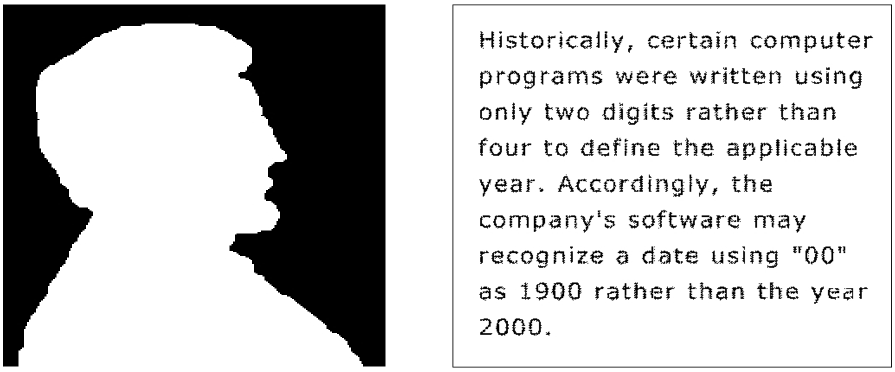
Types of Digital Images

The images types we will consider are: 1) binary, 2) gray-scale, 3) color, and 4) multispectral.

1. Binary images

Binary images are the simplest type of images and can take on two values, typically black and white, or 0 and 1. A binary image is referred to as a 1-bit image because it takes only 1 binary digit to represent each pixel. These types of images are frequently used in applications where the only information required is general shape or outline, for example optical character recognition (OCR).

Binary images are often created from the gray-scale images via a threshold operation, where every pixel above the threshold value is turned white (‘1’), and those below it are turned black (‘0’). In the figure below, we see examples of binary images.



(a) (b)

Figure 2.1 Binary images. (a) Object outline. (b) Page of text used in OCR application.

2. Gray-scale images

Gray-scale images are referred to as monochrome (one-color) images.

They contain gray-level information, no color information. The number of bits used for each pixel determines the number of different gray levels available. The typical gray-scale image contains 8bits/pixel data, which allows us to have 256 different gray levels. The figure below shows examples of gray-scale images.

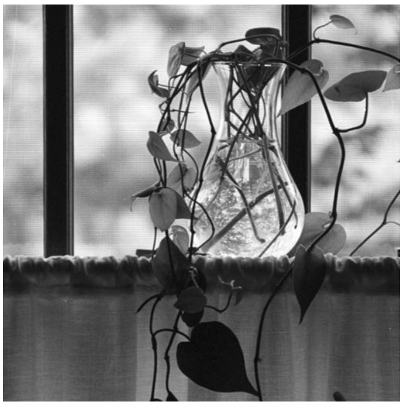



Figure 2.2 Examples of gray-scale images

In applications like medical imaging and astronomy, 12 or 16 bits/pixel images are used. These extra gray levels become useful when a small section of the image is made much larger to discern details.

3. Color images

Color images can be modeled as three-band monochrome image data, where each band of data corresponds to a different color. The actual information stored in the digital image data is the gray-level information in each spectral band.

Typical color images are represented as red, green, and blue (RGB images). Using the 8-bit monochrome standard as a model, the corresponding color image would have 24-bits/pixel (8-bits for each of the three color bands red, green, and blue). The figure below illustrates a representation of a typical RGB color image.

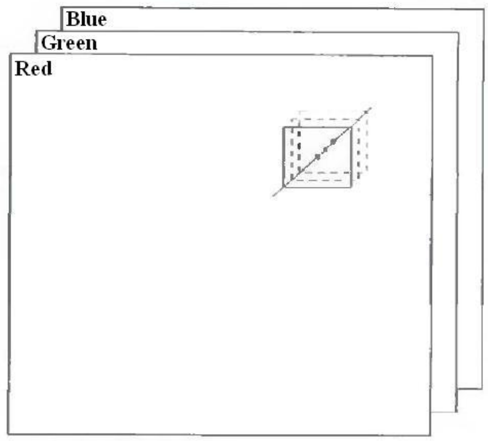


Figure 2.3 Representation of a typical RGB color image

4. Multispectral images

Multispectral images typically contain information outside the normal human perceptual range. This may include infrared, ultraviolet, X-ray, acoustic, or radar data. These are not images in the usual sense because the information represented is not directly visible by the human system. However, the information is often represented in visual form by mapping the different spectral bands to RGB components.

