

# Digital Image Fundamentals

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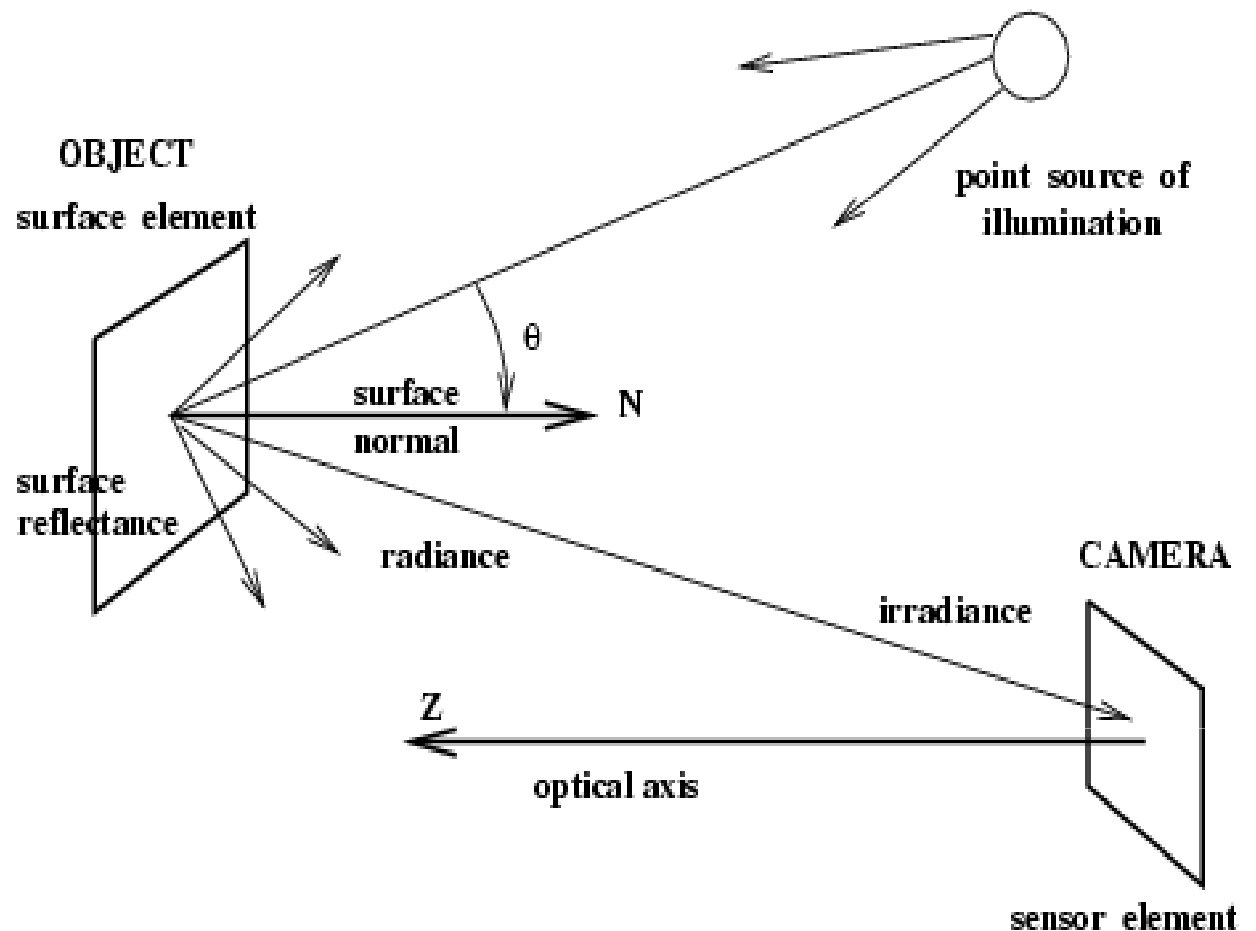
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# Imaging process

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



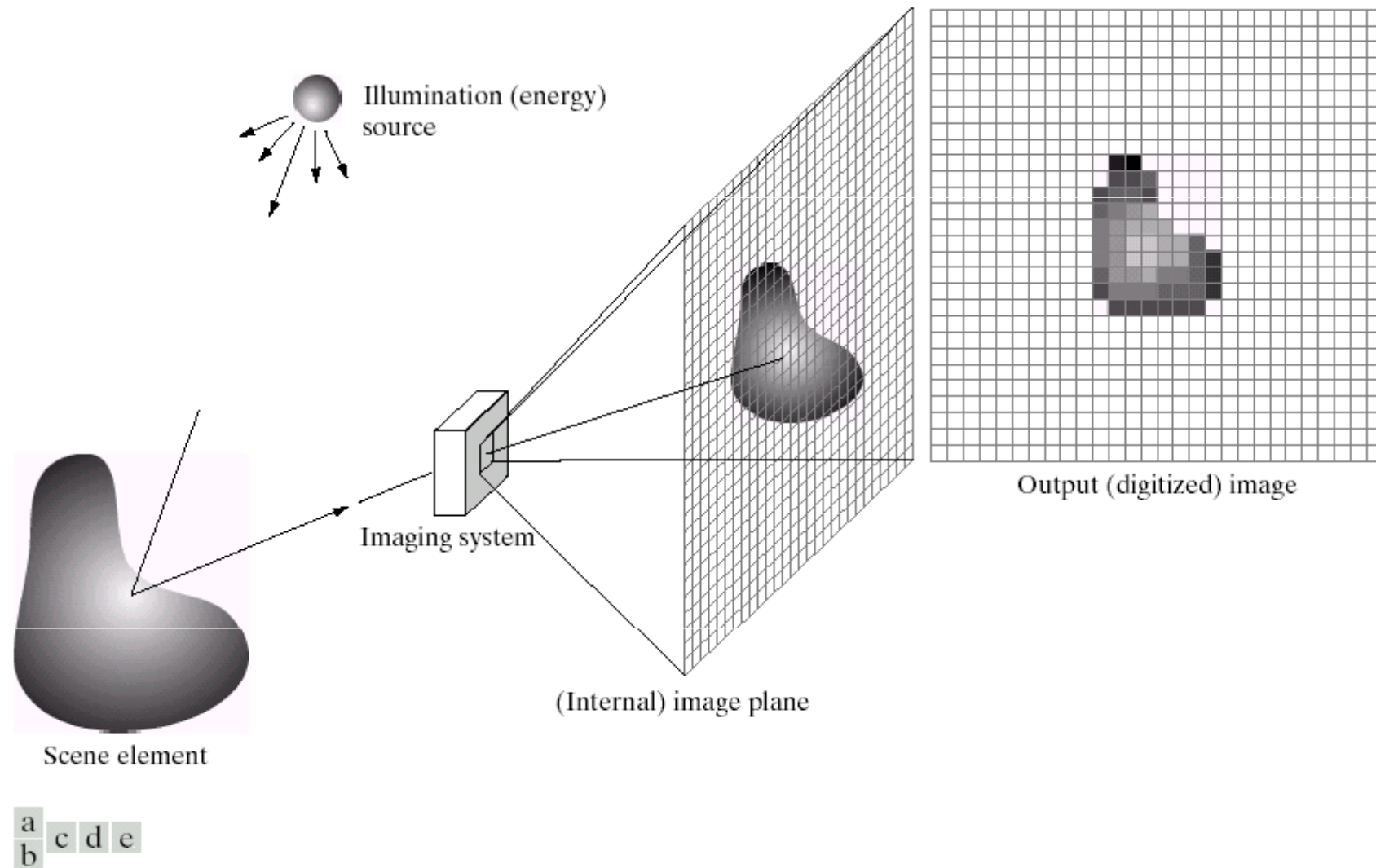
Adapted from Shapiro and Stockman

# Imaging process

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- **Radiometry** is a branch of physics that deals with the measurement of the flow and transfer of radiant energy.
- **Radiance** is the power of light that is emitted from a unit surface area into some spatial angle; the corresponding photometric term is brightness.
- **Irradiance** is the amount of energy that an image capturing device gets per unit of an efficient sensitive area of the camera. Quantizing it gives image gray tones.

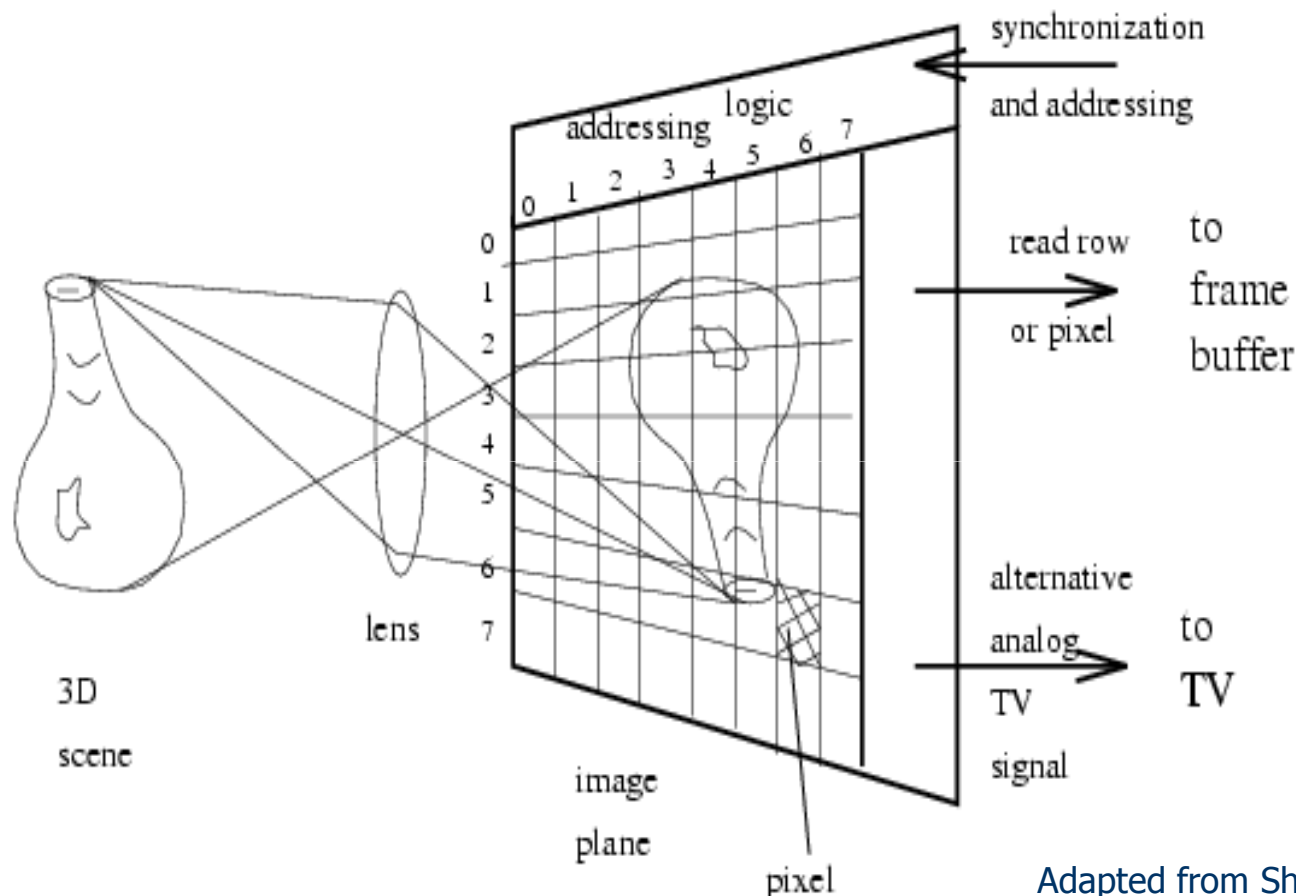
# Image acquisition



**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.

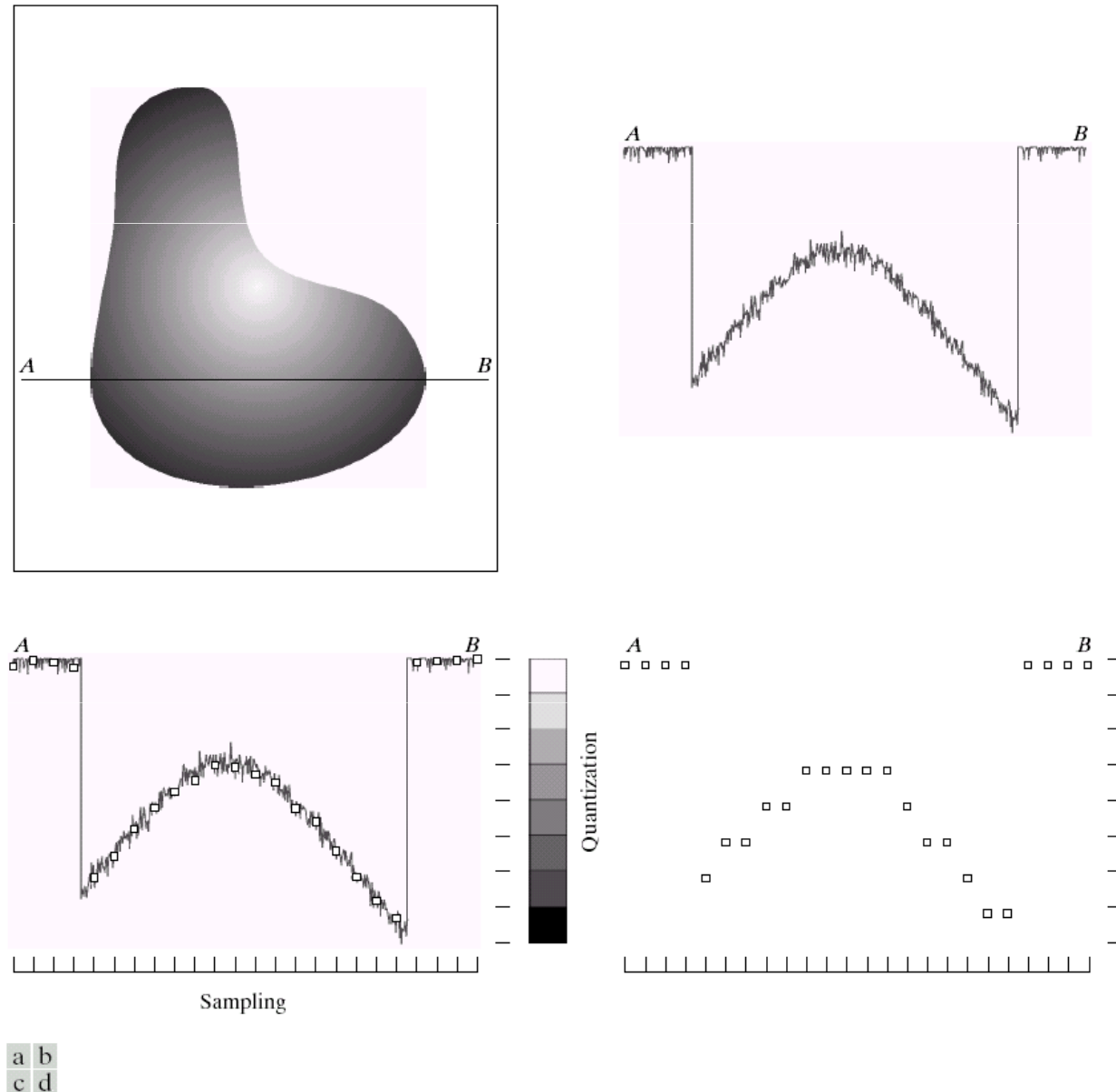
# CCD cameras

- Lens collects light arrays.
- Array of small fixed elements replace chemicals of film.
- Number of elements (**pixels**) less than with film (so far).



