Image Enhancement

Image enhancement aims to process an image so that the output image is "more suitable" than the original. It is used to solve some computer imaging problems, or to improve "image quality". Image enhancement techniques include smoothing, sharpening, highlighting features, or normalizing illumination for display and/or analysis.

Image Enhancement Approaches

Image enhancement approaches are classified into two categories:

- *Spatial domain methods*: are based on direct manipulation of pixels in an image.
- *Frequency domain methods*: are based on modifying the Fourier transform of an image.

Image Enhancement in the Spatial Domain

The term *spatial domain* refers to the image plane itself, i.e. the total number of pixels composing an image. To enhance an image in the spatial domain we transform an image by changing pixel values or moving them around. A spatial domain process is denoted by the expression:

$$s = T(r)$$

where r is the input image, s is the processed image, and $\boldsymbol{T}$ is an operator on r . The operator $\boldsymbol{T}$ is applied at each location (x, y) in r to yield the output, s, at that location.

Enhancement using basic gray level transformations

Basic gray level transformation functions can be divided into:

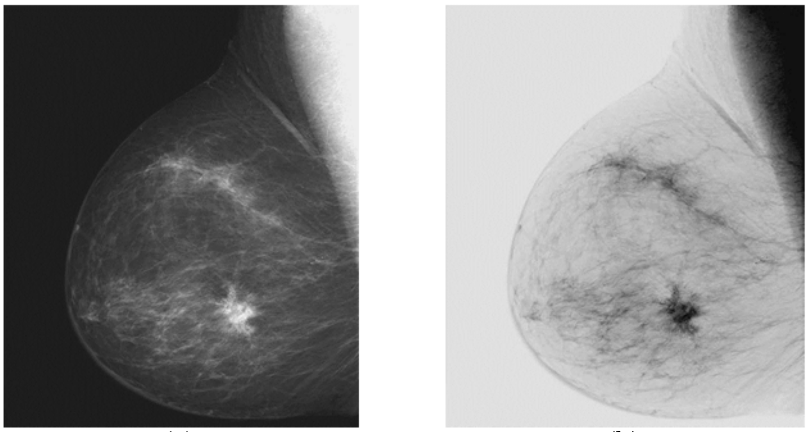
- Linear: e.g. image negatives and piecewise-linear transformation
- Non-linear: e.g. logarithm and power-law transformations

Image negatives

The negative of an image with gray levels in the range [0, L-1] is obtained by using the following expression

$$s = L - 1 - r$$

This type of processing is useful for enhancing white or gray detail embedded in dark regions of an image, especially when the black areas are dominant in size. An example of using negative transformation is analyzing digital mammograms as shown in the figure below.
Note how much easier it is to analyze the breast tissue in the negative image.



(a) (b)

Figure 4.1 (a) Original digital mammogram. (b) Negative image obtained by negative transformation

Piecewise-linear transformation

The form of piecewise linear functions can be arbitrarily complex. Some important transformations can be formulated only as piecewise functions, for example thresholding:

For any 0 < t < 255 the threshold transform Thr_t can be defined as:

$$s = Thr_t(r) = \begin{cases} 0 & if\ r < t \\ r & otherwise \end{cases}$$

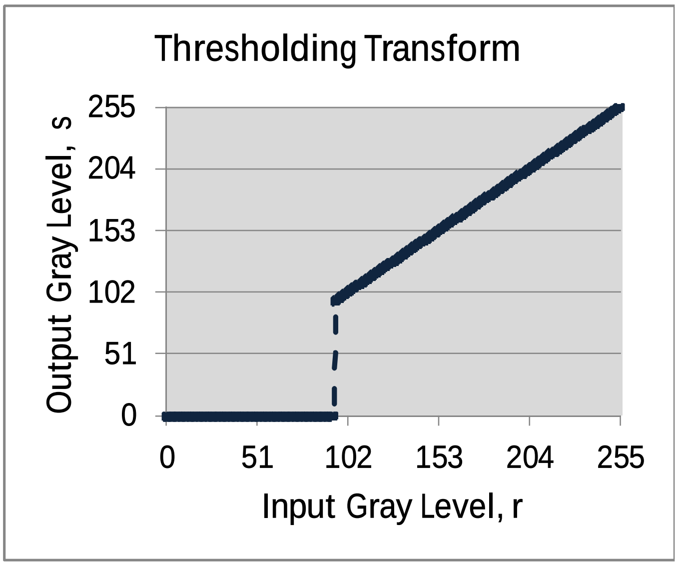


Figure 4.2 Form of thresholding transform

The figure below shows an example of thresholding an image by 80.

