DIGITAL RADIOGRAPHY IN PRACTICE

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By

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PREFACE

This work is intended to provide medical radiography programs with an economical textbook that focuses on the practical aspects of digital radiography, limited in scope to information that will be pertinent to each graduating student as he or she enters into clinical practice. Nearly all textbooks to date claiming the title "digital radiography" have dealt primarily with the managerial aspects of the topic at the expense of any practical information on how digital imaging actually works and its clinical implications for the daily practice of radiography.

Since no other books have yet filled this need, much of this information has originated primarily from direct contact by the author with scientists at Philips Healthcare, FujiMed and CareStream Health (previously Kodak), who were directly involved in actually developing these technologies, in addition to numerous "white papers" published by companies that produce digital radiography equipment. These sources are all listed at the end of the book in the References.

A much more extensive treatment of the subject is found in *Radiography in the Digital Age* (Charles C Thomas, Publisher, Ltd., 2018), a work by this author of over 900 pages that provides experimental evidence and in-depth explanations for all the various aspects of digital technology of interest to the radiographer, in addition to the underlying physics of radiography, principles of exposure and technique, and a thorough coverage of radiation biology and protection. Many of the lucid illustrations in this textbook are borrowed here to make digital radiography comprehensible to the student, but in this textbook we focus only on digital topics and state the facts with such brief explanatory material as each topic will allow.

Use of the *glossary* is highly recommended whenever a concise definition is needed for a particular term.

The goal of the author is to provide an accurate and adequate description of all of the aspects of digital images and digital equipment, and their implications for radiographic technique and clinical application, but to do so in the most student-friendly way possible by providing crisp, clear illustrations along with readable text. Many digital topics are intimidating, and every attempt is made to reduce these topics to a descriptive, non-mathematical level that can be intuitively understood by the average student. Feedback from educators and students is welcome.

Ancillary Resources

Instructor Resources CD for Digital Radiography in Practice: This disc includes hundreds of multiple-choice questions *with permission* for instructors' use. **Answer keys** for all chapter-end questions in the textbook are included, along with keys to the multiple-choice question banks. (Instructors desiring laboratory exercises and more extensive question banks are encouraged to purchase the *Instructor Resources CD for Radiography in the Digital Age,* also available from Charles C Thomas, Publisher, Ltd.) The website is ccthomas.com.

PowerPoint™ Slides for Digital Radiography in Practice: PowerPoint™ slides are available on DVD for classroom use. These are high-quality slides with large text, covering every chapter of the textbook. (Instructors desiring more extensive slides are encouraged to purchase the *PowerPoint™ Slides for Radiography in the Digital Age,* also available from Charles C Thomas, Publisher, Ltd.) The website is ccthomas.com.

Student Workbook for Digital Radiography in Practice: This classroom supplement is correlated with the PowerPoint™ slide series for in-classroom use. Although it can be used for homework assignments, it is designed to deliberately provoke student participation in classroom instruction while avoiding excessive note-taking. All questions are in "fill-in-the-blank" format, focusing on key words that correlate perfectly with the slide series. Available from Charles C Thomas, Publisher, Ltd. The website is ccthomas.com.

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I am grateful for the perpetual support of family, friends, and prior students who make all the effort meaningful. I dedicate this work to practicing radiographers everywhere, on the front-lines of patient care.

CONTENTS

DIGITAL RADIOGRAPHY IN PRACTICE

Chapter 1

NATURE OF THE DIGITAL RADIOGRAPH

Objectives

Upon completion of this chapter, you should be able to:

1. Analyze the differences between analog and digital data and how they relate to radiographic images.
2. Define the three steps in digitizing any analog image.
3. Explain the relationships between bit depth, dynamic range and image gray scale.
4. Describe the aspects of a digital image matrix and how it impacts image sharpness.
5. Define *voxels, dexels (dels),* and *pixels* and distinguish between them.
6. Describe the nature of *voxels* and how the x-ray attenuation coefficient for each is translated into the gray levels of pixels.

Development of Digital Radiography

The first application of digital technology to radiographic imaging occurred in 1979 when an analog-to-digital converter was attached to the TV camera tube of a fluoroscopy unit. It makes sense that digital conversion would first occur with fluoroscopy rather than "still" radiography, because the signal coming from a TV camera tube was in the form of electrical current rather than a chemical photographic image, and computers are based on electricity.