Digital Image File Formats

Types of image data are divided into two primary categories: bitmap and vector.

- *Bitmap images* (also called raster images) can be represented as 2-dimensional functions *f(x,y)*, where they have pixel data and the corresponding gray-level values stored in some file format.
- *Vector images* refer to methods of representing lines, curves, and shapes by storing only the key points. These key points are sufficient to define the shapes. The process of turning these into an

image is called *rendering*. After the image has been rendered, it can be thought of as being in bitmap format, where each pixel has specific values associated with it.

Most of the types of file formats fall into the category of bitmap images, for example:

- PPM (Portable Pix Map) format
- TIFF (Tagged Image File Format)
- GIF (Graphics Interchange Format)
- JPEG (Joint Photographic Experts Group) format
- BMP (Windows Bitmap)
- PNG (Portable Network Graphics)
- XWD (X Window Dump)

A simple image formation model

- In a mathematical view, a monochromatic image is a two-dimensional function, $f(x, y)$, where x and y are spatial (plane) coordinates, and the amplitude of f at any pair of coordinates (x, y) is called the *intensity* or *gray level* of the image at that point.
- The values of a monochromatic image (i.e. intensities) are said to span the *gray scale*.
- When x,y, and the amplitude value of f are all finite, discrete quantities, the image is called a *digital image*.

The function $f(x, y)$ must be nonzero and finite; that is,

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

The function *f(x, y)* is the product of two components: 1) the amount of source illumination incident on the scene *i(x, y)* and 2) the amount of illumination reflected by the objects in the scene *r(x, y)*:

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

where $0<i(x, y)<\infty$ and $0<r(x, y)<1$.

Note that the equation $0<r(x, y)<1$ indicates that reflectance is bounded by 0 (total absorption) and 1 (total reflectance).

The nature of *i(x, y)* is determined by the illumination source, and *r(x, y)* is determined by the characteristics of the imaged objects.

As mentioned earlier, we call the intensity of a monochrome image at any coordinates (x_a, y_b) the gray level (l) of the image at that point. That is,

$$l = f(x_a, y_b)$$

From the above equations, it is evident that l lies in the range

$$L_{min} \leq l \leq L_{max}$$

Where L_{min} is positive, and L_{max} is finite.

The interval $[L_{min}, L_{max}]$ is called the *gray scale*. Common practice is to shift this interval numerically to the interval [0, *L*-1], where $l = 0$ is considered black and $l = L-1$ is considered white on the gray scale. All intermediate values are shades of gray varying from black to white.

Image Sampling and Quantization

To convert the continuous function *f(x,y)* to digital form, we need to sample the function in both coordinates and in amplitude.

- Digitizing the coordinate values is called *sampling*.
- Digitizing the amplitude values is called *quantization*.

In the figure below, we show how to convert the continuous image in Figure 2.1(a) to the digital form using the sampling and quantization processes. The one-dimensional function shown in Figure 2.1(b) is a plot of amplitude (gray level) values of the continuous image along the line segment AB in Figure 2.1(a).

To sample this function, we take equally spaced samples along line AB, as shown in Figure 2.1(c). The samples are shown as small white squares superimposed on the function. The set of these discrete locations gives the sampled function.

In order to form a digital function, the gray-level values also must be converted (quantized) into discrete quantities. The right side of Figure 2.1(c) shows the gray-level scale divided into eight discrete levels, ranging from black to white. The continuous gray levels are quantized simply by assigning one of the eight discrete gray levels to each sample.

