CHAPTER 1

Introduction

1.1 INTRODUCTION

PACS (picture archiving and communication system) based on digital, communication, display, and information technologies has revolutionized the practice of radiology, and in a sense, of medicine during the past fifteen years. This textbook introduces the PACS basic concept, terminology, technological development, and implementation, as well as PACS-based applications to clinical practice and PACS-based imaging informatics. There are many advantages of introducing digital, communications, display, and information technologies (IT) to the conventional paper and film-based operation in radiology and medicine. For example, through digital imaging plate and detector technology, and various energy source digital imaging modalities, it is possible to improve the modality diagnostic value while at the same time reducing the radiation exposure to the patient; then through the computer and display, the digital image can be manipulated for value-added diagnosis. Also digital, communication, IT technologies can been used to understand the healthcare delivery workflow, resulting in a speed-up of healthcare delivery and reduction of medical operation costs.

With all these benefits, digital communication and IT are gradually changing the way medical images and related information in the healthcare industry are acquired, stored, viewed, and communicated. One natural development along this line is the emergence of digital radiology departments and digital healthcare delivery environment. A digital radiology department has two components: a radiology information management system (RIS) and a digital imaging system. RIS is a subset of the hospital information system (HIS) or clinical management system (CMS). When these systems are combined with the electronic patient (or medical) record (ePR or eMR) system, which manages selected data of the patient, we are envisioning the arrival of the total filmless and paperless healthcare delivery system. The digital imaging system, PACS, involves an image management and communication system (IMAC) for image acquisition, archiving, communication, retrieval, processing, distribution, and display. A digital healthcare environment consists of the integration of HIS/CMS, ePR, PACS and other digital clinical systems. The combination of HIS and PACS is sometime referred to as hospital-integrated PACS (HI-PACS). A PACS

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database contains voluminous health-related data. If organized and used properly, it can improve patient care and outcome. The art and science of utilizing these data is loosely termed as imaging informatics. The cost of healthcare delivery related to PACS, health-related IT, as well as imaging informatics has passed one billion dollars each year (excluding imaging modalities) and is still growing.

Up-to-date information on these topics can be found in multidisciplinary literature, reports from research laboratories of university hospitals and medical imaging manufacturers but not in a coordinated way. Therefore it is difficult for a radiologist, physician, hospital administrator, medical imaging researcher, radiological technologist, trainee in diagnostic radiology, and the student in physics, engineering, and computer science to collect and assimilate this information. The purpose of this book is to consolidate and to organize PACS and its integration with HIS and ePR, as well as imaging informatics-related topics, into one self-contained text. Here the emphasis is on the basic principles and augmented by discussion of current technological developments and examples.

1.2 SOME HISTORICAL REMARKS ON PICTURE ARCHIVING AND COMMUNICATION SYSTEMS (PACS)

1.2.1 Concepts, Conferences, and Early Research Projects

1.2.1.1 Concepts and Conferences The concept of digital image communication and digital radiology was introduced in the late 1970s and early 1980s. Professor Heinz U. Lemke introduced the concept of digital image communication and display in a paper in 1979 (Lemke, 1979). SPIE (International Society for Optical Engineering) sponsored a Conference on Digital Radiography held at the Stanford University Medical Center and chaired by Dr. William R. Brody (Brody, 1981). Dr. M. Paul Capp and colleagues introduced the idea of photoelectronic radiology department and depicted a system block diagram of the demonstration facility at the University of Arizona Health Sciences Center (Capp, 1981). Professor S. J. Dwyer, III (Fig. 1.1*a*) predicted the cost of managing digital diagnostic images in a radiology department (Dwyer, 1982). However, technology maturation was lacking, and it was not until the First International Conference and Workshop on Picture Archiving and Communication Systems (PACS) at Newport Beach, California, held in January 1982 and sponsored by SPIE (Duerinckx, 1982; Fig. 1.1*b*,*c*), that these concepts began to be recognized. During that meeting, the term PACS was coined. Thereafter, and to this day, the PACS and Medical Imaging Conferences have been combined into a joint SPIE meeting held each February in southern California.

In Asia and Europe a similar timeline has been noted. The First International Symposium on PACS and PHD (Personal Health Data) sponsored by the Japan Association of Medical Imaging Technology (JAMIT) was held in July 1982 (JAMIT, 1983; Fig. 1.1*d*). This conference, combined with the Medical Imaging Technology meeting, also became an annual event. In Europe, the EuroPACS (Picture Archiving and Communication Systems in Europe) has held annual meetings since 1983 (Niinimaki, 2003), and this group remains the driving force for European PACS information exchange (Fig. 1.1*e*,*f*).

Notable among the many PACS-related meetings that occur regularly are two others: the CAR (Computer-Assisted Radiology; Lemke, 2002) and IMAC (Image

Figure 1.1a The late Samuel J. Dwyer III in front of his early developed workstation.

Figure 1.1b Andre Duerinckx, the Conference Chairman of the First SPIE Medical Imaging Conference (International Society for Optical Engineering) where the term PACS was coined.

Management and Communication; Mun, 1989). CAR is an annual event organized by Professor Lemke of Technical University of Berlin since 1985 (CAR expanded its name to CARS in 1999, adding Computer-Assisted Surgery to the Congress, and Professor Lemke is now with the University of Southern California). The *Annual Proceeding of CARS* became the *International Journal of CARS* in 2005 (Fig. 1.1*g*). IMAC was started in 1989 as a biannual conference and organized by Professor Seong K. Mun of Georgetown University (Mun, 1989), and its meetings were stopped

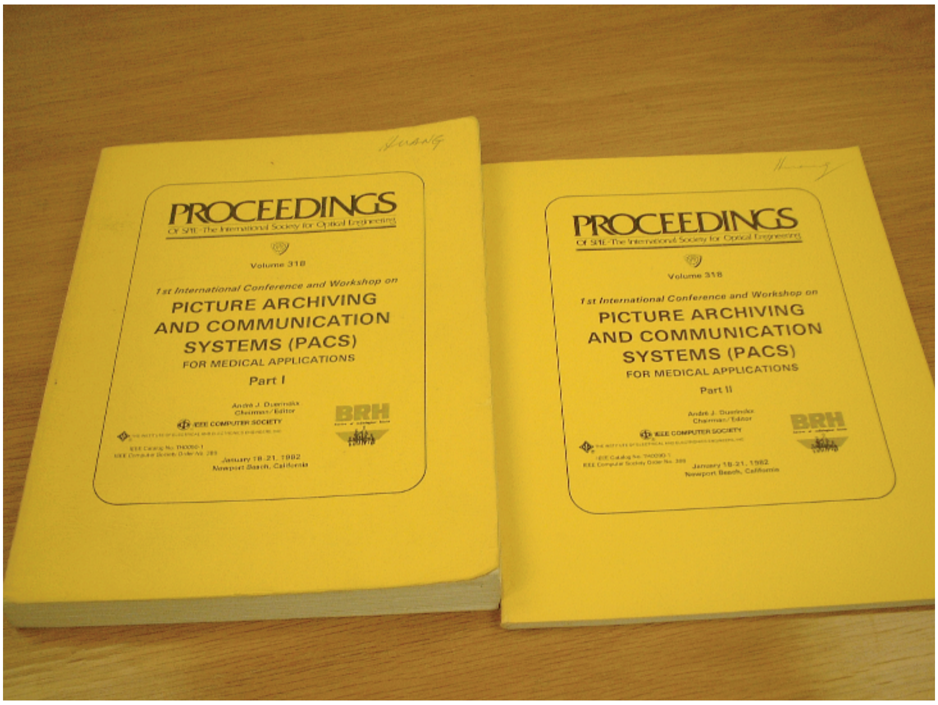

Figure 1.1c First set of PACS Conference Proceedings sponsored by SPIE at Newport Beach, CA, in 1982.

in late 1990s. SPIE, EuroPACS, and CARS annual conferences have been consistent in publishing conference proceedings and journals that provide fast information exchange for researchers working in this field, and many have been benefited from such information sources.

A meeting dedicated to PACS sponsored by NATO ASI (Advanced Study Institute) was a PACS in Medicine Symposium held in Evian, France, from October 12 to 24, 1990. Approximately 100 scientists from over 17 countries participated, and the *ASI Proceedings* summarized international efforts in PACS research and development at that time (Huang, 1991b; Fig. 1.1*h*). This meeting was central to the formation of a critical PACS project: the Medical Diagnostic Imaging Support System (MDIS) project sponsored by the U.S. Army Medical Research and Materiel Command, which has been responsible for large-scale military PACS installations in the United States (Mogel, 2003).