Three years later, in 1982, the introduction of digital picture archiving and communication systems (PACS) revolutionized the access, storage and management of radiographic images. Coupled with *teleradiology,* the ability to send electronic images almost instantly anywhere in the world, the efficiency of medical imaging departments in providing patient care and diagnoses was also revolutionized.

Computed radiography or "CR" became commercially available in the early 1980s, but was at first fraught with technical problems. It was found that "screens" coated with certain fluorescent materials, which had been used to convert x-ray energy into light that exposed films, could be made to glow a *second time* afterward when stimulated by laser beams. This stimulated light emission, using only the *residual energy* remaining in the screen after x-ray exposure, was very dim indeed. But, after being captured by light-sensitive diodes and converted into a meager electrical current, it could be electronically and digitally amplified before being processed by a computer to produce a bright radiographic image on a display monitor.

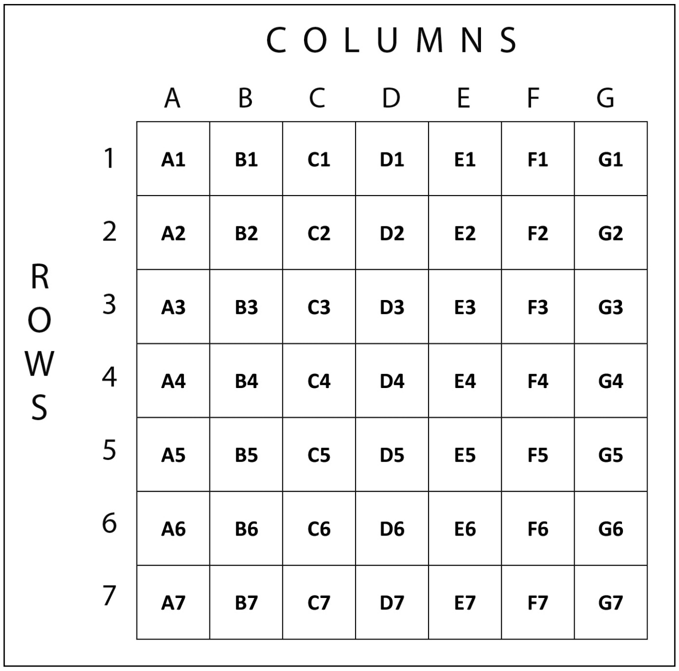
Early CR systems required an approximate doubling of x-ray technique, resulting in a doubling of patient exposure. But they were later refined and paved the way for the development of *digital radiography* or "DR," first demonstrated in 1996.

The advancing miniaturization of electronics finally led to x-ray detectors that are smaller than the human eye can detect at normal reading distance. By constructing image receptor "plates" with thousands of these small detectors laid out in an *active matrix array,* it was possible to convert the latent image carried by the remnant x-ray beam *directly* into electrical current, called *direct-conversion DR.* Indirect-conversion DR units use a phosphor plate to first convert the x-rays into light, then the active matrix array converts the light into electricity. Direct-conversion systems convert the x-ray energy directly into electricity without the intermediate step of converting x-rays into light. Indirect conversion units have the advantage of saving patient radiation dose, but direct-conversion units produce better resolution. Since these are both desirable outcomes, both types of systems continue in use.

All CR and DR imaging systems ultimately produce an *electronic signal* that represents the original image information. It is this electrical signal that is "fed" into a computer for digital processing and then finally displayed on an electronic display monitor. Although both CR and DR systems continue in use, after more than two decades of refinement DR has emerged as the state-of-the-art technology for medical radiography.

