

# Chapter 12

## Basic Principles of Digital Image Processing

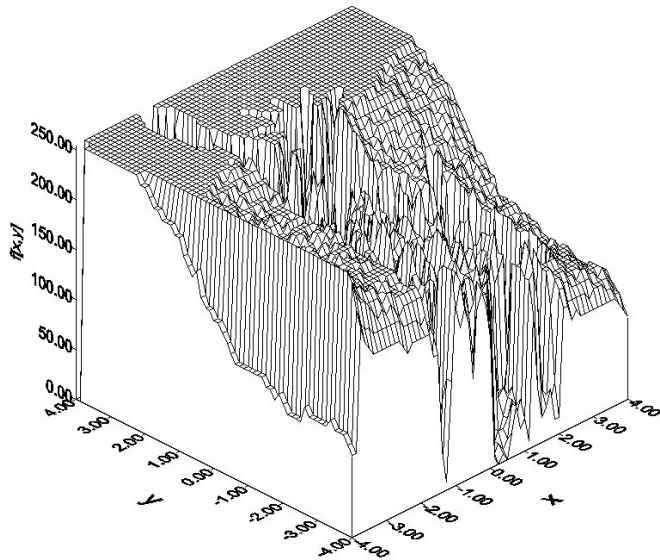
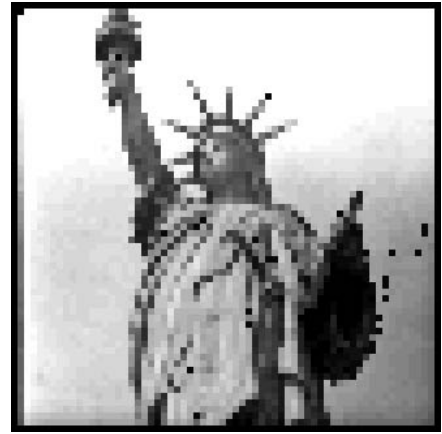
During the last decade, inexpensive yet powerful digital computers have become widely available and have been applied to a multitude of tasks. By hitching computers with imaging detectors and displays, very capable systems for creating and analyzing imagery have been constructed and are being applied in many arenas. For example, they now are used to reconstruct x-ray and magnetic resonance images in medicine, to analyze multispectral aerial and satellite images for environmental and military uses, to read Universal Product Codes that specify products and prices in retail stores, just to name a few.

This part of the course will investigate the basic principles and introductory applications of digital imaging systems, and includes many simple examples to illustrate the concepts. Most of the images used to illustrate the concepts are rather “crude”, consisting of only 4096 individual picture elements (pixels) in a  $64 \times 64$  array. Each pixel has one of up to 64 different brightnesses (gray values or digital counts). The crudeness of the examples is intentional because it allows the effects due to processing on individual pixels to be apparent. In no way do these examples represent the capabilities of most modern digital imaging systems; indeed, it is usually essential that individual pixels not be visible so that the image appears to be a continuously varying function.

*IMAGE: A reproduction or imitation of form of a person or thing.  
The optical counterpart of an object produced by a lens, mirror, etc.*  
.....Noah Webster

We normally think of an image in the sense of a picture, i.e., a planar representation of the brightness,  $I$ , i.e., the amount of light reflected or transmitted by an object.

An image is usually a function of two spatial variables, e.g.,  $f[x, y]$ , which represents the brightness  $f$  at the Cartesian location  $[x, y]$ . It may therefore be graphed in three dimensions, with brightness on the  $z$ -axis.

Function of Two Spatial Coordinates  $f[x, y]$ Image Representation of  $f[n, m]$ 

An image may have more than two coordinate dimensions, e.g.,

$f[x, y, t_n]$	monochrome “movie”
$f[x, y, \lambda]$	color image
$f[x, y, \lambda_n]$	discrete set of wavelengths, multispectral image
$f[x, y, t]$	time-varying monochrome image
$f[x, y, z]$	3-D image (e.g., hologram)
$f[x, y, t_n, \lambda_m]$	image discretely sampled in time and wavelength, e.g., color movie
$f[x, y, z, t_n, \lambda_m]$	reality

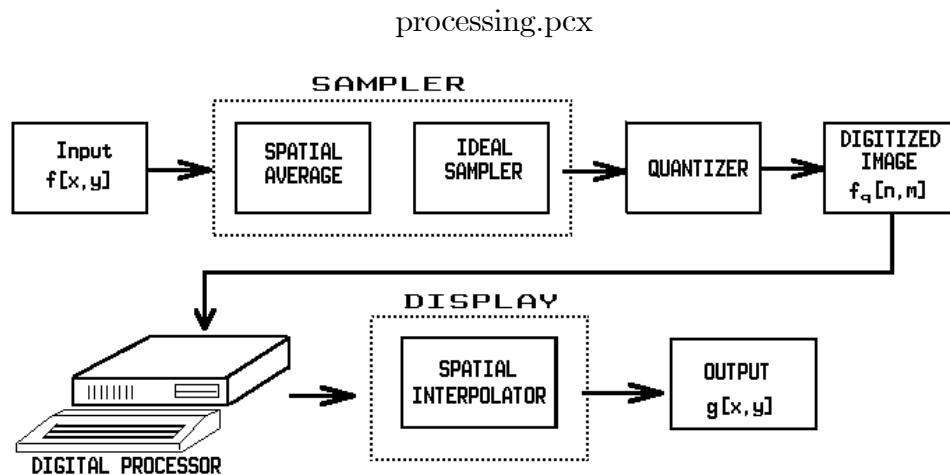
Note that 2-D slices can be “cut” from multidimensional images, and the resulting image needn’t be “pictorial,” e.g., consider the 2-D slices “cut” from the 3-D function  $f[x, y, t_n]$ ;  $f[x, y]$  is pictorial,  $f[x, t_n]$  is not. But the dimensionality of the axes has no effect on the computations; it is perfectly feasible for computers to process and display  $f[x, t_n]$  as well as  $f[x, y]$ .

After converting image information into an array of integers, the image can be manipulated, processed, and displayed by computer. Computer processing is used for image enhancement, restoration, segmentation, description, recognition, coding, reconstruction, transformation

## 12.1 Digital Processing

The general digital image processing system may be divided into three components: the input device (or digitizer), the digital processor, and the output device (image display).

1. The digitizer converts a continuous-tone and spatially continuous brightness distribution  $f[x, y]$  to an discrete array (the digital image)  $f_q[n, m]$ , where  $n, m$ , and  $f_q$  are integers.
2. The digital processor operates on the digital image  $f_q[n, m]$  to generate a new digital image  $g_q[k, \ell]$ , where  $k, \ell$ , and  $g_q$  are integers. The output image may be represented in a different coordinate system, hence the use of different indices  $k$  and  $\ell$ .
3. The image display converts the digital output image  $g_q[k, \ell]$  back into a continuous-tone and spatially continuous image  $g[x, y]$  for viewing. It should be noted that some systems may not require a display (e.g., in machine vision and artificial intelligence applications); the output may be a piece of information. For example, a digital imaging system that was designed to answer the question, Is there evidence of a cancerous tumor in this  $x$ -ray image?, ideally would have two possible outputs (YES or NO), , i.e., a single bit of information.



We shall first consider the mathematical description of image digitizing and display devices, and follow that by a long discussion of useful processing operations. Some aspects of this material are covered in more depth in the linear mathematics sequence, SIMG-716,717.