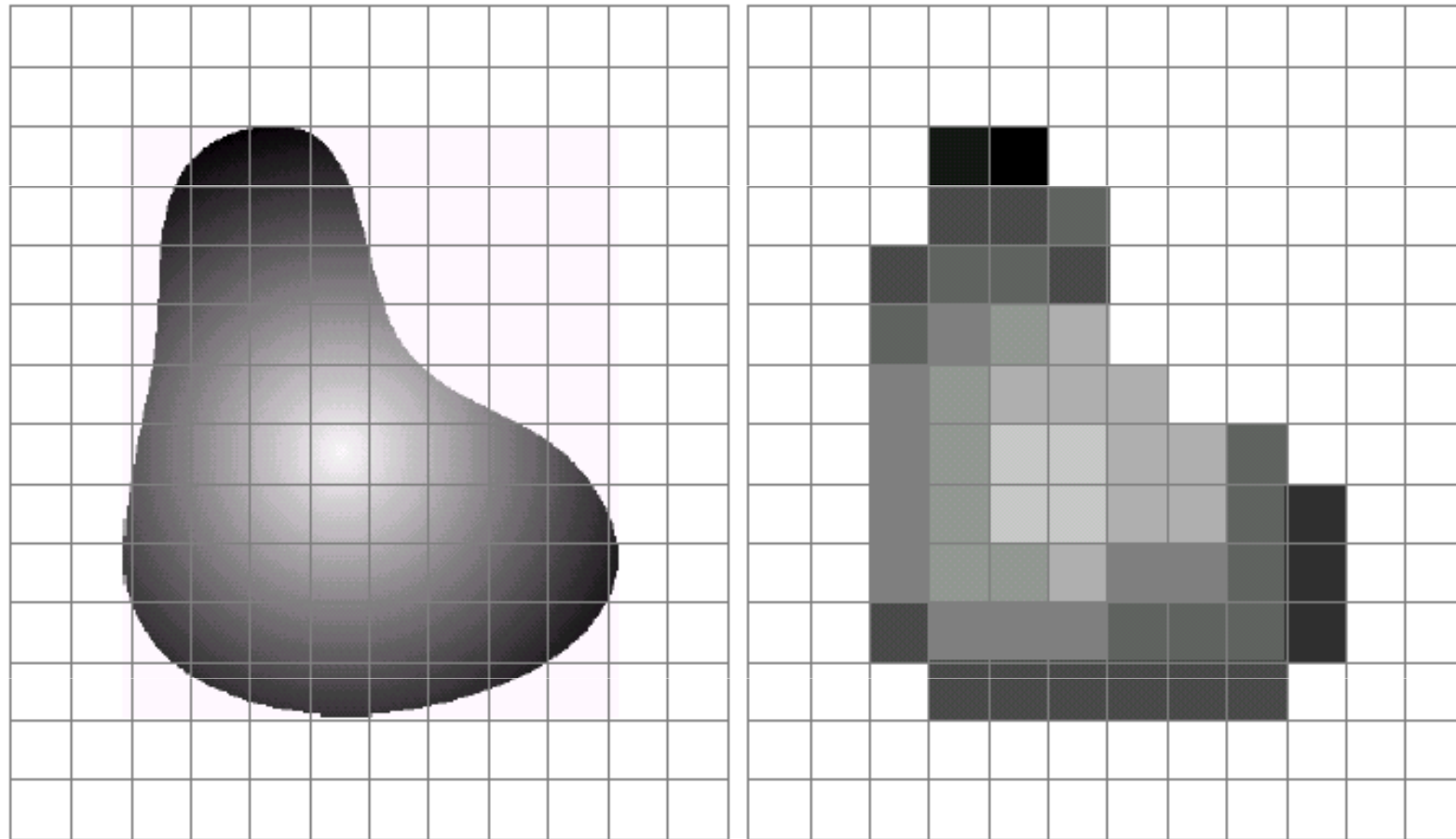
Adapted from Shapiro and Stockman

# Sampling and quantization



# Sampling and quantization

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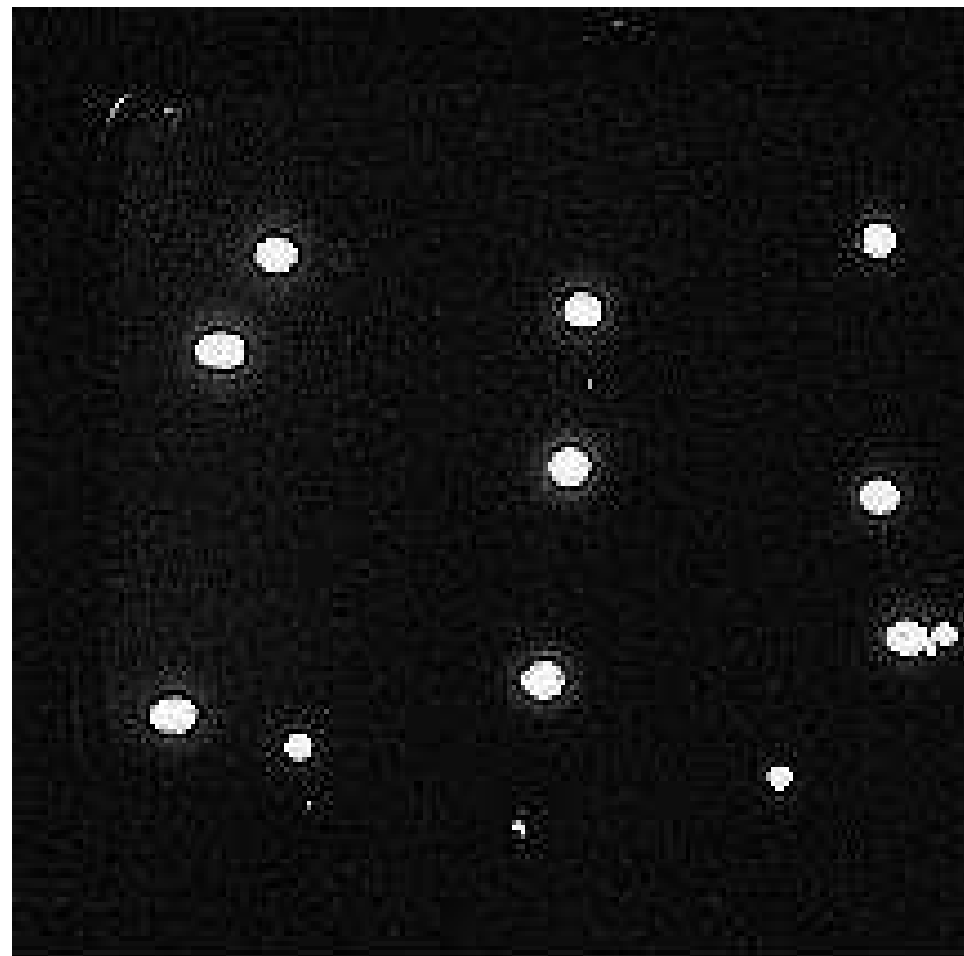
a b

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

# Problems with arrays

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- 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

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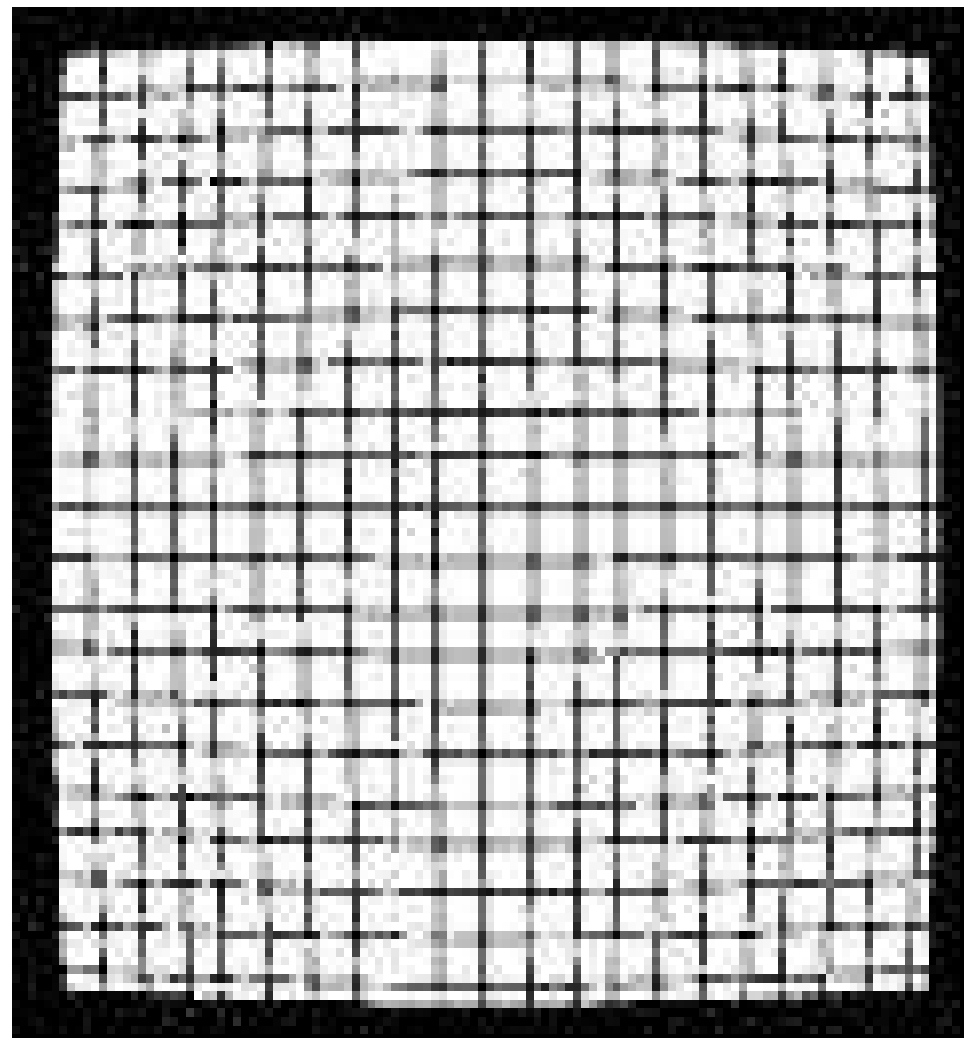
- Clipping: dark grid intersections at left were actually brightest of scene.
- In A/D conversion the bright values were clipped to lower values.

Adapted from Shapiro and Stockman

# Problems with arrays

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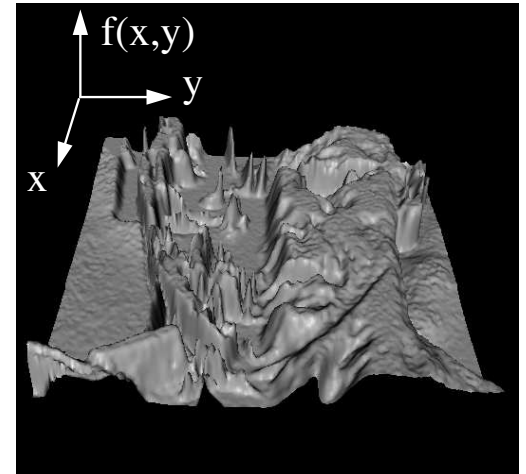
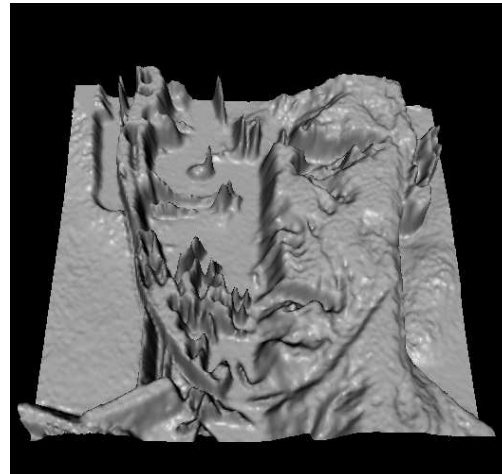
- Distortion: *Barrel distortion* of rectangular grid is common for cheap lenses.
- Zoom lenses often show severe distortion.



Adapted from Shapiro and Stockman

# Image representation

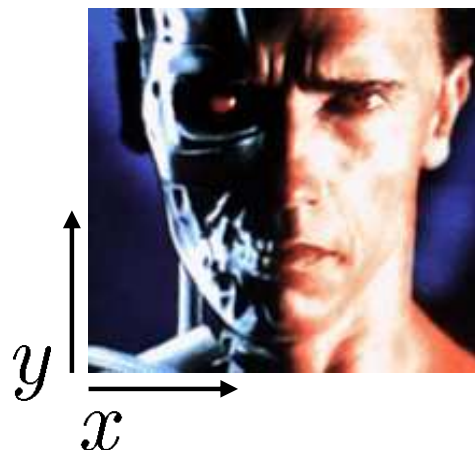
- Images can be represented by 2D functions of the form  $f(x,y)$ .
- The physical meaning of the value of  $f$  at spatial coordinates  $(x,y)$  is determined by the source of the image.



Adapted from Shapiro and Stockman

# Image representation

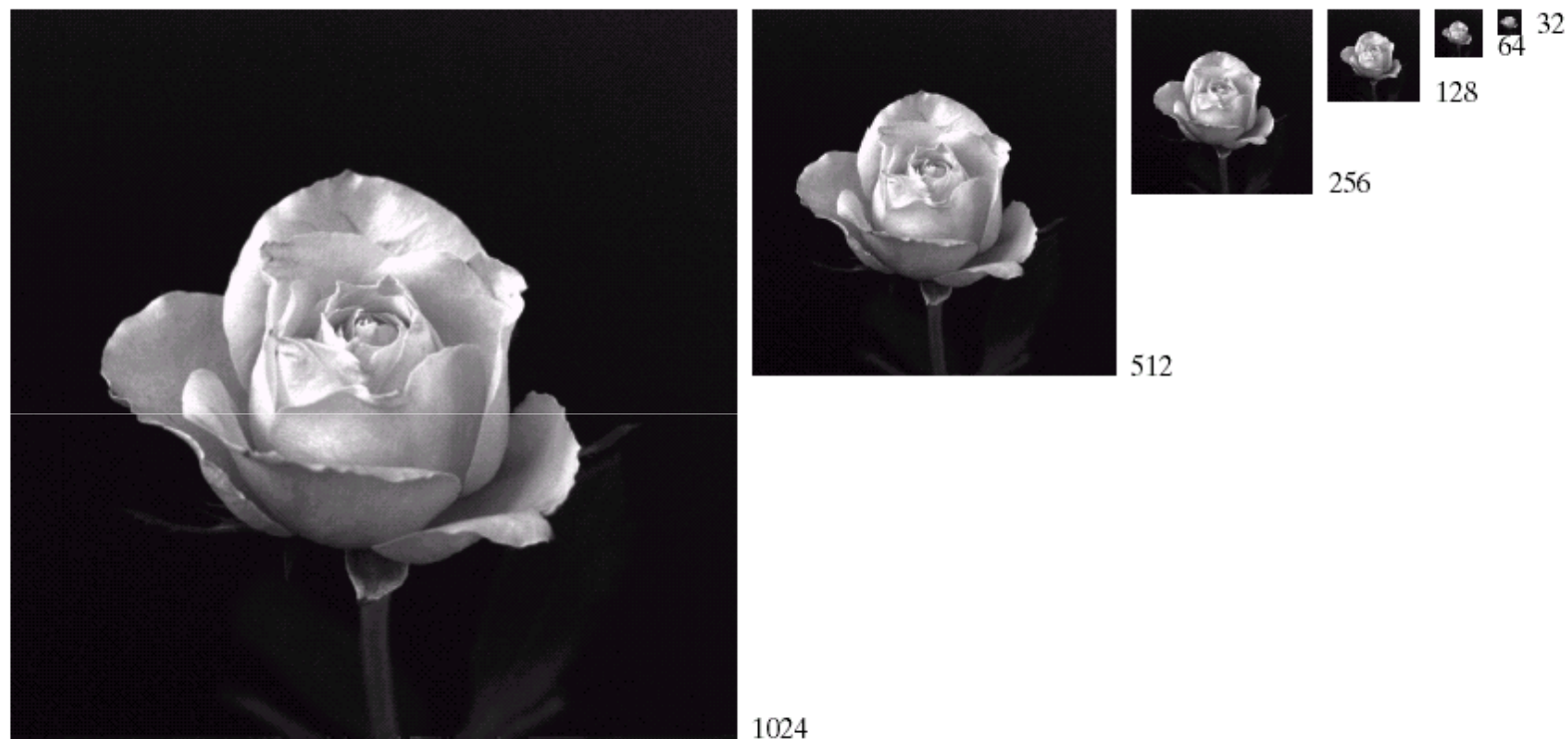
- In a **digital** image, both the coordinates and the image value become **discrete** quantities.
- Images can now be represented as 2D arrays (matrices) of integer values:  $I[i,j]$  (or  $I[r,c]$ ).
- The term **gray level** is used to describe monochromatic intensity.