Nature of the Digital Image

DR, CR, DF (digital fluoroscopy), digital photography, and all other methods of acquiring a digital image result in the creation of a *matrix* of numerical values that can be stored in computer memory. A matrix is a pattern of cells or locations laid out in rows and columns as shown in Figure 1.1. Each location or cell can be identified by its row and column designations, which the computer keeps track of throughout any processing operations. Each location or cell in the matrix is referred to as a *pixel,* a contraction of the term *picture element.* Each pixel in an image is assigned a single numerical value, the *pixel value.* For radiographs, the pixel value represents the brightness (or darkness) assigned to the pixel's location in the image. This brightness level is taken from a range of values stored in the computer that represent different shades



	A	B	C	D	E	F	G
1	**A1**	**B1**	**C1**	**D1**	**E1**	**F1**	**G1**
2	**A2**	**B2**	**C2**	**D2**	**E2**	**F2**	**G2**
3	**A3**	**B3**	**C3**	**D3**	**E3**	**F3**	**G3**
4	**A4**	**B4**	**C4**	**D4**	**E4**	**F4**	**G4**
5	**A5**	**B5**	**C5**	**D5**	**E5**	**F5**	**G5**
6	**A6**	**B6**	**C6**	**D6**	**E6**	**F6**	**G6**
7	**A7**	**B7**	**C7**	**D7**	**E7**	**F7**	**G7**

Figure 1-1. A digital image matrix with the location of each cell designated by column and row.

from "pitch black" all the way to "blank white," with hundreds of shades of gray in between.

Light images enter through the lens of a camera in *analog* form, that is, the various intensities of light can have any value. Likewise, x-rays from a radiographic projection enter the image receptor plate in analog form. During a medical sonogram procedure, sound waves enter the transducer in analog form, as do radio waves emanating from the patient during an MRI scan. All of these forms of input must be converted into *digital* form so that we can manipulate the resulting images as we wish to do.

To better distinguish between analog and digital data, imagine that you are standing on a railroad track (preferably with no trains coming) as shown in Figure 1-2. You can choose to walk along the metal rails, doing a balancing act. Or, you can choose to hop along the wooden crossbeams, stepping from tie to tie. The metal rails are *continuous,* consisting of smooth, unbroken lines. Your progress along the rails can be measured in *any fraction* of distance—meters, millimeters, microns—there is no limit to how many times you can divide these measurements into smaller and smaller units. An analog measurement can be as precise as we want, because, by using a continuous scale, it is *infinitely divisible.*

Now, suppose you choose to step along the cross-beams. The wooden ties are *discrete* or *separated* into distinct units. Your progress along them cannot be measured in fractions because of the spaces between them. You must count them in whole integers. Digitizing data *limits* the degree to which measurements can be subdivided. It also limits the *scale* from which measurements can be taken. For example, only so many railroad ties of a particular size can be laid between one point and another that is one kilometer away. In radiography, digitizing the pixel values limits the number of values that can exist between "pitch black" and "blank white." This makes them manageable, because there is not an *infinite number of values* to deal with.

For the purpose of building up an image and manipulating it, we need all pixel values to be *discrete,* that is, selected from a limited scale of pre-set values. If our scale is set from 0 (for blank white) to 4.0 (for pitch black), and we limit decimal places to the *thousandths,* then we will have 4000 values available to build up an image. This is more than enough to allow the image to be not only built up for initial display, but also to be "windowed" up and down, lighter

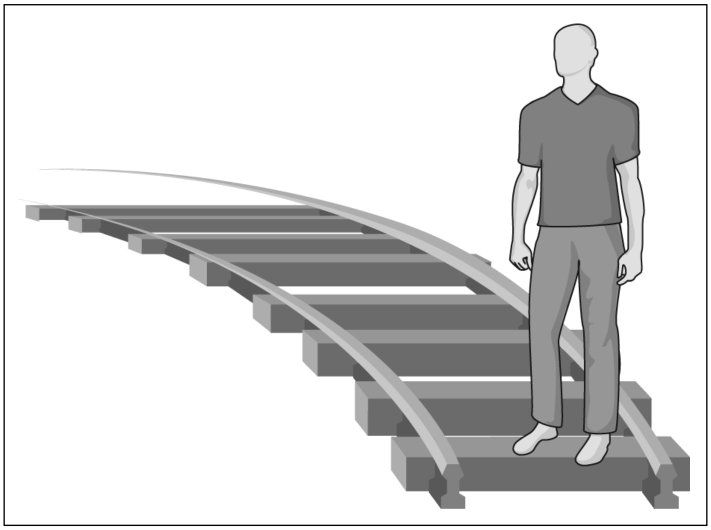


Figure 1-2. On a railroad track, the steel rails represent *analog* information—they are continuous and can be infinitely subdivided. On the other hand, the wooden ties represent *discrete* or *digital* information, since they cannot be subdivided into fractions as one steps from tie to tie. (From Q. B. Carroll, *Radiography in the Digital Age,* 3rd ed. Springfield, IL: Charles C Thomas, Publisher, Ltd., 2018. Reprinted by permission.)

or darker at will, across the entire range of human vision as needed. Yet, it is not an infinite range of values.