(a) Original image (b) Result of thresholding

Figure 4.3 Thresholding by 80

Thresholding has another form used to generate binary images from the gray-scale images, i.e.:

$$s = Thr_t(r) = \begin{cases} 0 & if\ r < t \\ 255 & otherwise \end{cases}$$

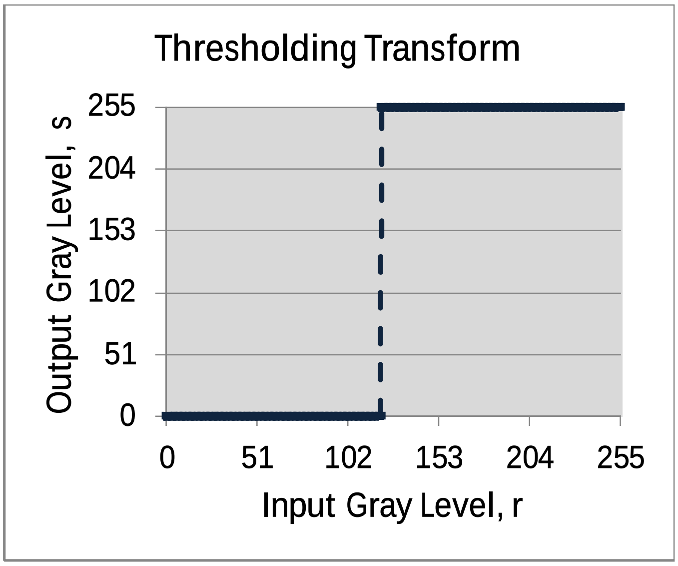
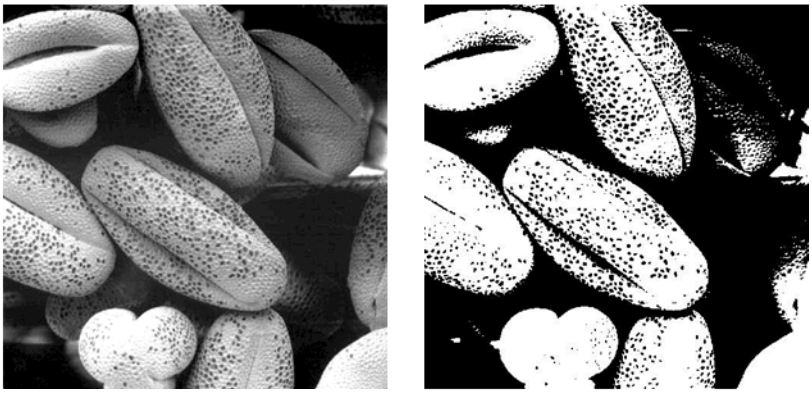


Figure 4.4 Form of thresholding transform to produce binary images

The figure below shows a gray-scale image and its binary image resulted from thresholding the original by 120:



(a) (b)

Figure 4.5 Thresholding. (a) Gray-scale image. (b) Result of thresholding (a) by 120

Another more complex piecewise linear function can be defined as:

$$s = \begin{cases} 2 * r & if \ \ r \leq 110 \\ r & if \ 110 < r \leq 200 \\ 255 & if \ r > 200 \end{cases}$$