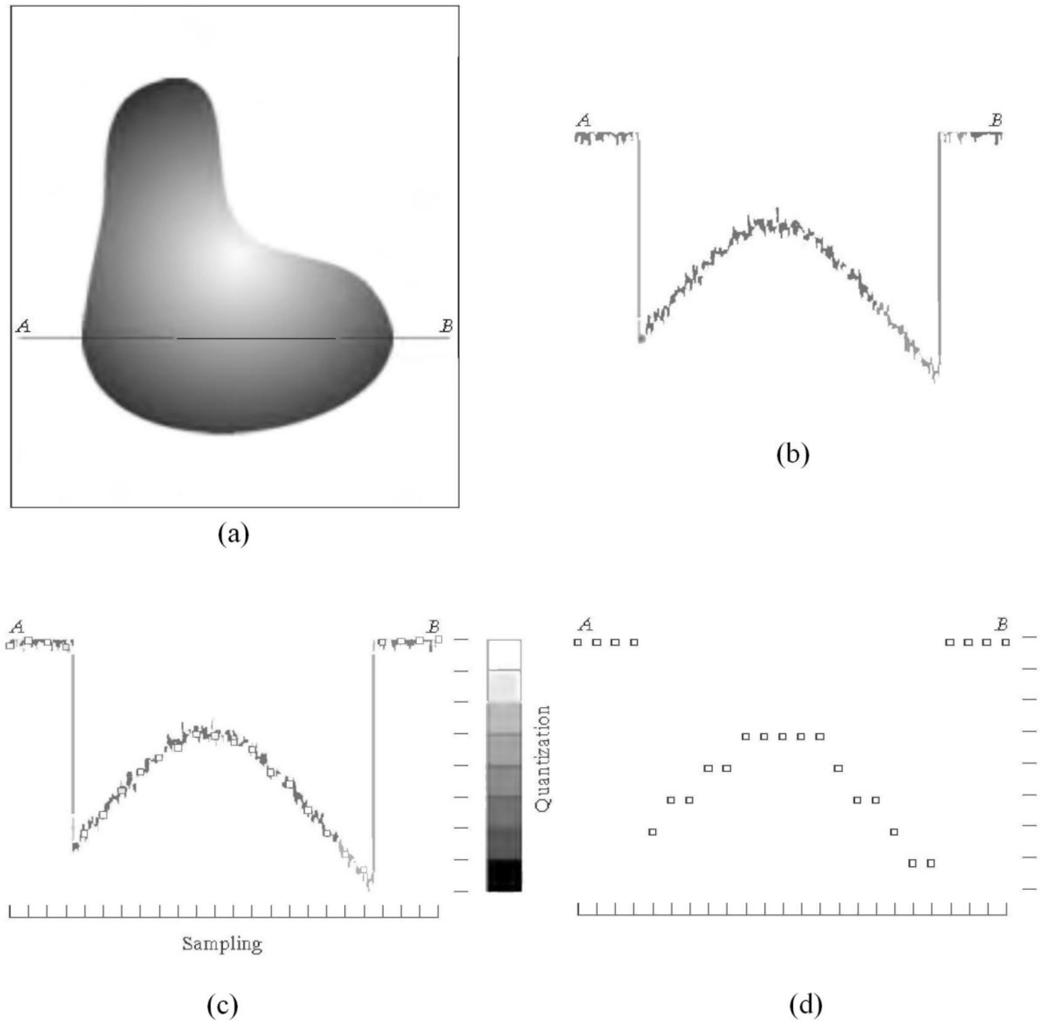


Figure 2.1 Generating a digital image. (a) Continuous image, (b) A scan line from A to B in the continuous image (c) Sampling and quantization, (d) Digital scan line.

The digital samples resulting from both sampling and quantization are shown in Figure 2.1(d). Starting at the top of the image and carrying out this procedure line by line produces a two-dimensional digital image as shown in Figure 2.3.

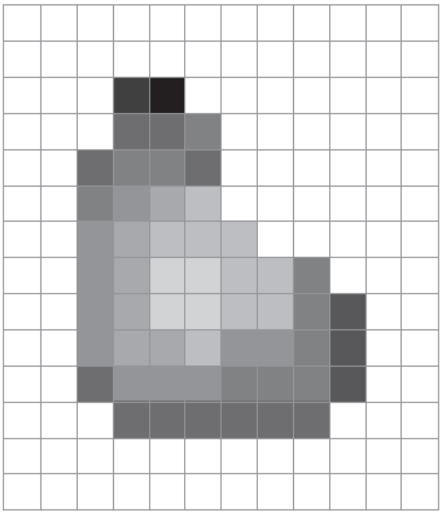


Figure 2.3 Digital image resulted from sampling and quantization

Note that:

- The number of selected values in the sampling process is known as the image *spatial resolution*. This is simply the number of pixels relative to the given image area.
- The number of selected values in the quantization process is called the *grey-level (color level) resolution*. This is expressed in terms of the number of bits allocated to the color levels.
- The quality of a digitized image depends on the resolution parameters on both processes.

