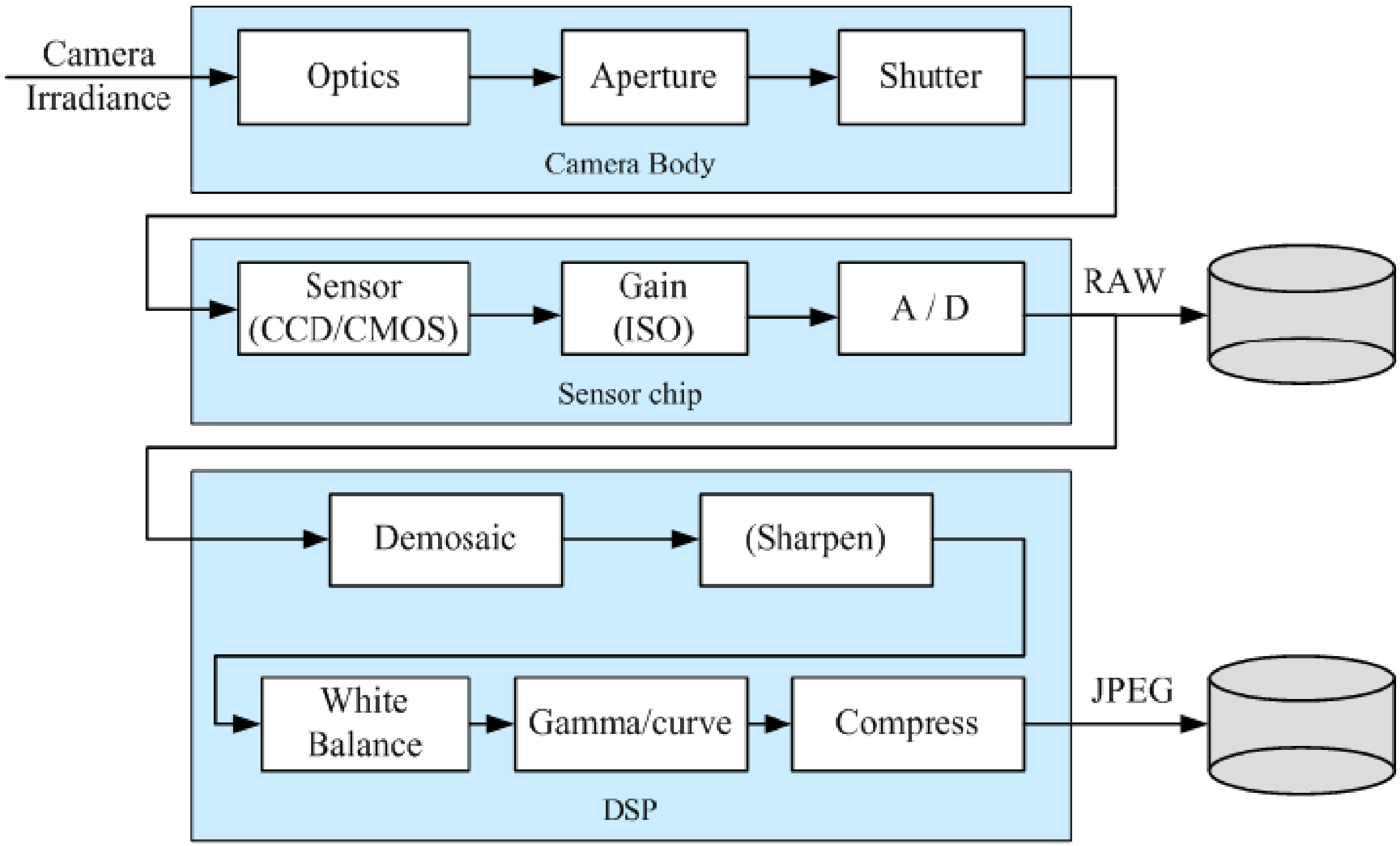
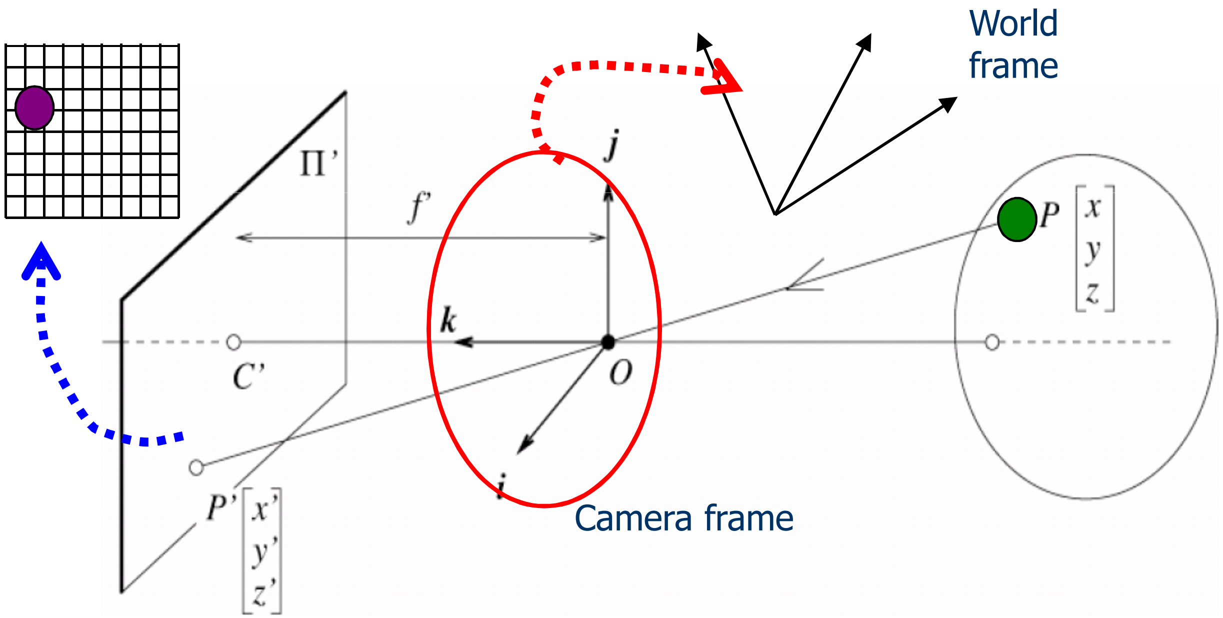


Figure 2.26: *Image sensing pipeline, showing the various sources of noise as well as the typical digital post-processing steps.*

Adapted from Rick Szeliski

Camera calibration



- Camera's extrinsic and intrinsic parameters are needed to calibrate the geometry.
- Extrinsic: camera frame $\leftrightarrow$ world frame
- Intrinsic: image coordinates relative to camera $\leftrightarrow$ pixel coordinates

Adapted from Trevor Darrell, UC Berkeley

Perspective effects

Adapted from Trevor Darrell, UC Berkeley

Aperture

- Aperture size affects the image we would get.

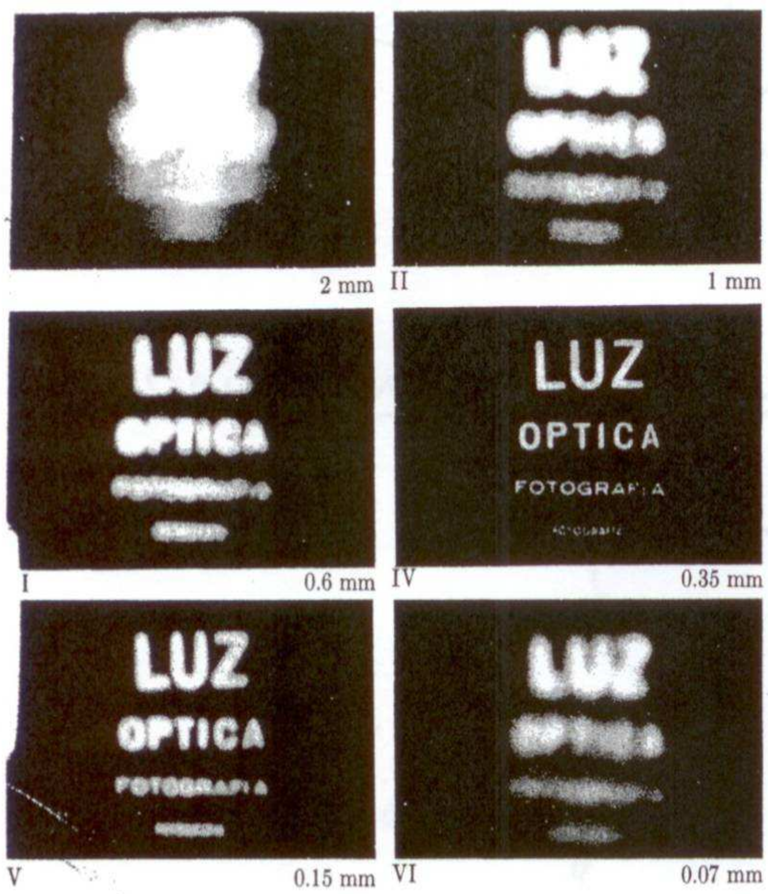


Fig. 5.96 The pinhole camera. Note the variation in image clarity as the hole diameter decreases. [Photos courtesy Dr. N. Joel, UNESCO.]

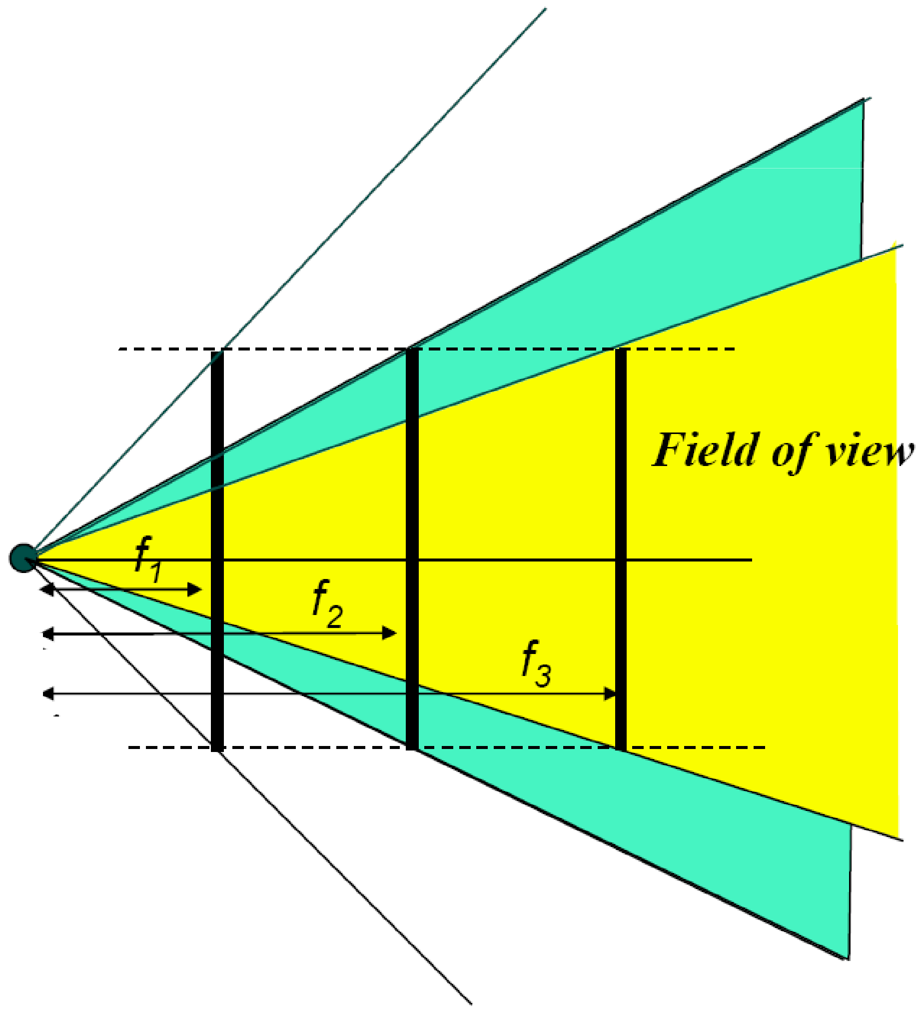
Larger

Smaller

Adapted from Trevor Darrell, UC Berkeley

Focal length

- Field of view depends on focal length.
- As **f** gets smaller, image becomes more *wide* angle
  - more world points project onto the finite image plane
- As **f** gets larger, image becomes more *telescopic*
  - smaller part of the world projects onto the finite image plane



Adapted from Trevor Darrell, UC Berkeley

Sampling and quantization

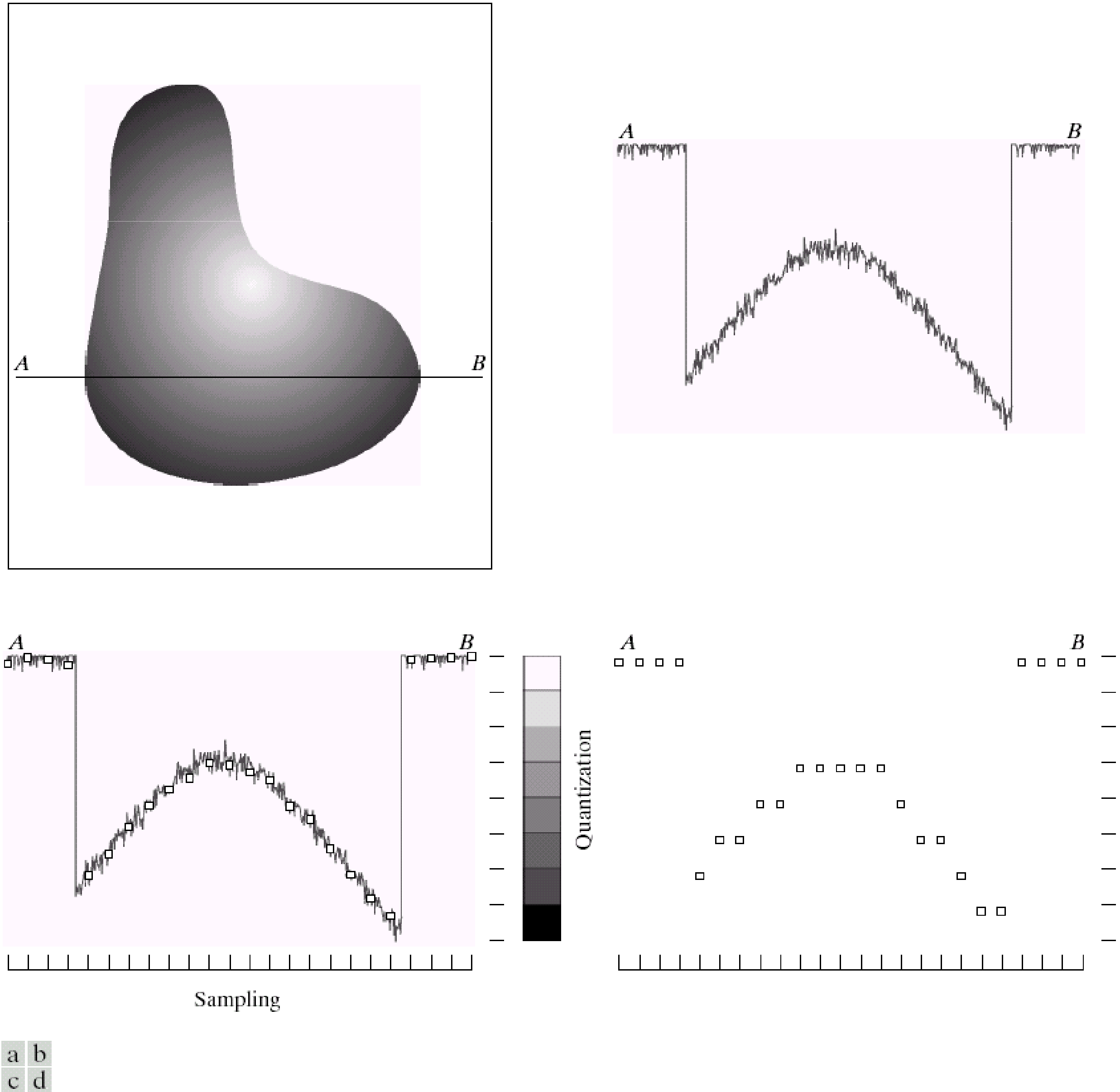
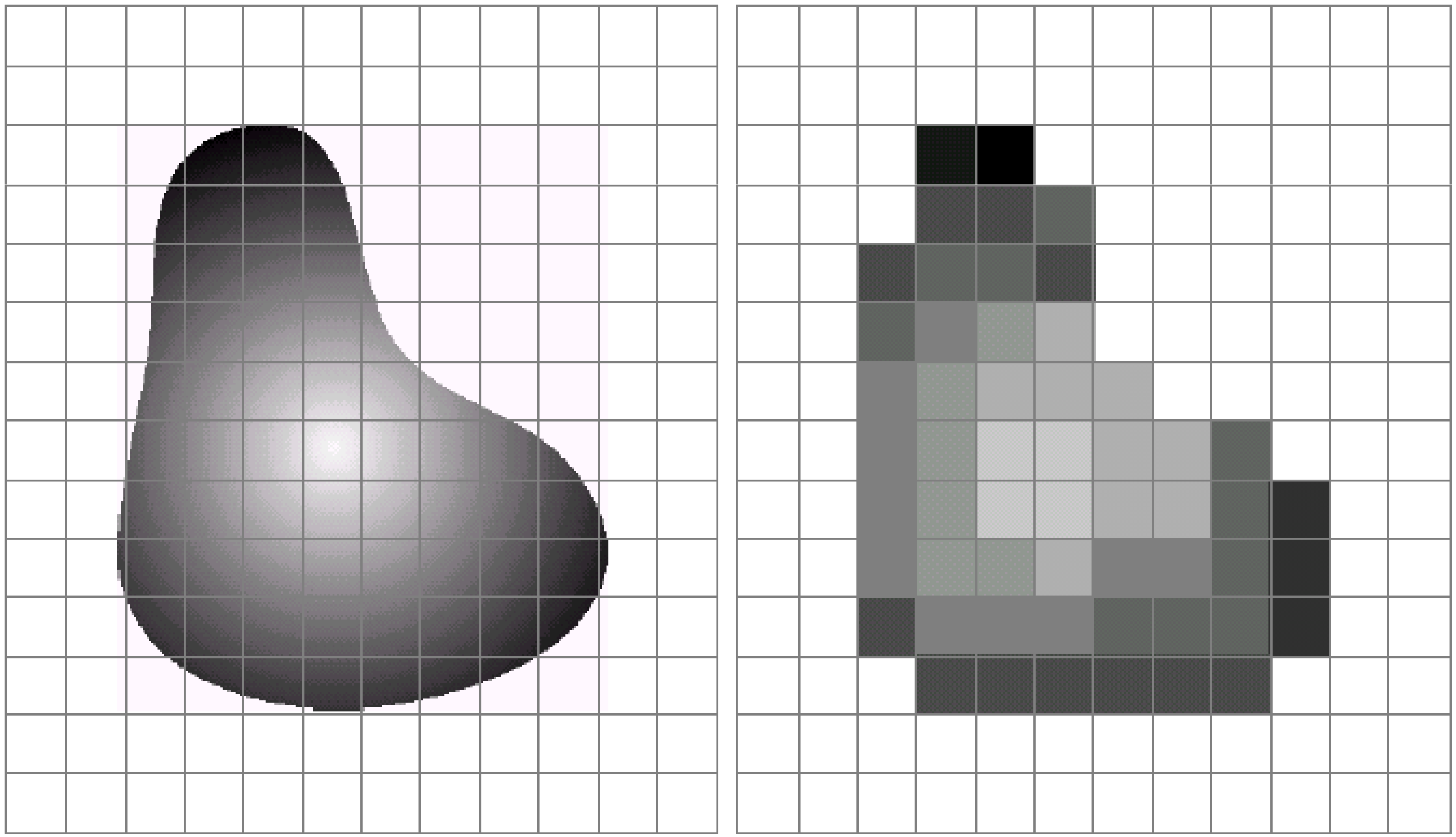