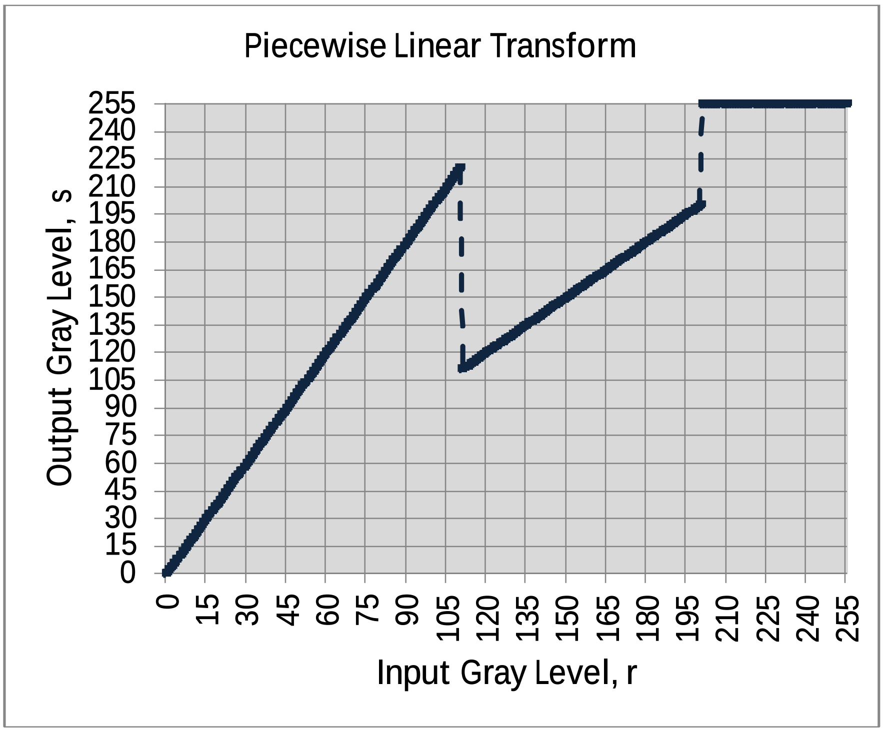


Figure 4.6 Form of previous piecewise linear transform

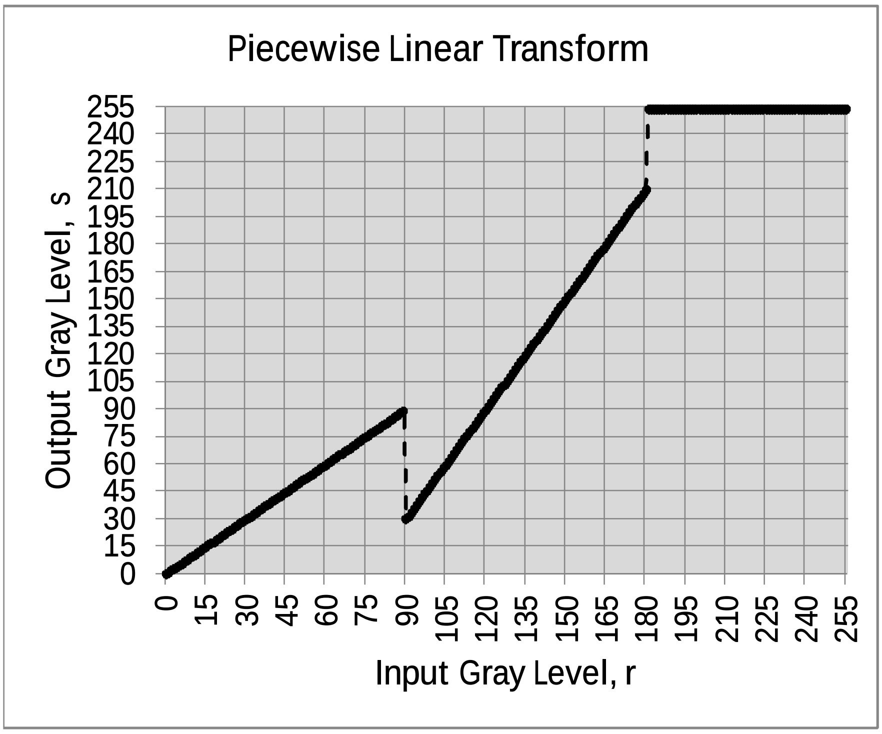
By applying this transform on the original image in Figure 4.3(a) we get the following output image:

Figure 4.7 Result of thresholding

Piecewise linear functions are commonly used for **contrast enhancement** and **gray-level slicing** as we will see in the next lecture.

Example:

For the following piecewise linear chart determine the equation of the corresponding grey-level transforms:



Solution

We use the straight line formula to compute the equation of each line segment using two points.

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1}(x - x_1)$$

Points of line segment 1:
(0,0) , (89,89)

$$y - 0 = \frac{89 - 0}{89 - 0}(x - 0)$$

$$y = x \qquad if\ x < 90$$

Points of line segment 2:
(90,30) , (180,210)

$$y - 30 = \frac{210 - 30}{180 - 90}(x - 90)$$

$$y = 2x - 150 \qquad if\ \ 90 \le x \le 180$$

Points of line segment 3:
(181,255),(255,255)

$$y - 255 = \frac{255 - 255}{255 - 181}(x - 181)$$

$$y = 255 \qquad if\ x > 180$$

The piecewise linear function is:

$$s = \begin{cases} r & if\ \ r < 90 \\ 2r - 150 & if\ 90 \le r \le 180 \\ 255 & if\ r > 180 \end{cases}$$

Log transformation

The general form of the log transformation is

$$s = c * \log(1 + r)$$

where c is a constant, and it is assumed that $r \geq 0$. This transformation is used to expand the values of dark pixels in an image while compressing the higher-level values as shown in the figure below.

