CHAPTER 10

DIGITAL IMAGING FUNDAMENTALS

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From its inception over a century ago, radiology has provided a view into human anatomy and pathology via signal detection and image generation. For decades, the only imaging modality available to the science was projection radiography, in which all nonabsorbed signals were converted to an image by a sheet of radiographic film. There was no opportunity for digital image processing because there were no digital images.

Things have changed drastically for radiology in the last half century. New digital methods of capturing anatomy, pathology, and physiology have been invented (e.g., computed tomography [CT], magnetic resonance [MR], ultrasound, and positron emission tomography), and even projection radiography has become digitized (e.g., computed radiography and direct radiography). It is this infiltration of digital imaging into radiology that has allowed digital image processing to become a fundamental part of all modern radiology departments.

WHY IMAGING?

One may ask, why generate images at all? Many of the native signals detected by radiological modalities today bear little resemblance to an image. Typically, extensive signal processing is necessary to generate even a rudimentary two-dimensional image, let alone the complex images that we are familiar with today. Keeping in mind that humans contain biological signal processors capable of interpreting all sorts of analog data, why not simply present the signal itself in its native form for interpretation? With more than half of the human brain dedicated to image processing, one can quickly see that a visual image is one of the best signals to use when representing data for sophisticated human interpretation.

Radiological modalities that convert their native signal information into visual images are far easier for humans to interpret. The more the resulting images resemble directly observed human anatomy, the easier it is for the observer to create a frame of reference for their subsequent interpretation. The ability to differentiate between normal and abnormal (pathologic states are detected by the identification of abnormal anatomy and/or physiology) is fundamental to the radiological diagnosis of disease. While much of the ability to differentiate these states depends on the observer's experience (knowledge of human pathophysiology and its imaging presentation states), creating an ideal image is paramount to making the correct diagnosis. It is, in large part, the science of digital image processing that will allow us to create an ideal image to enhance the interpretation process.

DIGITAL IMAGES

Before we begin exploring digital image processing, we must first understand how a digital image is constructed. A digital image is a representation of a two-dimensional image as a finite set of digital values called picture elements or pixels (Figure 10.1). (*Note:* The term "digital image" also applies to data associated with points scattered over a three-dimensional [3-D] region, such as those produced by CT and magnetic resonance imaging (MRI). In that case, each signal sample is called a voxel, or volume element, instead of a pixel. These 3-D image types are described in detail in Chapter 22.) Pixels are organized into rows and columns. In fact, the spatial resolution of an image is determined by the number of rows and columns. Typical resolutions for medical images are 512×512, 1024×1024 and 2048×2048. Pixels of medical images are typically so small and so numerous that, when dis-

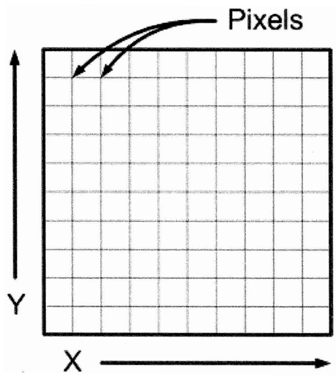

FIGURE 10.1

Digital image coordinate system (pixels).

played on a computer monitor, they appear to merge into a smooth continuous image.

SHADES OF GRAY

Though each pixel can represent a color and intensity of light, for most of radiology the color is limited to gray while the intensity determines the pixel's shade of gray. This is because each pixel typically represents the signal acquired by the modality for that location in space. As the signal intensity increases, the pixel shade becomes more black (or more white, depending on the modality). It is the difference in these shades of gray (contrast resolution) that allows us to visually differentiate between different tissues of the body in an image. Therefore, the greater the signal range of values detectable, the more shades of gray can be displayed, resulting in better image quality. Radiology modalities today can generate pixels with up to 65,536 different shades of gray, or a 16-bit grayscale. However, most computer monitors (and the human visual system) can only differentiate among about 256 different shades of gray, or an 8-bit grayscale. The issue is resolved by the concept of down sampling the higher-resolution grayscale (from 16-bit to 8-bit) by a method called windowing and leveling.

The *window width* determines how many of the original shades will be displayed at once by dividing each pixel by a fixed value (*width*). The *window level* determines where to focus attention in the original grayscale by adding an offset number (*level*) to each pixel (Figure 10.2). These values are then

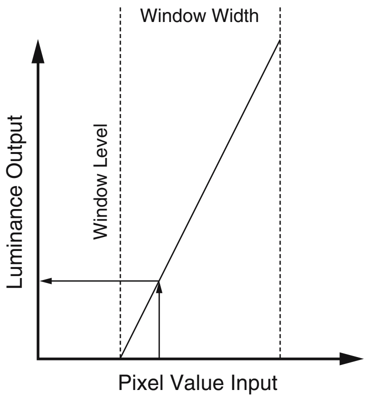

FIGURE 10.2

Visual representation of window level techniques.

normalized down to a resultant 8-bit pixel for subsequent computer monitor display.

IMAGE PROCESSING

Image processing can be thought of as the digital manipulation of an image that results in a new (and, one hopes, improved) image (Table 10.1). A good example of this is the windowing and leveling algorithm described above. It provides the observer with the ability to enhance different aspects of the original image, producing new images that when collectively displayed provide more information to the observer than the original image did. Other algorithms used for image processing include histogram equalization, geo-

TABLE 10.1
Digital Imaging Techniques

Technique	In	Out
Image Processing	Image	Image
Image Analysis	Image	Measurements
Image Understanding	Image	High-Level Description

metric transformations (zoom, rotate, pan), image fusion, noise reduction, edge enhancement, segmentation, frequency transformations, and image compression. Many of these rudimentary image-processing functions are available with picture archiving and communication systems (PACS) and their respective primary interpretation workstations.

IMAGE ANALYSIS

Where image processing ends, image analysis typically begins. Image analysis is defined as the processing performed on an image that results in measurements or other low-level descriptors. Examples of image analysis are the algorithms used to measure bone density on CT, cardiac index on CT angiography, or tumor volumes on MR. The results are measurements that can be compared to an index and/or previous values to monitor disease progression. Most medical image analysis algorithms today require some manual intervention (semiautomated analysis) using the human to begin the process (seed planting) with the computer providing tireless consistency to the remaining, otherwise subjective, measurement tasks.

IMAGE UNDERSTANDING

Beyond image analysis is the complex field of image understanding. In medical imaging, image understanding is often referred to as CAD, or computer-aided diagnosis. Most CAD systems of today attempt to find (through feature extraction) an aspect of the medical image data that suggests the presence of disease. Oftentimes these areas of concern are indicated to the radiologist by an overlay (i.e., arrow, circle) produced by the image-understanding algorithm. It remains the responsibility of the radiologist to determine the validity of these automatically identified areas of concern.

CONCLUSION

The use of digital imaging in medicine has provided a wealth of value to radiology in the healthcare enterprise. It has allowed for the elimination of film and for the digital storage, retrieval, transfer, and display of images anywhere throughout the enterprise, or throughout the world. Though image-processing algorithms are performed daily in hospitals everywhere, image-analysis and image-understanding methods remain elusive. It is these authors' belief that the next great digital revolution in medical imaging will occur when the secrets to these final challenges start to be revealed. For more information on digital-imaging fundamentals, please visit http://www.MyRadiology.com.