The InfoRAD Section at the RSNA (Radiological Society of North America) Scientific Assembly has been instrumental to the continued development of PACS technology and its growing clinical acceptance. Founded in 1993 by Dr. Laurens V. Ackerman (and subsequently managed by Dr. C. Carl Jaffe, and others), InfoRAD has showcased live demonstrations of DICOM and IHE (Integrating the Healthcare Enterprise) compliance by manufacturers. InfoRAD has repeatedly set the tone for industrial PACS renovation and development. Many refresher courses in PACS during RSNA have been organized by Dr. C. Douglas Maynard, Dr. Edward V. Staab, and subsequently by the RSNA Informatics committee, to provide continuing

Figure 1.1d Cover of *Journal of the Japan Association of Medical Imaging Technology* (*JAMIT*), July 1986 issue.

education in PACS and informatics to the radiology community. When Dr. Roger A. Bauman became editor in chief of the then new *Journal of Digital Imaging* in 1998, the consolidation of PACS research and development peer-reviewed papers in one representative journal became possible. Editor-in-chief Bauman was succeeded by Dr. Steve Horii, followed by Dr. Janice C. Honeyman-Buck. The *Journal of Computerized Medical Imaging and Graphics* (*JCMIG*) published two special Issues on PACS in 1991 (Huang, 1991a); *PACS—Twenty Years Later* summarized in 2003 (Huang, 2003a) the progress of PACS before 2003 in two 10-year intervals (Fig. 1.1*i*).

1.2.1.2 Early Funded Research Projects by the U.S. Federal Government One of the earliest research projects related to PACS in the United States was a teleradiology project sponsored by the U.S. Army in 1983. A follow-up project was the Installation Site for Digital Imaging Network and Picture Archiving and Communication System (DIN/PACS) funded by the U.S. Army and administered by the MITRE Corporation in 1986 (MITRE, 1986). Two university sites were selected for the implementation, University of Washington in Seattle and Georgetown University/George Washington University Consortium in Washington, DC, with the participation of Philips Medical Systems and AT &T. The U.S. National

Figure 1.1e EuroPACS Conference held at Pisa, Italy in 1997.

Figure 1.1f Davide Caramella presenting the 25th EuroPACS Anniversary Lecture.

Cancer Institute, National Institutes of Health (NCI, NIH) funded the University of California, Los Angeles (UCLA) several large-scale PACS-related research program projects under the titles of Multiple Viewing Stations for Diagnostic Radiology, Image Compression, and PACS in Radiology started in mid-1980s and early 1990s.

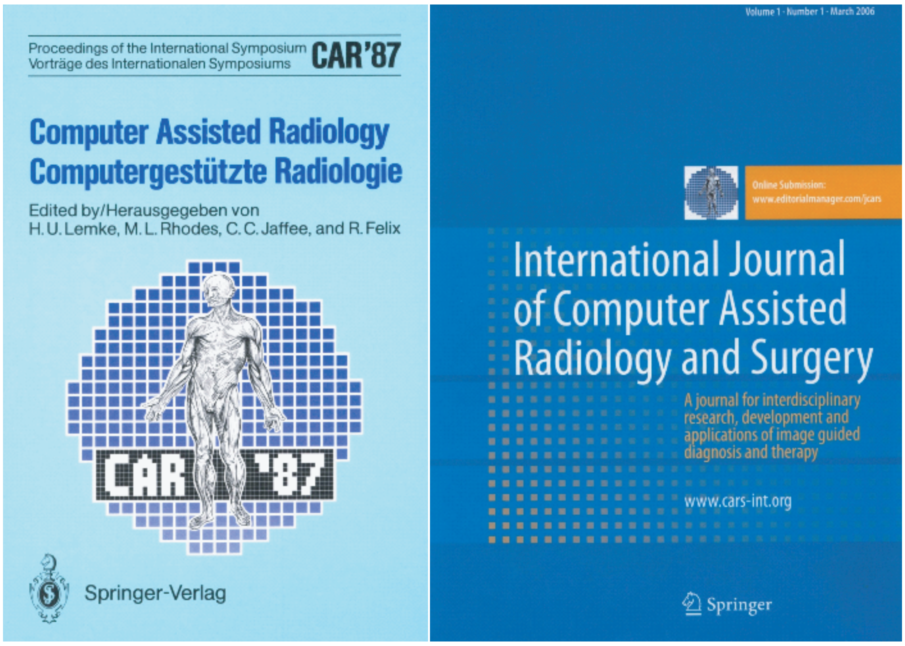

Figure 1.1g Cover of the *Proceedings of the CAR'87 Annual International Symposium* (left), Cover of the *International Journal of Computer Assisted Radiology and Surgery*, March 2006, the first issue (right).

1.2.2 PACS Evolution

1.2.2.1 In the Beginning A PACS integrates many components related to medical imaging for clinical practice. Depending on the application, a PACS can be simple, consisting of a few components, or it can be a complex hospital-integrated or an enterprise system. For example, a PACS for an intensive care unit in the early days may comprise no more than a scanner adjacent to the film developer for digitization of radiographs, a base band communication system to transmit, and a video monitor in the ICU (Intensive care unit) to receive and display images. Such a simple system was actually implemented by Dr. Richard J. Steckel (Steckle, 1972) as early as 1972. Nowadays some hospitals install a CT (computed tomography) or MRI (magnetic resonance imaging) scanner connected with a storage device and several viewing stations would also call these components as a PACS. On the other hand, implementing a comprehensive hospital-integrated or enterprise PACS is a major undertaking that requires careful planning and multimillion US dollars of investment.

PACS operating conditions and environments have differed in North America, Europe, and Asia, and consequently has PACS evolution in these regions. Initially PACS research and development in North America was largely supported by government agencies and manufacturers. In the European countries, development was supported through a multinational consortium, a country, or a regional resource. European research teams tended to work with a single major manufacturer, and since most early PACS components were developed in the United States and Japan, they

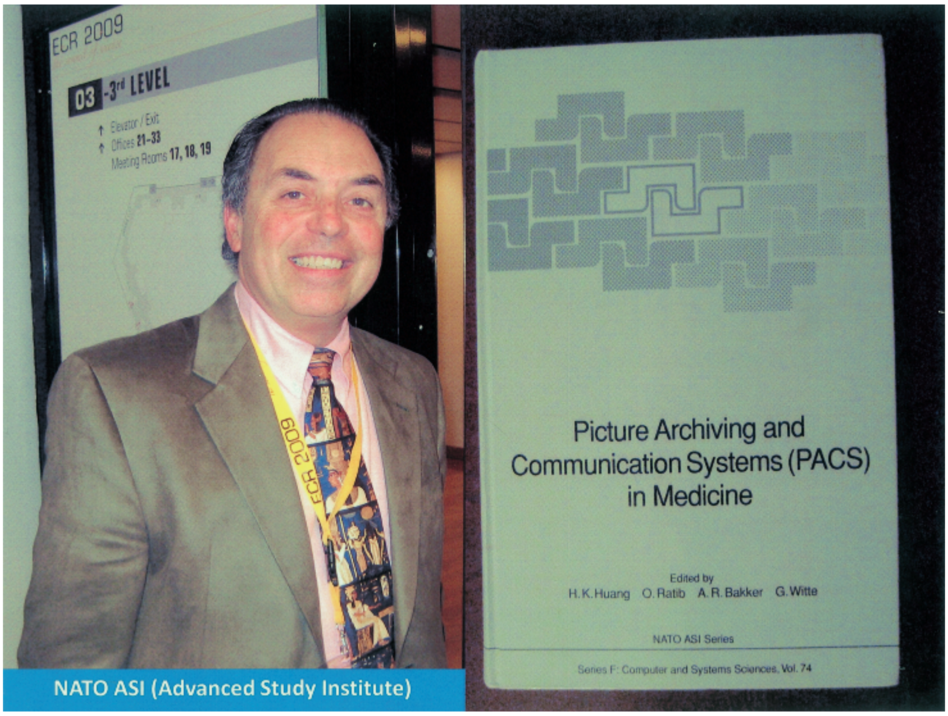

Figure 1.1h Cover of the *Proceedings of the NATO ASI* (Advanced Study Institute): Picture Archiving and Communication Systems (PACS) in Medicine, Series F, Vol 74. Evian France, 1990 (right), Osman Ratib (left) taken during the EuroPACS Annual meeting at Vienna, Austria, March 2009.

were not as readily available to the Europeans. European research teams emphasized PACS modeling and simulation, as well as the investigation of image processing components of PACS. In Asia, Japan led the PACS research and development and treated it as a national project. The national resources were distributed to various manufacturers and university hospitals. A single manufacturer or a joint venture from several companies integrated a PACS system and installed it in a hospital for clinical evaluation. The manufacturer's PACS specifications tended to be rigid and left little room for the hospital research teams to modify the technical specifications.

During the October 1997 IMAC meeting in Seoul, South Korea, three invited lectures described the evolution of PACS in Europe, America, and Japan, respectively. It was apparently from these presentations that these regional PACS research and development enterprises gradually merged and led to many successful international PACS implementation. Five major factors contributed to these successes: (1) information exchanges from the SPIE, CAR, IMAC, and RSNA conferences; (2) introduction of image and data format standards (DICOM) and gradual mature concepts and their acceptance by private industry; (3) globalization of the imaging manufacturers; (4) development and sharing of solutions to difficult technical and clinical problems in PACS; and (5) promotion by RSNA through demonstrations and refresher courses.