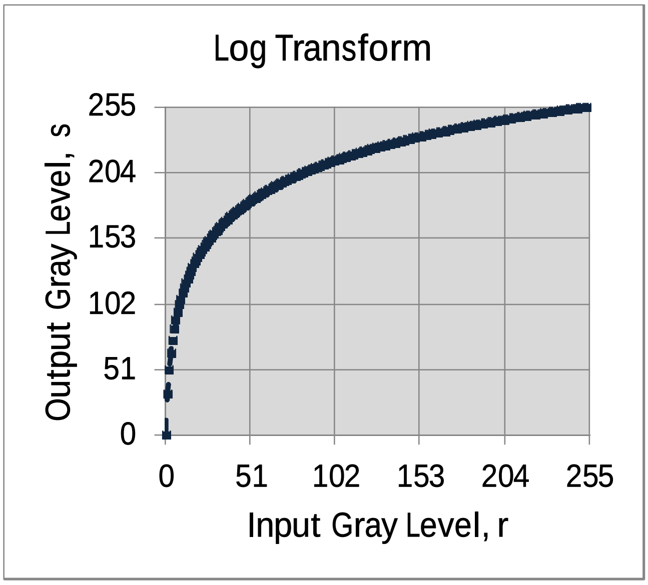
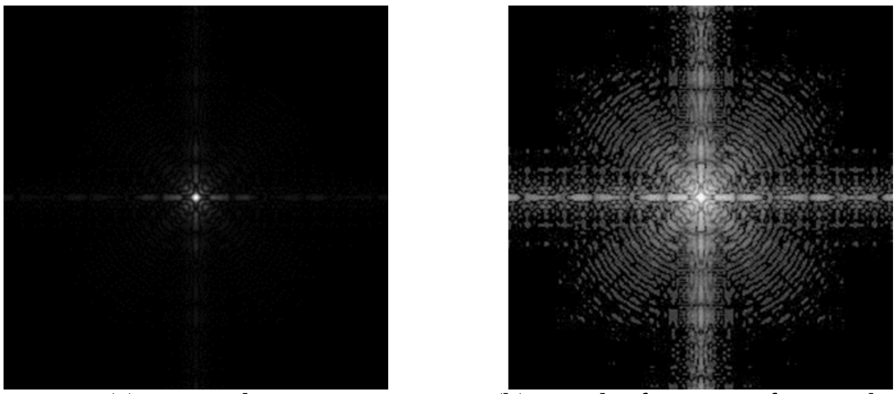


Figure 4.8 Form of Log transform

The figure below shows an example of applying Log transform.



(a) Original image (b) Result of Log transform with $c = 1$

Figure 4.9 Applying log transformation

Note the wealth of detail visible in transformed image in comparison with the original.

Power-law transformation

Power-law transformations have the basic form:

$$s = c * r^y$$

where c and y are positive constants. The power y is known as *gamma*, hence this transform is also called *Gamma transformation*. The figure below shows the form of a power-law transform with different gamma (y) values.