	$j$							
	$\rightarrow$							
$i$	62	79	23	119	120	105	4	0
$\downarrow$	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

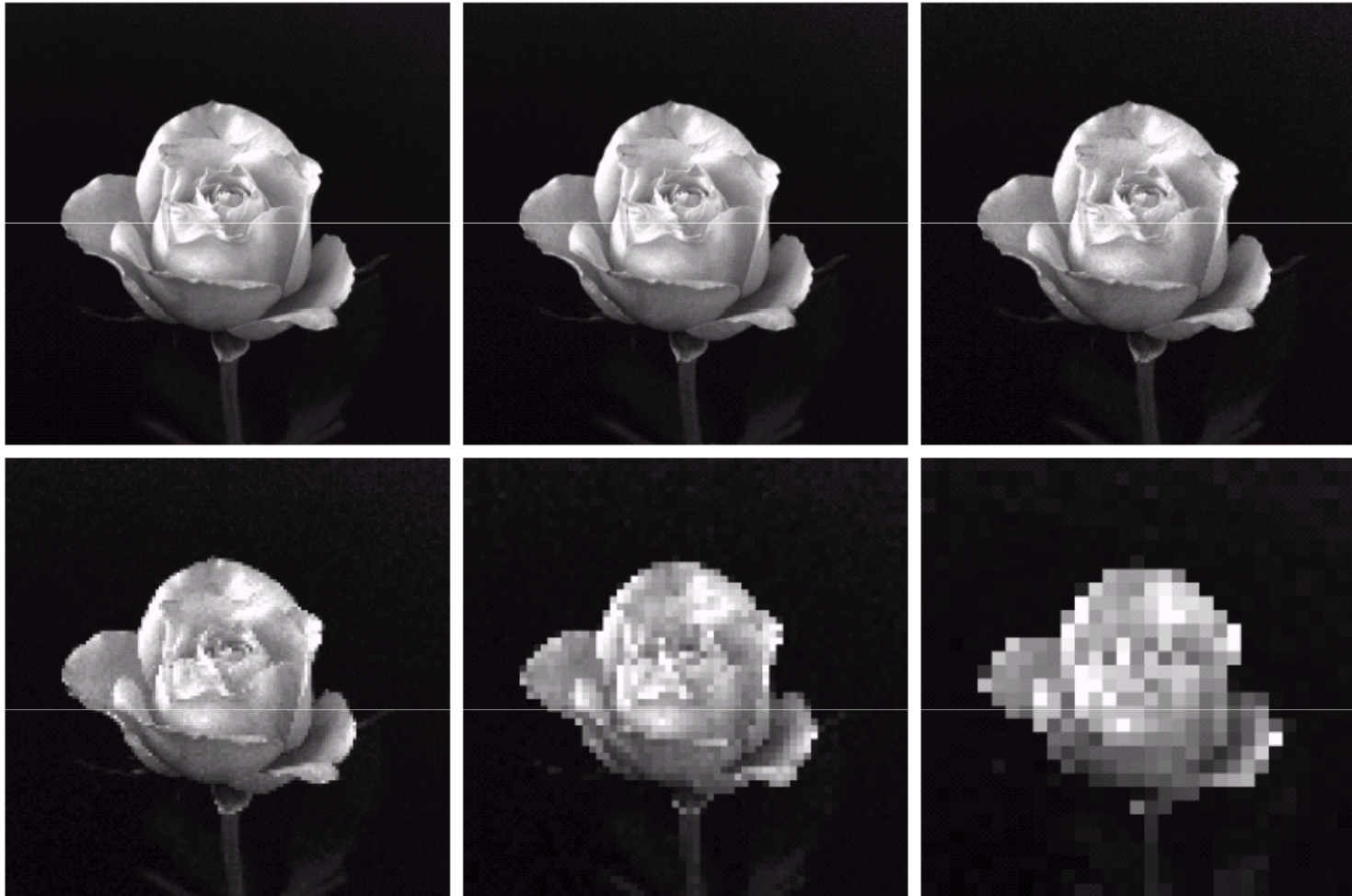
# Spatial resolution

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



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

# Spatial resolution

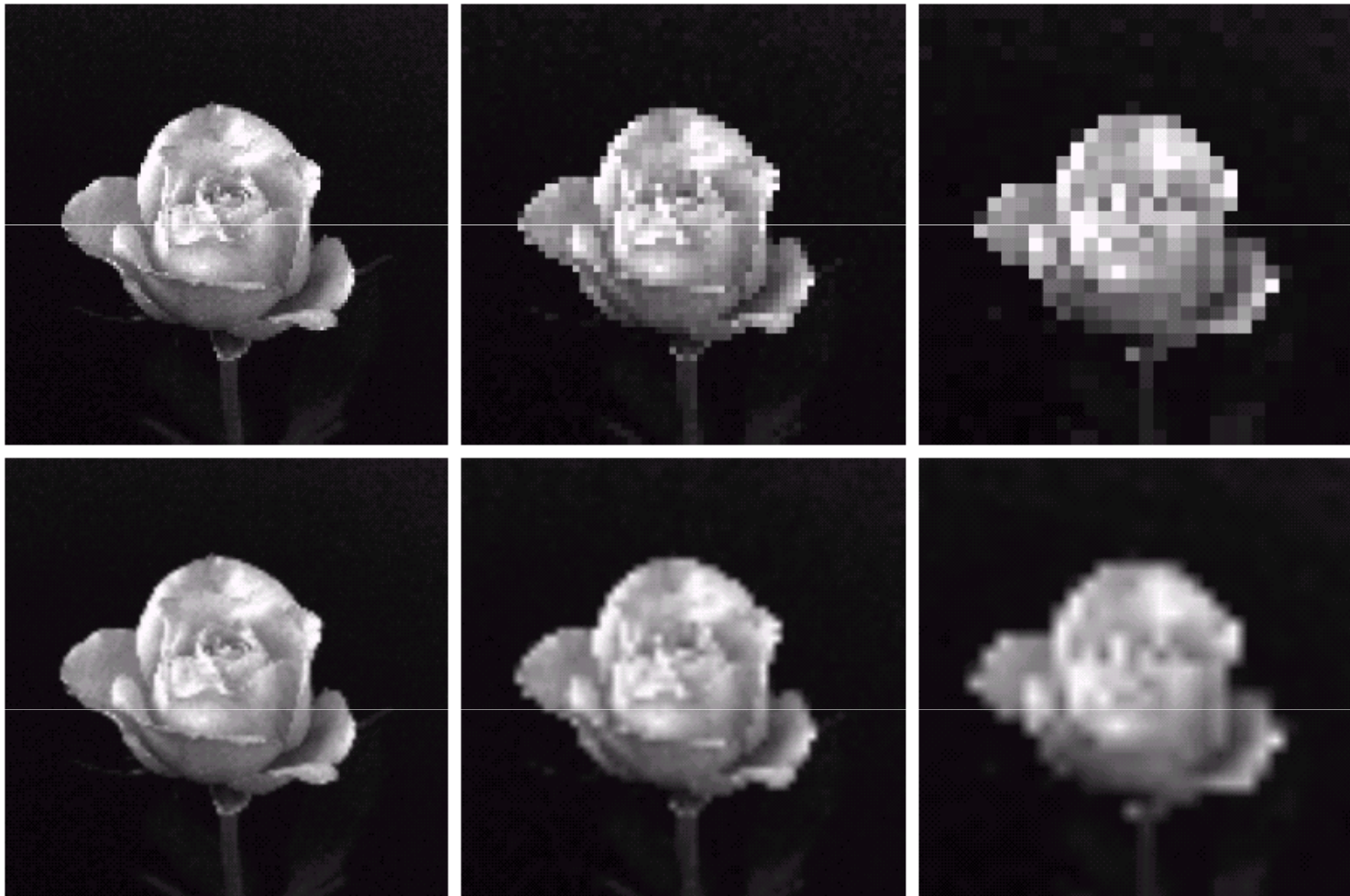


a	b	c
d	e	f

**FIGURE 2.20** (a)  $1024 \times 1024$ , 8-bit image. (b)  $512 \times 512$  image resampled into  $1024 \times 1024$  pixels by row and column duplication. (c) through (f)  $256 \times 256$ ,  $128 \times 128$ ,  $64 \times 64$ , and  $32 \times 32$  images resampled into  $1024 \times 1024$  pixels.



# Spatial resolution

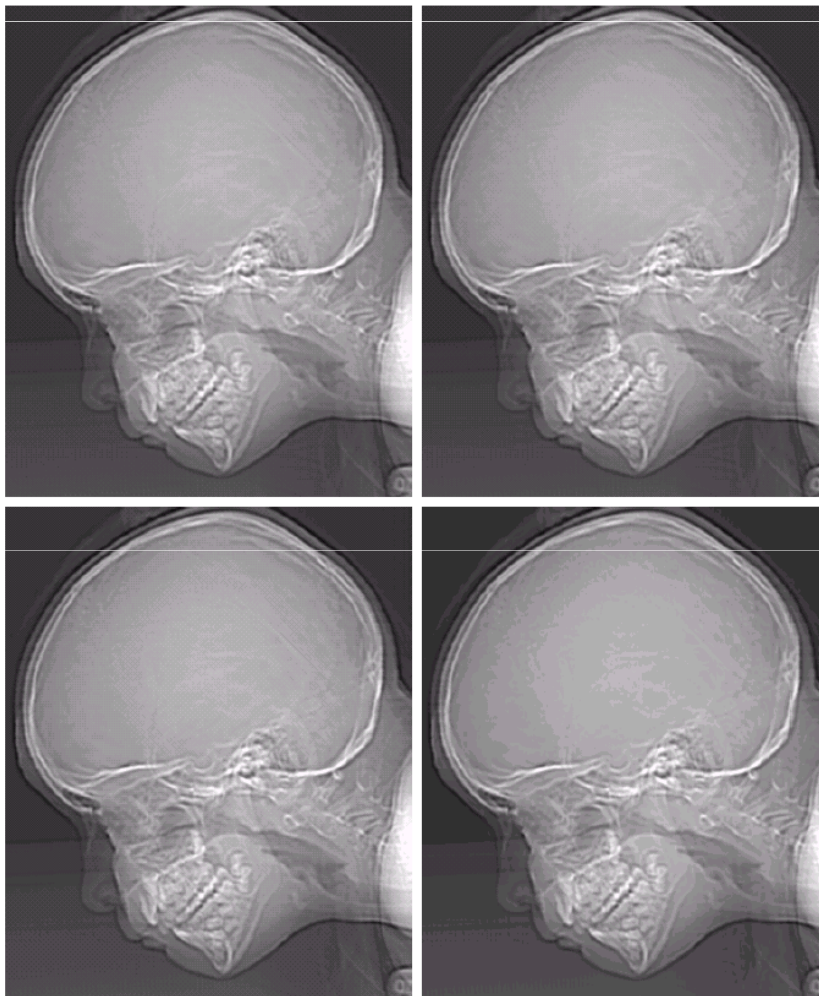


a b c  
d e f

**FIGURE 2.25** Top row: images zoomed from  $128 \times 128$ ,  $64 \times 64$ , and  $32 \times 32$  pixels to  $1024 \times 1024$  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

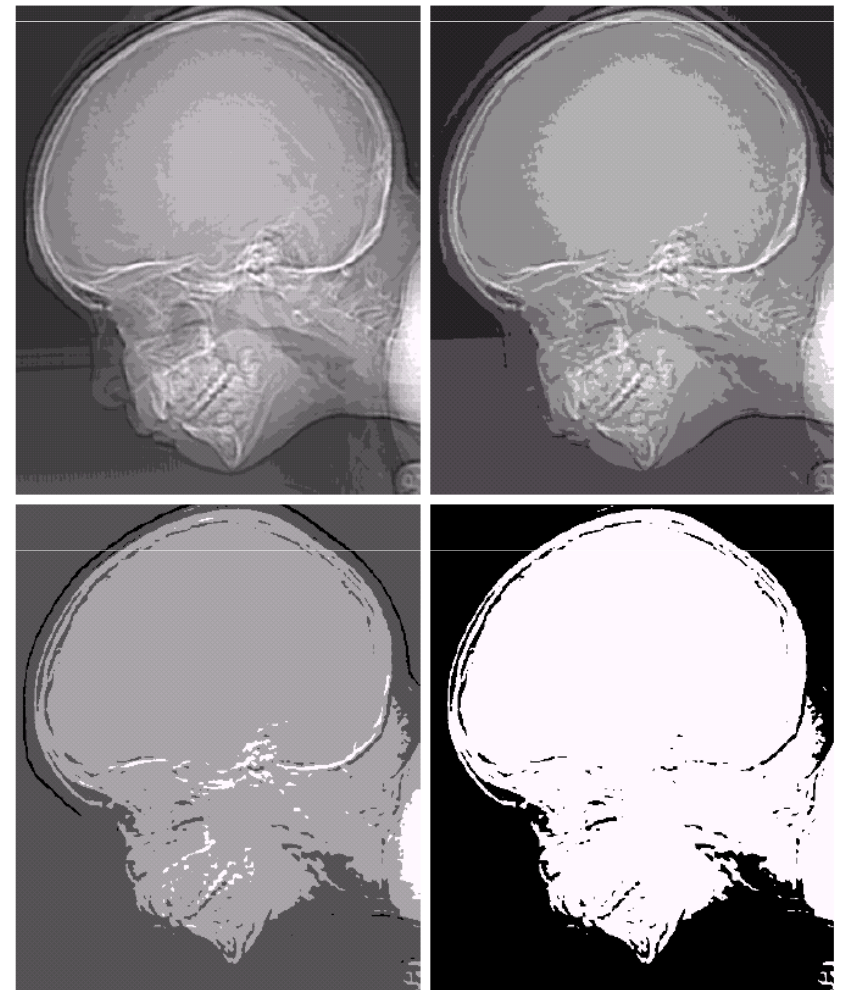
**FIGURE 2.21**

(a)  $452 \times 374$ , 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.)





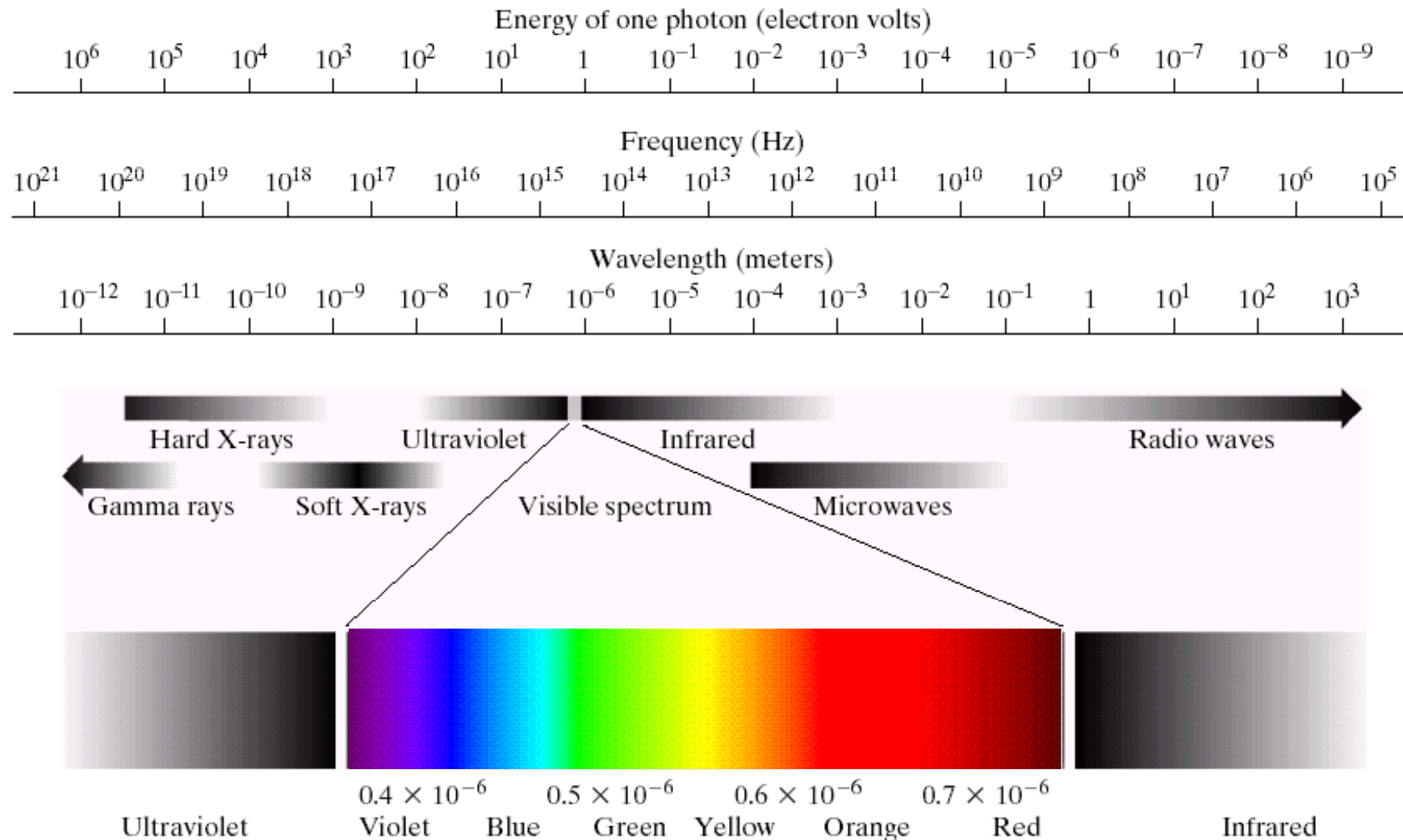
# Bit planes



a	b	c
d	e	f
g	h	i

**FIGURE 3.14** (a) An 8-bit gray-scale image of size  $500 \times 1192$  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.