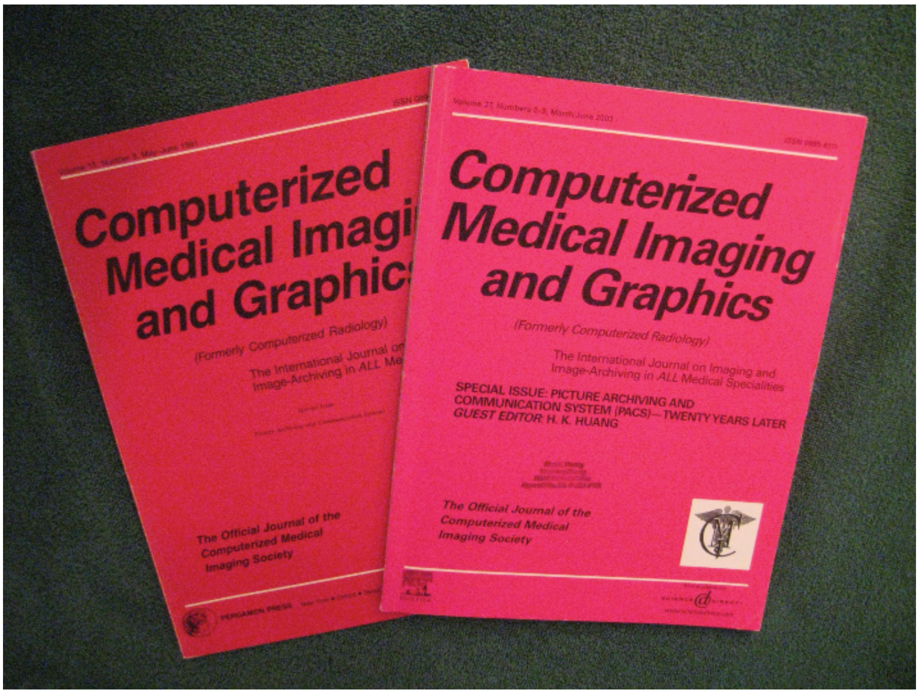

Figure 1.1i Covers of two special Issues: PACS 1991, and PACS—Twenty years later in the 2003 *Journal of Computerized Medical Imaging and Graphics*.

1.2.2.2 Large-Scale PACS The late Roger Bauman, in two papers in the *Journal of Digital Imaging* (Bauman, 1996a, b), defined a large-scale PACS as one that satisfies the following four conditions:

1. Use in daily clinical operation.
2. Augmented by at least three or four imaging modalities connected to the system.
3. Containing workstations inside and outside of the radiology department.
4. Able to handle at least 20,000 radiological procedures a year.

Such a definition loosely separated the large and the small PACS at that time. However, nowadays most PACS installed except teleradiology are meeting these requirements.

Colonel Fred Goeringer instrumented the Army MDIS project, which resulted in several large-scale PACS installations and provided a major stimulus for the PACS industry (Mogel 2003). Dr. Walter W. Hruby opened a completely digital radiology department in the Danube Hospital, Vienna in April, 1992 setting the tone for future total digital radiology departments (Hruby and Maltsidis, 2000; Fig. 1.1*j*). Figure 1.1*k* depicts two medical imaging pioneers, Professor Heniz Lemke (left) and Professor Michael Vannier (right, then editor in chief, *IEEE Transactions on Medical Imaging*) at the Danube Hospital's opening ceremony. These two projects set the stage for the continuing PACS development.

Figure 1.1j W. Hruby (right, in a dark suit), Chairman of Radiology at the Danube Hospital, Vienna, during the PACS Open House Ceremony in 1990.

Figure 1.1k Heinz Lemke (left) and Michael Vannier (right) during the Danube Hospital PACS Open House Ceremony, Vienna.

1.2.3 Standards

The ACR-NEMA (American College of Radiology–National Electrical Manufacturers' Association) and later DICOM (Digital Imaging and Communication in Medicine) standards (DICOM, 1996) are the necessary requirements of system integration in PACS. The establishment of these standards and their acceptance by the medical imaging community required the contributions of many people from both industry and academe. On the private industry side, major PACS manufactures

Figure 1.1l Steve Horii presenting one of his DICOM lectures.

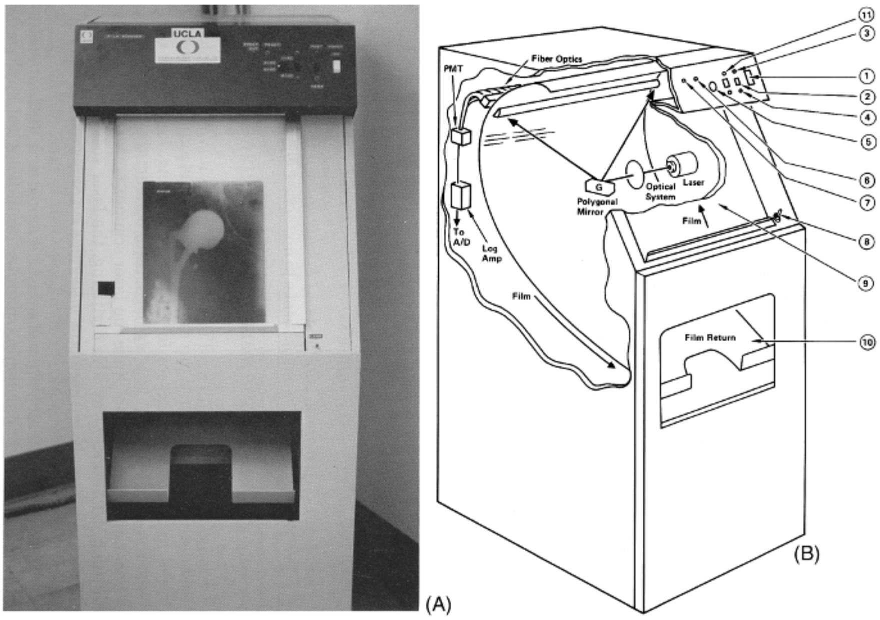

Figure 1.1m First laser film scanner by Konica at UCLA.

often assigned their own personnel to DICOM committees. Participants from academe have been mostly individuals with more altruistic interests. Among these scholars, special mention should be given Professor Steve Horii. His unselfish and tireless efforts in educating others about the concept and importance of DICOM have been vital to the success of PACS (Fig. 1.1*l*).

1.2.4 Early Key Technologies

Many key technologies developed over the past 20 years have contributed to the success of PACS operation. Although many such technologies have since been gradually replaced by more up-to-date technologies, it is instructive for historical purposes to review them. This section only lists these technologies (Huang, 2003a). Because these technologies are well known by now, only a line of introduction for each is given. For more detailed discussions of these technologies, the reader is referred to other Huang references (1987, 1996, 1999, 2004).

The key technologies are as follows:

- The first laser film digitizers developed for clinical use by Konica (Fig. 1.1*m*) and Lumisys, and the direct CR chest unit by Konica (Fig. 1.1*n*).
- Computed radiography (CR) by Fuji and its introduction from Japan to the United States (Fig. 1.1*o*) by Dr. William Angus of Philips Medical Systems of North America (PMS).
- The first digital interface unit using DR11-W technology transmitting CR images to outside of the CR reader designed and implemented by the UCLA PACS team (Fig. 1.1*p*).
- Hierarchical storage integrating a large-capacity optical disk Jukebox by Kodak with the then innovative redundant array of inexpensive disks (RAID), using the AMASS software designed by the UCLA PACS team (Fig. 1.1*q*).

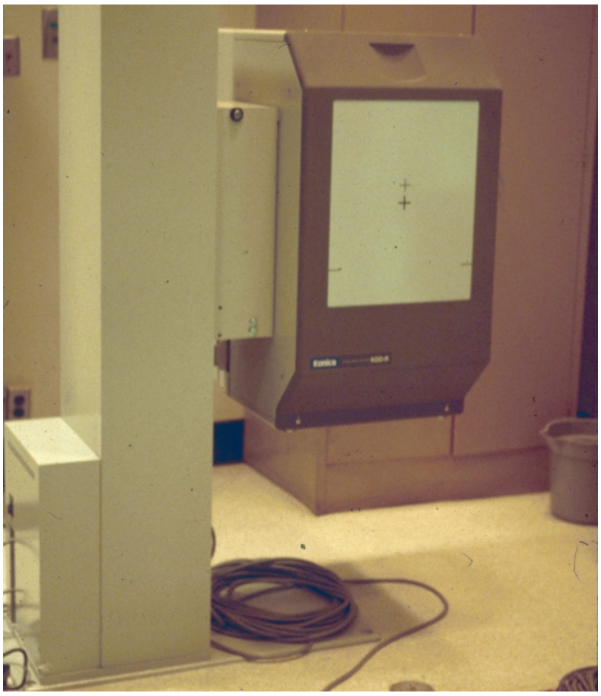

Figure 1.1n First dedicated chest CR (computed radiography) system by Konica at UCLA. The concept matured later and became the DR (digital radiography) system.