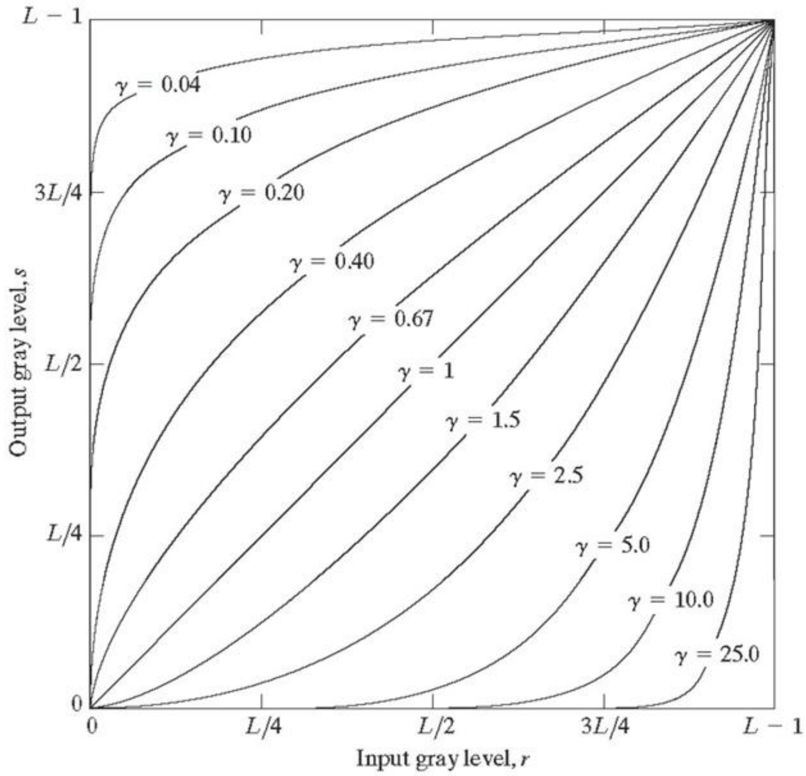


Figure 4.10 Form of power-law transform with various gamma values (c = 1 in all cases)

Power-law transformations are useful for contrast enhancement. The next figure shows the use of power-law transform with gamma values less than 1 to enhance a dark image.

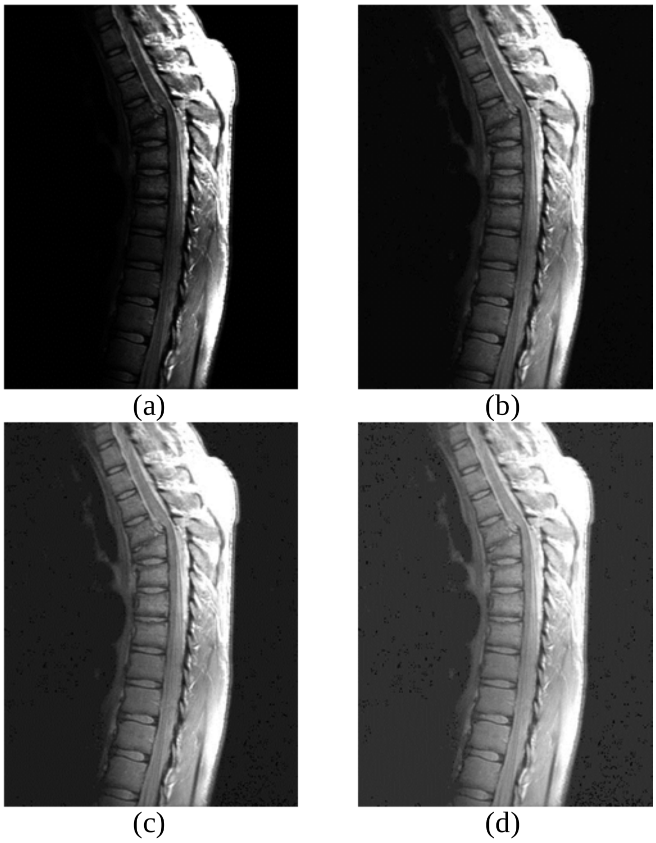


Figure 4.11 (a) Original MRI image of a human spine. (b)-(d) Results of applying power-law transformation with c = 1 and y = 0.6,0.4, and 0.3, respectively.

We note that, as gamma decreased from 0.6 to 0.4, more detail became visible. A further decrease of gamma to 0.3 enhanced a little more detail in the background, but began to reduce contrast ("washed-out" image).

The next figure shows another example of power-law transform with gamma values greater than 1, used to enhance a bright image.