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Sampling and quantization

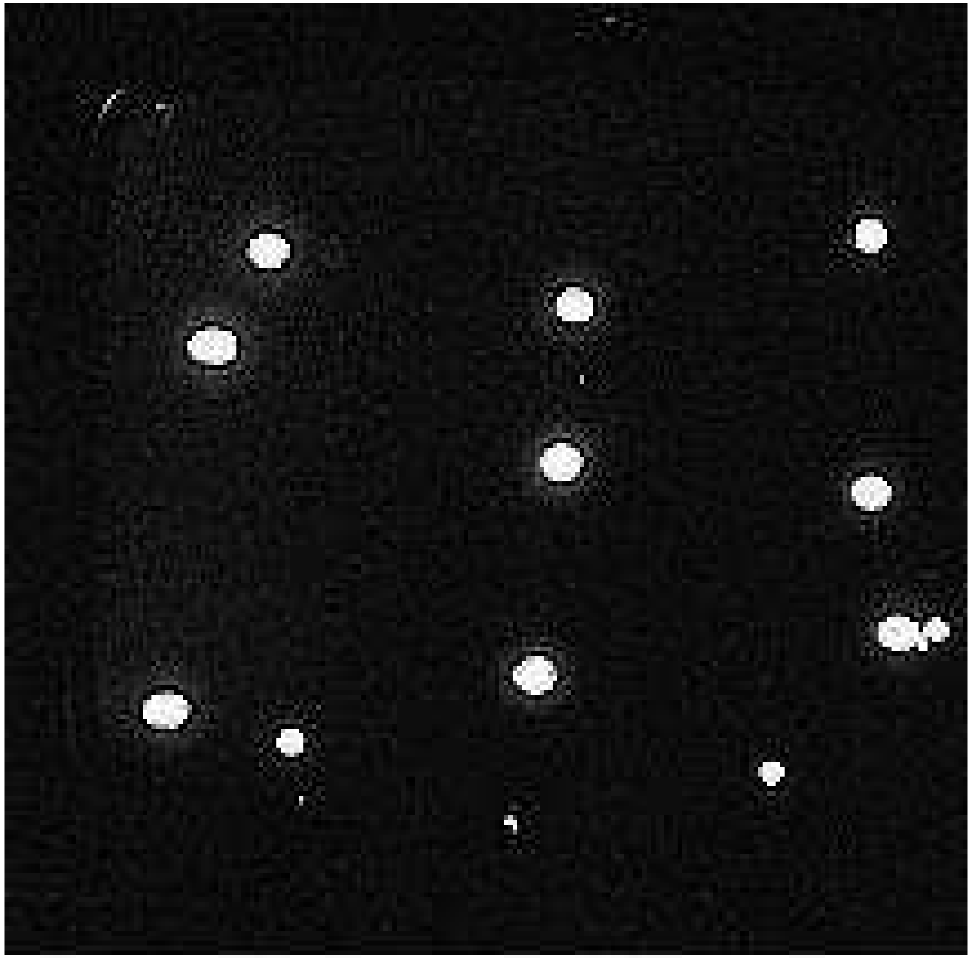


a b

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

Problems with arrays

- Blooming: difficult to insulate adjacent sensing elements.
- Charge often leaks from hot cells to neighbors, making bright regions larger.



Adapted from Shapiro and Stockman

Problems with arrays

- Clipping: dark grid intersections at left were actually brightest of scene.
- In A/D conversion the bright values were clipped to lower values.

Adapted from Shapiro and Stockman

Problems with lenses

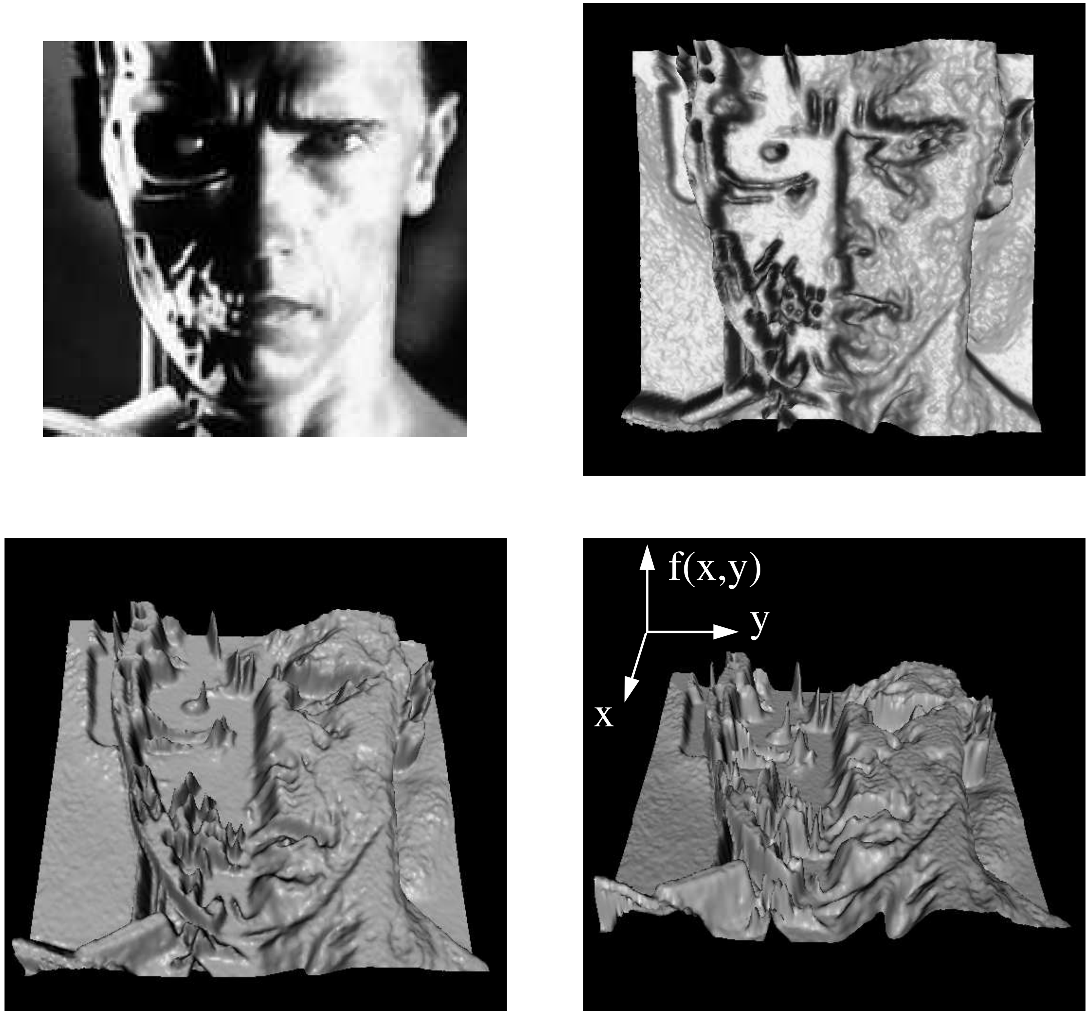
(a) (b) (c)

Figure 2.13: *Examples of radial lens distortion: (a) barrel, (b) pincushion, and (c) fisheye. The fisheye image spans almost a complete* 180° *from side-to-side.*

Adapted from Rick Szeliski

Image representation

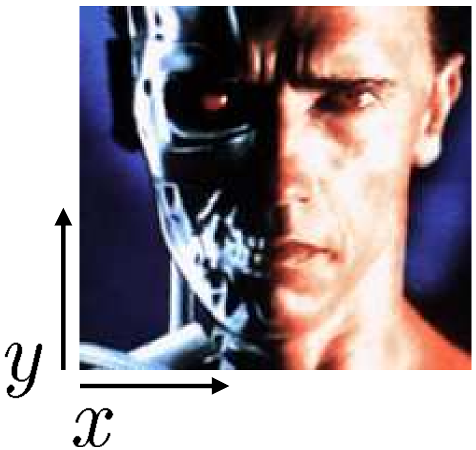
- Images can be represented by 2D functions of the form f(x,y).
- The physical meaning of the value of f at spatial coordinates (x,y) is determined by the source of the image.



Adapted from Shapiro and Stockman

Image representation

- In a digital image, both the coordinates and the image value become discrete quantities.
- Images can now be represented as 2D arrays (matrices) of integer values: I[i,j] (or I[r,c]).
- The term gray level is used to describe monochromatic intensity.



$j \rightarrow$, $i \downarrow$

62	79	23	119	120	105	4	0
10	10	9	62	12	78	34	0
10	58	197	46	46	0	0	48
176	135	5	188	191	68	0	49
2	1	1	29	26	37	0	77
0	89	144	147	187	102	62	208
255	252	0	166	123	62	0	31
166	63	127	17	1	0	99	30

Spatial resolution

- Spatial resolution is the smallest discernible detail in an image.
- Sampling is the principal factor determining spatial resolution.

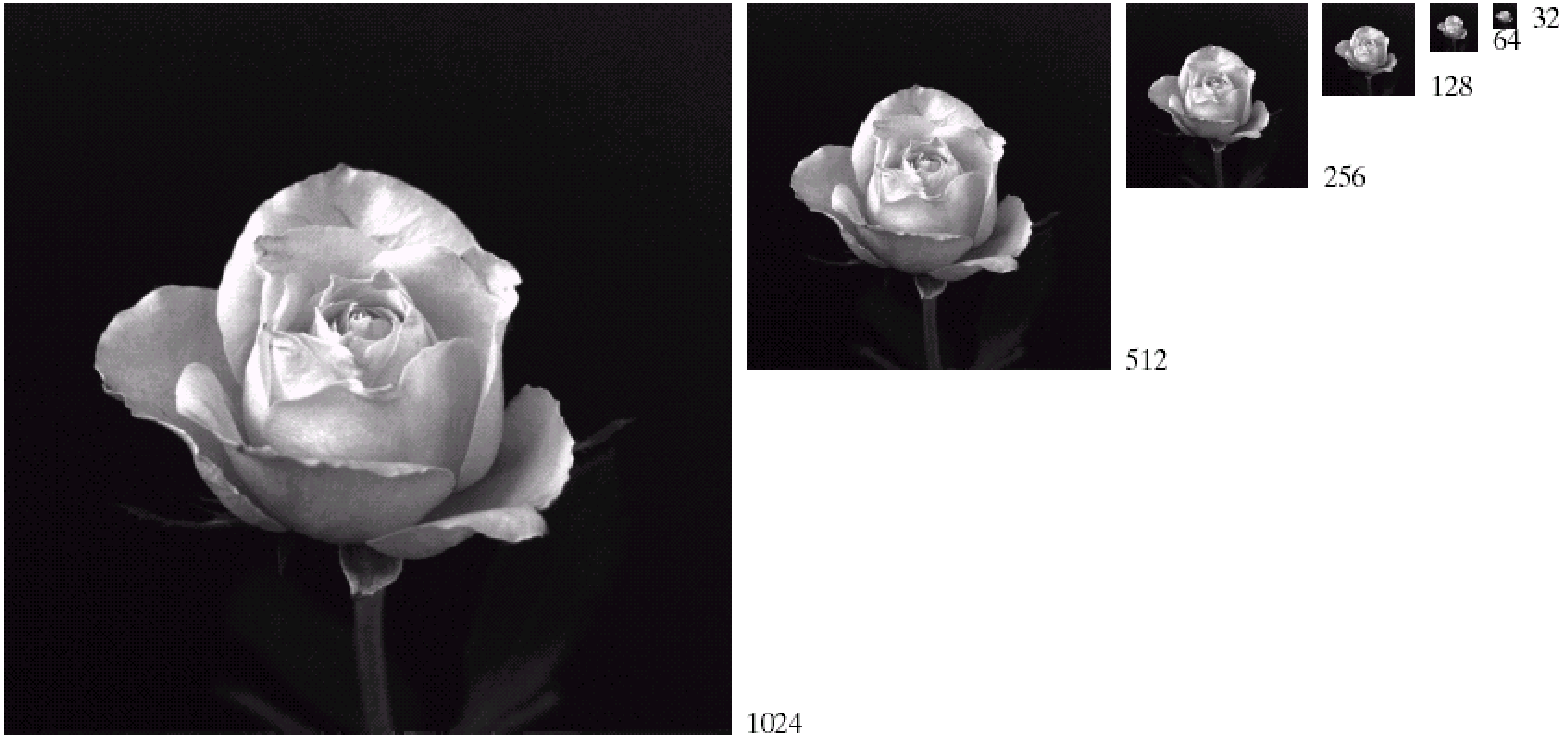
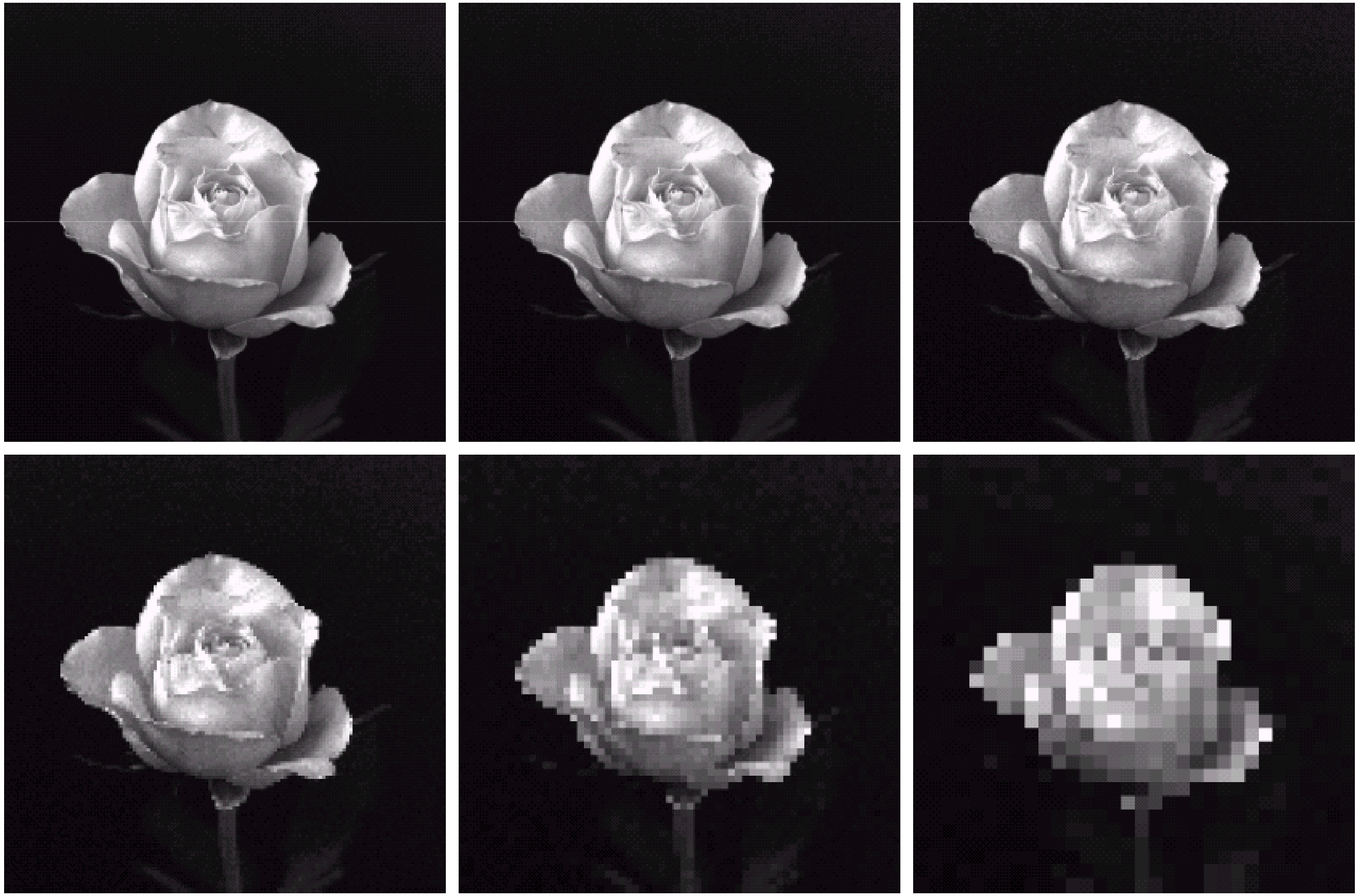


FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

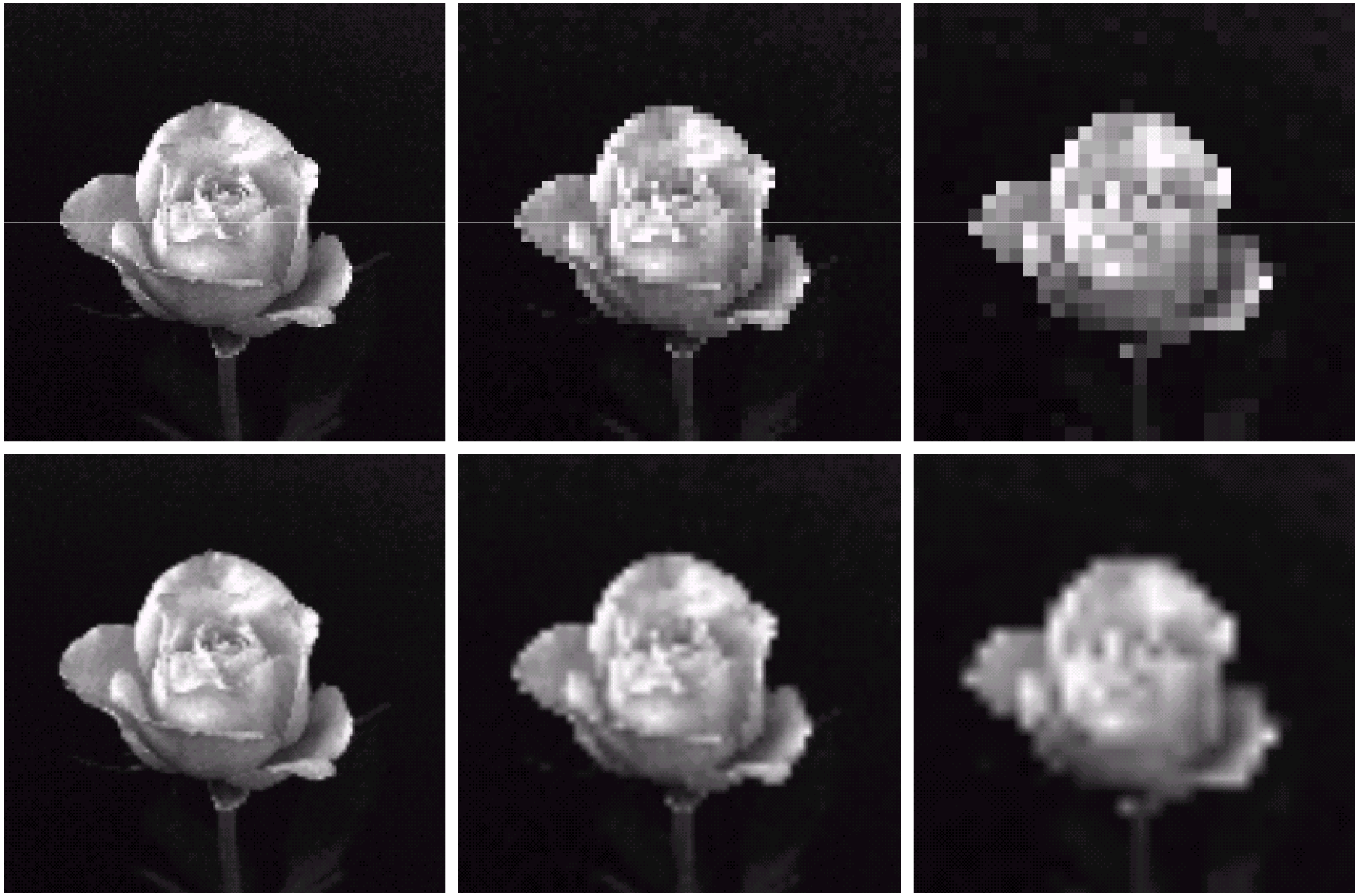
Spatial resolution



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.

Spatial resolution

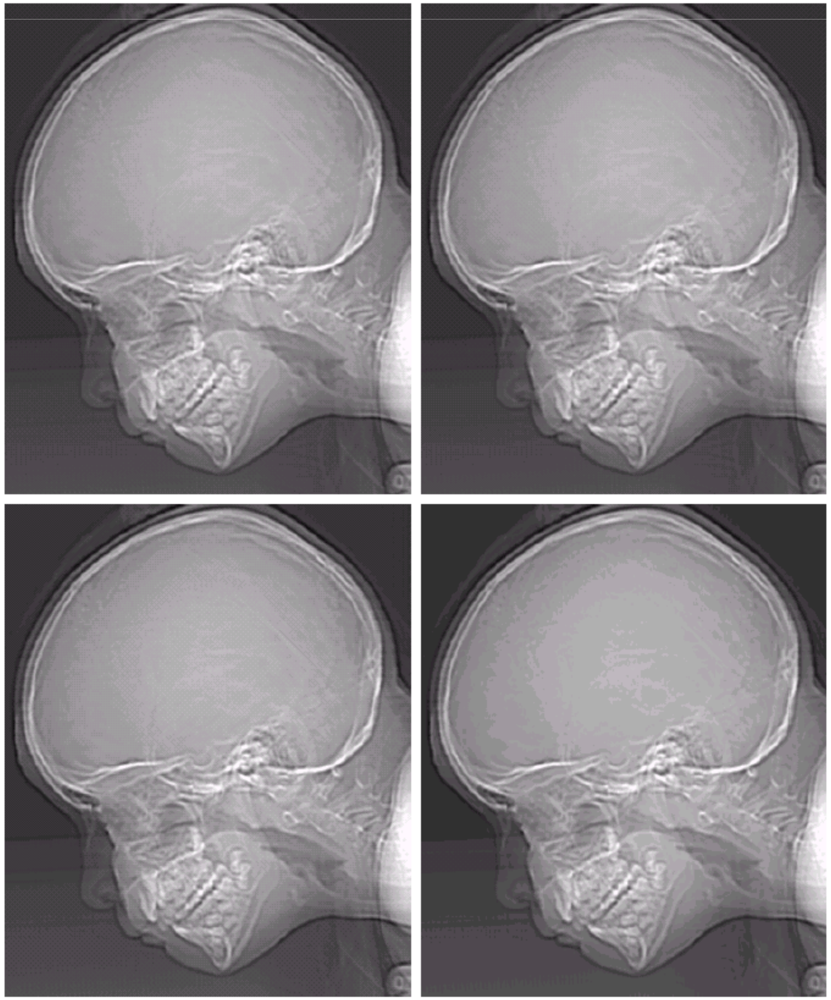


a b c
d e f

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.

Gray level resolution

- Gray level resolution refers to the smallest discernible change in gray level (often power of 2).

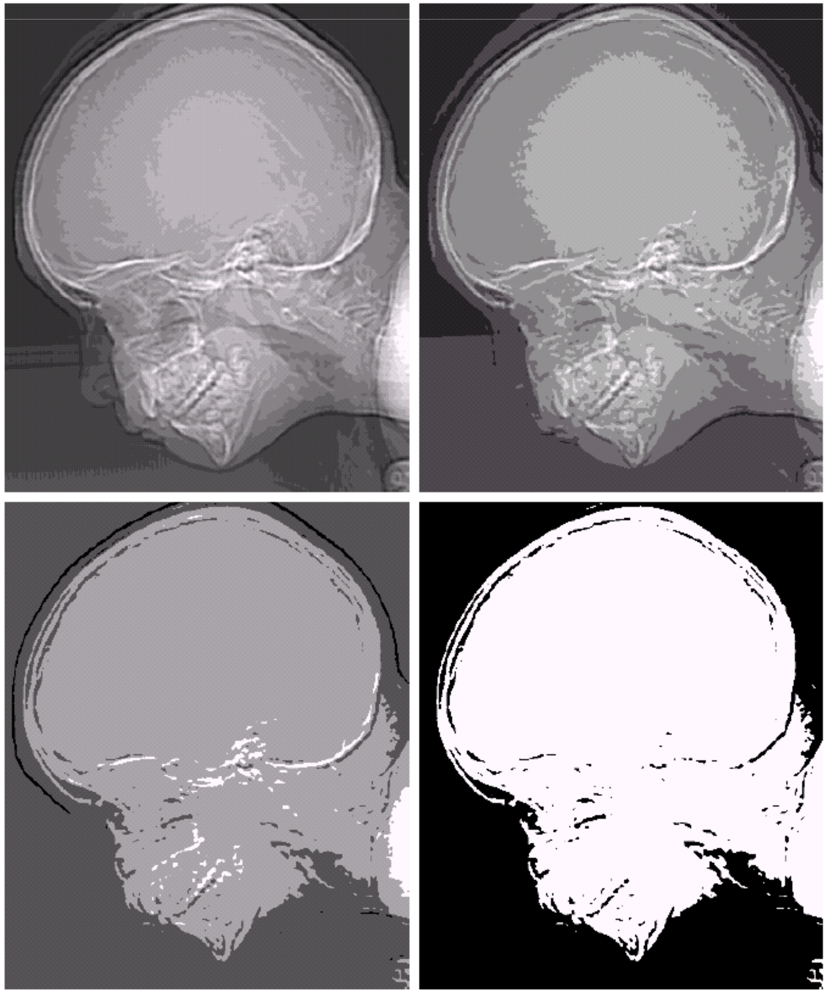


a b
c d

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.)



Bit planes

a	b	c
d	e	f
g	h	i

FIGURE 3.14 (a) An 8-bit gray-scale image of size 500 × 1192 pixels. (b) through (i) Bit planes 1 through 8, with bit plane 1 corresponding to the least significant bit. Each bit plane is a binary image.

Electromagnetic (EM) spectrum

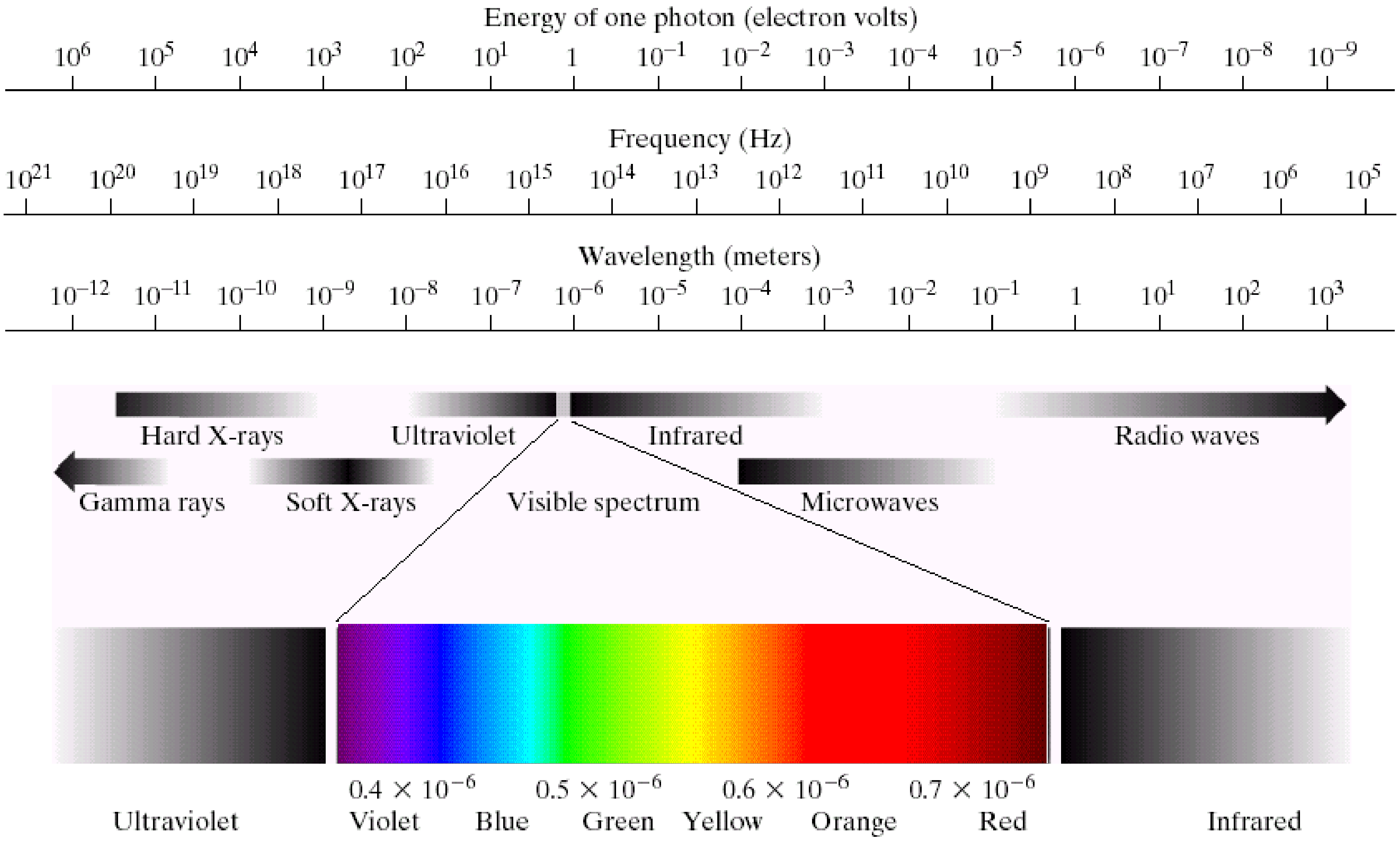
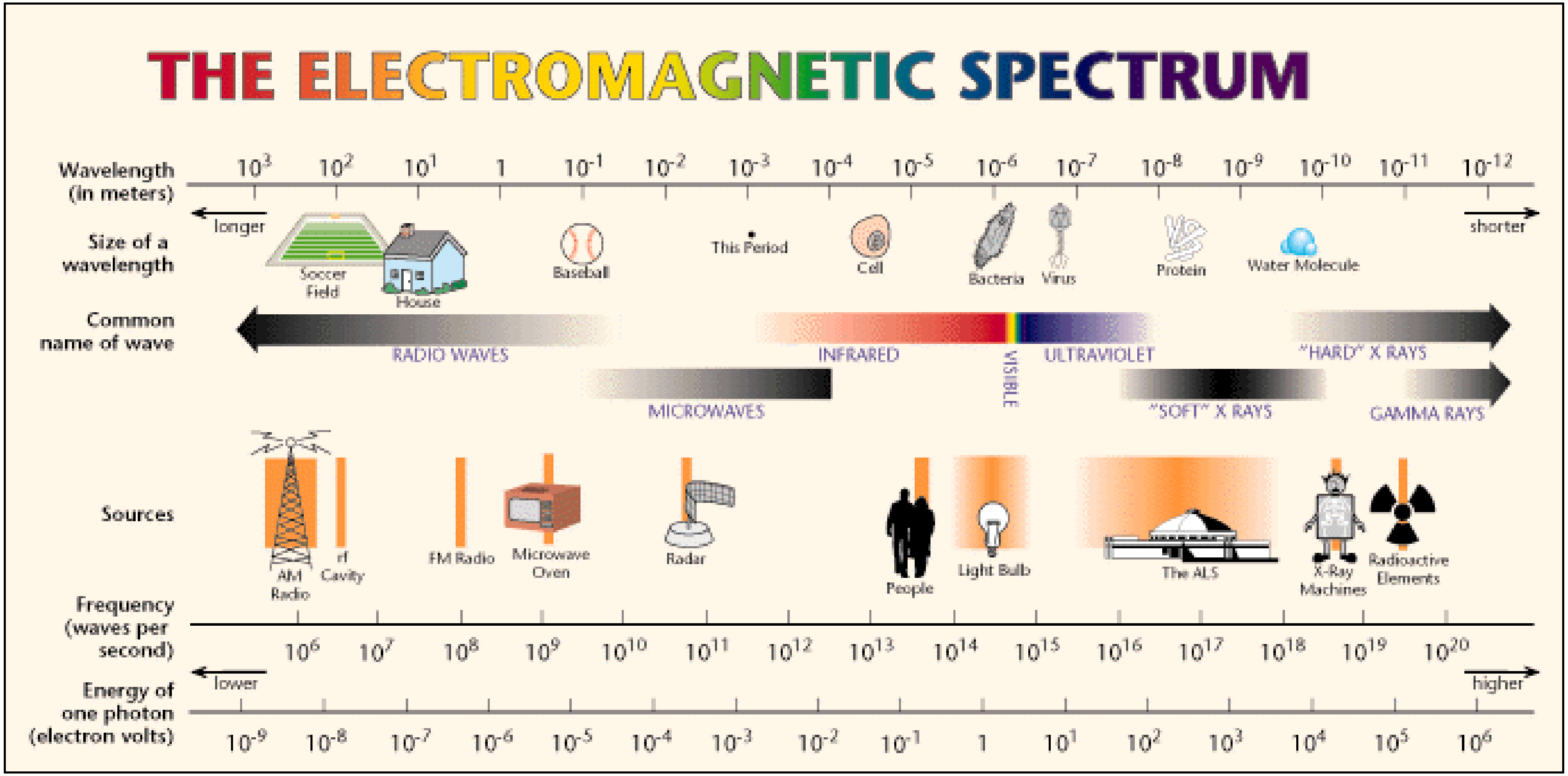


FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

Electromagnetic (EM) spectrum

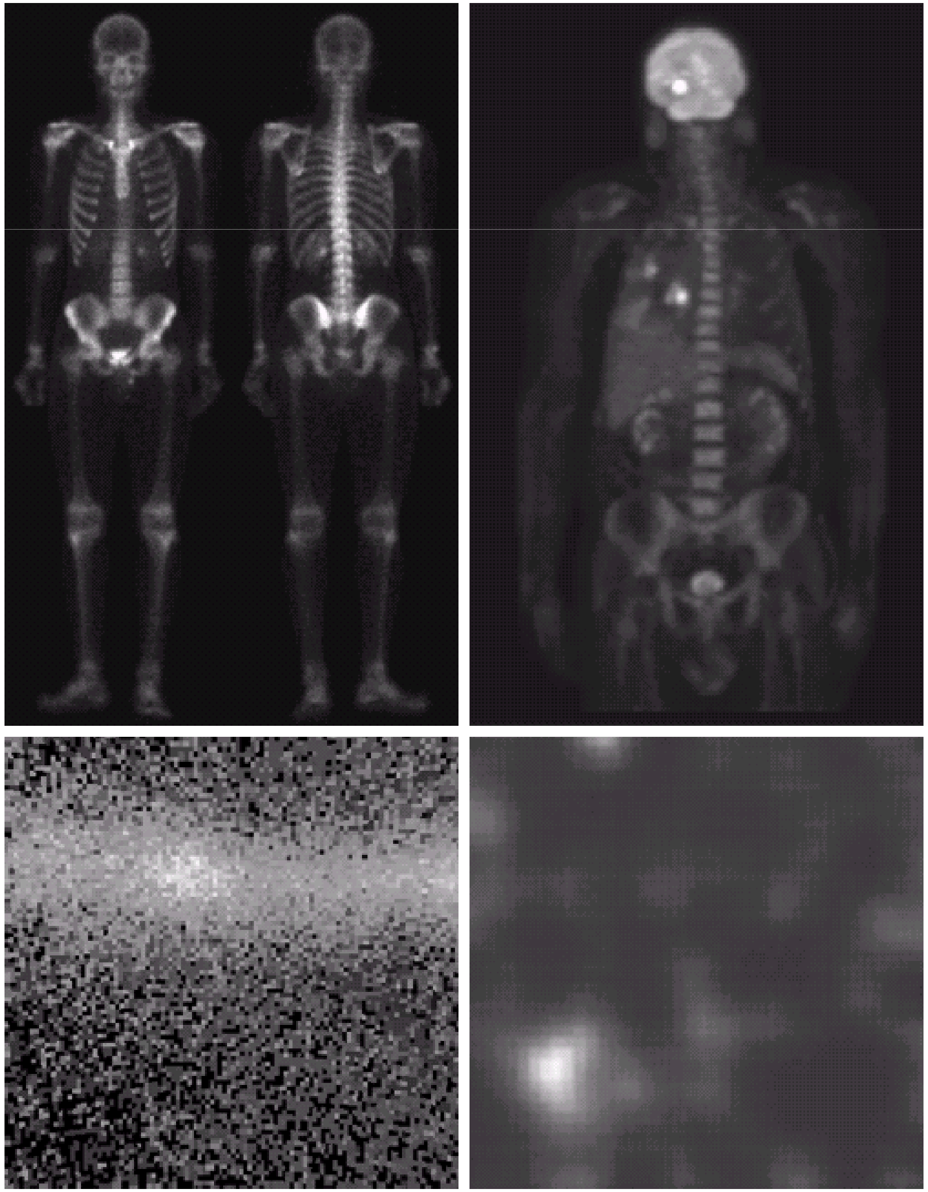
- The wavelength of an EM wave required to "see" an object must be of the same size as or smaller than the object.

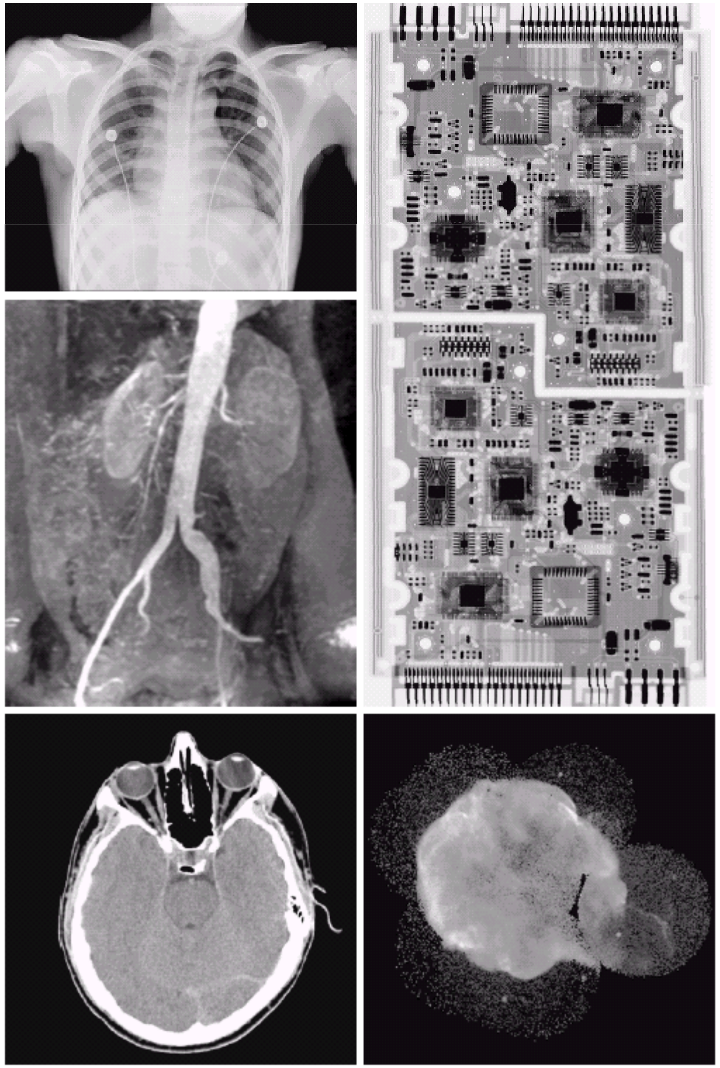


Other types of sensors

a b
c d

FIGURE 1.6 Examples of gamma-ray imaging. (a) Bone scan. (b) PET image. (c) Cygnus Loop. (d) Gamma radiation (bright spot) from a reactor valve. (Images courtesy of (a) G.E. Medical Systems, (b) Dr. Michael E. Casey, CTI PET Systems, (c) NASA, (d) Professors Zhong He and David K. Wehe, University of Michigan.)





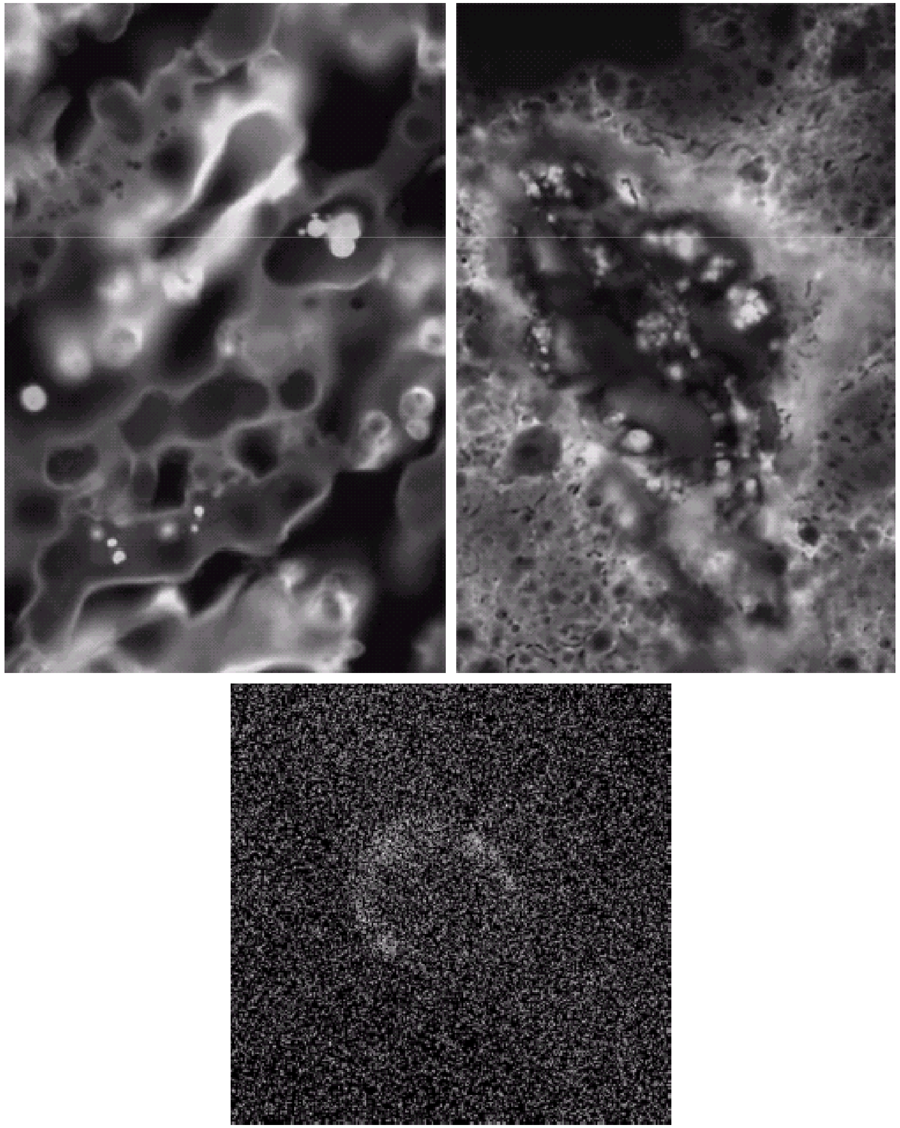
a d
b
c e

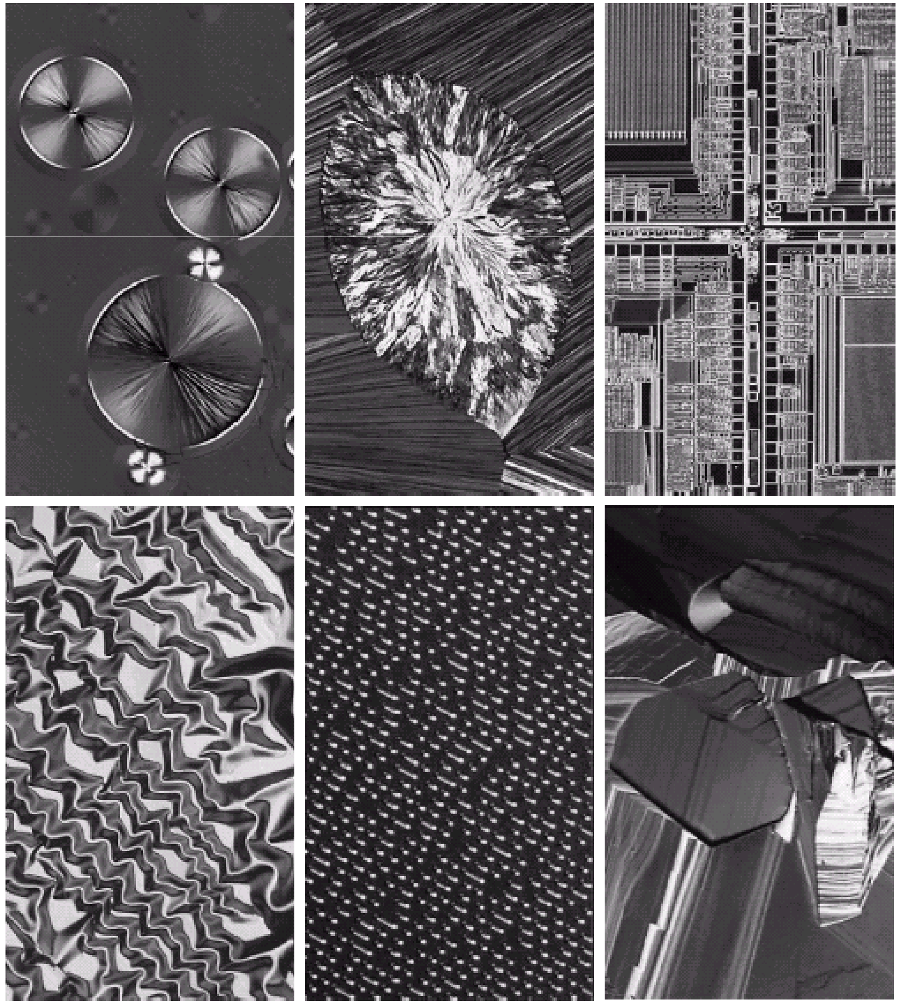
FIGURE 1.7 Examples of X-ray imaging. (a) Chest X-ray. (b) Aortic angiogram. (c) Head CT. (d) Circuit boards. (e) Cygnus Loop. (Images courtesy of (a) and (c) Dr. David R. Pickens, Dept. of Radiology & Radiological Sciences, Vanderbilt University Medical Center, (b) Dr. Thomas R. Gest, Division of Anatomical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

Other types of sensors

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.)





a b c
d e f

FIGURE 1.9 Examples of light microscopy images. (a) Taxol (anticancer agent), magnified 250×. (b) Cholesterol—40×. (c) Microprocessor—60×. (d) Nickel oxide thin film—600×. (e) Surface of audio CD—1750×. (f) Organic superconductor—450×. (Images courtesy of Dr. Michael W. Davidson, Florida State University.)

Other types of sensors

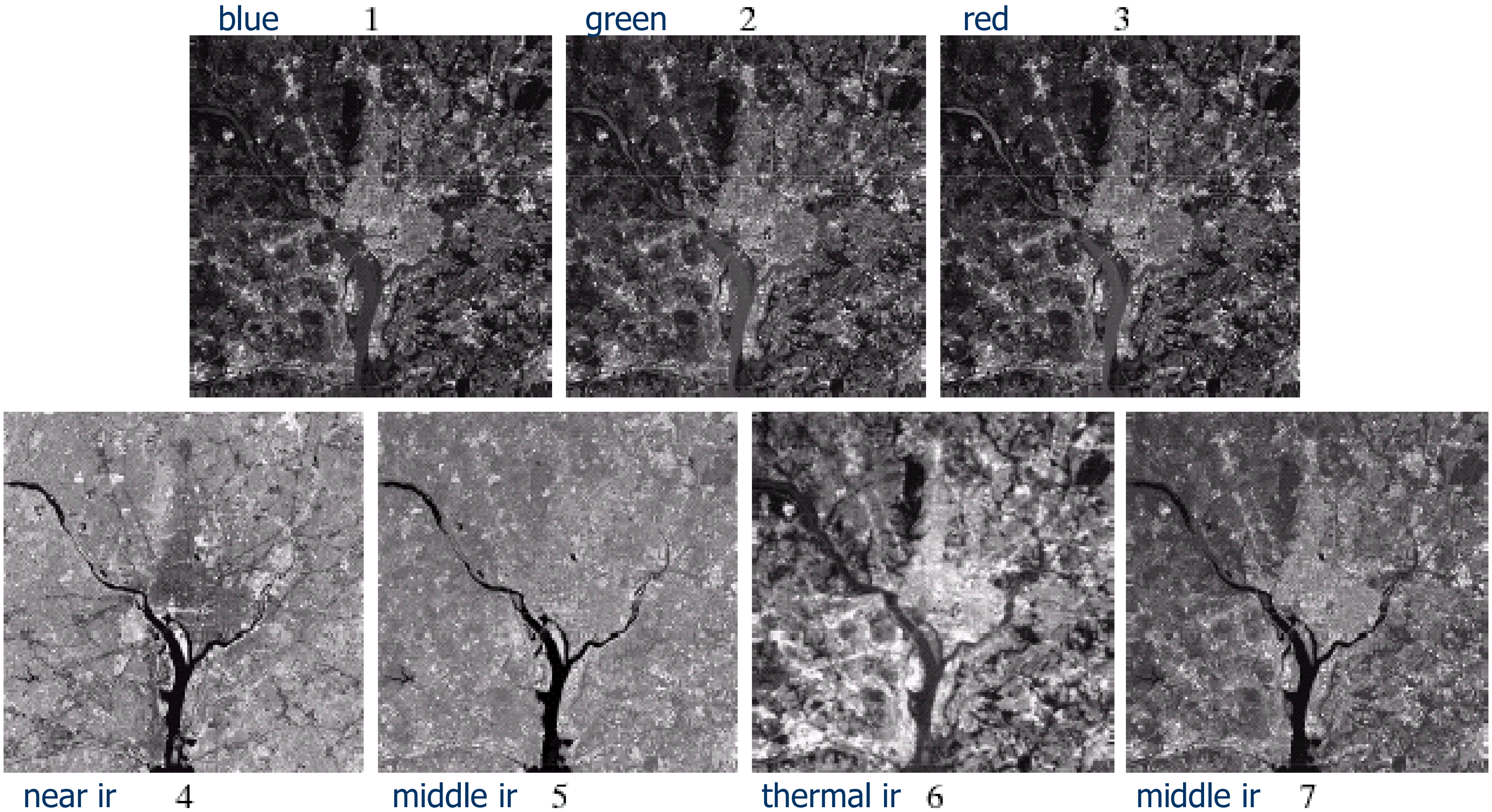


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

Other types of sensors

FIGURE 1.12 Infrared satellite images of the Americas. The small gray map is provided for reference. (Courtesy of NOAA.)