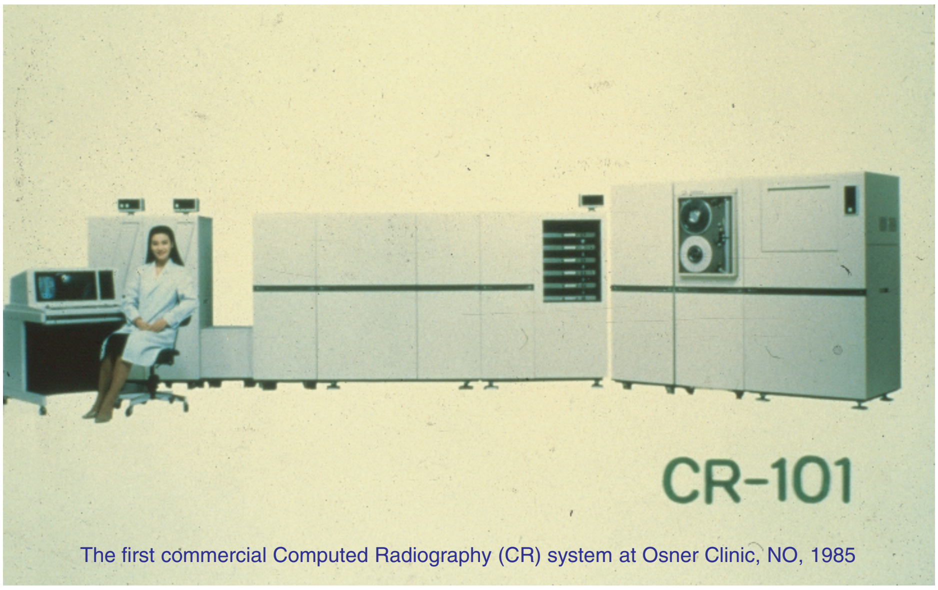

Figure 1.1o First Fuji CR system, CR-101 at the Osner Clinics, New Orleans.

Figure 1.1p First interface box using the DR-11 W technology transmitting digital CR images out of the PCR-901 and PCR-7000 systems (Philips Medical Systems) to a PACS acquisition computer at UCLA. The concept allowing direct transmission of a full CR image to the outside world as input to PACS was the cornerstone of viewing direct digital projection image on a display monitor.

Figure 1.1q Hierarchical storage system of a PACS, consisting of a Kodak Optical Disk Library (left) with one hundred 14-inch disk platters, a RAID (right), and AMASS file management software at UCLA. Similar systems were used in later military MDIS PAC systems.

- Multiple display using six 512 monitors at UCLA (Fig. 1.1*r*).
- Multiple display using three 1024 monitors (Fig. 1.1*s*) and the controller (Fig. 1.1*t*, blue) at UCLA with hardware supported by Dr. Harold Rutherford of the Gould DeAnza.
- Various spatial resolution 512, 1024, 1400 display systems at UCLA (Fig. 1.1*u*)
- Two 2000-line and 72 Hz CRT monitors display system by MegaScan at UCLA (Fig. 1.1v).
- System integration methods developed by the Siemens Gammasonics and Loral for large-scale PACS in the MDIS project.
- Asynchronous transfer mode (ATM) technology by Pacific Bell, merging the local area network and high-speed wide area network communications for PACS application in teleradiology by the Laboratory for Radiological Informatics, University of California, San Francisco (UCSF; Huang, 1995).

1.2.5 Medical Imaging Modality, PACS, and Imaging Informatics R&D Progress Over Time

Over the past 25 years three developments have mainly propelled the advancement of imaging modalities and the clinical acceptance of PACS. They are sizable funding to academe by the U.S. federal government for early key technology research and development, adoption of medical imaging standards by the imaging community, and manufacturers' developing workflow profiles for large-scale PACS operation. The large amount of imaging/data now available is enabling the next wave of innovation

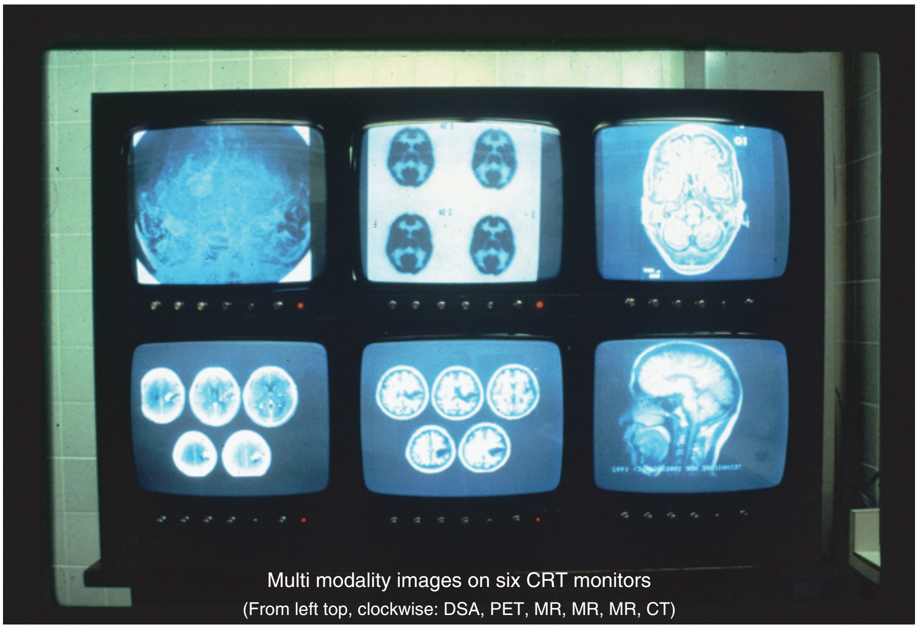

Figure 1.1r Display system showing six 512-line multiple modality images at UCLA.

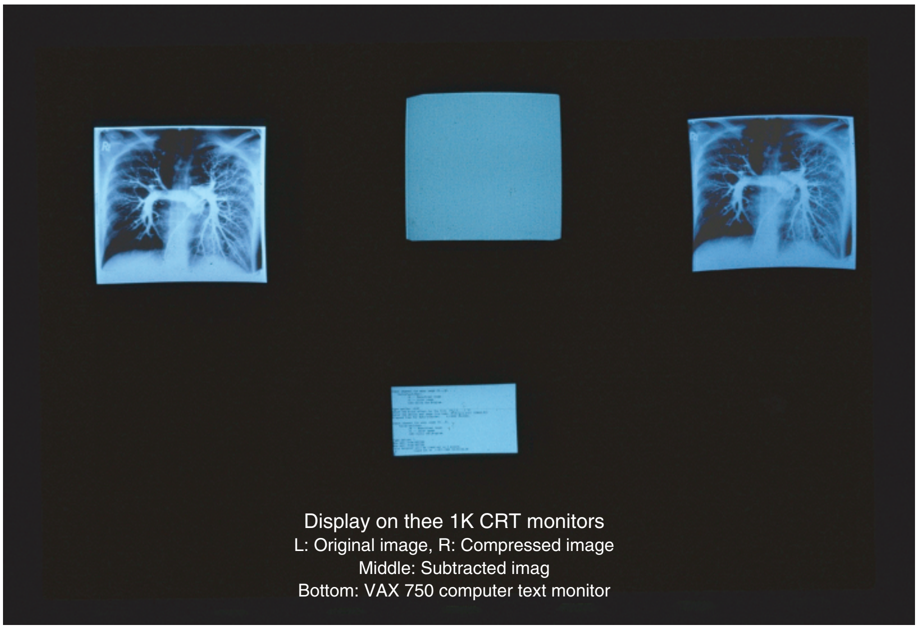

Figure 1.1s Gould system displaying three 1K images used in image compression study at UCLA: The original image (left); compressed (right); subtraction (middle). The system was the first to use for comparing the quality of compressed images with different compression ratios.

Figure 1.1t Gould DeAnza display controller (middle, blue) for a 1024-line 3-color display system (24 bits/pixel) with the VAX 750 (left) as the control computer.