Digital Image Representation

The monochrome digital image *f(x,y)* resulted from sampling and quantization has finite discrete coordinates *(x,y)* and intensities (gray levels). We shall use integer values for these discrete coordinates and gray levels. Thus, a monochrome digital image can be represented as a 2-dimensional array (matrix) that has *M* rows and *N* columns:

$$f(x,y) = \begin{pmatrix} f(1,1) & f(1,2) & \ldots\ldots & f(1,N) \\ f(2,1) & f(2,2) & \ldots\ldots & f(2,N) \\ . & . & & . \\ . & . & & . \\ . & . & & . \\ f(M,1) & f(M,2) & \ldots\ldots & f(M,N) \end{pmatrix}$$

Each element of this matrix array is called *pixel*. The spatial resolution (number of pixels) of the digital image is $M * N$. The gray level resolution (number of gray levels) L is

$$L = 2^k$$

Where k is the number of bits used to represent the gray levels of the digital image. When an image can have 2^k gray levels, we can refer to the image as a "k-bit image". For example, an image with 256 possible gray-level values is called an 8-bit image.

The gray levels are integers in the interval [0, L-1]. This interval is called the *gray scale*.

The number, b, of bits required to store a digitized image is

$$b = M * N * k$$

Example:

For an 8-bit image of size 512×512, determine its gray-scale and storage size.

Solution ∴ $k = 8$, $M = N = 512$

Number of gray levels $L = 2^k = 2^8 = 256$

The gray scale is [0 , 255]

Storage size (b) = $M * N * k$ = 512 * 512 * 8 = 2,097,152 bits

Spatial and Gray-level Resolution

Spatial resolution is the smallest discernible detail in an image. It is determined by the sampling process. The spatial resolution of a digital image reflects the amount of details that one can see in the image (i.e. the ratio of pixel "area" to the area of the image display). If an image is spatially sampled at $M \times N$ pixels, then the larger $M \times N$ the finer the observed details.

Gray-level resolution refers to the smallest discernible change in gray level. It is determined by the quantization process. As mentioned earlier, the number of gray levels is usually an integer power of 2. The most common number is 8 bits, however, 16 bits is used in some applications where enhancement of specific gray-level ranges is necessary.

Effect of reducing the spatial resolution

Decreasing spatial resolution of a digital image, within the same area, may result in what is known as *checkerboard pattern*. Also image details are lost when the spatial resolution is reduced.

To demonstrate the checkerboard pattern effect, we subsample the 1024×1024 image shown in the figure below to obtain the image of size 512×512 pixels. The 512×512 is then subampled to 256×256 image, and so on until 32×32 image. The subsampling process means deleting the appropriate number of rows and columns from the original image. The number of allowed gray levels was kept at 256 in all the images.