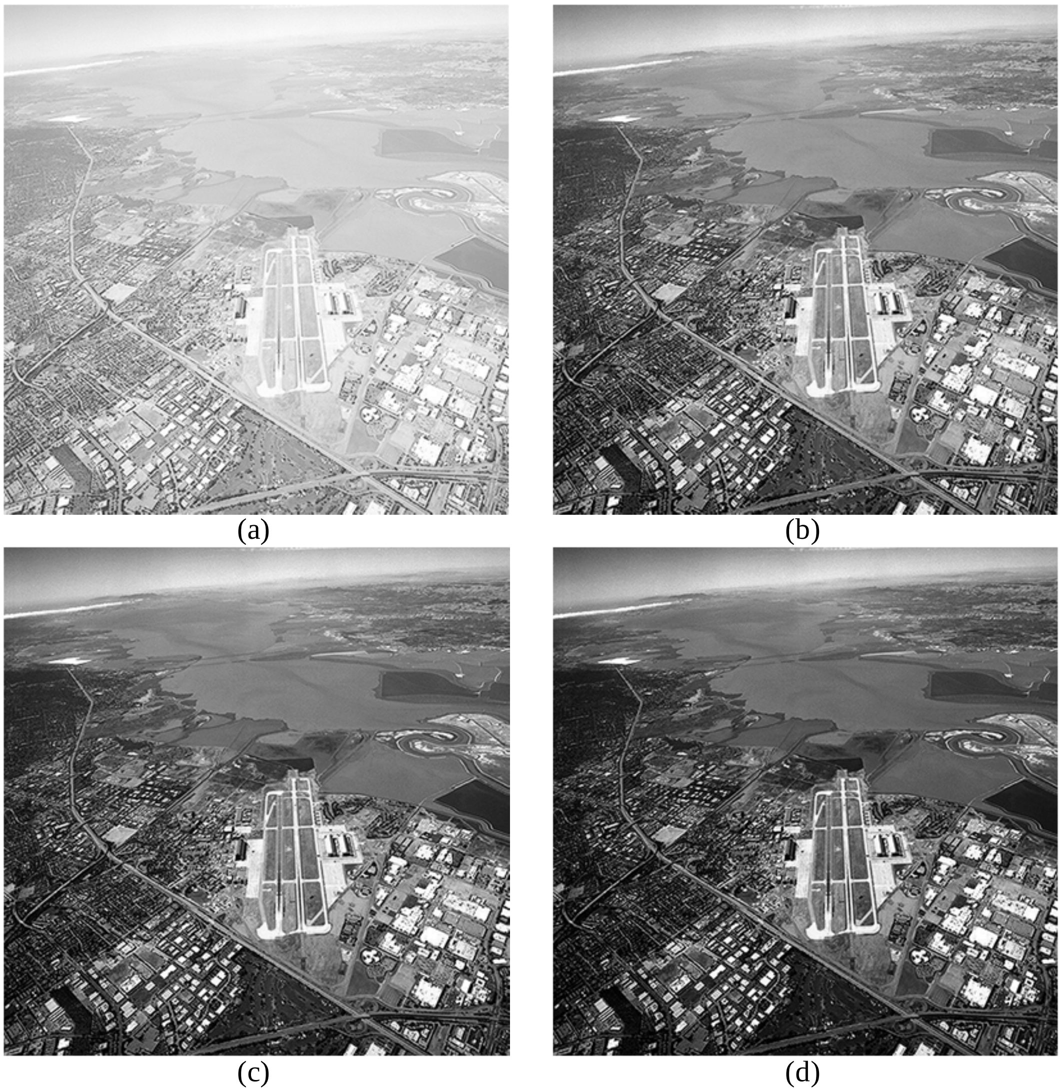


Figure 4.12 (a) Original bright image. (b)-(d) Results of applying power-law transformation with c = 1 and y = 3, 4, and 5, respectively.

We note that, suitable results were obtained with gamma values of 3.0 and 4.0. The result obtained with y = 5.0 has areas that are too dark, in which some detail is lost.

From the two examples, we note that:

- Dark areas become brighter and very bright areas become slightly darker.
- Faint (bright) images can be improved with *y* >1, and dark images benefit from using *y* <1.

Image Dynamic range, Contrast and Brightness

The *dynamic range* of an image is the exact subset of gray values {0,1,…,L-1} that are present in the image. The image histogram gives a clear indication on its dynamic range.

Image contrast is a combination of the range of intensity values effectively used within a given image and the difference between the image's maximum and minimum pixel values.

- When the dynamic range of an image is concentrated on the low side of the gray scale, the image will be a dark image.
- When the dynamic range of an image is biased toward the high side of the gray scale, the image will be a bright (light) image.
- An image with low contrast has a dynamic range that will be narrow and will be centered toward the middle of the gray scale. Low-contrast images tend to have a dull, washed-out gray look, and they can result from 1) poor illumination, 2) lack of dynamic range in the imaging sensor, or 3) wrong setting of lens aperture at the image capturing stage.
- When the dynamic range of an image contains a significant proportion (i.e. covers a broad range) of the gray scale, the image is said to have a high dynamic range, and the image will have a high contrast. In high-contrast images, the distribution of pixels is not too far from uniform, with very few vertical lines being much higher than the others.