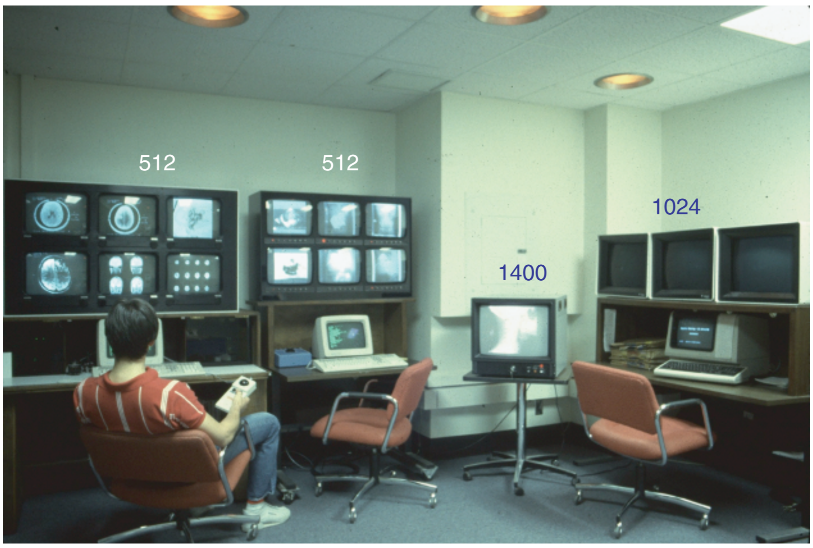

Figure 1.1u Workstation room with multiple resolution workstations at UCLA, with two six-monitor display systems (512×512), one three-monitor display system (1K x 1K), and one 1400 line single-monitor system by Mitsubishi. This workstation room was used to perform the first large-scale study in quality of image display with different spatial resolutions.

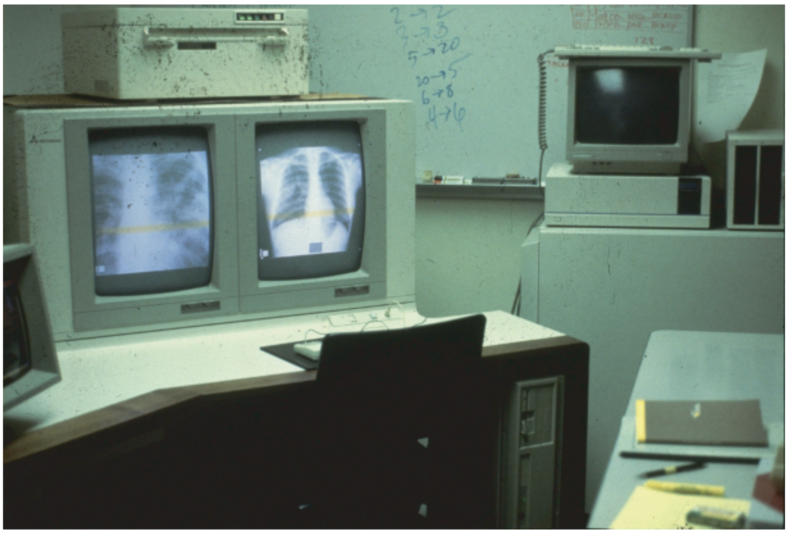

Figure 1.1v Early display system with two Megascan 2K monitors at UCLA.

and fruition of the concept of medical imaging informatics. Table 1.1 summarizes the progress made in imaging modalities, PACS, and imaging informatics R&D over time.

1.3 WHAT IS PACS?

1.3.1 PACS Design Concept

A picture archiving and communication system (PACS) consists of medical image and data acquisition, storage, and display subsystems integrated by digital networks and application software. It can be as simple as a film digitizer connected to several display workstations with a small image data base and storage device or as complex as an enterprise image management system. PACS developed in the late 1980s were designed mainly on an ad hoc basis to serve small subsets, called modules, of the total operation of a radiology department. Each PACS module functioned as an isolated island unable to communicate with other modules. Although the PACS concepts proved to work adequately for different radiology and clinical services, the piecemeal approach was weak because it did not address connectivity and cooperation between modules. This problem became exacerbated as more PACS modules were added to hospital networks. The maintenance, routing decisions, coordination of machines, fault tolerance, and expandability of the system became increasingly difficult to manage. This inadequacy of the early PACS design was due partially to a lack of understanding by the designers and implementers of PACS's potential for large-scale applications, clearly because at that time the many necessary PACS-related key technologies were not yet available.

PACS design, we now understand, should focus on system connectivity and workflow efficiency. A general multimedia data management system that is expandable, flexible, and versatile in its operation calls for both top-down

TABLE 1.1 Medical imaging, PACS, and imaging informatics R&D progress over time

Decade	R&D Progress
1980s	Medical imaging technology development • CR, MRI, CT, US, DR, WS, storage, networking
Late 1980s	Imaging systems integration • PACS, ACR/NEMA, DICOM, high-speed networks
Early 1990s	Integration of HIS/RIS/PACS • DICOM, HL7, Intranet and Internet
Late 1990s–present	Workflow and application servers • IHE, ePR, enterprise PACS, Web-based PACS
2000s–present	Imaging informatics • Computer-aided diagnosis (CAD), image contents indexing, • Knowledge base, decision support, • Image-assisted diagnosis and treatment

management to integrate various hospital information systems and a bottom-up engineering approach to build its foundation (i.e., PACS infrastructure). From the management point of view, a hospital-wide or enterprise PACS is attractive to administrators because it provides economic justification for implementing the system. Proponents of PACS are convinced that its ultimately favorable cost–benefit ratio should not be evaluated as the balance of the resource of the radiology department alone but should extend to the entire hospital or enterprise operation. As this concept has gained momentum, many hospitals, and some enterprise level healthcare entities around the world have been implementing large- scale PACS and have provided solid evidence that PACS does improve the efficiency of healthcare delivery and at the same time saves hospital operational costs. From the engineering point of view, the PACS infrastructure is the basic way to introduce such critical features as standardization, open architecture, expandability for future growth, connectivity, reliability, fault-tolerance, workflow efficiency, and cost effectiveness. This design approach can be modular with an infrastructure as described in the next section.

1.3.2 PACS Infrastructure Design

The PACS infrastructure design provides the necessary framework for the integration of distributed and heterogeneous imaging devices and makes possible intelligent database management of all patient-related information. Moreover it offers an efficient means of viewing, analyzing, and documenting study results, and thus a method for effectively communicating study results to the referring physicians. PACS infrastructure consists of a basic skeleton of hardware components (imaging device interfaces, storage devices, host computers, communication networks, and display systems) integrated by a standardized, flexible software system for communication, database management, storage management, job scheduling, interprocessor communication, error handling, and network monitoring. The infrastructure is versatile and can incorporate more complex research, clinical service, and education needs. The software modules of the infrastructure are embedded with sufficient learning capacity and interactivity at a system level to permit the components to work together as a system rather than as individual networked computers.

Hardware components include patient data servers, imaging modalities, data/modality interfaces, PACS controller with database and archive, and display workstations connected by communication networks for handling the efficient data/image flow in the PACS and satisfying the clinical workflow requirements. Image and data stored in the PACS can be extracted from the archive and transmitted to application servers for various uses. Nowadays PACS should also consider the enterprise level interconnectivity for image/data communication throughout several healthcare providers. Figure 1.2 shows the PACS basic components and data flow. This diagram will be expanded to finer details in later chapters. The PACS application servers and Web servers concepts are shown at the bottom of the diagram; these components enriche the role of PACS in the healthcare delivery system and have contributed to the advancement of PACS utilization over the past several years. These servers are cornerstones of PCAS- and DICOM-based imaging informatics.

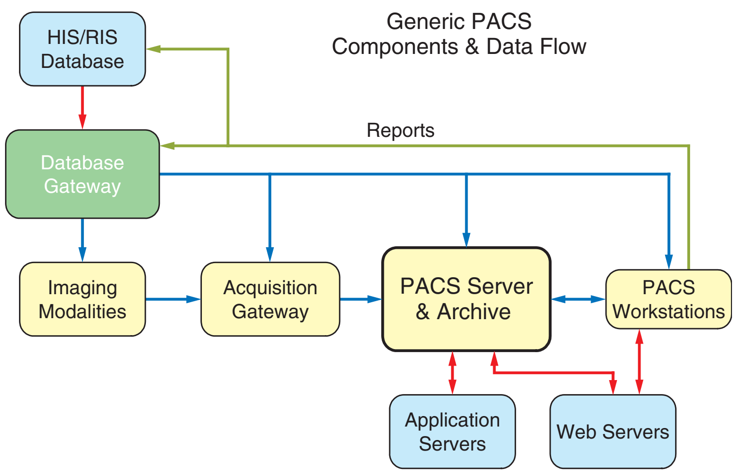

Figure 1.2 PACS basic components (yellow) and data flow (blue: internal; green and orange: external between PACS and other information systems); other information systems (light blue). HIS: Hospital Information System; RIS: Radiology Information System. System integration and clinical implementation are two other components necessary for implementation after the system is physically connected. Application servers and Web servers connected to the PACS server enrich the PACS infrastructure for other clinical, research and education applications.

1.4 PACS IMPLEMENTATION STRATEGIES

1.4.1 Background

The many technical and clinical components of PACS related to medical imaging form an integrated healthcare information technology (IT) system. For the past 20 years many hospitals and manufacturers in the United States and abroad have researched and developed PACS of varying complexity for daily clinical use. These systems can be loosely grouped into six models according to their methods of implementation as described next in the Section 1.4.2.