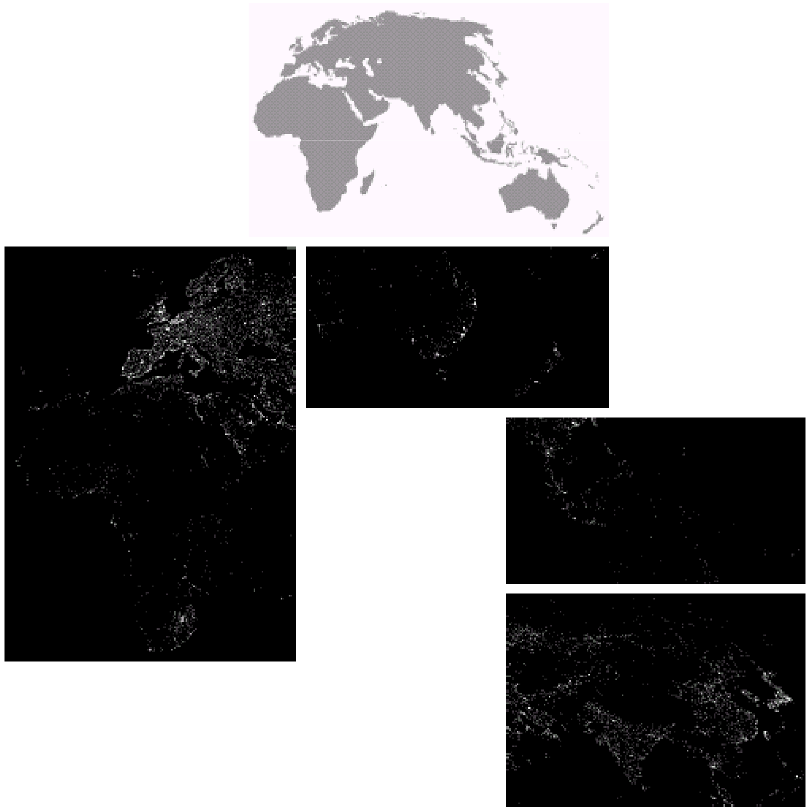
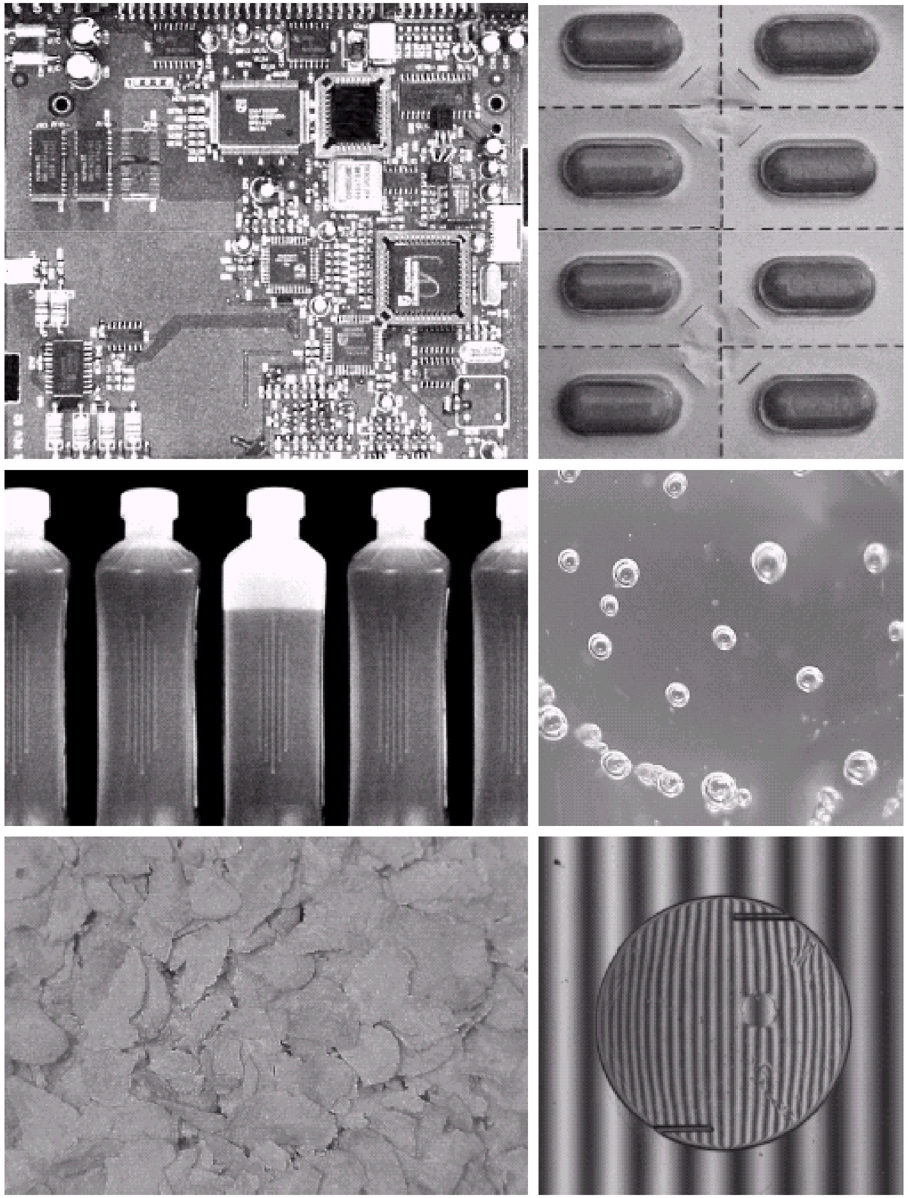


FIGURE 1.13 Infrared satellite images of the remaining populated part of the world. The small gray map is provided for reference. (Courtesy of NOAA.)

Other types of sensors



a	b
c	d
e	f

FIGURE 1.14 Some examples of manufactured goods often checked using digital image processing. (a) A circuit board controller. (b) Packaged pills. (c) Bottles. (d) Bubbles in clear-plastic product. (e) Cereal. (f) Image of intraocular implant. (Fig. (f) courtesy of Mr. Pete Sites, Perceptics Corporation.)

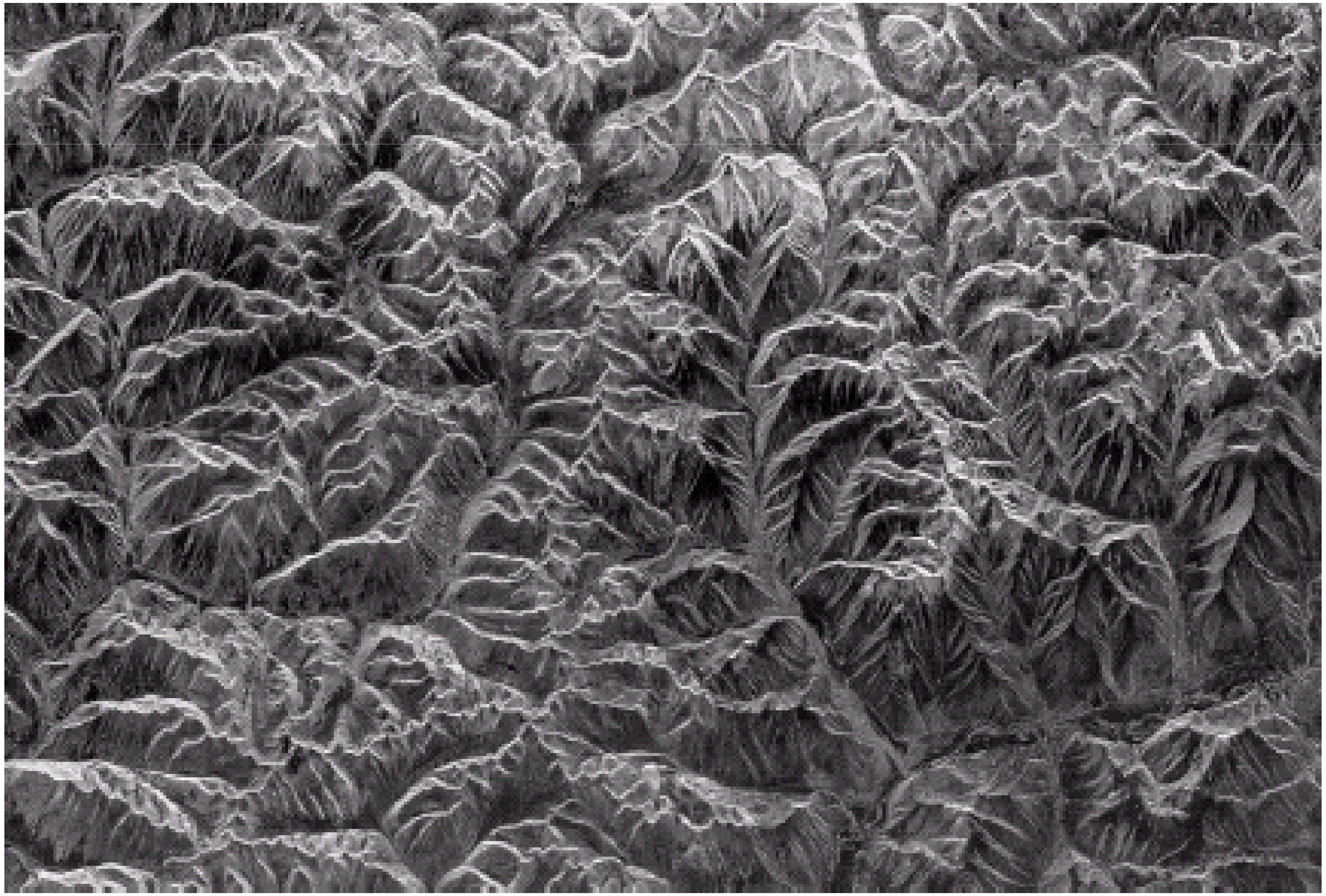
Other types of sensors

a b
c
d

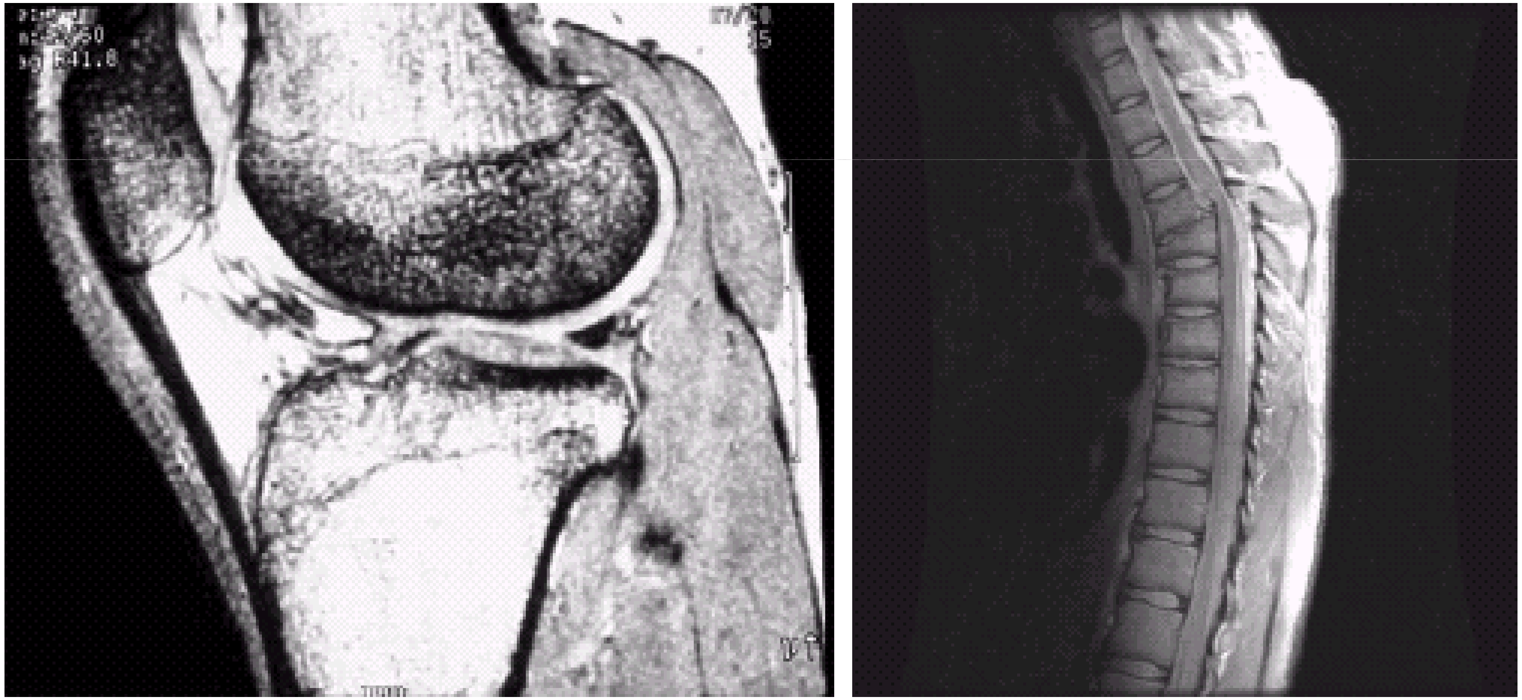
FIGURE 1.15 Some additional examples of imaging in the visual spectrum. (a) Thumb print. (b) Paper currency. (c) and (d) Automated license plate reading. (Figure (a) courtesy of the National Institute of Standards and Technology. Figures (c) and (d) courtesy of Dr. Juan Herrera, Perceptics Corporation.)