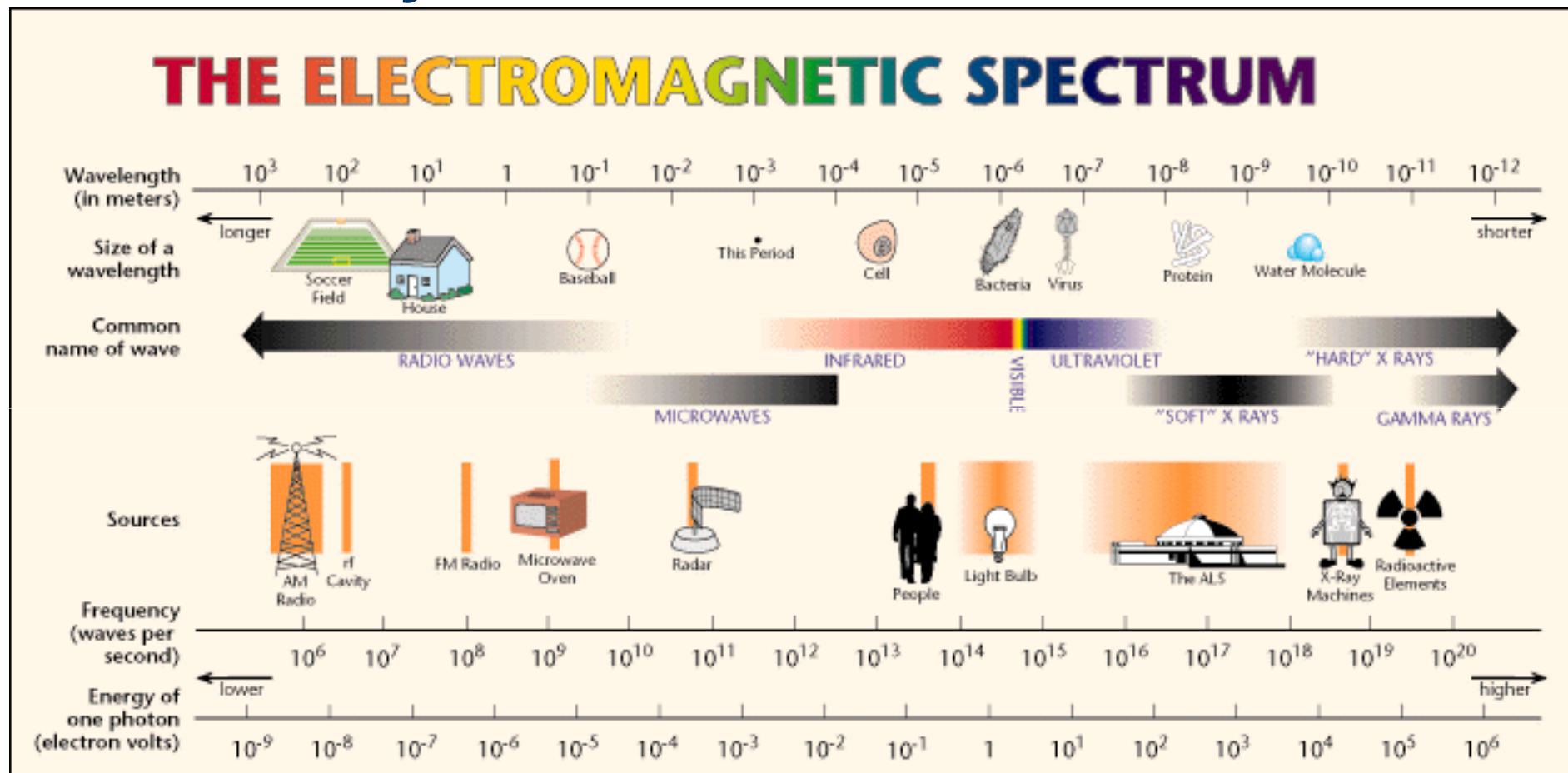
# Electromagnetic (EM) spectrum



**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.

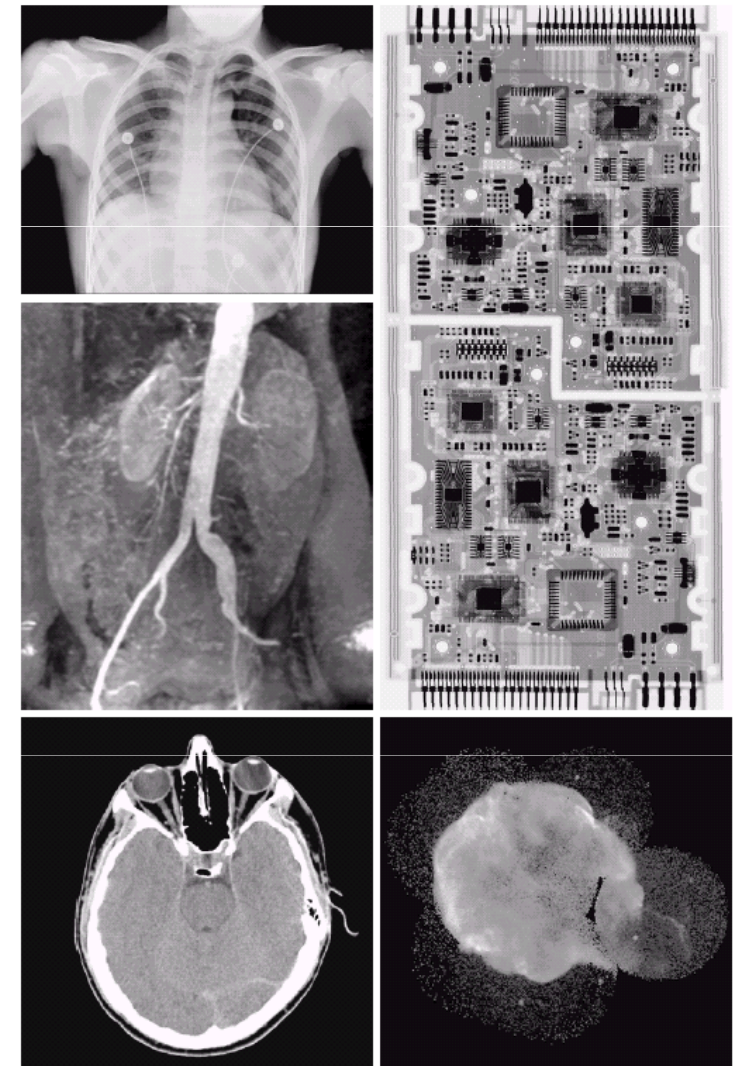
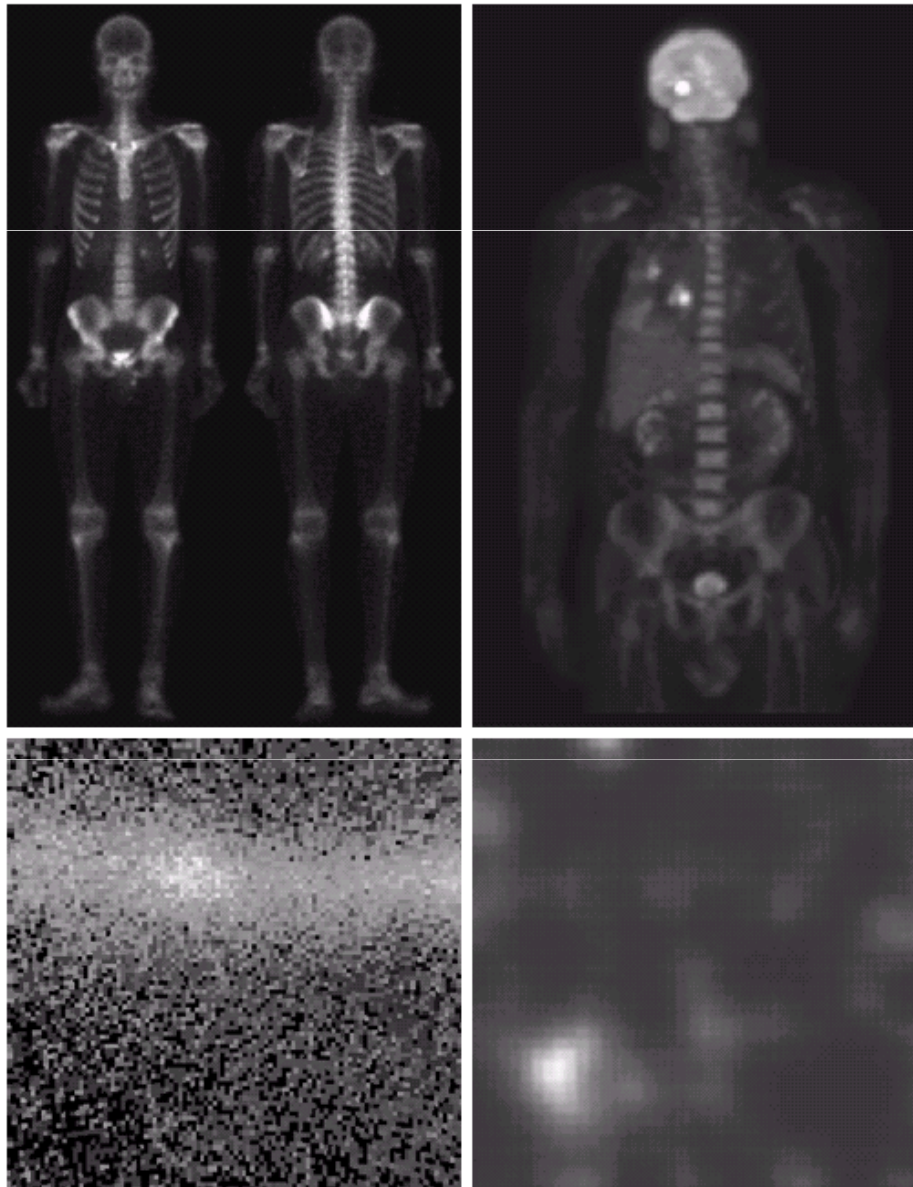




# Other types of sensors

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  
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.)



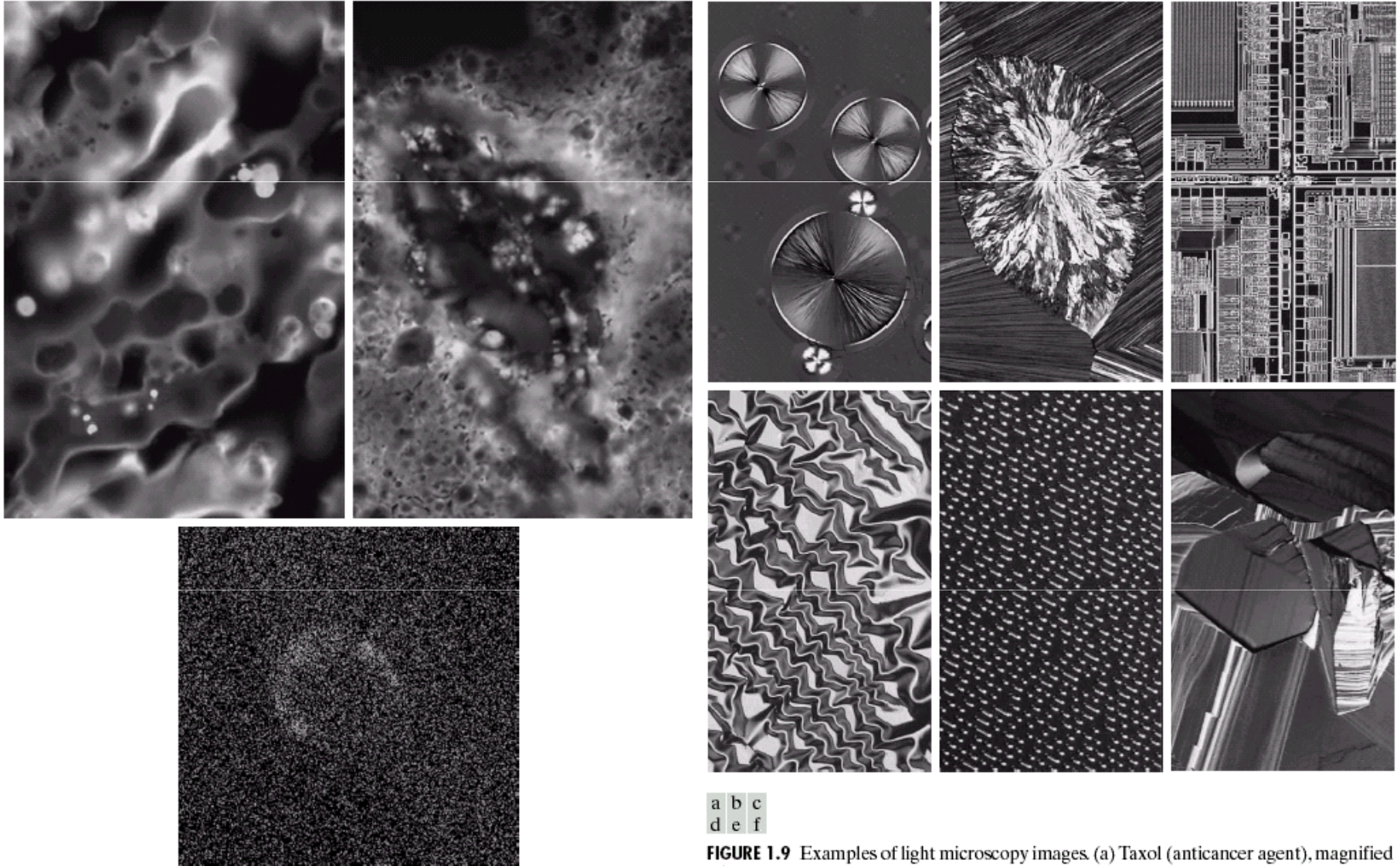
# Other types of sensors

a b  
c

**FIGURE 1.8**

Examples of ultraviolet imaging.

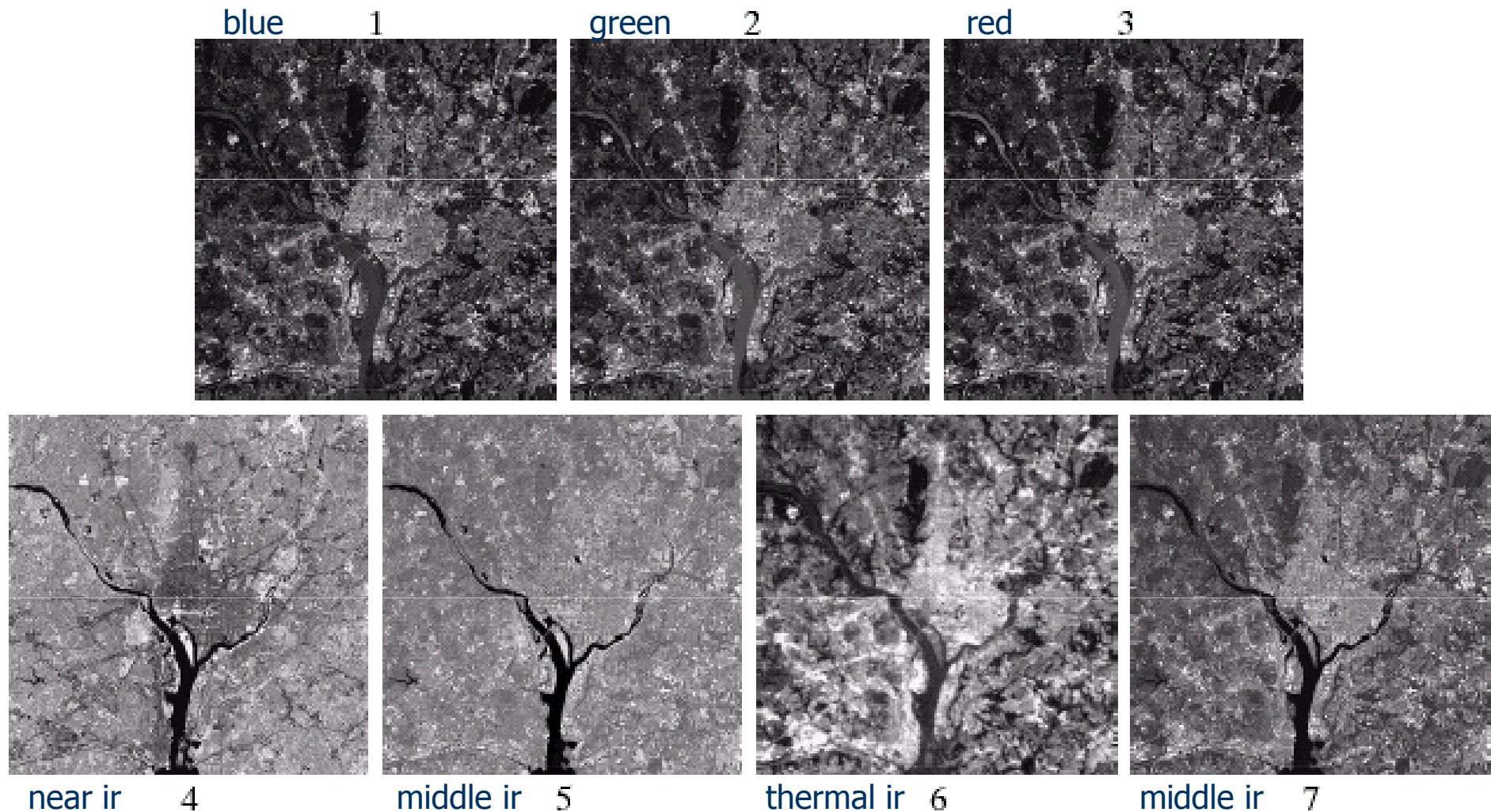
(a) Normal corn.  
(b) Smut corn.  
(c) Cygnus Loop.  
(Images courtesy of (a) and (b) Dr. Michael W. Davidson, Florida State University, (c) NASA.)