Mathematically, digitizing means *rounding* all measurements to the nearest available digital value. In the above example, an analog measurement of 1.0006 must be rounded up to the nearest thousandth or 1.001, a measurement of 1.00049 will be rounded down to 1.000. This rounding-out process may seem at first to be a disadvantage for digital computers. Strictly speaking, it is less accurate. However, when we take into consideration the limitations of the human eye and ear, we find that digitized information can actually be *more* accurate when *reading out* the measurement. This is why digital equipment is used to clock the winner of a race in the Olympics: you may not be able to *see* that the winning racer was just two-thousandths of a second ahead of the second-place racer, but a digital readout can make this distinction. *As long as the discrete units for a digital computer are smaller than a human can detect, digitizing the data improves readout accuracy.*

For digital photography and for digital radiography, if the units for pixel values are smaller than the human eye can detect, the resulting digital image will appear to have the same quality as an analog photograph or radiograph. Digitization of incoming analog data is the function of a device called the *analog-to-digital converter (ADC),* which is used in all forms of medical digital imaging.

Digitizing the Analog Image

We can identify three basic steps to *digitizing* an image that apply to all forms of images. The first step is *scanning,* in which the field of the image is divided into a matrix of small cells. Each cell will become a *pixel* or picture element in the final image. In Figure 1-3***A***, the field is divided into 7 columns and 9 rows, resulting in a matrix size of 63 pixels. The photocopy scanner connected to your home computer can be heard making a pre-copying sweep before it makes the actual copy, performing this function of pixel allocation and matrix size determination. For computed radiography (CR), the processor or reader scans the exposed PSP plate in a predetermined number of lines (rows) and samplings (columns) that define the corresponding pixels.

For digital radiography (DR), the number of *available* pixels is determined at the detector plate by the number of hardware detector elements (*dexels*) physically built into the plate in rows and columns. In this case, *collimation* of the x-ray beam is analogous to the *scanning* function, because collimation effectively *selects* which of these detector elements will comprise the initial matrix of the latent image that will be fed into the computer for processing. A similar concept holds true for digital fluoroscopy (DF): The initial field of view (FOV) selected for a dynamic flat-panel system, or determined by the magnification mode of an image intensifier at the input phosphor, are analogous to collimation—they determine the matrix size, the pixel size, and the spatial resolution of the input mage that will be processed by the computer.

All forms of digital imaging require the preliminary step of *formatting a matrix with a designated pixel size,* and whatever method is used, it would fall under the broad definition of *scanning.*

The second step in digitizing an image is *sampling,* defined as the detection and *measurement* of the intensity of signal coming into the system at each pixel location, Figure 1-3***B***. For standard photography, for CR, for indirect-conversion DR, and for CCD or CMOS cameras mounted atop a fluoroscopic image intensifier, this signal consists of the intensity of *light* striking each designated pixel area. For direct-conversion DR, the signal consists of the intensity of *x-rays* striking each pixel area. For an MRI machine, the signal consists of radio waves, and for sonography, sound waves. The type of imaging equipment being used determines the size and shape of the *aperture* or opening through which these signal measurements are taken. For example, the detector elements of a DR machine are essentially square, whereas the pixel aperture inside a CR reader is round, and the initial pixel samplings overlap each other, because a round laser beam is used to stimulate the PSP plate to