Other types of sensors

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



Other types of sensors



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 types of sensors

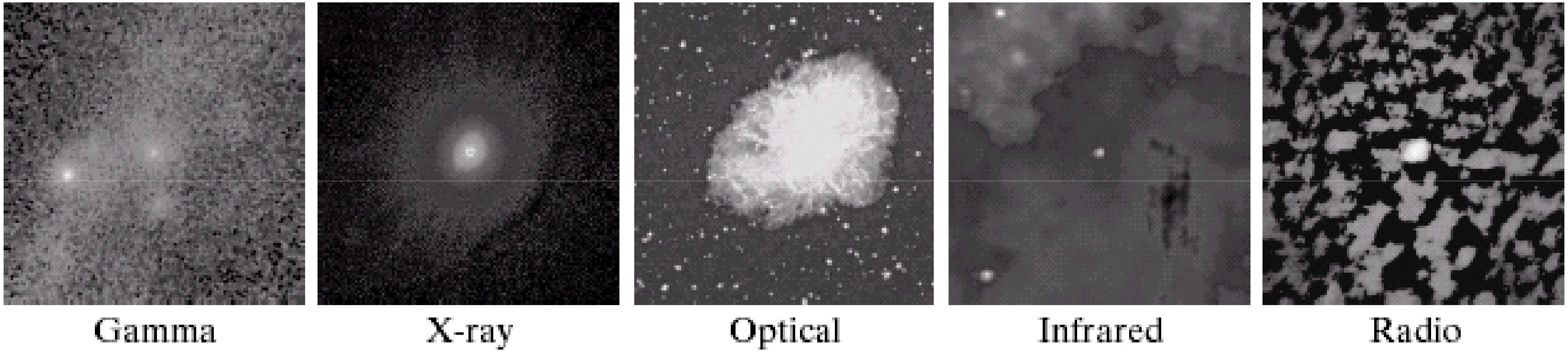
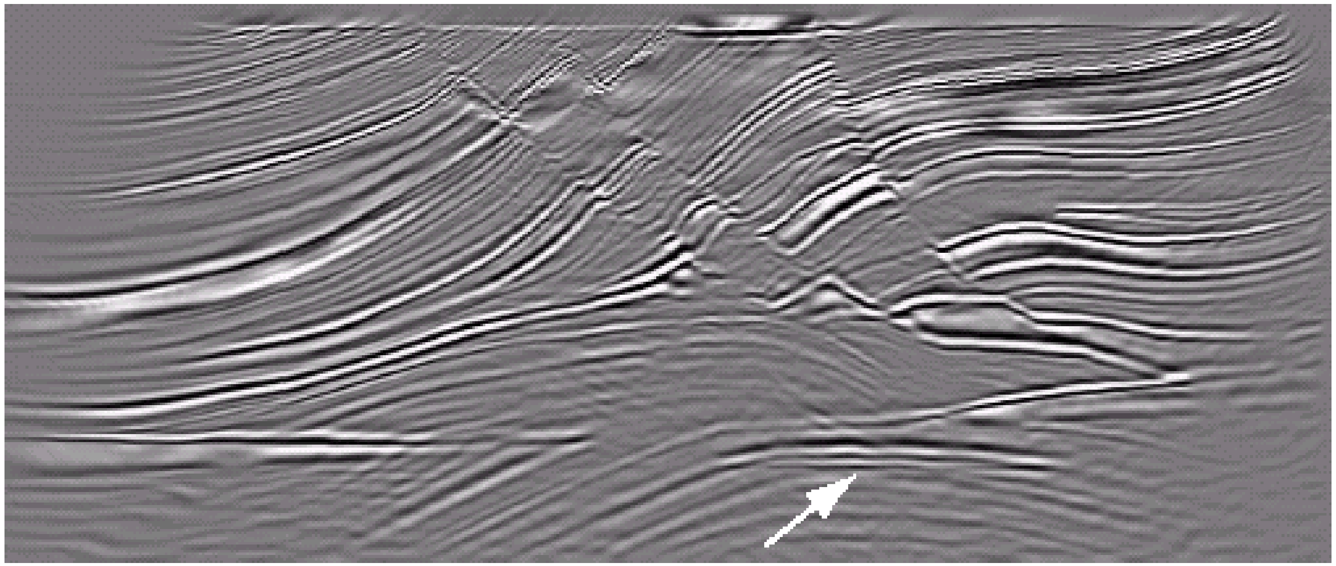
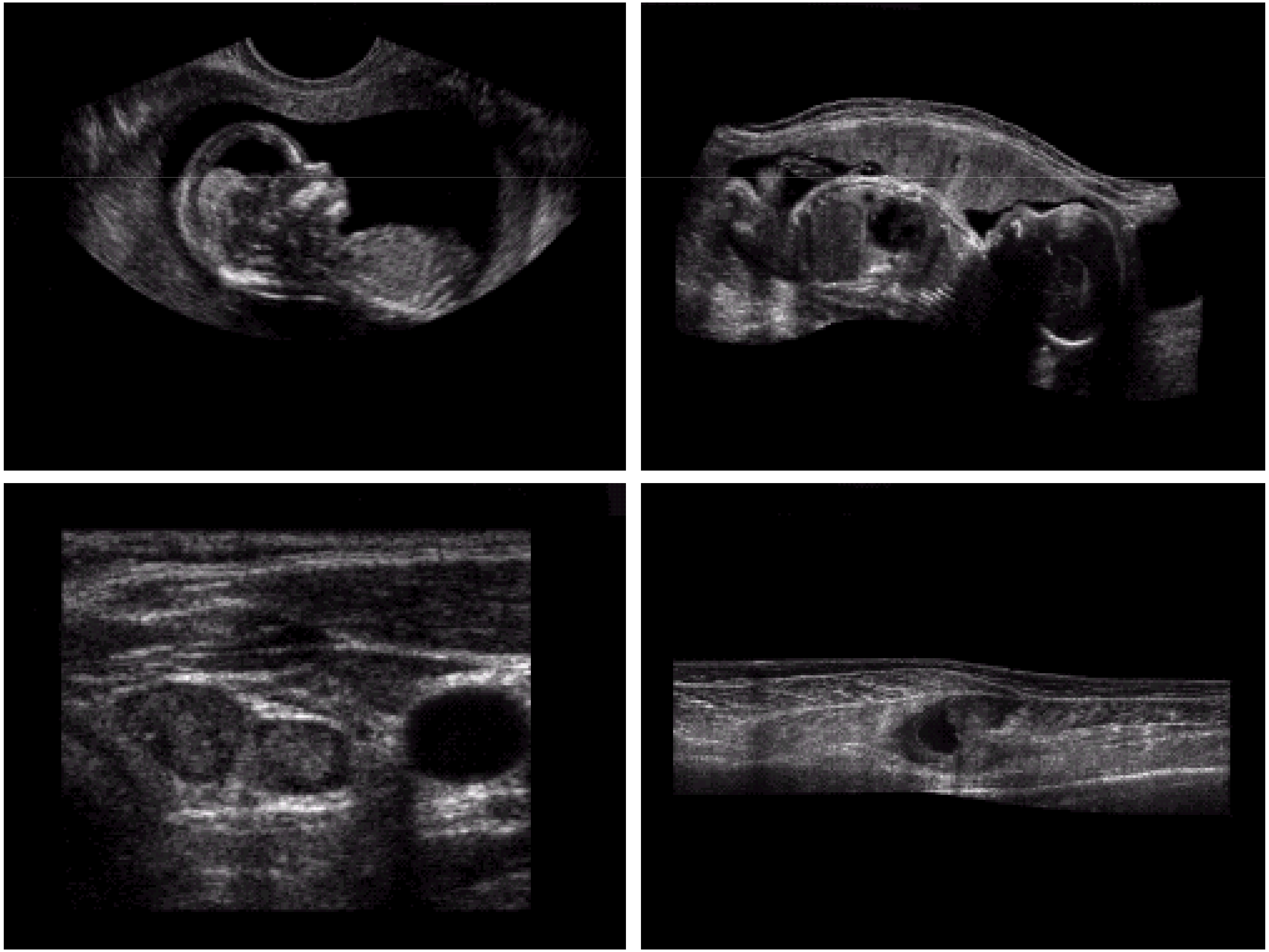


FIGURE 1.18 Images of the Crab Pulsar (in the center of images) covering the electromagnetic spectrum. (Courtesy of NASA.)

FIGURE 1.19 Cross-sectional image of a seismic model. The arrow points to a hydrocarbon (oil and/or gas) trap. (Courtesy of Dr. Curtis Ober, Sandia National Laboratories.)



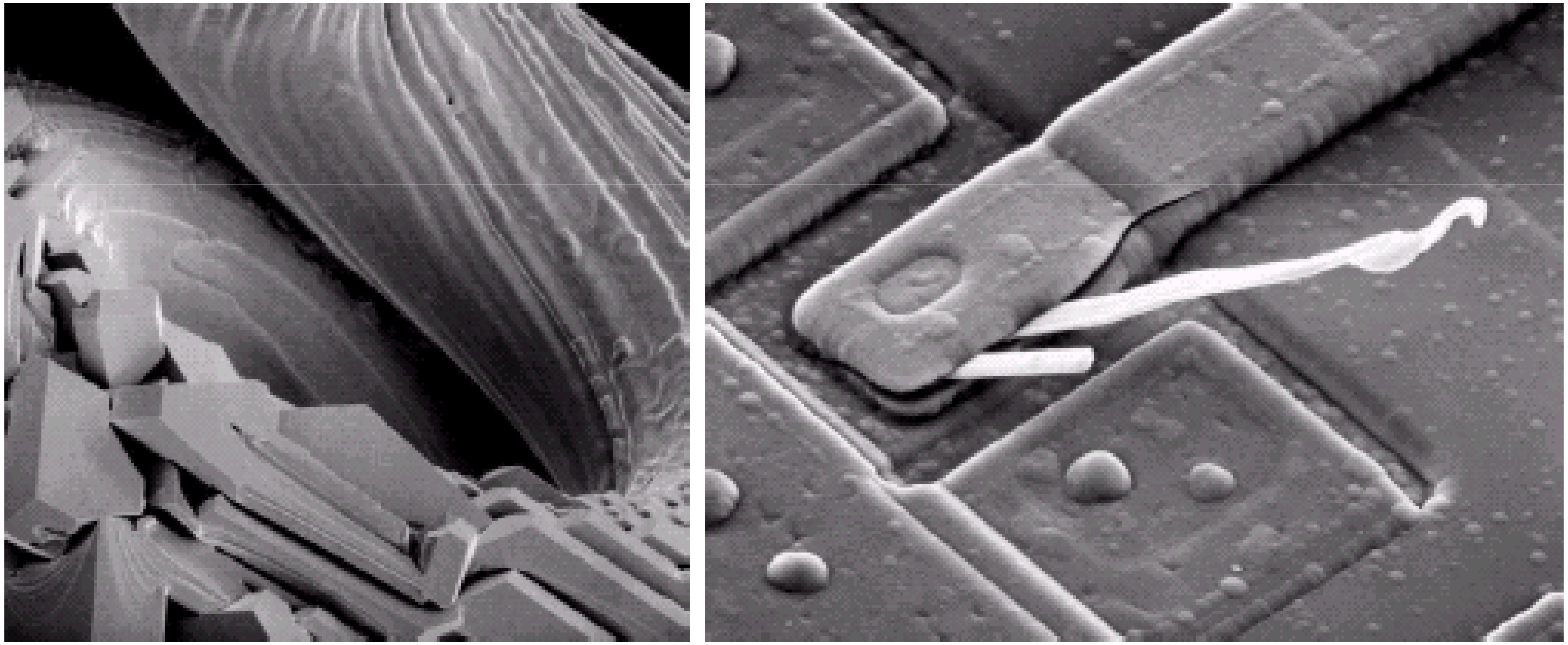
Other types of sensors



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.)

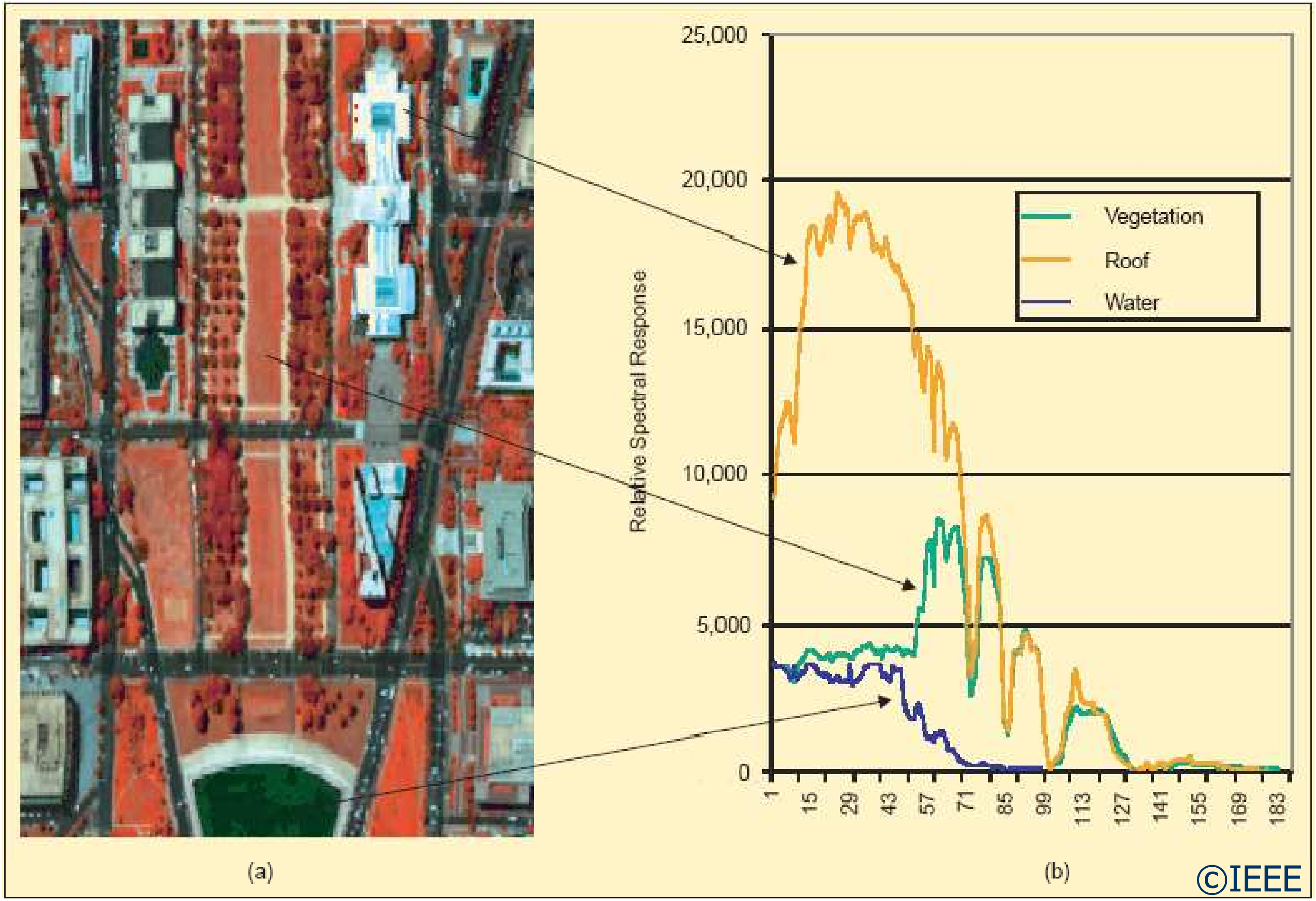
Other types of sensors



a b

FIGURE 1.21 (a) 250× SEM image of a tungsten filament following thermal failure. (b) 2500× SEM image of damaged integrated circuit. The white fibers are oxides resulting from thermal destruction. (Figure (a) courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene; (b) courtesy of Dr. J. M. Hudak, McMaster University, Hamilton, Ontario, Canada.)

Other types of sensors



▲ 1. *(a) A simulated color IR image of an urban area, the Washington, D.C., mall. This image is made using three bands of the 210 bands collected by the sensor system, one band from the visible green, one from the visible red, and one from the near infrared. Such displays are referred to as displays in image space. (b) A display of the data of pixels of three materials as a function of wavelength by spectral band number. The bands in this case are approximately 10 nm wide over the range of 0.4-2.4 μm. This type of data display is referred to as a display in spectral space.*

Image enhancement

- The principal objective of enhancement is to process an image so that the result is more suitable than the original for a *specific* application.
- Enhancement can be done in
  - Spatial domain,
  - Frequency domain.
- Common reasons for enhancement include
  - Improving visual quality,
  - Improving machine recognition accuracy.

Image enhancement

- First, we will consider point processing where enhancement at any point depends only on the image value at that point.
- For gray level images, we will use a transformation function of the form

  $$s = T(r)$$

  where "r" is the original pixel value and "s" is the new value after enhancement.

Image enhancement

FIGURE 3.3 Some basic gray-level transformation functions used for image enhancement.