a b c  
d e f

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

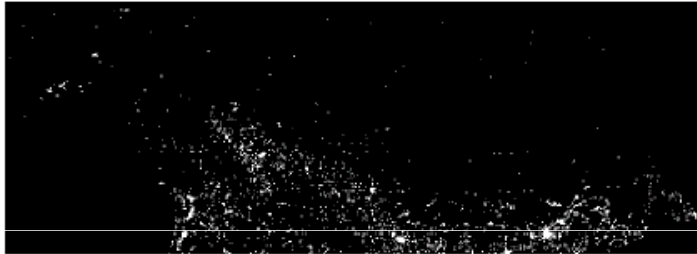
# Other types of sensors



**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.)



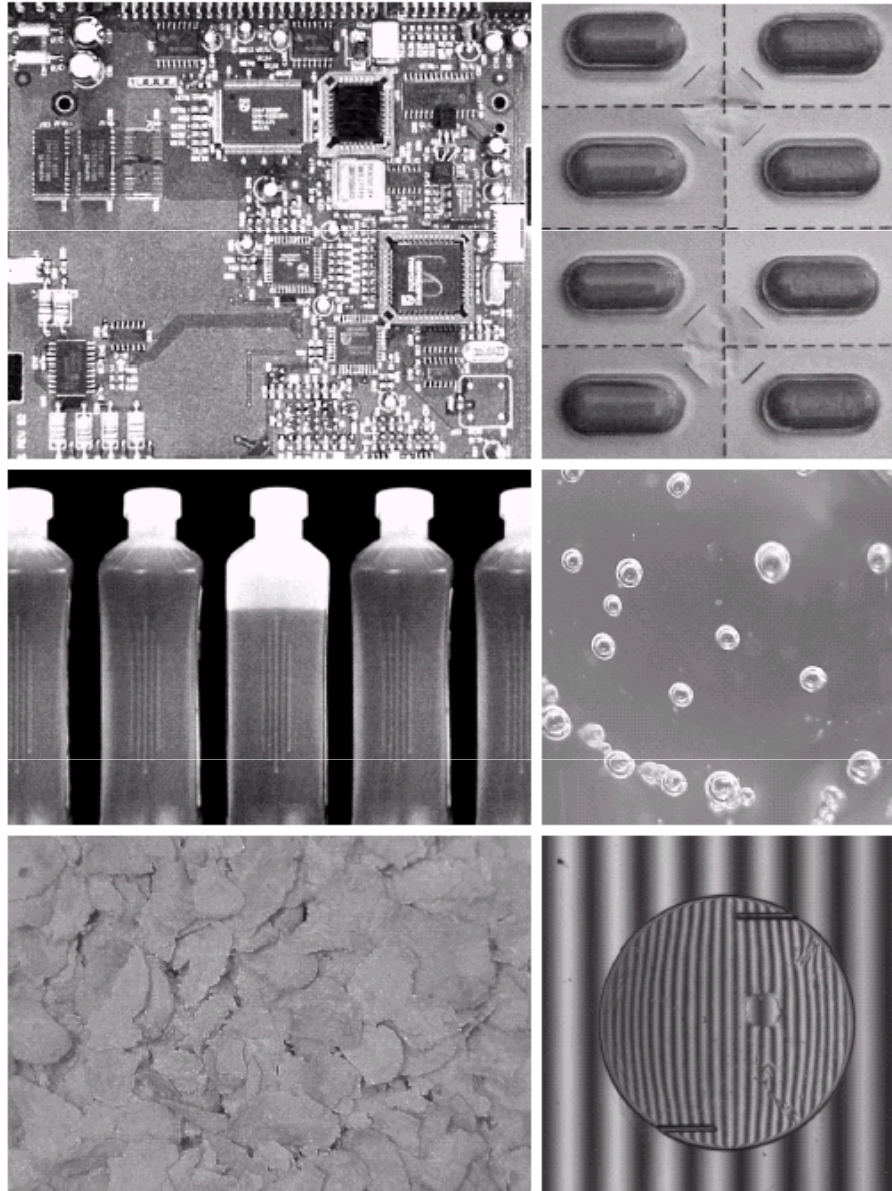


# Other types of sensors

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

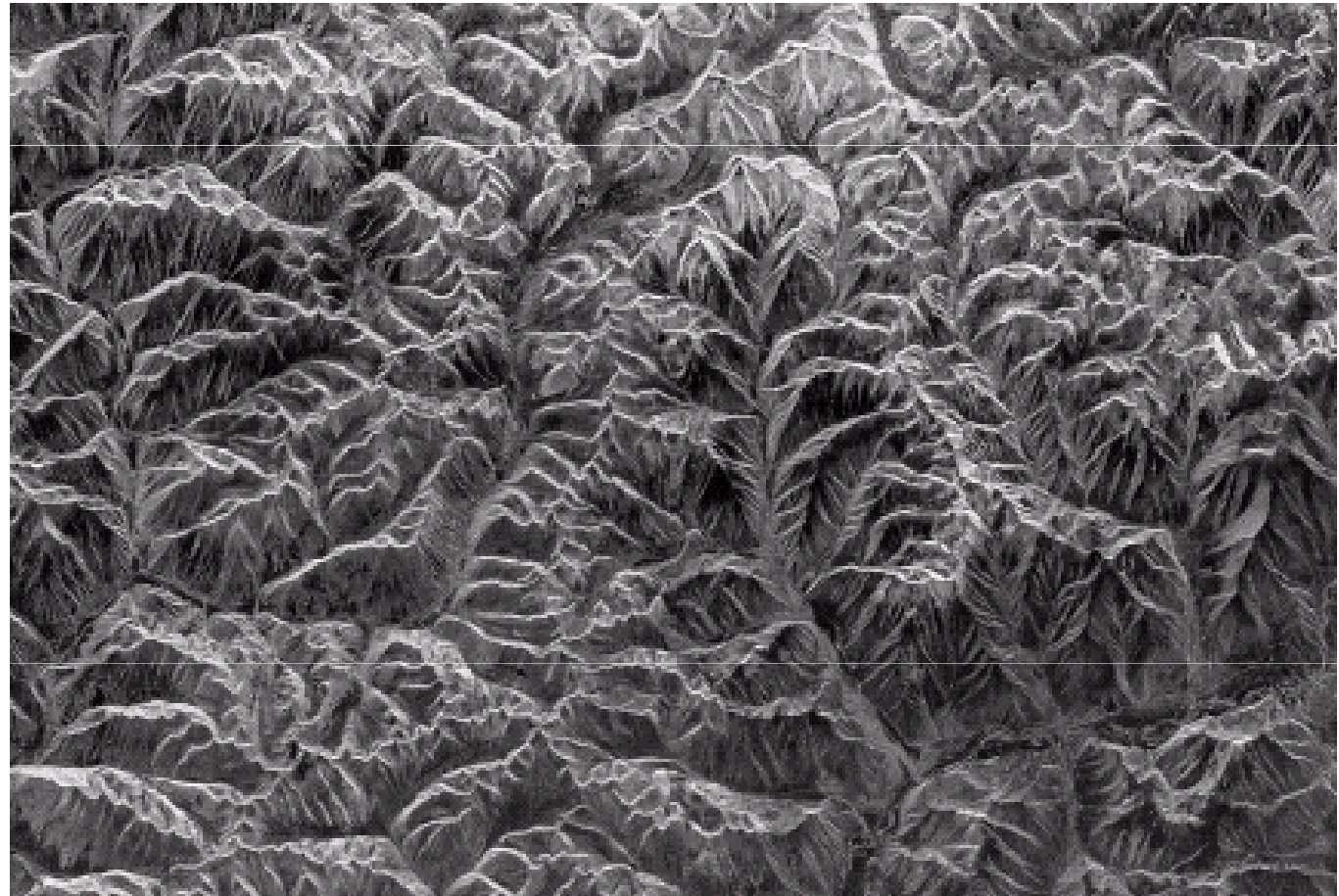
**FIGURE 1.15**  
Some additional examples of imaging in the visual spectrum. (a) Thumb print. (b) Paper currency. (c) and (d) Automated license plate reading. (Figure (a) courtesy of the National Institute of Standards and Technology. Figures (c) and (d) courtesy of Dr. Juan Herrera, Perceptics Corporation.)

# Other types of sensors

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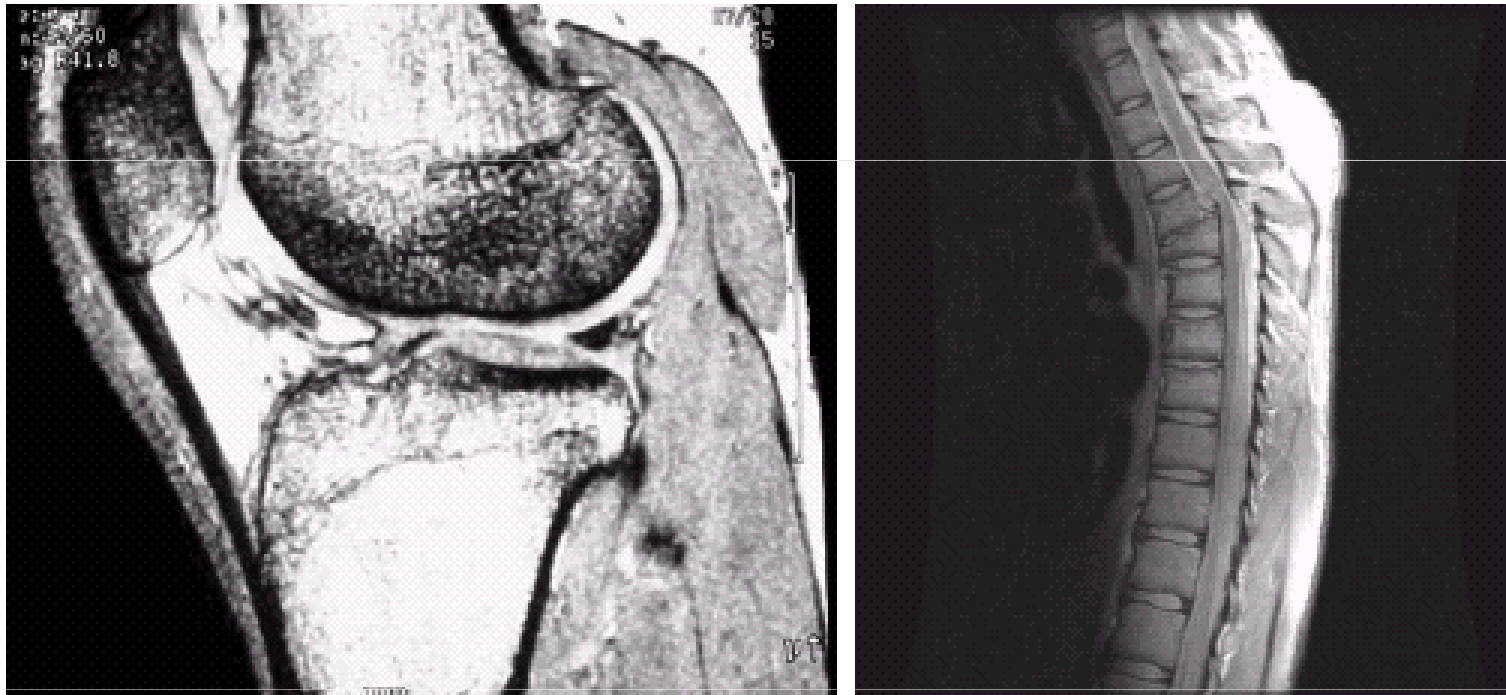
**FIGURE 1.16**  
Spaceborne radar  
image of  
mountains in  
southeast Tibet.  
(Courtesy of  
NASA.)

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# Other types of sensors

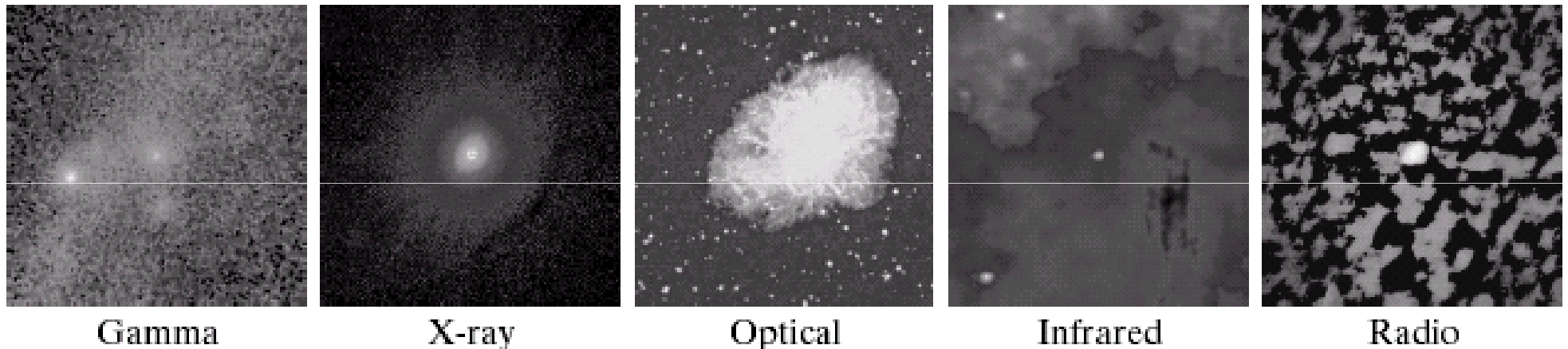
---



a b

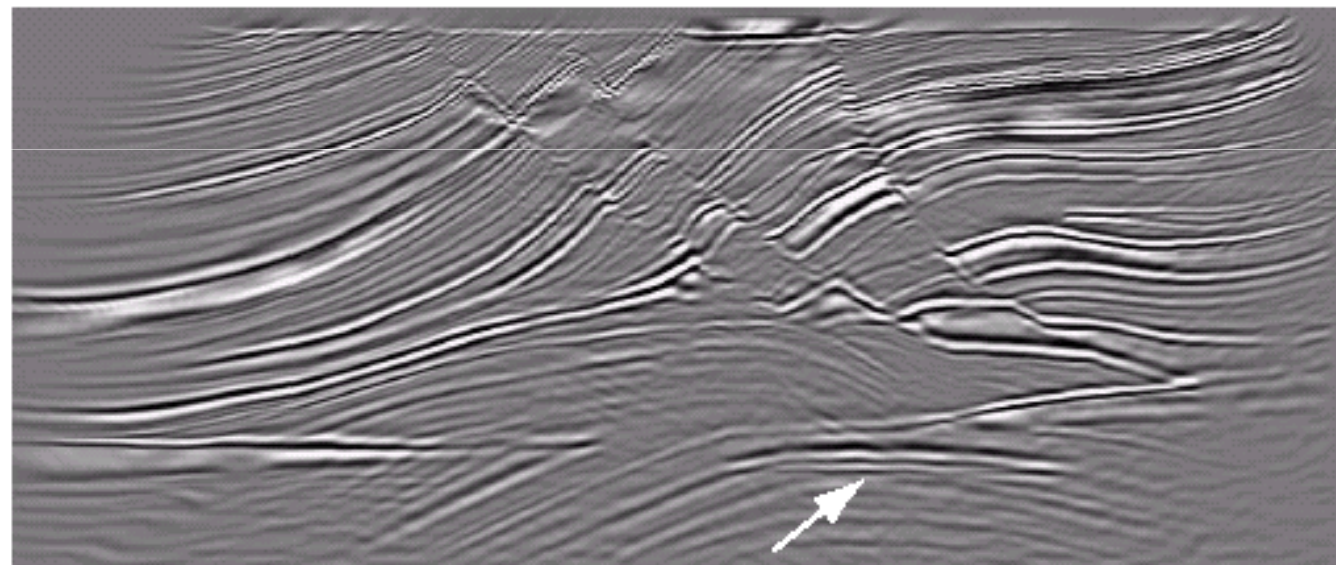
**FIGURE 1.17** MRI images of a human (a) knee, and (b) spine. (Image (a) courtesy of Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, and (b) Dr. David R. Pickens, Department of Radiology and Radiological Sciences, Vanderbilt University Medical Center.)

# Other types of sensors

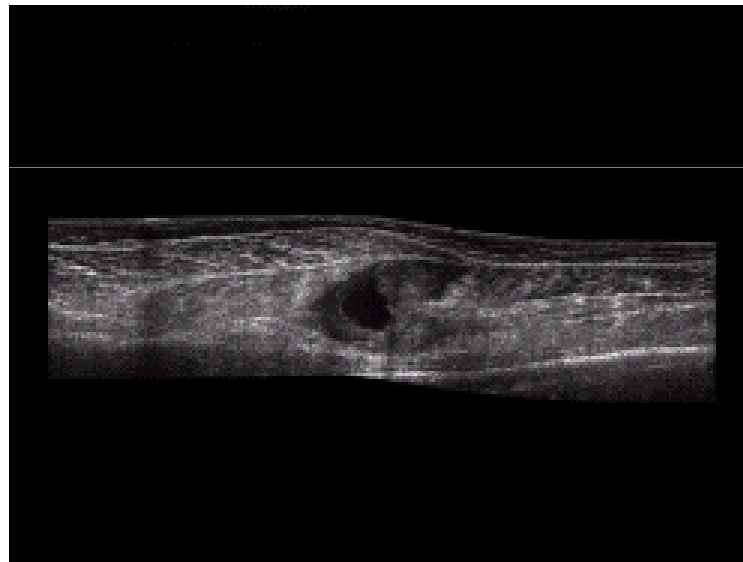
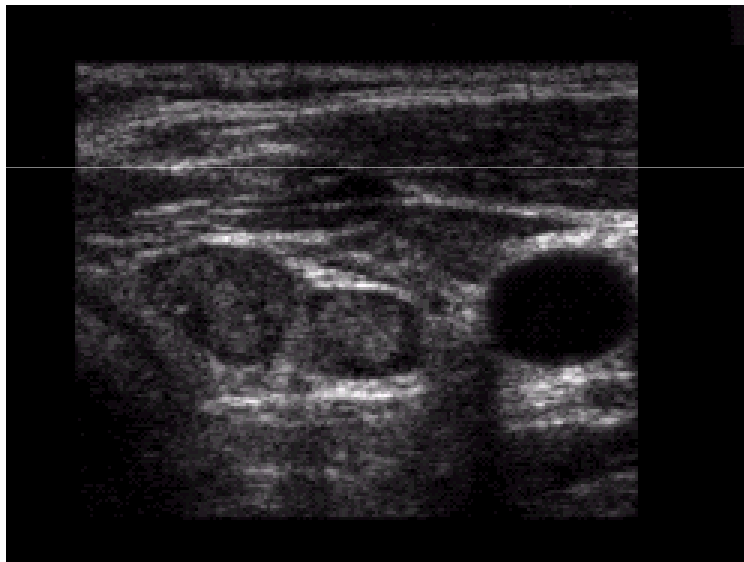
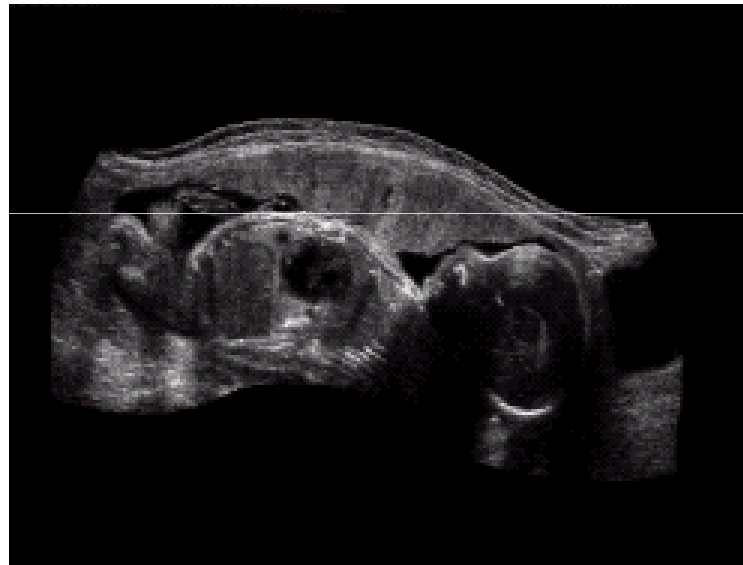


**FIGURE 1.18** Images of the Crab Pulsar (in the center of images) covering the electromagnetic spectrum. (Courtesy of NASA.)