1.4.2 Six PACS Implementation Models

1.4.2.1 Home-Grown Model Most early PACS models were implemented by university hospitals, academic departments, and research laboratories of major imaging manufacturers. For implementation of a model a multidisciplinary team with technical knowledge was assembled by the radiology department or hospital. The team became a system integrator, selecting PACS components from various manufacturers. The team developed system interfaces and wrote the PACS software according to the clinical requirements of the hospital.

Such a model allowed the research team to continuously upgrade the system with state-of-the-art components. The system so designed was tailored to the clinical environment and could be upgraded without depending on the schedule of the manufacturer. However, a substantial commitment was required of the hospital to assemble the multidisciplinary team. In addition, since the system developed was to be one of a kind, consisting of components from different manufacturers, system service and maintenance proved to be difficult. Today PACS technology has so matured that very few institutions depend on this form of PACS implementation. Nevertheless, the development of specific PACS application servers shown in Figure 1.2 does require knowing the basic concept and construction of the model.

1.4.2.2 Two-Team Effort Model In the two-team model, a team of experts, both from outside and inside the hospital, is assembled to write detailed specifications for the PACS for a certain clinical environment. A manufacturer is contracted to implement the system. Such a model of team effort between the hospital and manufacturers was chosen by US military services when they initiated the Medical Diagnostic Imaging Support System (MDIS) concept in the late 1980s. The MDIS follows military procurement procedures in acquiring PACS for military hospitals and clinics.

The primary advantage of the two-team model is that the PACS specifications are tailored to a certain clinical environment, yet the responsibility for implementing is delegated to the manufacturer. The hospital acts as a purchasing agent and does not have to be concerned with the installation. However, there are disadvantages. Specifications written by a hospital team often tend to be overambitious because they underestimate the technical and operational difficulty in implementing certain clinical functions. The designated manufacturer, on the other hand, could lack clinical experience and thus overestimate the performance of each component. As a result the completed PACS will not meet the overall specifications. Also, because the cost of contracting the manufacturer to develop a specified PACS is high, only one such system can be built. For these reasons this model is being gradually replaced by the partnership model described in Section 1.4.2.4.

1.4.2.3 Turnkey Model The turnkey model is market driven. The manufacturer develops a turnkey PACS and installs it in a department for clinical use. The advantage of this model is that the cost of delivering a generic system tends to be lower. However, some manufacturers could see potential profit in developing a specialized turnkey PACS to promote the sale of other imaging equipment, like a CR (computed radiography) or DR (digital radiography).

Another disadvantage is that the manufacturer needs a couple of years to complete the equipment production cycle, the fast moving computer and communication technologies may render the PACS becomes obsolete after only several years of use. Further it is doubtful whether a generalized PACS can be used for every specialty in a single department and for every radiology department.

1.4.2.4 Partnership Model The partnership model is very suitable for large-scale PACS implementation. In this model the hospital and a manufacturer form a partnership to share the responsibility of implementation of a PCAS. Over the past few years, because of the availability of PACS clinical data, healthcare centers have learned to take advantages of the good and discard the bad features of a PACS for their clinical environments. As a result the boundaries between the aforementioned three implementation models have gradually fused resulting in the emergent partnership model. Because the healthcare center forms a partnership with a selected manufacturer or a system integrator, responsibility is shared in its PACS implementation, maintenance, service, training, and upgrading. The arrangement can be a long-term purchase with a maintenance contract, or a lease of the system. A tightly coupled partnership can even include the manufacturer training the hospital personnel in engineering, maintenance, and system upgrade. Financial responsibility is then shared by both parties.

1.4.2.5 The Application Service Provider (ASP) Model In the ASP model, a system integrator provides all PACS-related services to a client, which can be the entire hospital or a small radiology practice group. No on-site IT specialty is needed by the client. ASP is attractive for smaller subsets of the PACS, for examples, off-site archive, long-term image archive/retrieval or second copy archive, DICOM-Web server development, and Web-based image database. For larger comprehensive PACS implementations, the ASP model requires detailed investigation by the healthcare provider, and a suitable and reliable system integrator must be identified.

1.4.2.6 Open Source Model As PACS technologies have matured, specialties have gradually migrated to commodities, especially knowledge of the DICOM (Digital Imaging and Communication in Medicine) standard, IHE (Integrating the Healthcare Enterprise) workflow profiles, and Web technology. Many academic centers and some manufacturers R&D personnel have deposited their acquired knowledge in the public domain as open source software. This phenomenon encourages use of the home-grown model described in Section 1.4.2.1 whereby the healthcare providers utilize their in-house clinical and IT personnel to develop PACS application servers and Web servers described in Figure 1.2 These PACS components once were of the manufacturer's domain as the after sale add-on profits earned upon installing a PACS for the healthcare provider. Open source PACS related software has gained momentum in recent years among home-grown teams that develop special applications components of PACS and Web servers. For example, the healthcare provider would purchase off-the-shelf computer and communication hardware and use open source PACS software to develop in-house special PACS applications.

Each of these six models has its advantages and disadvantages. Table 1.2 summarizes the comparisons.

1.5 A GLOBAL VIEW OF PACS DEVELOPMENT

1.5.1 The United States

PACS development in the United States has benefited from four factors:

1. Many university research laboratories and small private companies that have entered the field since 1982 were supported by government agencies, venture capital, and IT industries.
2. The heaviest support of PACS implementation has come from the U.S. Department of Defense hospitals (Mogel, 2003) and the Department of Veterans Affairs (VA) Medical Center Enterprise (see Chapter 22 for more details).
3. A major imaging equipment and PACS manufacturer is US based.
4. Fast moving and successful small IT companies have contributed their innovative technologies to PACS development.

There are roughly 300 large and small PAC systems in use today. Nearly every new hospital being built or designed has a PACS implementation plan attached to its architectural blue prints.

1.5.2 Europe

PACS development in Europe has advanced remarkably:

1. Hospital information system- and PACS- related research and development were introduced to European institutions in the early 1980s.
2. Three major PACS manufactures are based in Europe.
3. Two major PACS-related annual conferences, EuroPACS and CARS, are based in Europe.

Many innovative PACS-related technologies were even invented in Europe. Still there are presently far more working PACS installations in the United States than in Europe. Lemke studied the factors that may account for this phenomenon and came up with results shown in Table 1.3 (Lemke, 2003). However, over the past five years European countries have recognized the importance of PACS contribution to regional healthcare, so inter-hospital communications have led to an enterprise-level PACS concept and development. The United Kingdom, Sweden, Norway, Finland, France, Italy, Austria, Germany, and Spain are all developing PACS for large-scale

TABLE 1.2 Advantages and disadvantages of six PACS implementation models

Method	Advantages	Disadvantages
Home-Grown system	Built to specifications State-of-the-art technology Continuously upgrading Not dependent on a single manufacturer	Difficult to assemble a team One-of-a-kind system Difficult to service and maintain
Two-team effort	Specifications written for a certain clinical environment Implementation delegated to the manufacturer	Specifications overambitious Underestimated technical and operational difficulty Manufacturer lacks clinical experience Expensive
Turnkey	Lower cost Easier maintenance	Too general Not state-of-the-art technology
Partnership	System will keep up with technology advancement Health center does not deal with the system becoming obsolete, but depends on manufacturer's long-term service contract	Expensive to the health center, Manufacturer may not want to sign a partnership contract with less prominent center Center has to consider the longevity and stability of the manufacturer
ASP	Minimizes initial capital cost May accelerate potential return on investment No risk of technology obsolescence Provides flexible growth No space requirement in data center	More expensive over 2–4 year time frame comparing to a capital purchase Customer has no ownership in equipment
Open source	Healthcare provider purchases computer and communication equipment Good for special PACS application server Lower cost	Open source software may not be robust for daily clinical use Maintenance and upgrade of the software may be a problem May not be good for a full large-scale PACS

enterprises, typically at the province or state level; many PACS implementation models have been installed or are in the implementation stage.

1.5.3 Asia

Driving PACS development in Asia are Japan, South Korea, and Taiwan as well as China including Hong Kong. Japan entered PACS research, development, and

TABLE 1.3 Nine positive factors (for the United States) and hindering factors (for Europe) related to PACS implementation

Favorable Factors in USA	Hindering Factors in Europe
Flexible investment culture	Preservation of workplace culture
Business infrastructure of health care	Social service oriented healthcare
Calculated risk mindedness	Security mindedness
Competitive environment control	Government and/or professional associates
Technological leadership drive	No change “if it works manually”
Speed of service oriented	Quality of service oriented
Include PACS experts consultants	“Do it yourself” mentality
“Trial-and-error” approach	“Wait and see” approach
Personal gain driven	If it fails “Find someone to blame”

implementation in 1982. According to a survey by Inamura (2003), as of 2002 there are a total of 1468 PACS in Japan:

- Small: 1174 (fewer than 4 display workstations)
- Medium: 203 (5–14 display workstations)
- Large: 91 (15–1300 display workstations)

Some of the large PACS systems are the result of legacy PAC systems being interconnected with newer PAC systems. Earlier Japan PAC systems were not necessarily DICOM compliant, nor connected to HIS. Recently, however, more PAC systems are adhering to the DICOM standard and coupling HIS, RIS, and PACS.