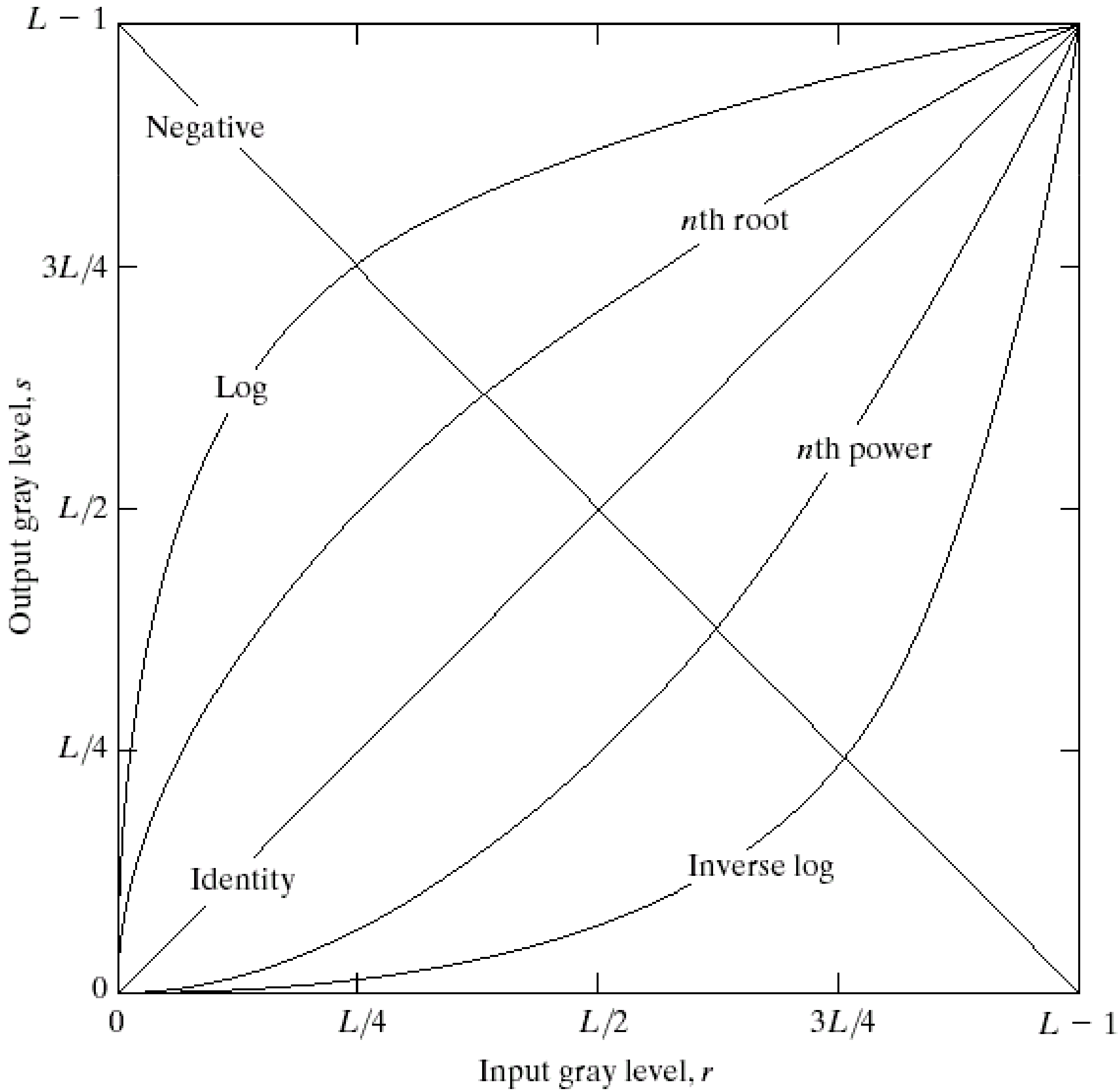
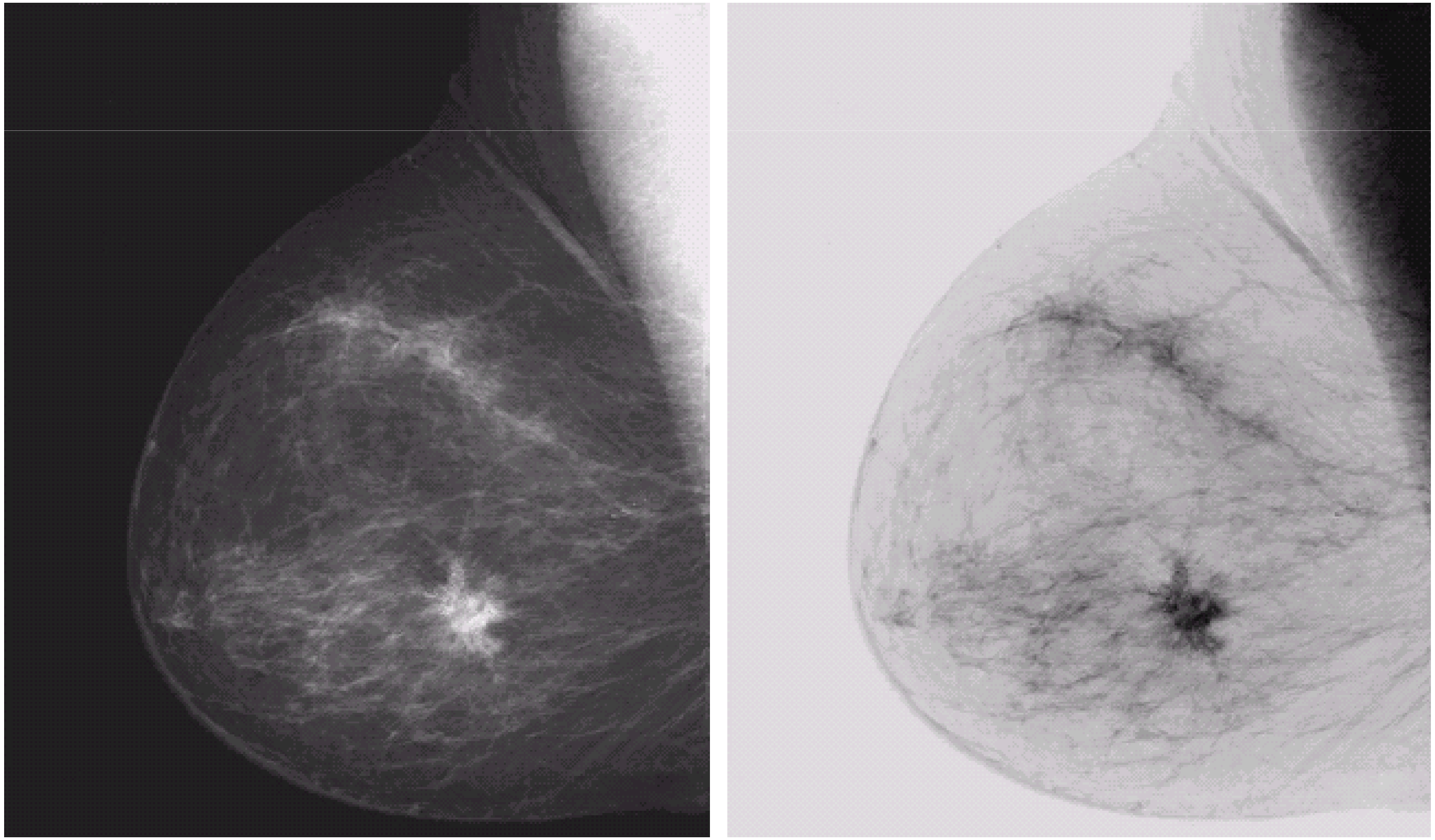


Image enhancement



a b

FIGURE 3.4 (a) Original digital mammogram. (b) Negative image obtained using the negative transformation in Eq. (3.2-1). (Courtesy of G.E. Medical Systems.)

Image enhancement

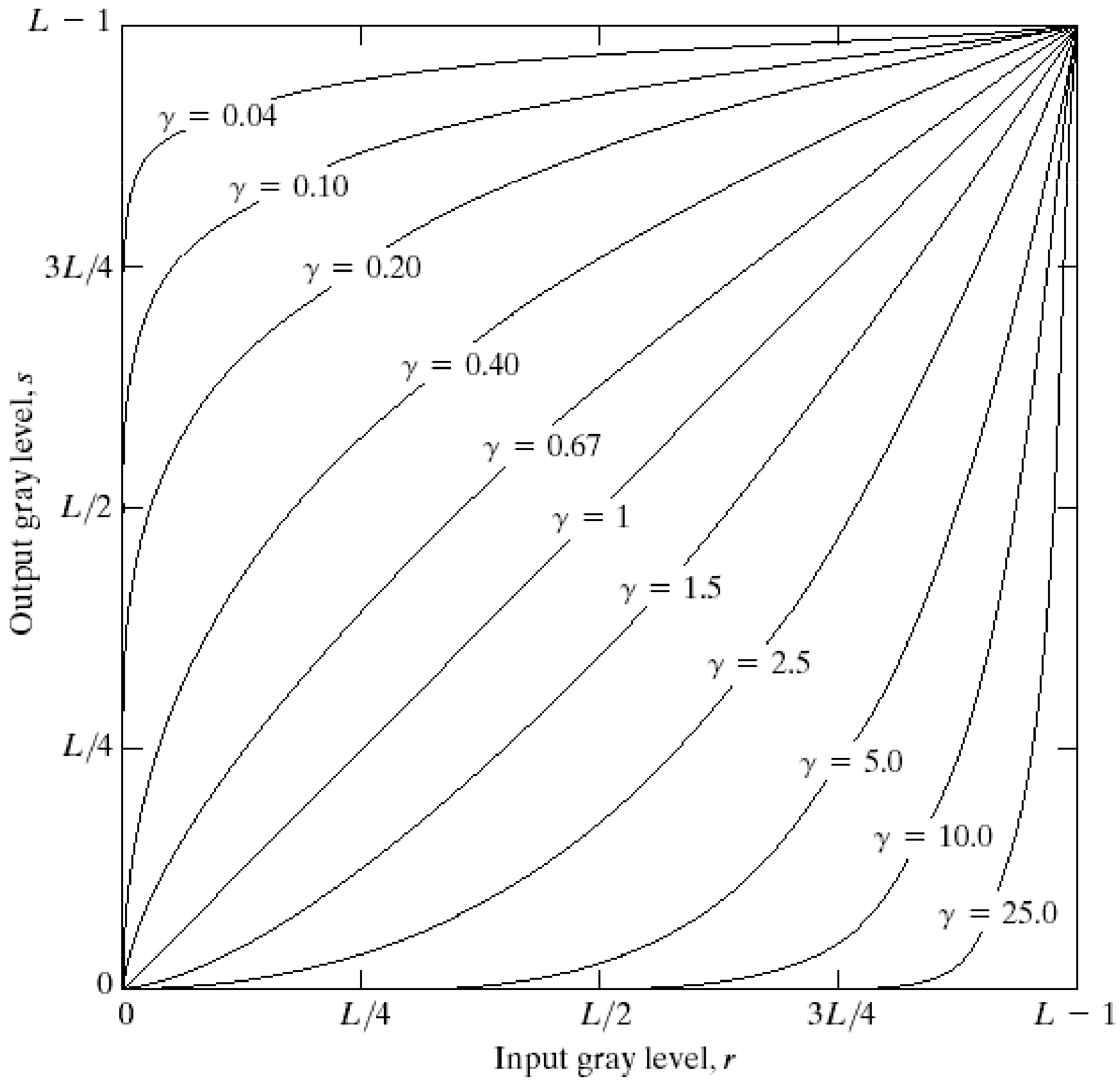


FIGURE 3.6 Plots of the equation $s = cr^{\gamma}$ for various values of γ ($c = 1$ in all cases).

Image enhancement

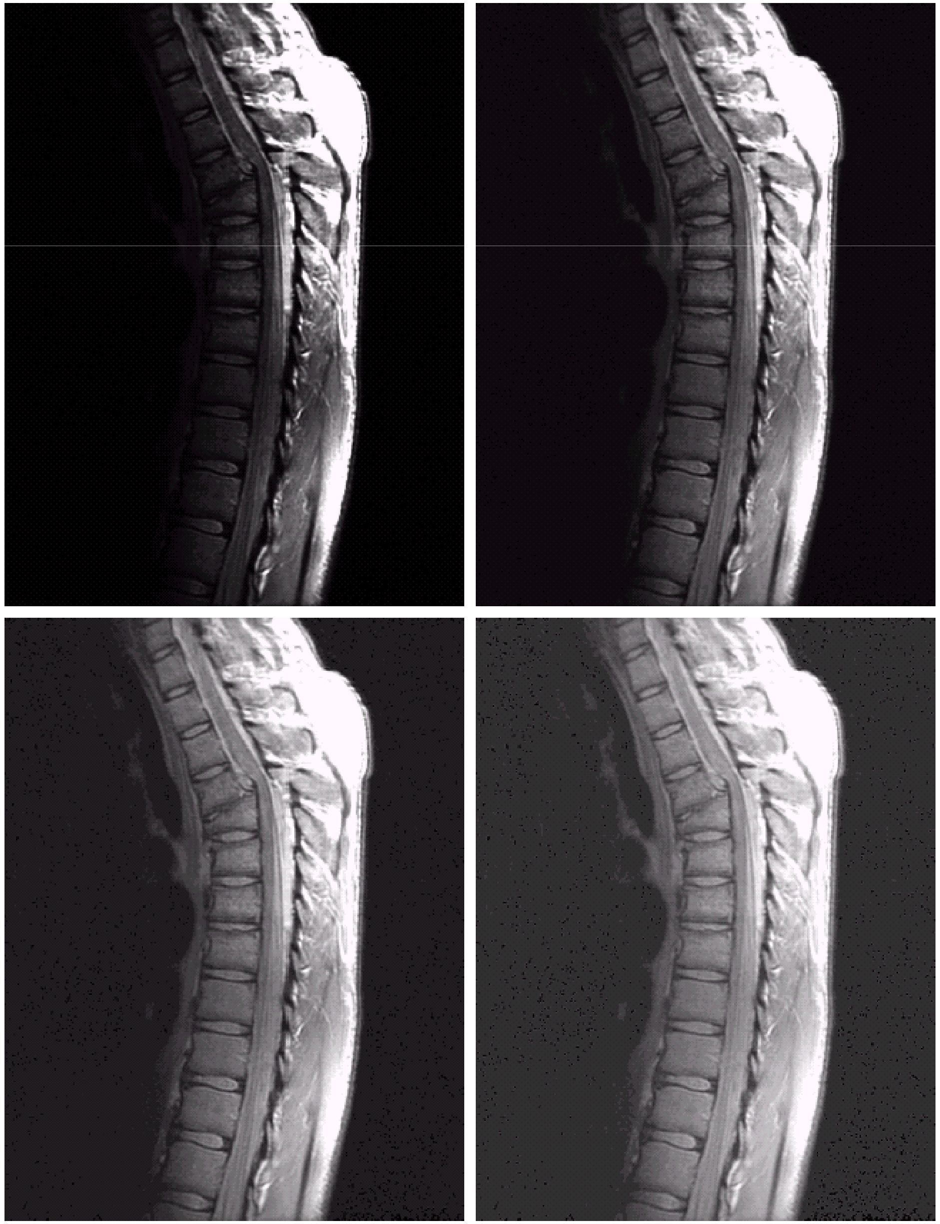


FIGURE 3.8 (a) Magnetic resonance (MR) image of a fractured human spine. (b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 0.6, 0.4,$ and 0.3, respectively. (Original image for this example courtesy of Dr. David R. Pickens, Department of Radiology and Radiological Sciences, Vanderbilt University Medical Center.)

Image enhancement

a b
c d

FIGURE 3.9
(a) Aerial image. (b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 3.0, 4.0,$ and 5.0, respectively. (Original image for this example courtesy of NASA.)

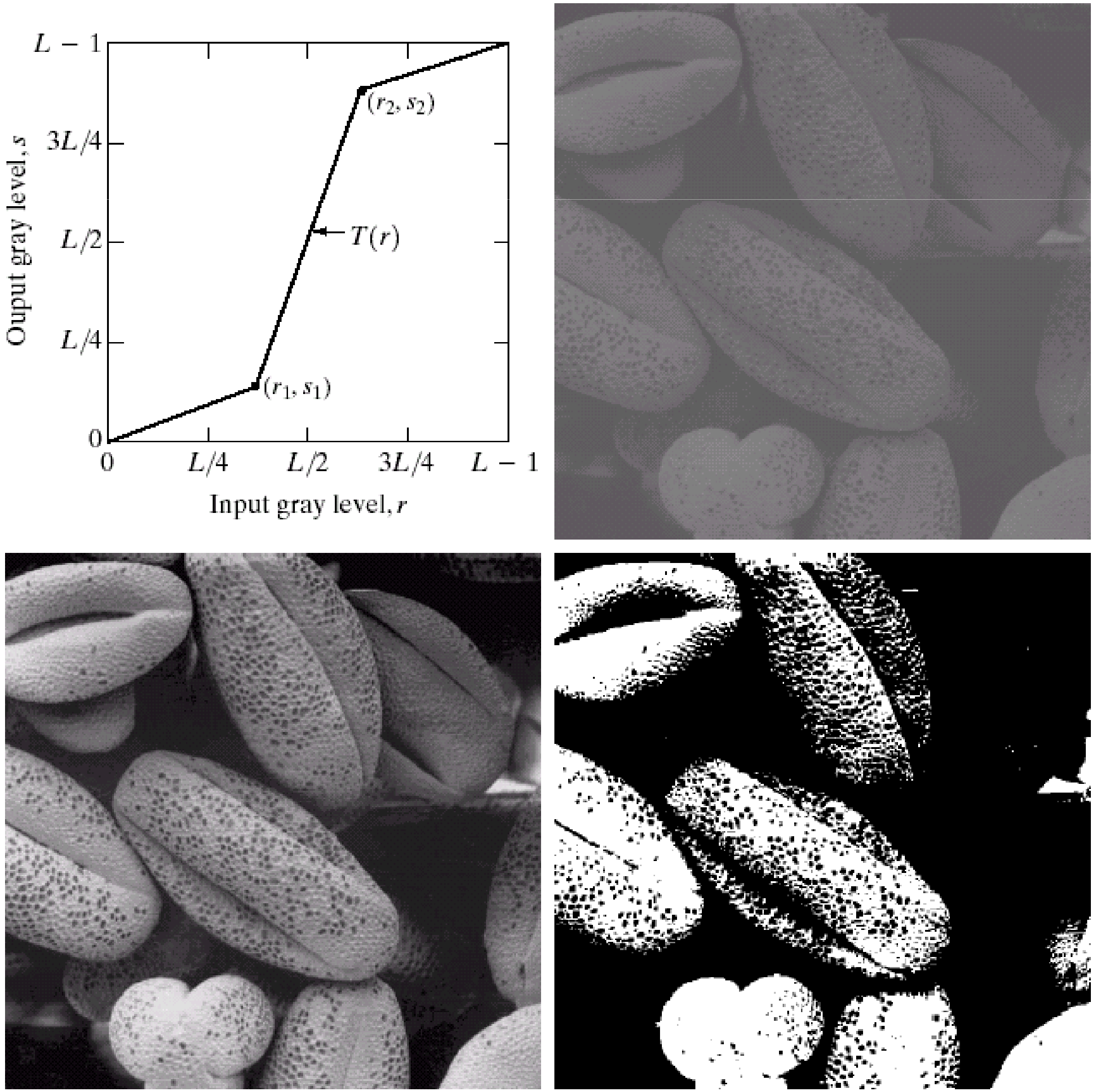
Image enhancement

- Contrast stretching:

$$I'[r,c] = \frac{I[r,c] - \min}{\max - \min}$$

$$I'[r,c] = \begin{cases} 0 & I[r,c] \leq \text{low} \\ \frac{I[r,c] - \text{low}}{\text{high} - \text{low}} & \text{low} < I[r,c] < \text{high} \\ 1 & I[r,c] \geq \text{high} \end{cases}$$