**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

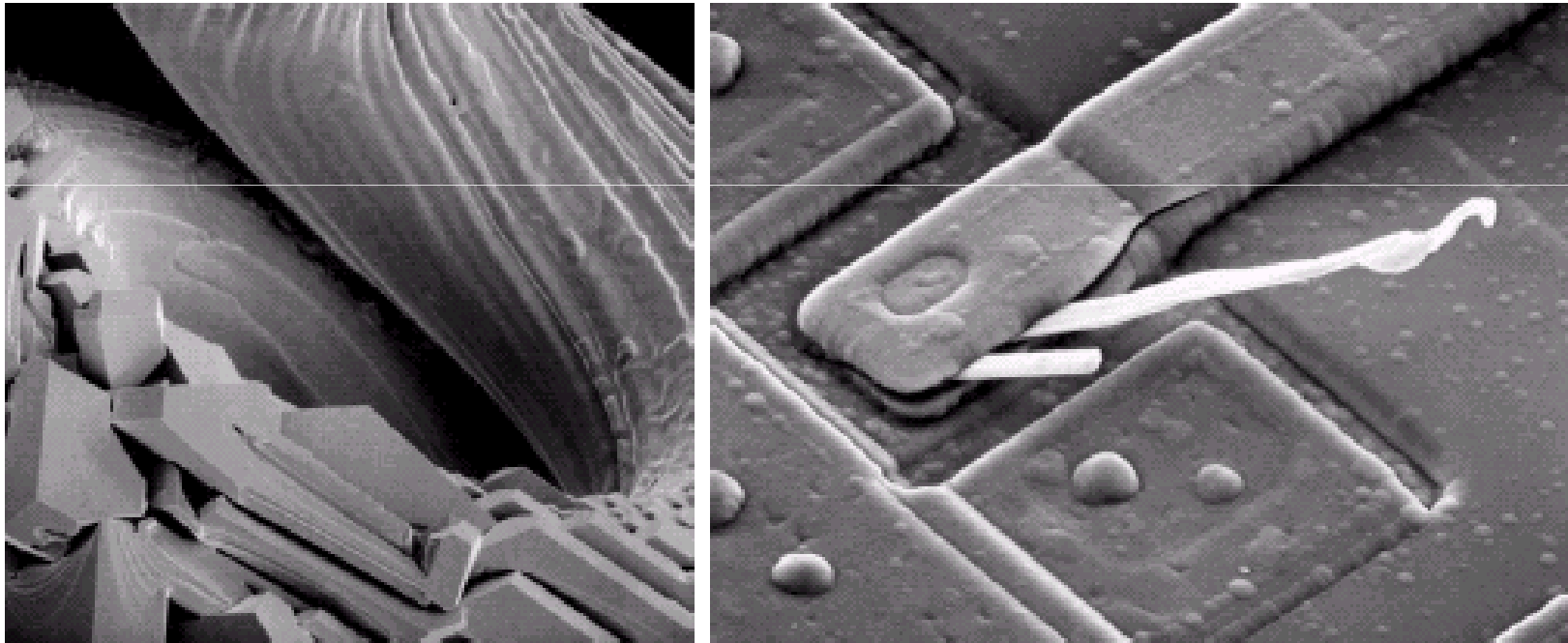


a	b
c	d

**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

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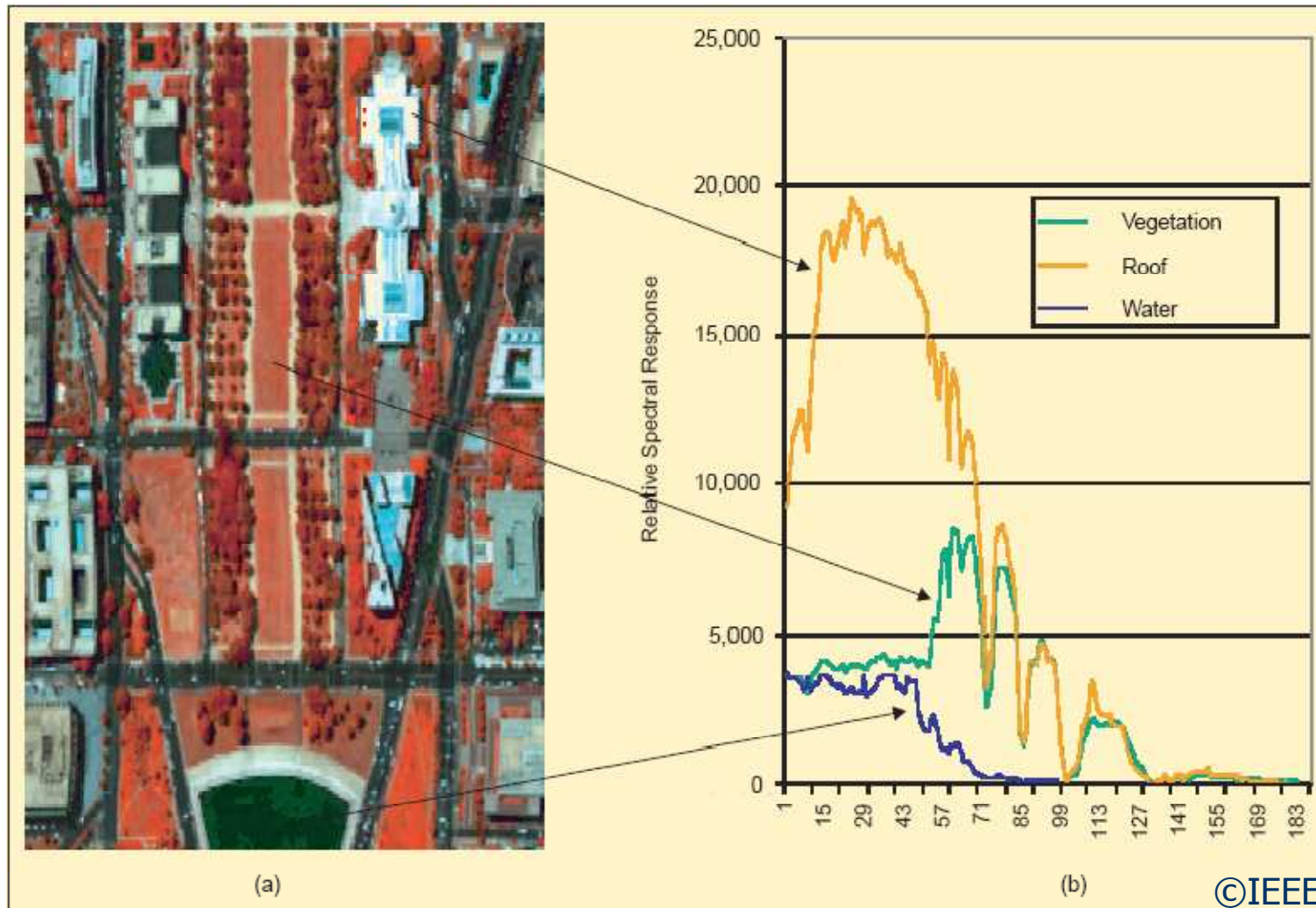


a b

**FIGURE 1.21** (a)  $250\times$  SEM image of a tungsten filament following thermal failure. (b)  $2500\times$  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  $\mu\text{m}$ . This type of data display is referred to as a display in spectral space.

# Image enhancement

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- 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

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- First, we will consider **point processing** where enhancement at any point depends only on the image value at that point.

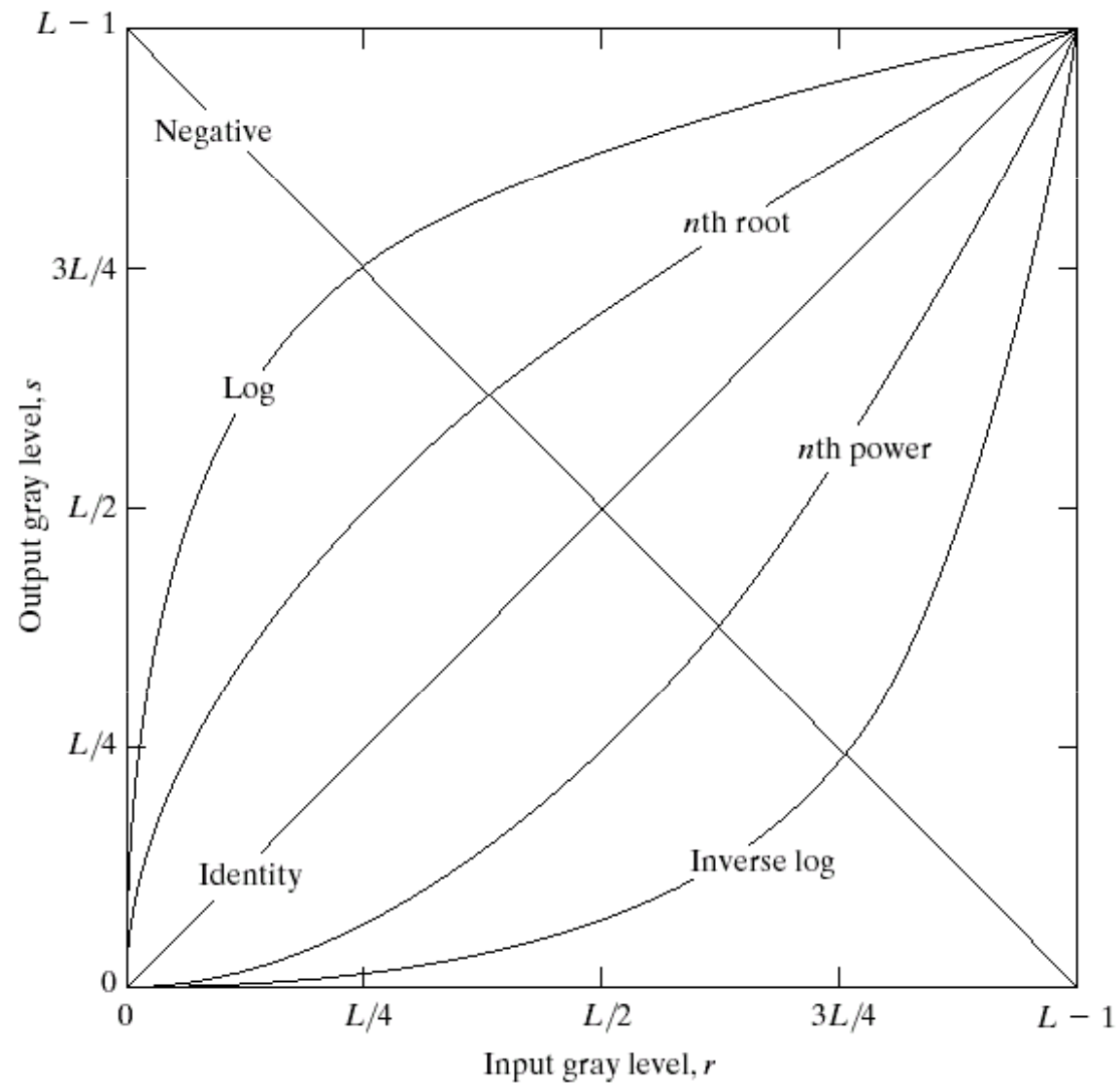
- For gray level images, we will use a **transformation function** of the form

$$s = T(r)$$

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

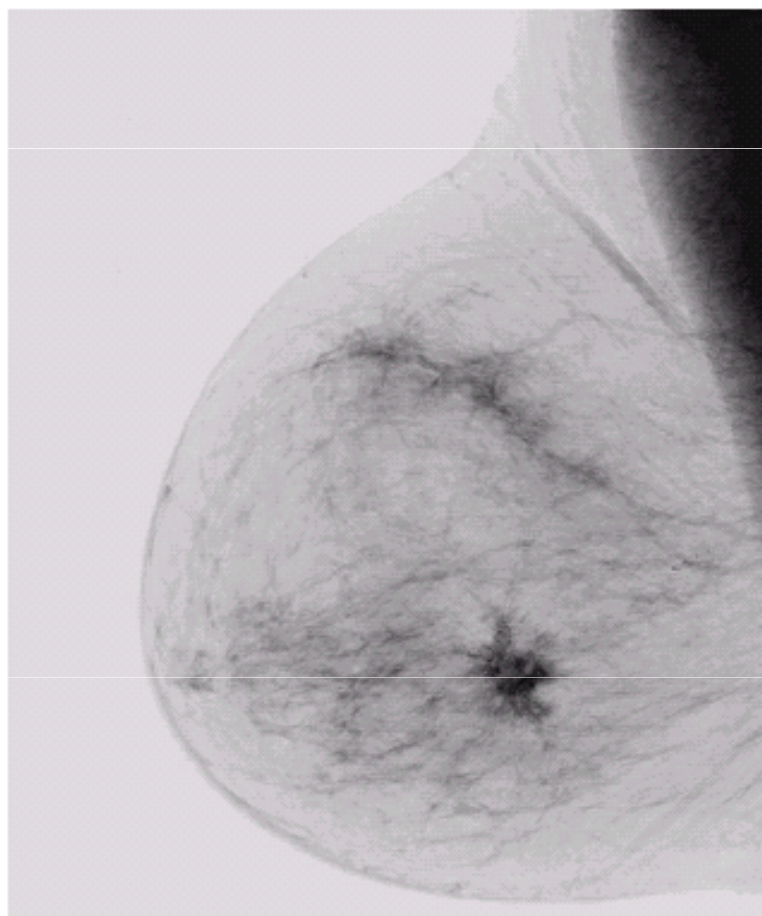
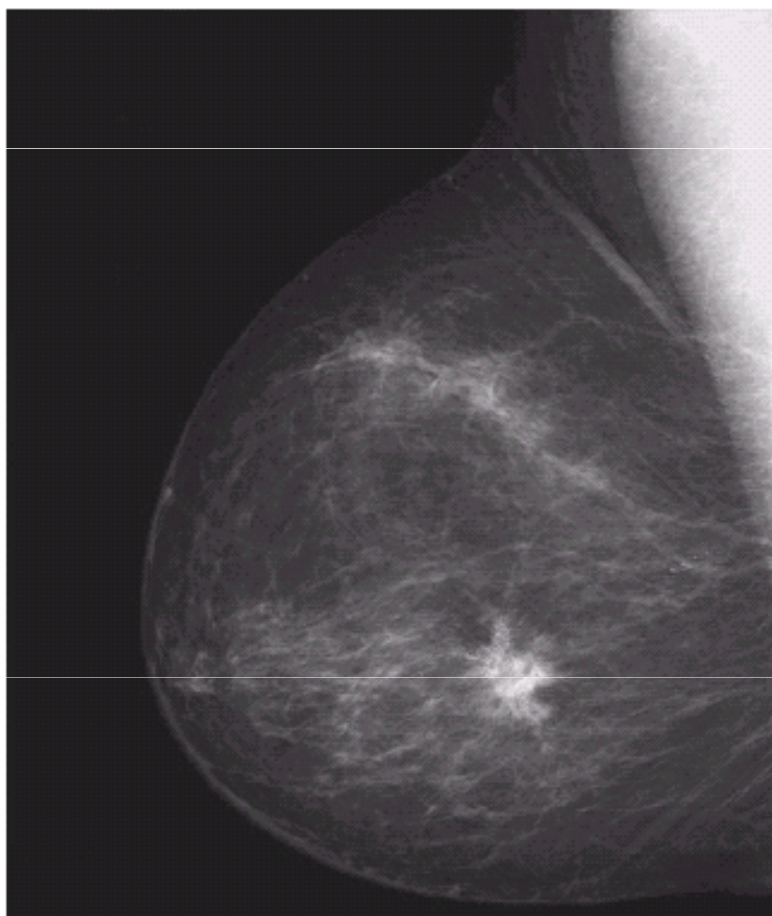
# Image enhancement