South Korea’s large-scale countrywise PACS development was almost a miracle. Its fast growth path of PACS development over the past seven years occurred despite no domestic X-ray film industry, an economic crisis in 1997, and the National Health Insurance PACS Reimbursement Act. We will return to study this case in more depth in later chapters (Huang, 2003b).

The third major development of PACS in Asia over the past five years involves China, Hong Kong, and Taiwan. China mainland has installed many small- and medium-size PAC systems even though their HIS and RIS are still lacking maturity. A major contribution to PACS in Asia is the ePR (electronic patient record) with image distribution technology developed by the Hong Kong Hospital Authority (HKHA). This system has been gradually implemented hospital-by-hospital in 44 hospitals since the early 2000s (Cheung, 2005). A case study will be described in Chapter 22. Taiwan has had many large- and medium-scale PACSs and ePRs designed and implemented by local PACS manufacturers throughout the island since the late 1990s.

1.6 ORGANIZATION OF THE BOOK

This book consists of an introductory chapter and four parts. Figure 1.3, shows the organization of this book. In Part I are covered the principles of medical imaging

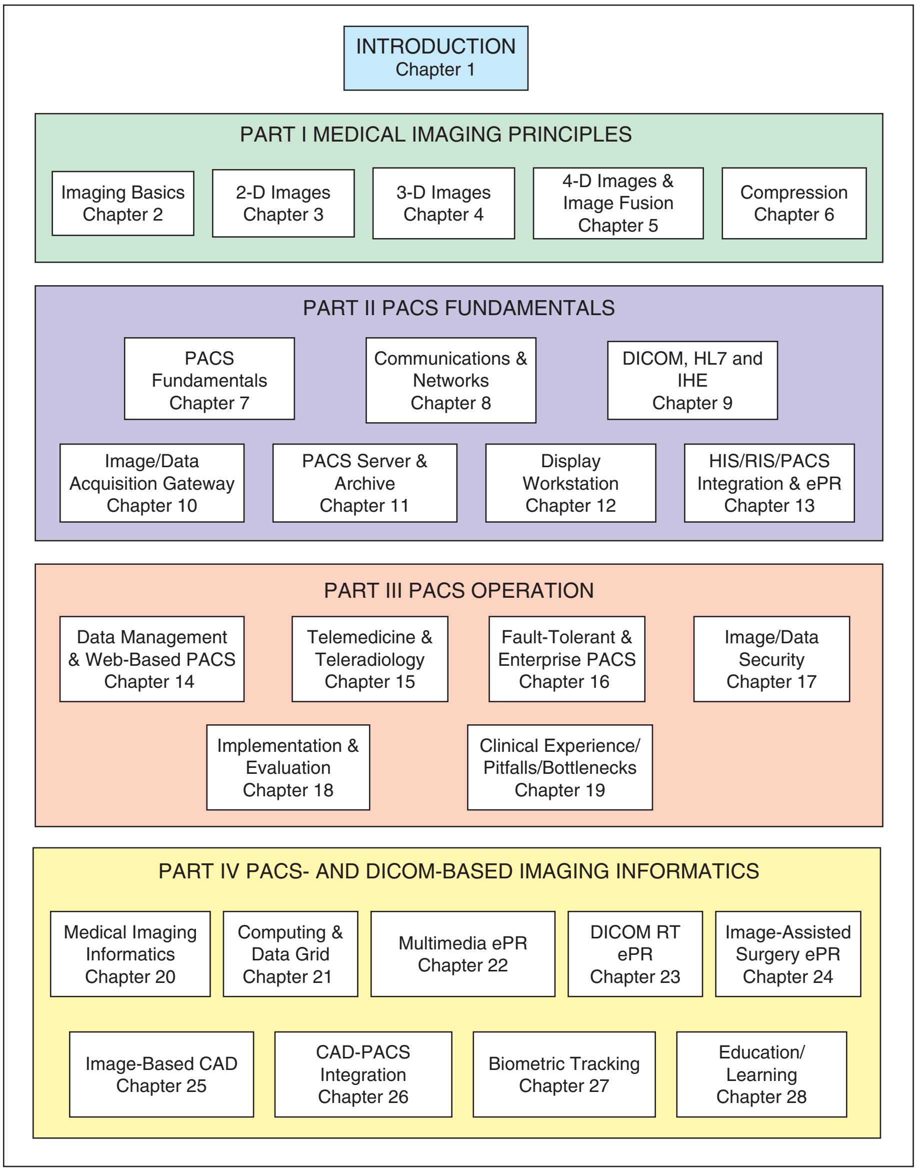

Figure 1.3 Organization of the book.

technology. Chapter 2 describes the fundamentals of digital radiological imaging. It is assumed that the reader already has some basic background in conventional radiographic physics. This chapter introduces the terminology used in digital radiological imaging with examples. Familiarizing oneself with this terminology will facilitate the reading of later chapters.

Chapters 3, 4, and 5 discuss commonly used radiological and medical light imaging acquisition systems. The concepts of patient workflow and data workflow are also introduced. Chapter 3 presents two-dimensional (2-D) projection images. Since radiography still accounts for over 60% of current examinations in a typical radiology department, methods of obtaining digital output from radiographs are crucial for the success of implementing a PACS. For this reason laser film scanner, digital fluorography, laser-stimulated luminescence phosphor imaging plate (computed radiography), and digital radiography (DR) technologies, including full-field direct digital mammography are discussed. In addition 2-D nuclear medicine and ultrasound imaging are presented, followed by 2-D microscopic and endoscopic light imaging; all these are today used extensively in medical diagnosis and image-assisted therapy and treatment.

Chapter 4 presents three-dimensional (3-D) imaging. The third dimension in 3-D imaging can be space (x, y, z) or time (x, y, t). The concept of image reconstruction from projections is first introduced, followed by the basic physics involved in transmission and emission computed tomography (CT), ultrasound (US) imaging, magnetic resonance imaging (MRI), and light imaging.

Chapter 5 discusses four-dimensional (4-D) imaging. If 3-D imaging represents a 3-D space volume of the anatomical structure, the fourth dimension then is the time component (x, y, z, t), and it accounts for the fusion of images from different modalities. Developing effective methods of displaying a 4-D volume set with many images on a 2-D display device is challenging, as is discussed in Chapter 12.

Chapters 3, 4, and 5 nevertheless do not provide comprehensive treatment of 2-D, 3-D, and 4-D imaging. The purpose of these chapters is to review the basic imaging and informatics terminologies commonly encountered in medical imaging; these chapters emphasize the digital and communication aspects, and not of the physics and formation of the images. Understanding the basics of the digital procedure of these imaging modalities facilitates PACS design and implementation, as well as imaging informatics applications. A thorough understanding of digital imaging is essential for interfacing these imaging modalities to a PACS and for utilizing image databases for clinical applications.

Chapter 6 covers image compression. After an image or an image set has been captured in digital form from an acquisition device, it is transmitted to a storage device for long-term archiving. A digital image file requires a large storage capacity for archiving. For example, a two-view computed radiography (CR) or an average computed tomography (CT) study comprises over 20 to 40 Mbytes. Therefore it is necessary to consider how to compress an image file into a compact form before storage or transmission. The concept of reversible (lossless) and irreversible (lossy) compression are discussed in detail followed by the description of cosine and wavelet transformation compression methods. Techniques are also discussed on how to handle 3-D and 4-D data sets that often occur in dynamic imaging.

In Part II PACS fundamentals are introduced. Chapter 7 covers PACS components, architecture, workflow, operation models, and the concept of image-based electronic patient records (ePR). These PACS fundamentals are discussed further in next chapters. Chapter 8 is on image communications and networking. The latest technology in digital communications using asynchronous transfer mode (ATM), gigabit Ethernet, and Internet 2 technologies is described. In Chapter 9 industrial standards and protocols are introduced. For medical data, HL7 (Health Level), is reviewed. For image format and communication protocols ACR-NEMA (American College of Radiology–National Electrical Manufacturers Association) standard is briefly mentioned followed by a detailed discussion of the DICOM

(Digital Imaging and Communication in Medicine) standard that has been adopted by the PACS community. IHE (Integrating of Healthcare Enterprise) workflow protocols, which allow smooth workflow execution between PACS, DICOM components, are described with examples. HL7, DICOM, and IHE have been well documented, the purpose of Chapter 9 is to explain the concepts and guide the reader on how to use the documents and search for details.