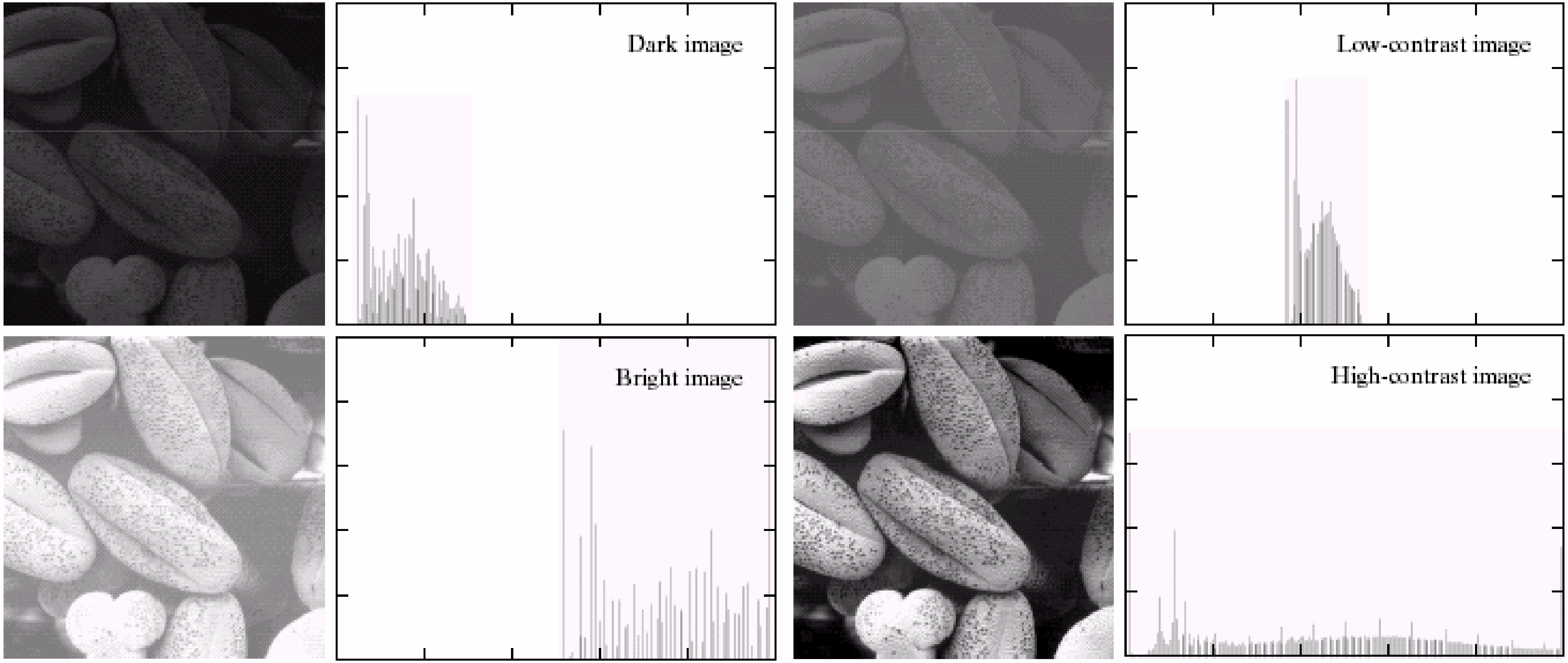
Image enhancement



a b
c d

FIGURE 3.10 Contrast stretching. (a) Form of transformation function. (b) A low-contrast image. (c) Result of contrast stretching. (d) Result of thresholding. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)

Histogram processing

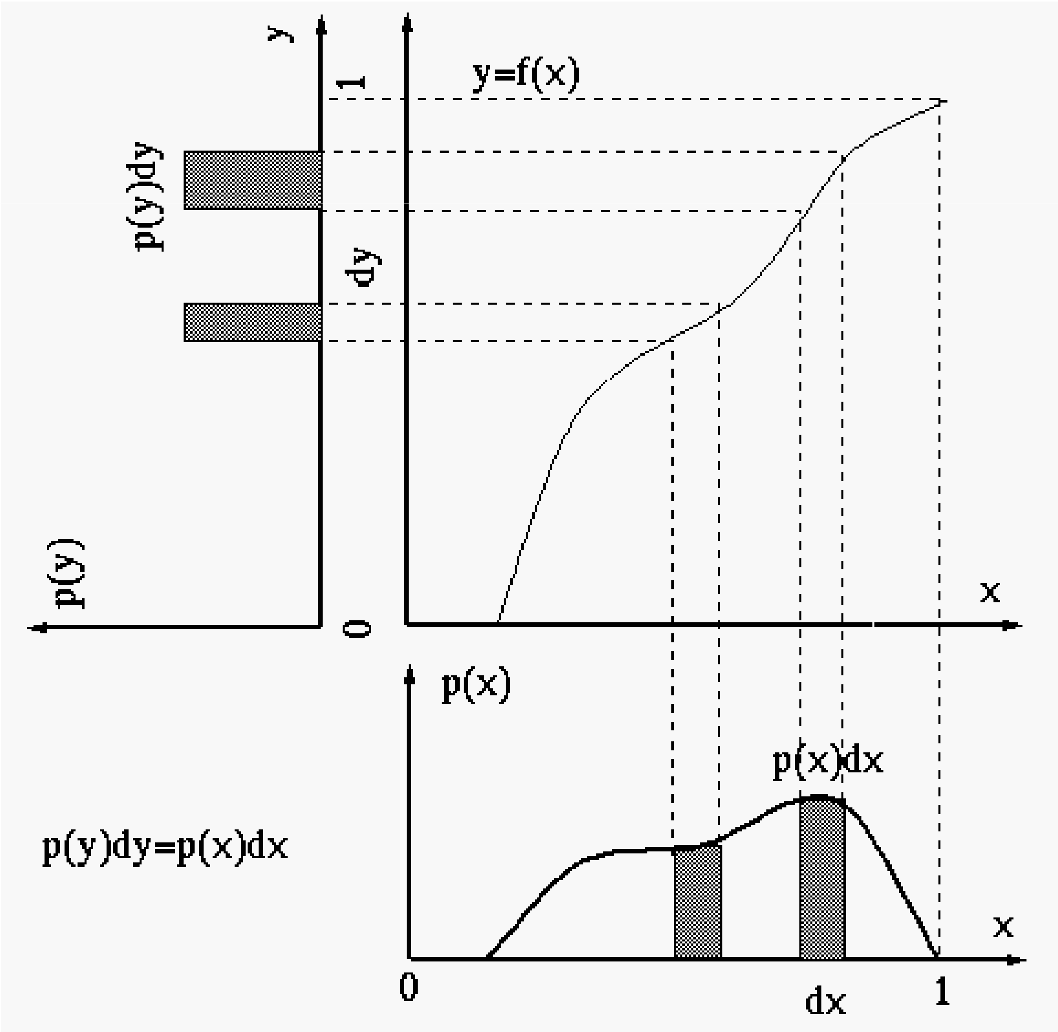


Histogram processing

- Intuitively, we expect that an image whose pixels
  - tend to occupy the entire range of possible gray levels,
  - tend to be distributed uniformly

  will have a high contrast and show a great deal of gray level detail.
- It is possible to develop a transformation function that can achieve this effect using histograms.

Histogram equalization



$p(x), 0 < x < 1$, is the pdf of the input image.
$p(y), 0 < y < 1$, is the pdf of the output image.
Number of pixels mapped from x to y is unchanged, so

$$p(y)dy = p(x)dx.$$

Let $p(y)$ be constant, i.e., $p(y) = 1, 0 < y < 1$. Then,

$$dy = p(x)dx$$
$$\frac{dy}{dx} = p(x)$$
$$y = \int_0^x p(u)du = F(x) - F(0) = F(x)$$

where $F(x)$ is the cdf of the input image.

http://fourier.eng.hmc.edu/e161/lectures/contrast_transform/node3.html

Histogram equalization

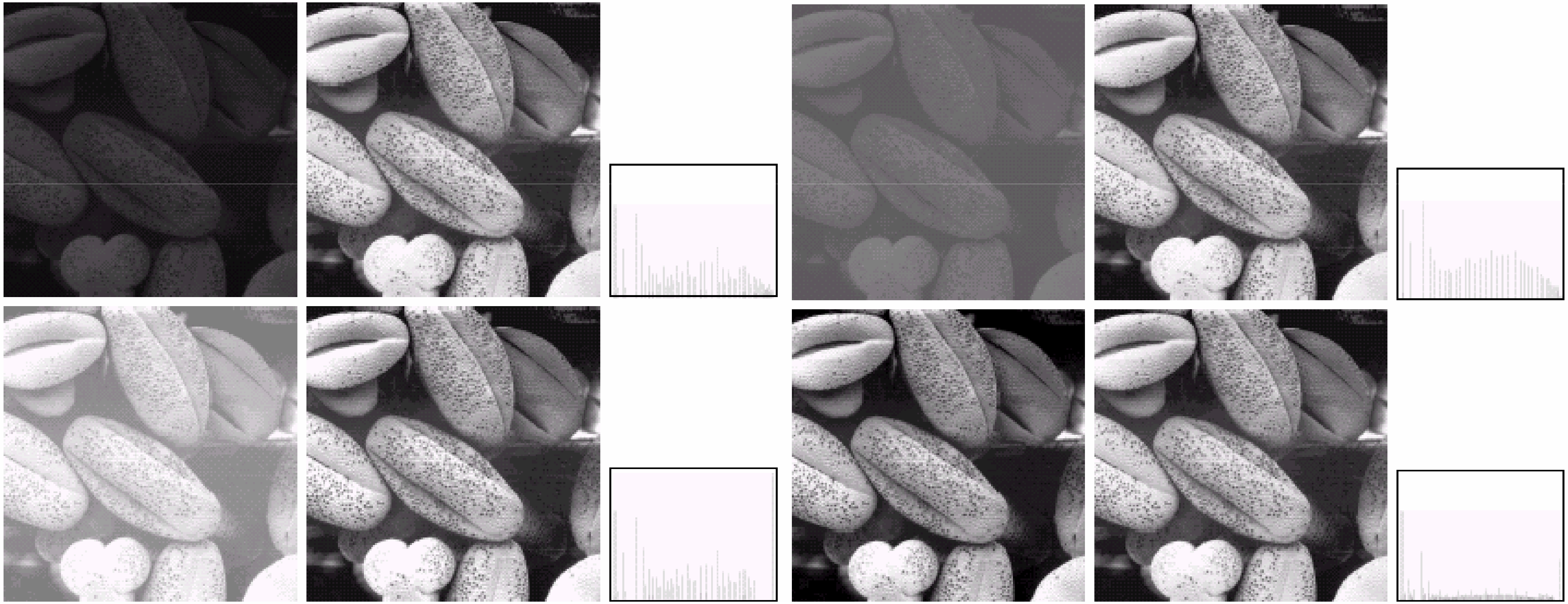
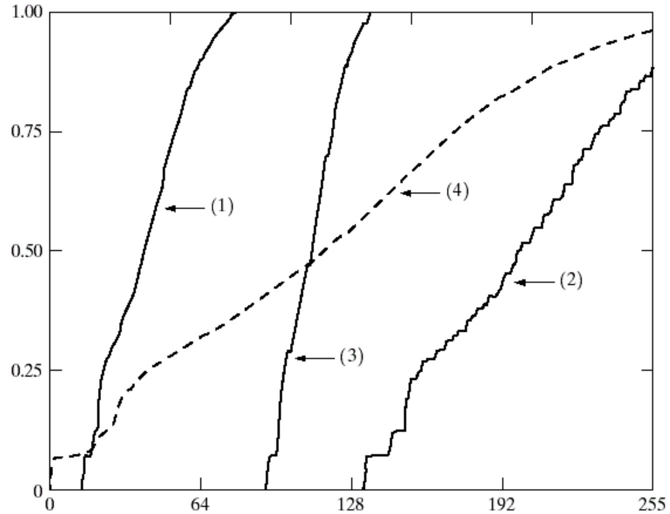
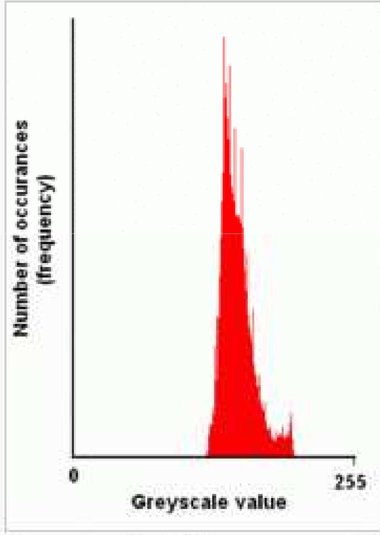


FIGURE 3.18 Transformation functions (1) through (4) were obtained from the histograms of the images in Fig.3.17(a), using Eq. (3.3-8).



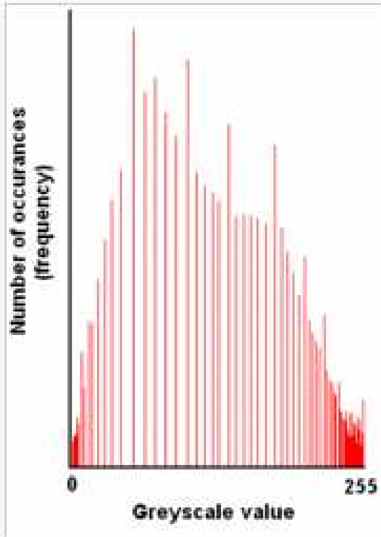
Histogram equalization

An unequalized image



Corresponding histogram

Same image after histogram equalization



Corresponding histogram

Adapted from Wikipedia

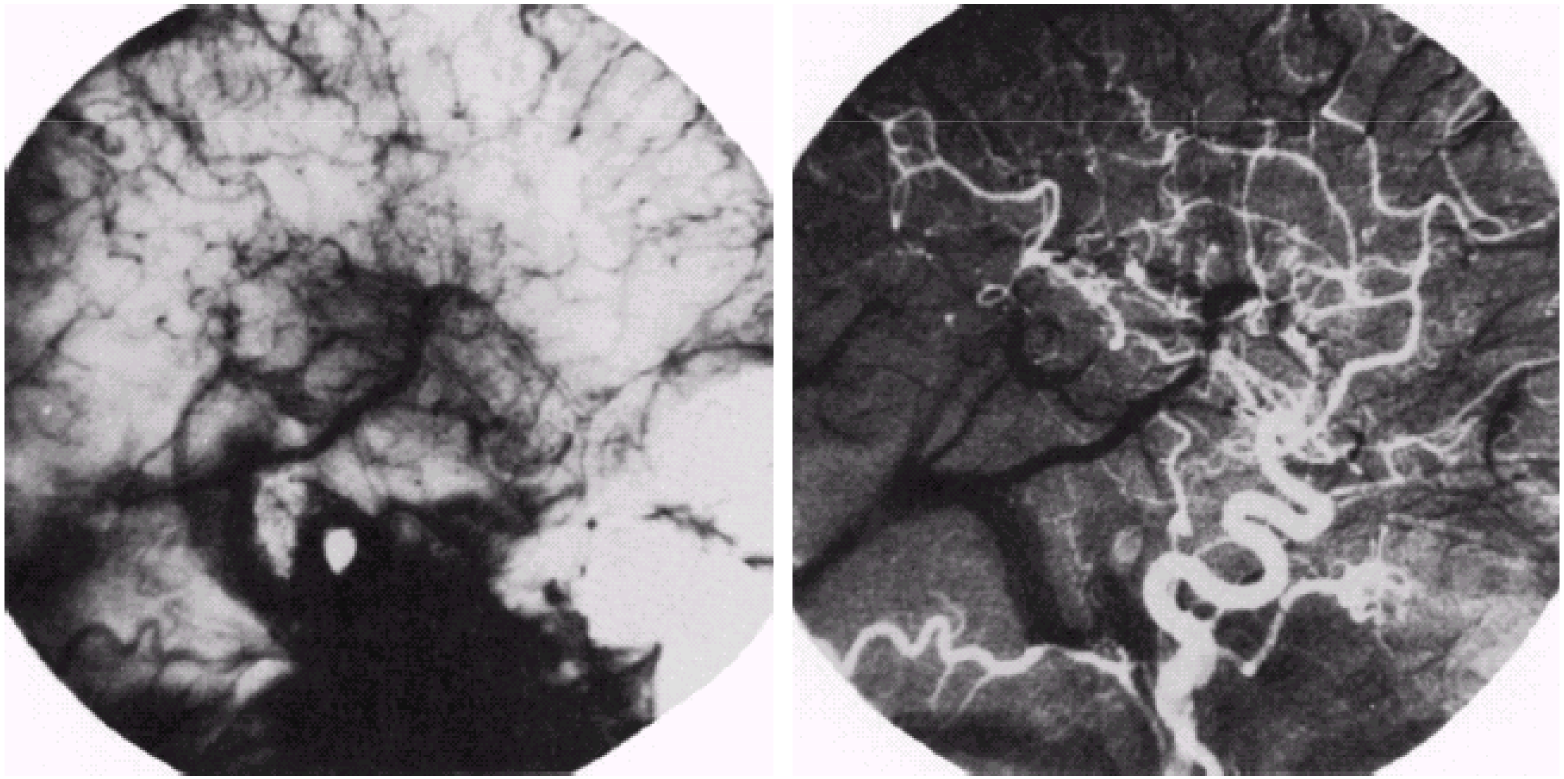
Histogram equalization

Original RGB image

Histogram equalization of each individual band/channel

Histogram stretching by removing 2% percentile from each individual band/channel

Enhancement using arithmetic operations



a b

FIGURE 3.29 Enhancement by image subtraction. (a) Mask image. (b) An image (taken after injection of a contrast medium into the bloodstream) with mask subtracted out.

Image formats

- Popular formats:
  - BMP Microsoft Windows bitmap image
  - EPS Adobe Encapsulated PostScript
  - GIF CompuServe graphics interchange format
  - JPEG Joint Photographic Experts Group
  - PBM Portable bitmap format (black and white)
  - PGM Portable graymap format (gray scale)
  - PPM Portable pixmap format (color)
  - PNG Portable Network Graphics
  - PS Adobe PostScript
  - TIFF Tagged Image File Format

Image formats

- ASCII or binary
- Number of bits per pixel (color depth)
- Number of bands
- Support for compression (lossless, lossy)
- Support for metadata
- Support for transparency
- Format conversion
- …
  http://en.wikipedia.org/wiki/Graphics_file_format_summary
  http://en.wikipedia.org/wiki/Comparison_of_graphics_file_formats