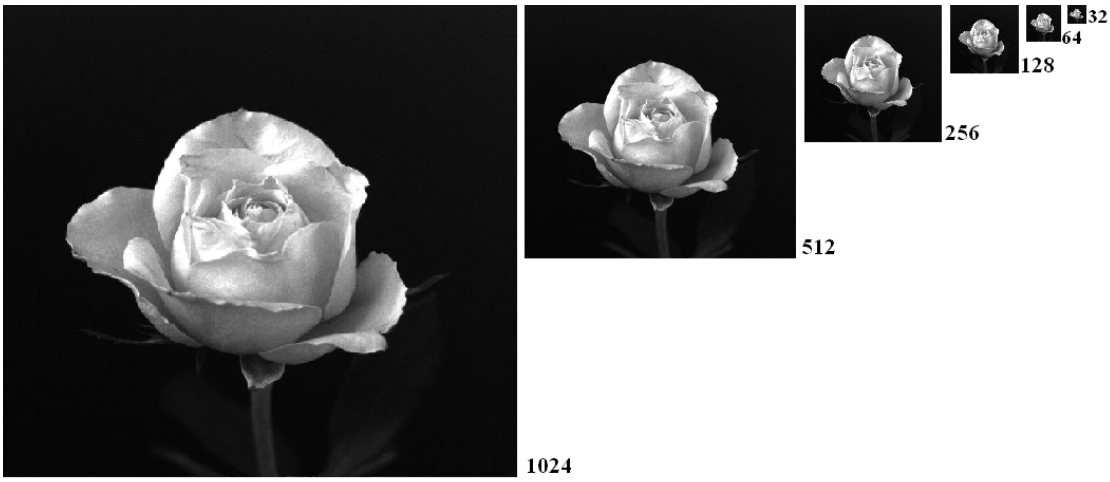


Figure 2.4 A 1024×1024, 8-bit image subsampled down to size 32×32 pixels.

To see the effects resulting from the reduction in the number of samples, we bring all the subsampled images up to size 1024×1024 by row and column pixel replication. The resulted images are shown in the figure below.

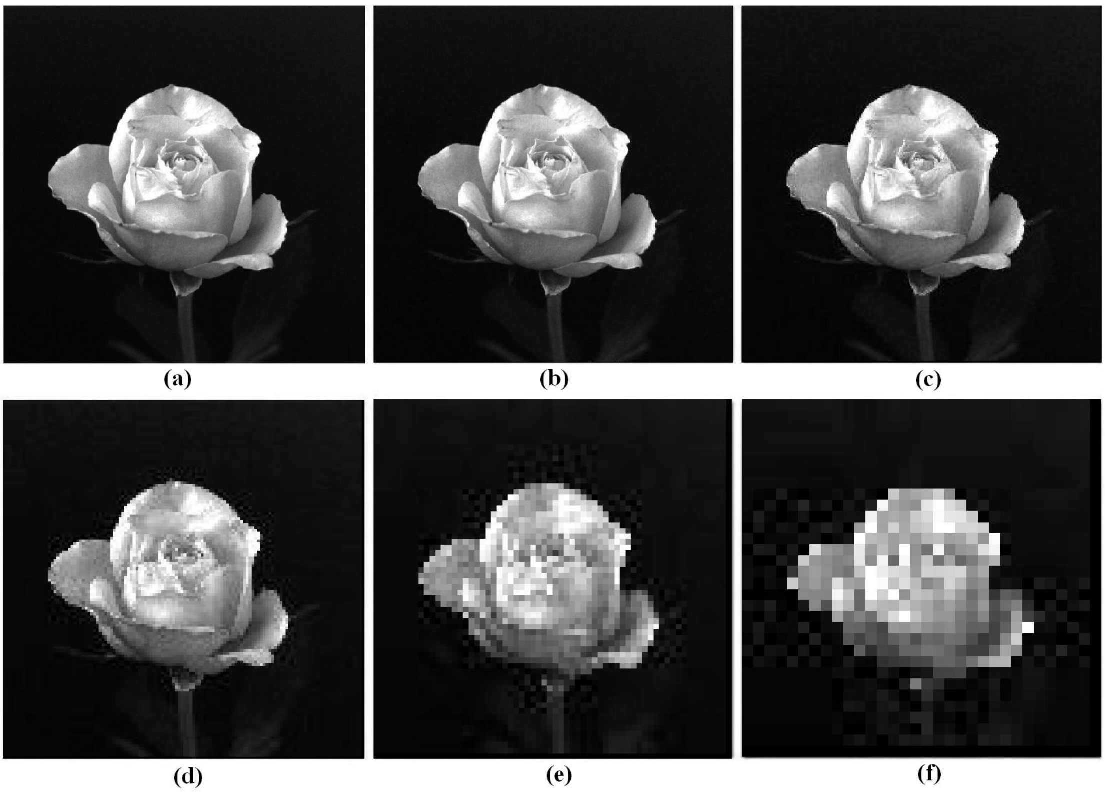


Figure 2.5 (a) 1024×1024, 8-bit image. (b) through (f) 512×512, 256×256, 128×128, 64×64, and 32×32 images resampled into 1024×1024 pixels by row and column duplication

Compare Figure 2.5(a) with the 512×512 image in Figure 2.5(b), we find that the level of detail lost is simply too fine to be seen on the printed page at the scale in which these images are shown. Next, the 256×256 image in Figure 2.5(c) shows a very slight fine checkerboard pattern in the borders between flower petals and the black background. A slightly more pronounced graininess throughout the image also is beginning to appear. These effects are much more visible in the 128×128 image in Figure 2.5(d), and they become pronounced in the 64×64 and 32×32 images in Figures 2.5(e) and (f), respectively.