Chapter 10 presents the image acquisition gateway. It covers the systematic method of interfacing imaging acquisition devices using the HL 7 and DICOM standards, and discusses automatic error recovery schemes. The concept of the DICOM Broker is introduced, which allows the direct transfer of patient information from the hospital information system (HIS) to the imaging device, eliminating potential typographical errors by the radiographer/technologist at the imaging device console.

Chapter 11 presents the DICOM PACS server and image archive. The PACS image management design concept and software are first discussed, followed by the presentation of storage technologies essential for PACS operation. Four archive concepts: off-site backup, ASP (application service provider) backup, data migration, and disaster recovery are presented.

Chapter 12 is on image display. A historical review of the development of image display is introduced, followed a discussion on types of workstations. The DICOM PC-based display workstation is presented. LCD (liquid crystal display) is gradually replacing the CRT (cathode ray tube) for display of medical images, so a review of this technology is given. The challenges and methods of displaying 3-D and 4-D image set with many images per set, as well as data flow in real-time image-assisted therapy and treatment are discussed.

Chapter 13 describes the integration of PACS with the hospital information system (HIS), the radiology information system (RIS), and other medical databases, including voice recognition. This chapter forms the cornerstones for the extension of PACS modules to hospital-integrated PACS, and to the enterprise-level PACS.

In Part III the chapters focus on PACS operation. Chapter 14 presents PACS data management, distribution, and retrieval. The concept of Web-based PACS and its dataflow are introduced. Web-based PACS can be used to cost-effectively populate the number of image workstations throughout the whole hospital and the enterprise, and be integrated with the ePR system with image distribution.

Chapter 15 describes Telemedicine and teleradiology. State-of-the-art technologies are given, including the Internet 2 and teleradiology service models. Some important issues in teleradiology regarding cost, quality, and medical-legal issues are discussed, as well as current concepts in telemammography and telemicroscopy.

Chapter 16 explains the concept of fault-tolerance and enterprise PACS. Causes of PACS failure are first listed, followed by explanations of no loss of image data and no interruption of the PACS dataflow. Current PACS technology in addressing fault-tolerance is presented. The full discussion of continuous available (CA) PACS design is given along with an example of a CA PACS archive server. The basic infrastructures of enterprise-level PACS and business models are also covered.

Chapter 17 considers the concept of image data security. Data security has become an important issue in tele-health and teleradiology, which use public high-speed wide area networks connecting examination sites with expert centers. This chapter reviews current available data security technology and discusses the concept of image digital signature.

Chapter 18 describes PACS implementation and system evaluation. Both the institutional and manufacturer's point of view in PACS implementation are discussed. Some standard methodologies in the PACS system implementation, acceptance, and evaluation are given.

Chapter 19 describes some PACS clinical experience, pitfalls, and bottlenecks. For clinical experience, special interest is shown for hospital-wise performance. For pitfalls and bottlenecks, some commonly encountered situations are illustrated and remedies recommended.

In Part IV the book ends with much up-dated discussion of PACS- and DICOM-based imaging informatics. This part has been greatly expanded from four chapters in the original book to the current nine chapters. The imaging informatics topics discussed include computing and data grid, ePR, image-assisted therapy and treatment, CADe/CADx (computer-aided detection/diagnosis), biometric tracking, and education. Chapter 20 describes the PACS- and DICOM-based imaging informatics concept and infrastructure. Several examples are used to illustrate components and their connectivity in the infrastructure. Chapter 21 presents Data Grid and its utilization in PACS and imaging informatics.

Chapter 22 presents ePR with image distribution. Two examples are used to illustrate its connectivity to PACS, and methods of image distribution. The discussion picks up the example given in Chapter 16 and follows its PACS workflow to image distribution using the Web-based ePR system.

Chapters 23 and 24 discuss two treatment-based ePR systems, one for radiation therapy (RT) applications and the second for image-assisted surgery. In RT ePR, the DICOM-RT is introduced to form the foundation of a DICOM-based RT ePR. In image-assisted surgery, minimally invasive spinal surgery is used to introduce the concept of digital pre-surgical consultation authoring, real-time intra-operative image/data collection and post-surgical patient outcome analysis. Chapters 25 and 26 are on PACS-based computer-aided detection/diagnosis (CADe/CADx), and CAD-PACS integration, respectively. Chapter 25 focuses on case studies, to demonstrate how a CAD is developed for daily clinical use, starting from problem definition, CAD algorithms, data collection for CAD validation, validation methodology, and ending with clinical evaluation. Chapter 26 presents methods of connecting CAD results to the PACS seamlessly for daily clinical use without interrupting its normal workflow.

Chapter 27 presents the concept of patient and staff member tracking in clinical environment, using the biometric parameters of the subject. In Chapters 22 through 27, the emphasis is on the connectivity of the informatics components with PACS, as shown in Figure 1.3. In these chapters the theory, concept, and goals are first defined, followed by methodology used for solving the problems, and concluded with actual examples.

Chapter 28 first discusses PACS training, and then expands the training methodology to include medical imaging informatics. Five topics are presented: new directions in PACS and imaging informatics education and training; examples of PACS and Imaging Informatics Training Program; concept of the PACS Simulator; teaching Medical Imaging Informatics for interdisciplinary candidates; and changing PACS learning with new interactive and media-rich learning environments.

References

Bauman RA, Gell G, Dwyer SJ III. Large picture arching and communication systems of the world—Parts 1 and 2. *J Digital Imag* 9(3,4): 99–103, 172–7; 1996.

Brody WR., ed. Conference on Digital Radiography. *Proc SPIE* 314: 14–16; 1981.

Capp MP, Nudelman S, et al. Photoelectronic radiology department. *Proc SPIE* 314: 2–8, 1981.

Cheung NT, Lam A, et al., Integrating Images into the electronic patient record of the Hospital Authority of Hong Kong. *Comp Med Imag Graph* 29(2–3): 137–42; 2005.

Digital Imaging and Communications in Medicine (DICOM). National Electrical Manufacturers' Association. Rosslyn, VA: NEMA, 1996; PS 3.1.

Duerinckx A, ed. Picture archiving and communication systems (PACS) for medical applications. *First Int Conf Workshop. Proc SPIE* 318(1–2); 1982.

Dwyer SJ III, et al. Cost of managing digital diagnostic images. *Radiology* 144: 313; 1982.

Hruby W, Maltsidis A. A view to the past of the future—a decade of digital revolution at the Danube hospital. In: Hruby W, ed. *Digital Revolution in Radiology*. Vienna: Springer; 2000.

Huang HK. *Elements of Digital Radiology: A Professional Handbook and Guide*. Englewood Cliffs, NJ: Prentice-Hall; 1987.

Huang HK. 1991a. Editorial: Picture and communication systems. *Comp Med Imag Graph* 15(3): 133; 1991a.

Huang HK, Ratib O, et al. *Picture Archiving and Communication System (PACS)*. Berlin: Springer 1991b.

Huang HK. *Picture Archiving and Communication Systems: Principles and Applications*. New York: Wiley; 1999, p. 521.

Huang HK. 2003a. Editorial: Some historical remarks on picture and communication systems. *Comp Med Imag Graph* 27(2–3): 93–9; 2003a.

Huang HK. Enterprise PACS and image distribution. *Comp Med Imag Graph* 27(2–3): 241–53; 2003b.

Huang HK. *PACS and Imaging Informatics: Principles and Applications*. Hoboken, NJ: Wiley; 2004.

Inamura K. PACS development in Asia. *Comp Med Imag Graph* 27(2–3): 121–8; 2003.

JAMIT. First International Symposium on PACS and PHD. *Proc. Med Imag Tech* 1; 1983.

Law M, Huang HK. Concept of a PACS and imaging informatics-based server for radiation therapy. *Comp Med Imag Graph* 27: 1–9; 2003.

Lemke HU, A network of medical work stations for integrated word and picture communication in clinical medicine. Technical report. Technical University Berlin; 1979.

Lemke HU, Vannier MW, et al. Computer assisted radiology and surgery (CARS). *Proc 16th Int Congr Exhibit* Paris. CARS 2002.

Lemke HU. PACS development in Europe. *Comp Med Imag Graph* 27(2–3): 111–20; 2003.

MITRE/ARMY. RFP B52-15645 for University Medical Center Installation Sites for Digtial Imaging Network and Picture Archiving and Communication System (DIN/PACS), October 18, 1986.

Mogel GT. The role of the Department of Defense in PACS and telemedicine research and development. *Comp Med Imag Graph* 27(2–3): 129–35; 2003.

Mun SK, ed. Image management and communication. *The First International Conference* Washington, DC: 1989. IEEE Computer Society Press; 1989.

Niinimaki J, Ilkko E, Reponen J. *Proc 20th EuroPACS* Oulu, Finland, EuroPACS; 2002

Steckel RJ. Daily X-ray rounds in a large teaching hospital using high-resolution closed-circuit television. *Radiology* 105: 319–21; 1972.