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



# Image enhancement

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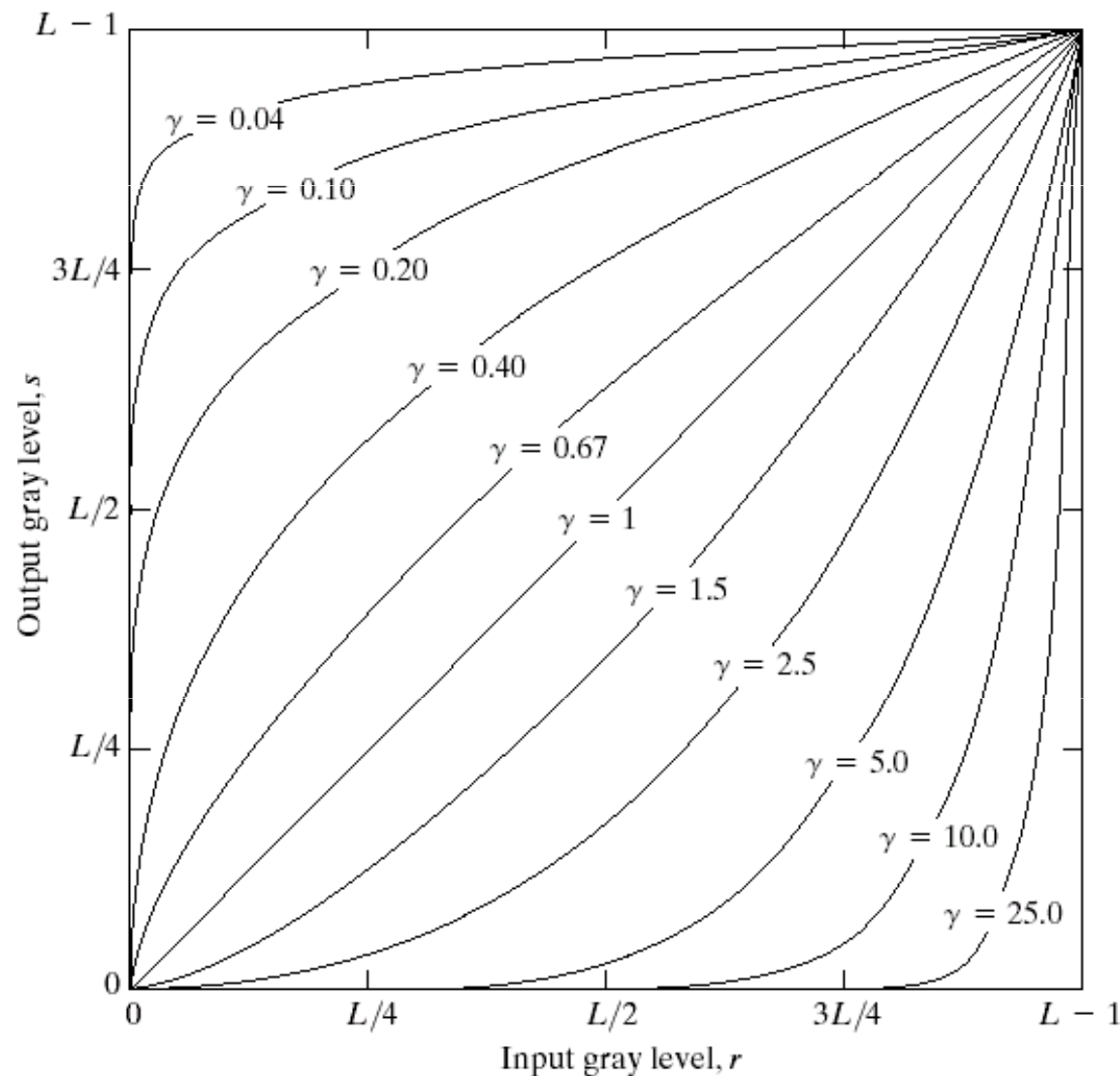


a b

## FIGURE 3.4

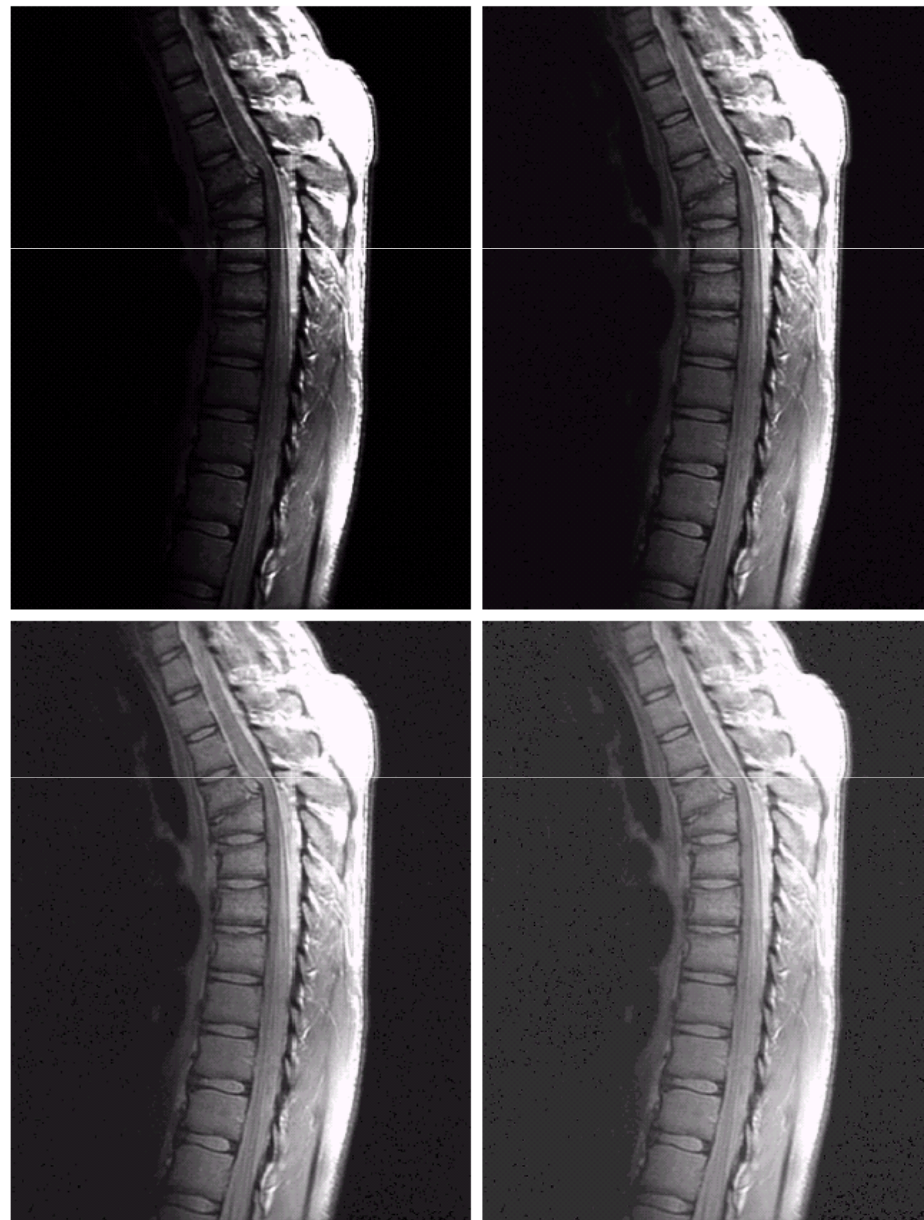
(a) Original digital mammogram.  
(b) Negative image obtained using the negative transformation in Eq. (3.2-1).  
(Courtesy of G.E. Medical Systems.)

# Image enhancement



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

# Image enhancement



a	b
c	d

**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

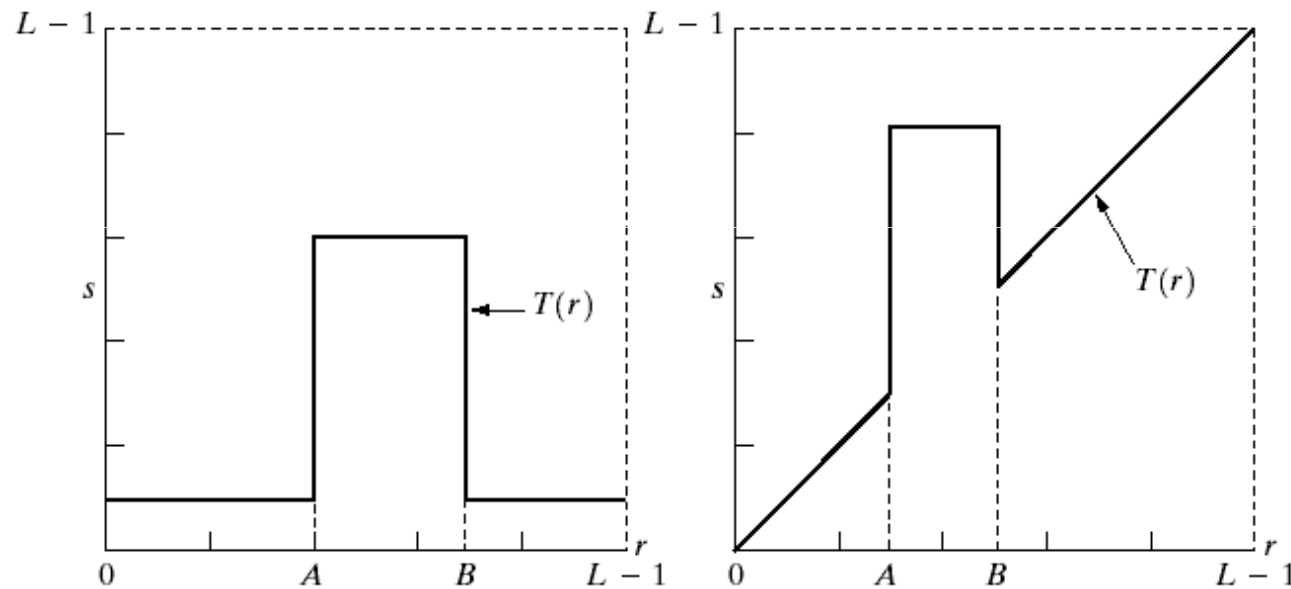
a b  
c d

**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



a	b
c	d

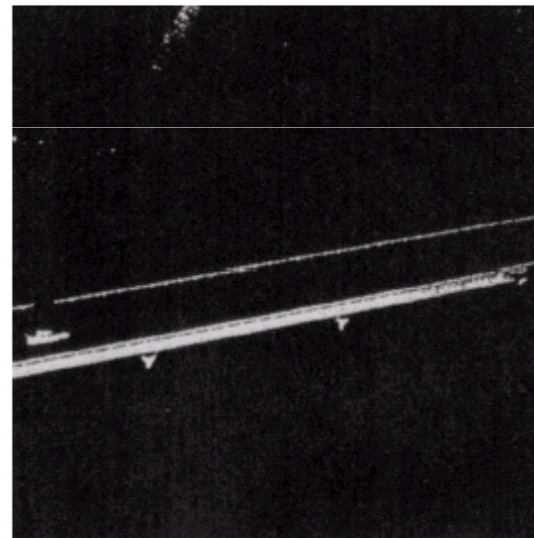
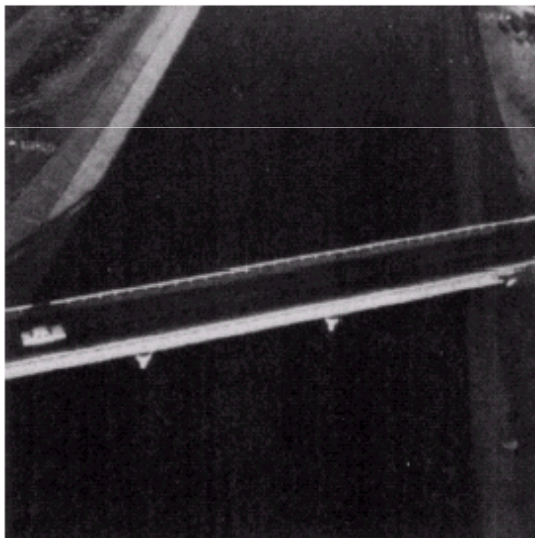
**FIGURE 3.11**

(a) This transformation highlights range  $[A, B]$  of gray levels and reduces all others to a constant level.

(b) This transformation highlights range  $[A, B]$  but preserves all other levels.

(c) An image.

(d) Result of using the transformation in (a).



# Image enhancement

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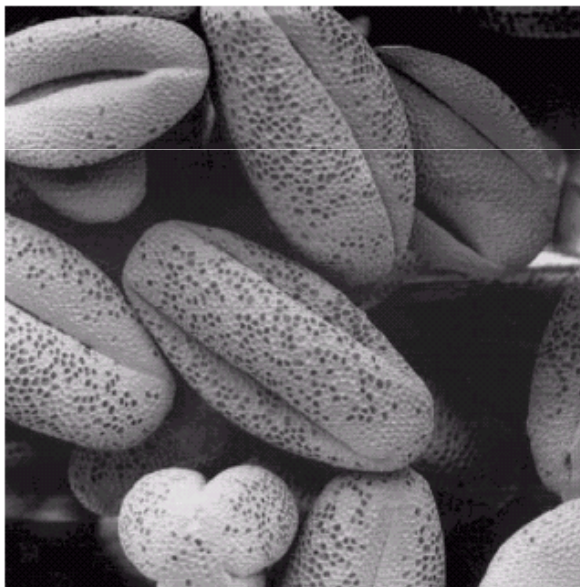
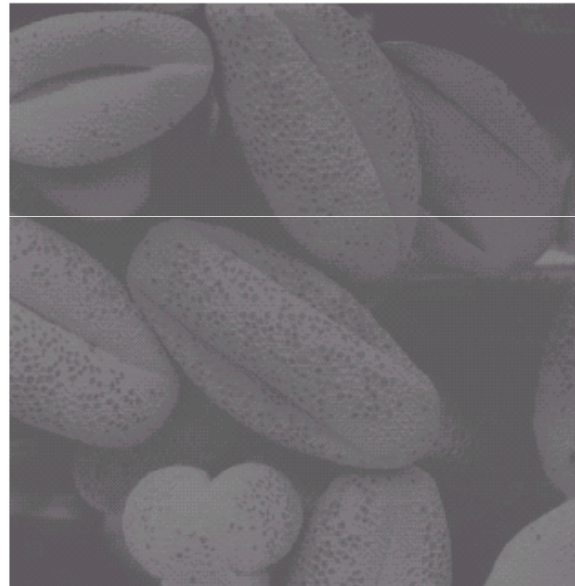
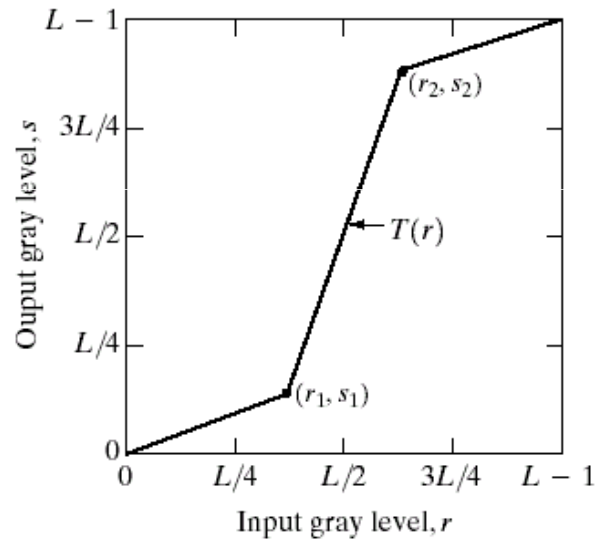
- Contrast stretching:

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

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



# Image enhancement



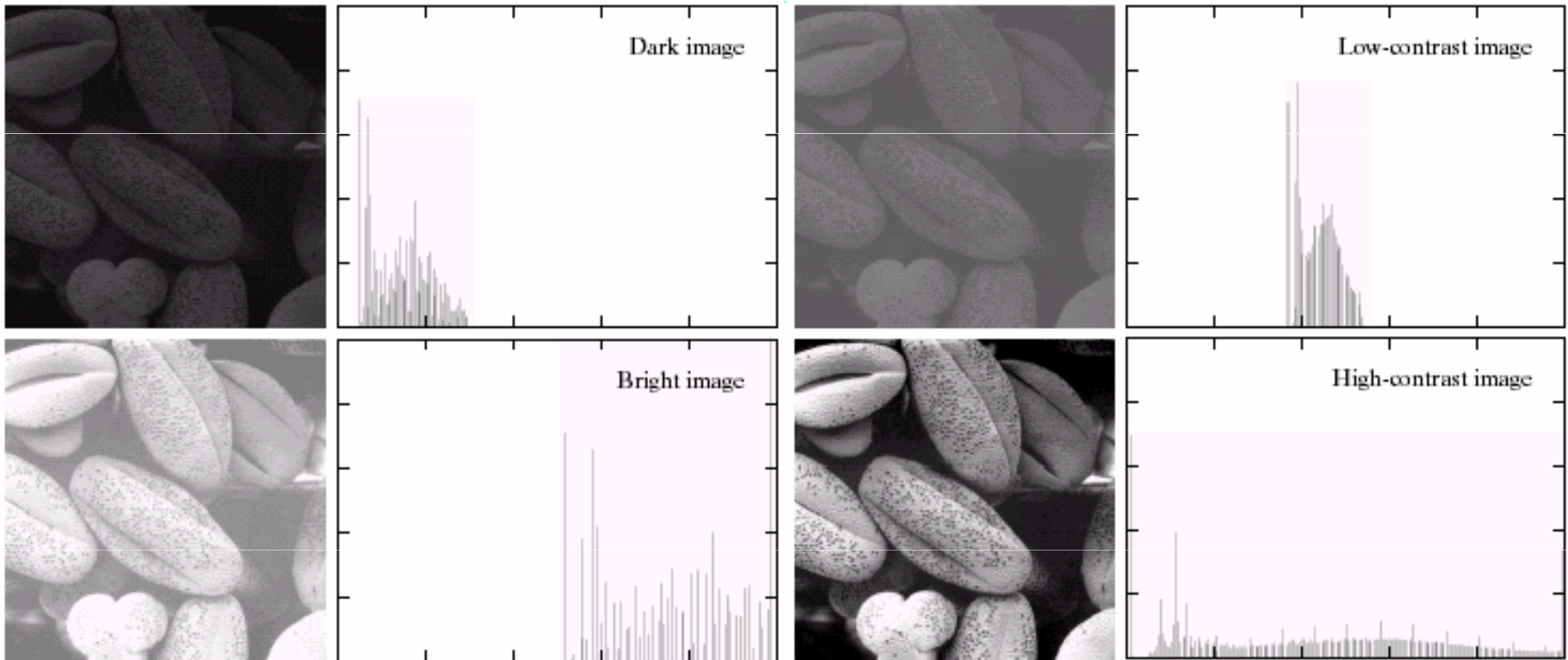
a b  
c d

**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

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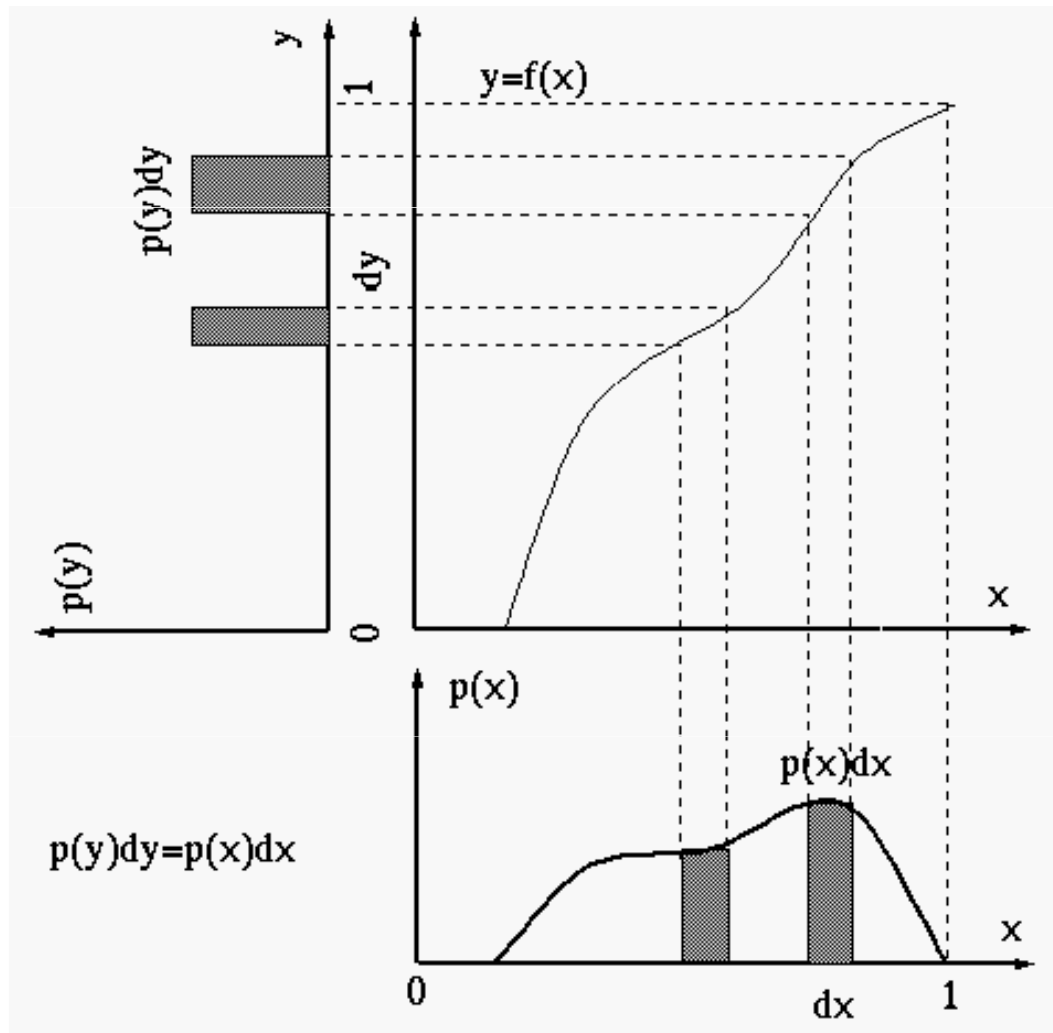


# Histogram processing

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

$$dy = p(x)dx$$

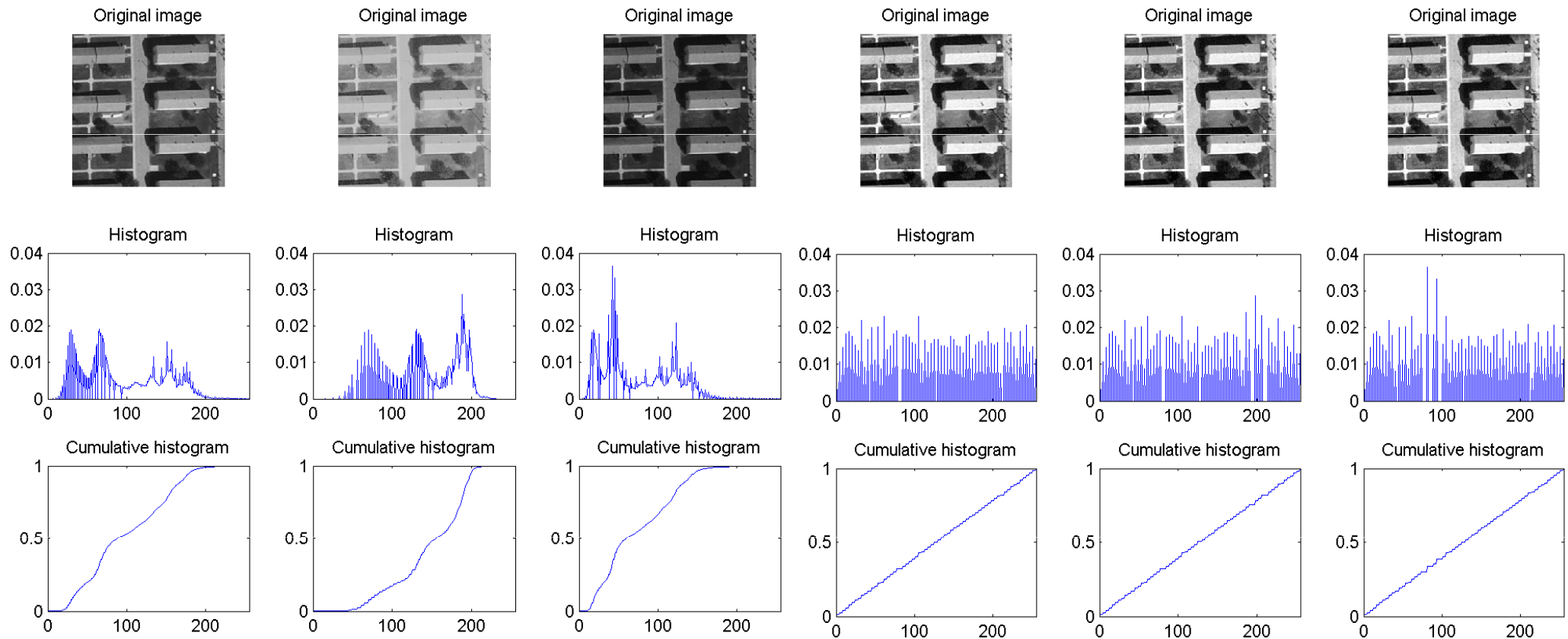
$$\frac{dy}{dx} = p(x)$$

$$y = \int_0^x p(u)du = F(x) - F(0) = F(x)$$

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

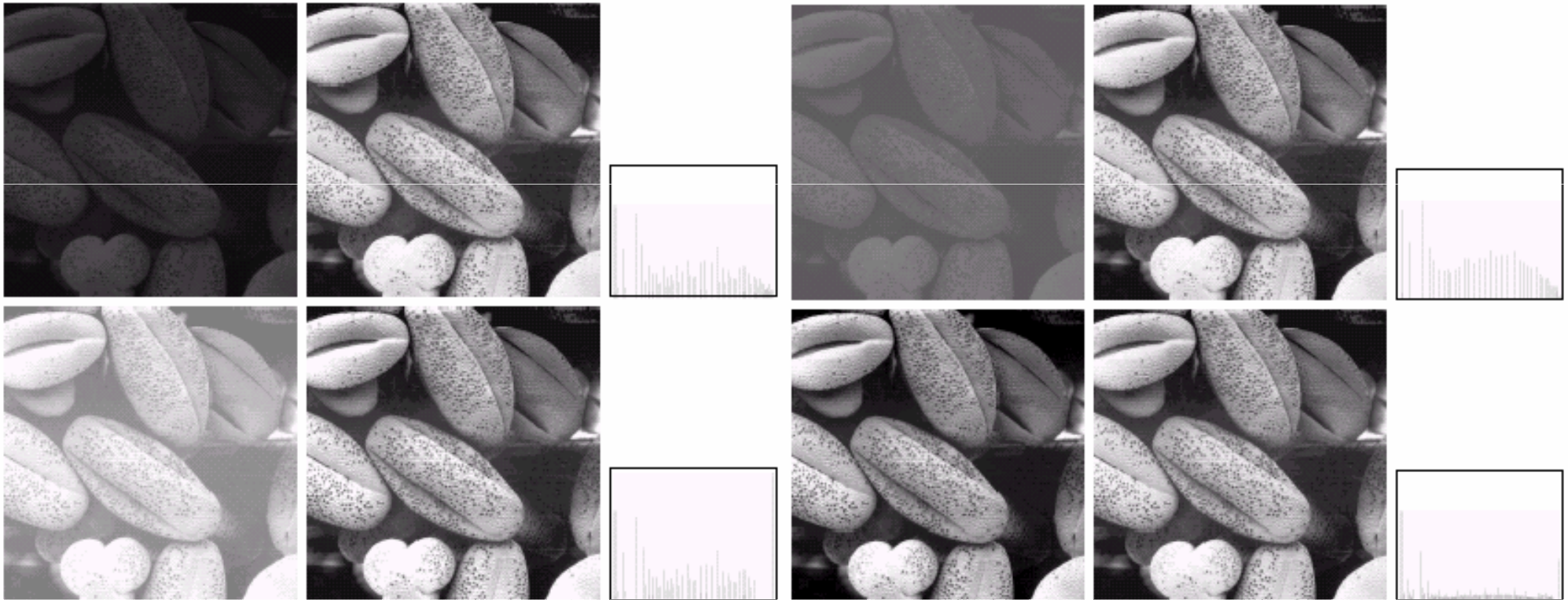
[http://fourier.eng.hmc.edu/e161/lectures/contrast\\_transform/node3.html](http://fourier.eng.hmc.edu/e161/lectures/contrast_transform/node3.html)

# Histogram equalization

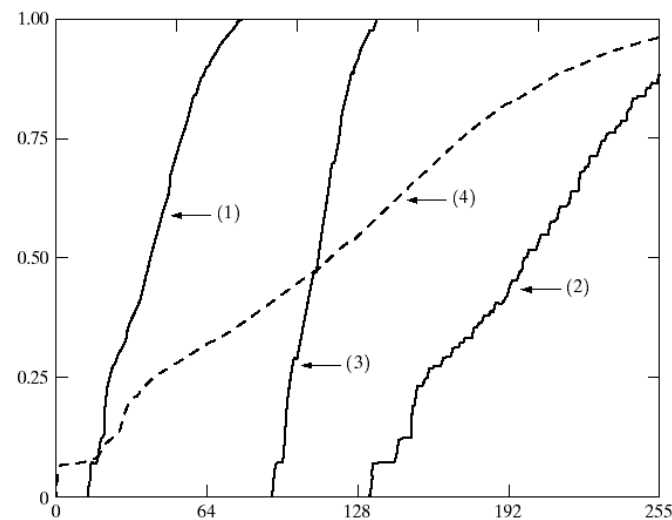




# Histogram equalization



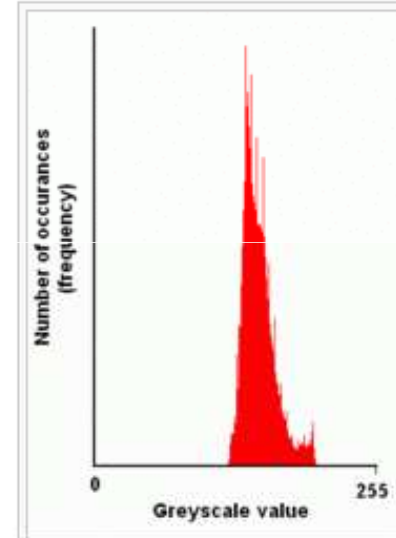
**FIGURE 3.18**  
Transformation functions (1) through (4) were obtained from the histograms of the images in Fig. 3.17(a), using Eq. (3.3-8).



# Histogram equalization



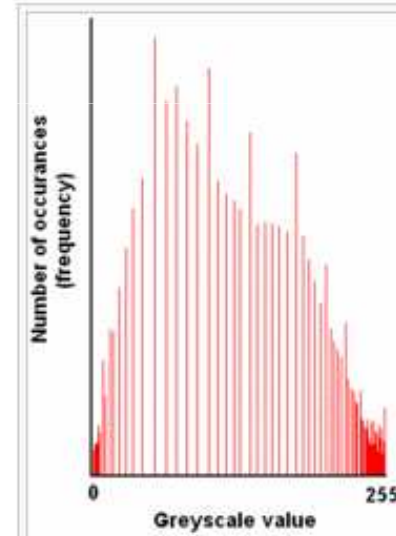
An unequalized image



Corresponding histogram



Same image after histogram equalization



Corresponding histogram

Adapted from Wikipedia



# Histogram equalization

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Original RGB image



Histogram equalization of each individual band/channel

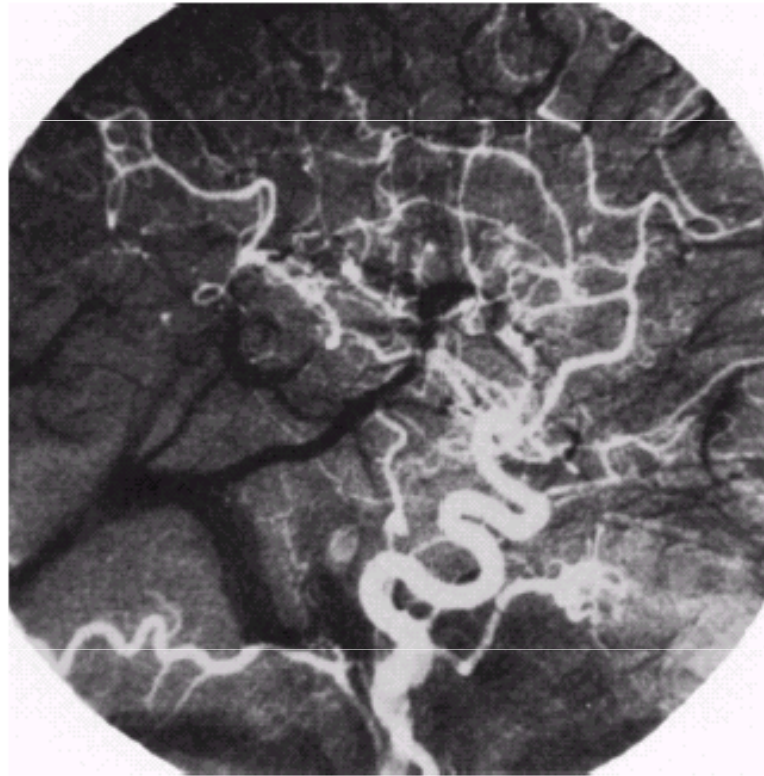
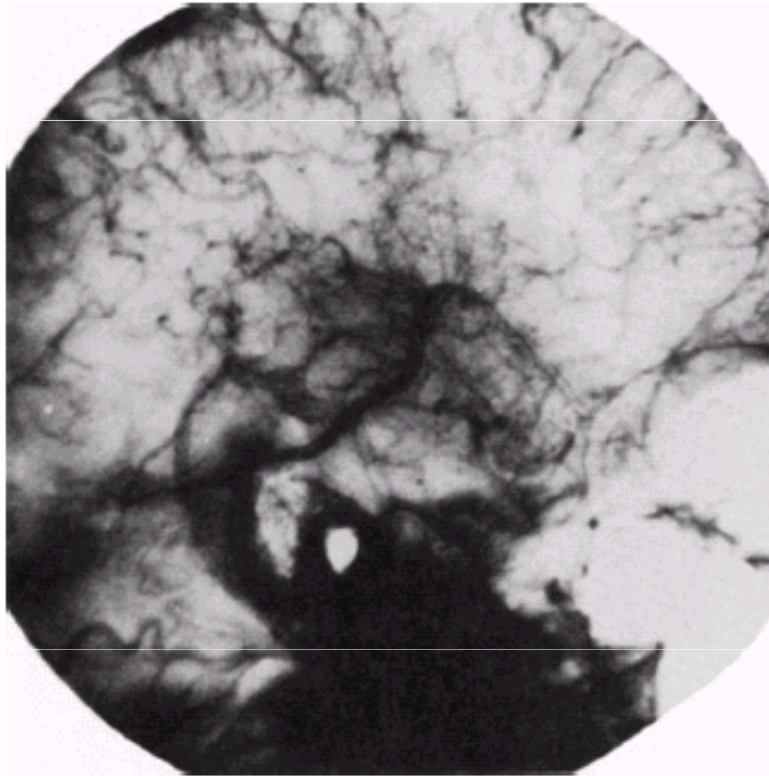


Histogram stretching by removing 2% percentile from each individual band/channel



# Enhancement using arithmetic operations

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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.

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# Image formats

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- 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

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- 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/Graphics_file_format_summary)

[http://en.wikipedia.org/wiki/Comparison of graphics file formats](http://en.wikipedia.org/wiki/Comparison_of_graphics_file_formats)