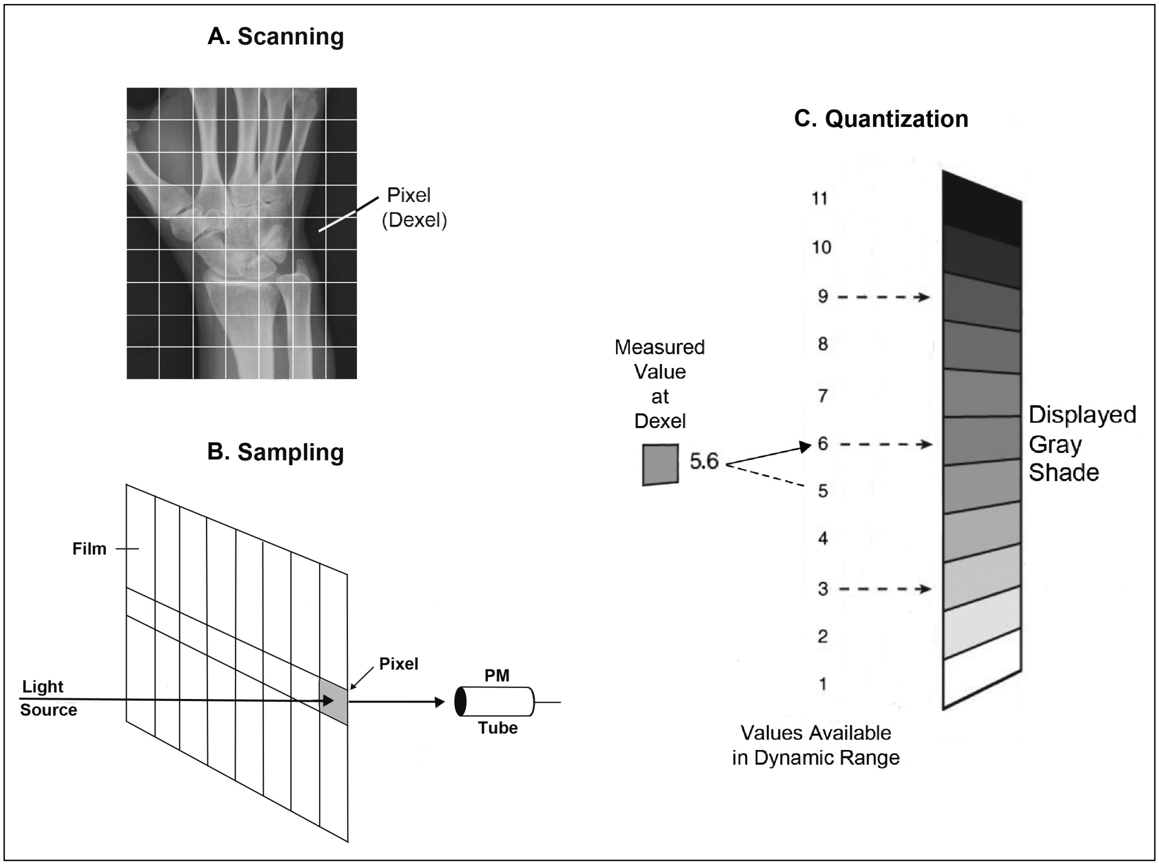


Figure 1-3. Three steps for digitizing an image: ***A***) *Scanning* to format the image into a matrix of defined pixels (or dexels); ***B***) *Sampling,* in which measurements are taken from each pixel or dexel; and ***C***) *Quantizing,* in which each measurement is rounded to the nearest digital value available within the dynamic range.

glow, Figure 1-4. This overlapping effect must be "cropped" in order to form roughly square-shaped pixels for the final displayed image.

The third and final step in digitizing an image is *quantization.* In the previous section, we described how analog values must be effectively *rounded out* to form discrete values that the digital computer can recognize and manipulate. These values must be selected from a predetermined scale of numbers called the *dynamic range.* The dynamic range of any imaging system is the *range of pixel values, or shades of gray, made available by the combined hardware and software of the system to build up a final displayed image.* Actual values of the signal intensity measured, which will become the brightness level for every pixel, must each be rounded up or down by an *analog-to-digital converter (ADC)* to the nearest available gray level in the preset dynamic range. In Figure 1-3***C***, there are only 11 such values available to choose from to build up this simplified image. This is the process of quantization or *quantizing the image.*

Bit Depth, Dynamic Range, and Gray Scale

The term *dynamic range* is frequently misapplied, even by physicists, and can be a source of confusion. For example, some have limited the term to describing the characteristics of a DR detector plate. But, with such a narrow definition, digital features such as *dynamic range compression* or *dynamic range control (DRC),* which alter the dynamic range during processing, would imply that we have effectively gone backward