Effect of reducing the gray-level resolution

Decreasing the gray-level resolution of a digital image may result in what is known as *false contouring*. This effect is caused by the use of an insufficient number of gray levels in smooth areas of a digital image.

To illustrate the false contouring effect, we reduce the number of gray levels of the 256-level image shown in Figure 2.6(a) from 256 to 2. The resulted images are shown in the figures 2.6(b) through (h). This can be achieved by reducing the number of bits from k = 7 to k = 1 while keeping the spatial resolution constant at 452×374 pixels.

We can clearly see that the 256-, 128-, and 64-level images are visually identical. However, the 32-level image shown in Figure 2.6(d) has an almost imperceptible set of very fine ridgelike structures in areas of smooth gray levels (particularly in the skull).False contouring generally is quite visible in images displayed using 16 or less uniformly spaced gray levels, as the images in Figures 2.6(e) through (h) show.

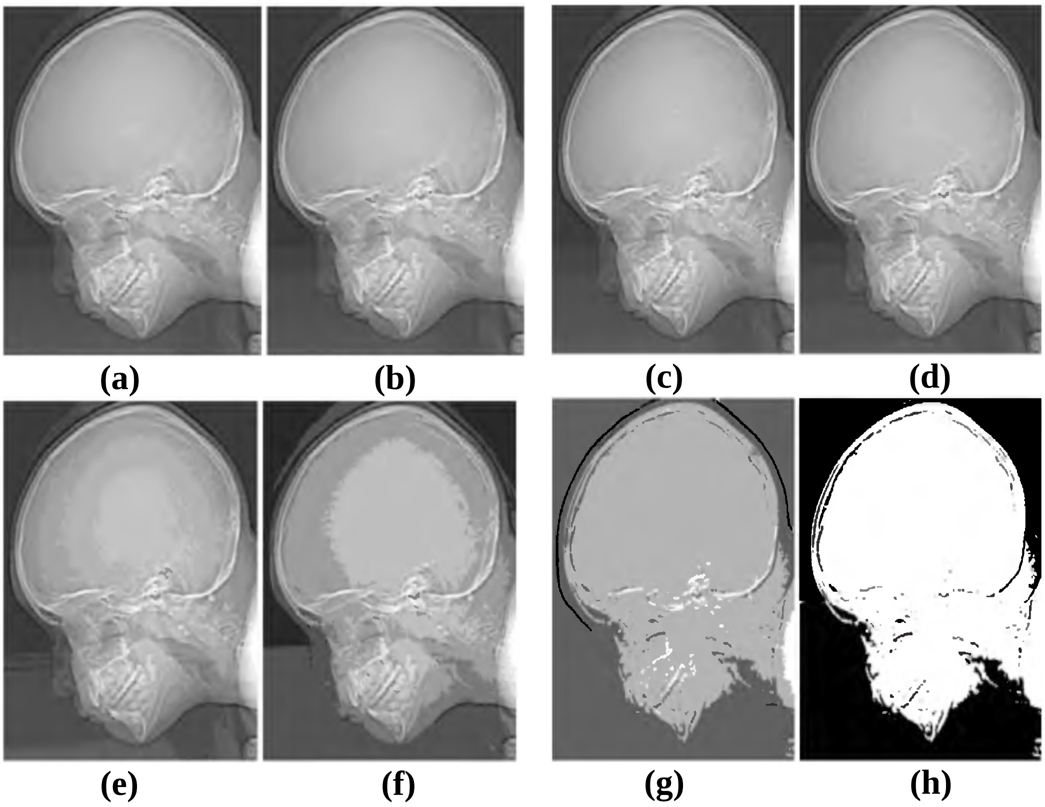


Figure 2.6 (a) 452×374, 256-level image. (b)-(h) Image displayed in 128, 64, 32, 16, 8, 4, and 2 gray levels, while keeping the spatial resolution constant.