The next figure illustrates a gray image shown in four basic gray-level characteristics: dark, light, low-contrast, and high-contrast. The right side of the figure shows the histograms corresponding to these images.

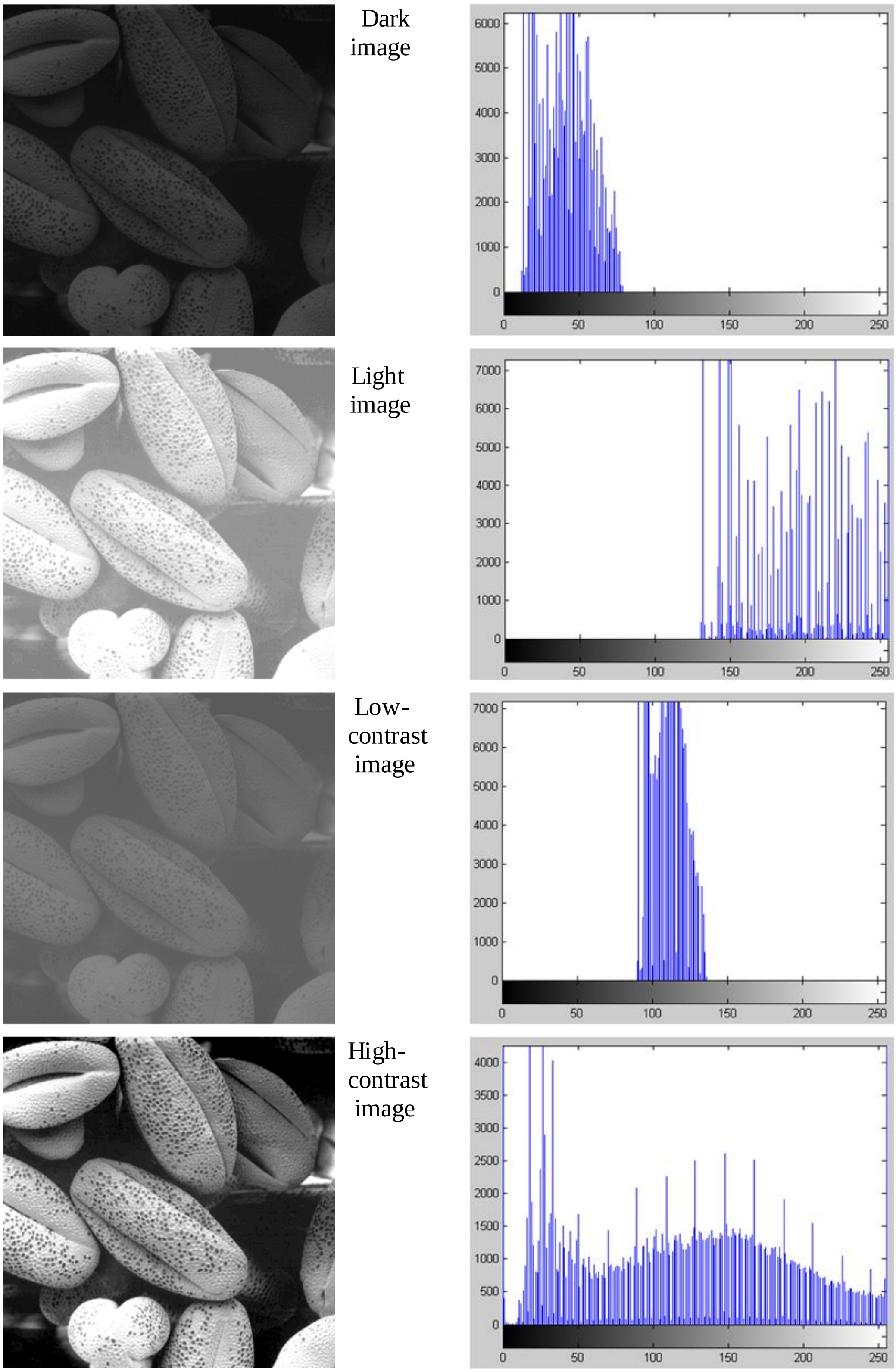


Figure 4.13 Four basic image types: dark, light, low-contrast, high-contrast, and their corresponding histograms.