The National Institutes of Health Clinical Center Digital Imaging Network, Picture Archival and Communication System, and Radiology Information System

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In this work, we describe the digital imaging network (DIN), picture archival and communication system (PACS), and radiology information system (RIS) currently being implemented at the Clinical Center, National Institutes of Health (NIH). These systems are presently in clinical operation. The DIN is a redundant meshed network designed to address gigabit density and expected high bandwidth requirements for image transfer and server aggregation. The PACS projected workload is 5.0 TB of new imaging data per year. Its architecture consists of a central, high-throughput Digital Imaging and Communications in Medicine (DICOM) data repository and distributed redundant array of inexpensive disks (RAID) servers employing fiber-channel technology for immediate delivery of imaging data. On demand distribution of images and reports to clinicians and researchers is accomplished via a clustered web server. The RIS follows a client-server model and provides tools to order exams, schedule resources, retrieve and review results, and generate management reports. The RIS-hospital information system (HIS) interfaces include admissions, discharges, and transfers (ATDs)/demographics, orders, appointment notifications, doctors update, and results.

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IN THIS WORK, we describe the digital imaging network (DIN), picture archival and communication system (PACS), and radiology information system (RIS) currently being deployed at the Clinical Center, National Institutes of Health (NIH). The first phase of the NIH Clinical Center DIN/PACS/RIS solution was implemented within a 10-month period and followed a master plan that started with the issuance of a PACS Request for Proposal (RFP).¹ During this initial phase, all systems were brought into "live state," ie, into clinical operation.

Historically, the deployment of a modern RIS and implementation of a fast DIN at the NIH Clinical Center were driven by needs created by a PACS environment. In fact, we consider a RIS and a properly sized DIN mandatory prerequisites for an enterprise-wide PACS. The RIS, in turn, has its own prerequisites that are related to the existence of a bidirectional messaging mechanism with the hospital information system (HIS), preferably using electronic data sharing standards such as Health Level 7 (HL-7).² Once the RIS/HIS and

associated interfaces are in place, as well as a network capable of handling imaging density, then one is ready to start a successful deployment of an enterprise-wide PACS. This statement does not imply that the physical implementation of these systems should happen in a serial fashion. Actually, in our case, all of these systems were implemented in parallel, yielding greater economies of scale and resource optimization.

RADIOLOGY INFORMATION SYSTEM

The RIS follows a client-server model and provides tools to order examinations, schedule resources, retrieve and review results (including images, as an option), chart clinical data, and generate management reports. The RIS also offers interesting possibilities related to increased research support. The benefits yielded by a well-design, well-deployed RIS are associated with enhancements in the quality of radiologic services, improvements in data access, potential cost reductions, and improvements in operational processes. Ultimately, the goal of our DIN/PACS/RIS project is to improve workflow within the enterprise.

In order to allow interoperability across the enterprise, the RIS must be integrated or, at least, interfaced to other medical information systems and mission-critical legacy systems. Our RIS interfaces include a PACS/RIS broker engine, a bidirectional interface to the digital dictation system, and several bidirectional interfaces to the HIS including incoming/outgoing admissions, discharges, and transfers (ATDs/demographics), orders (with statuses), appointment notifications, doctors update lists, and results interface. At a

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minimum, the RIS must be interfaced to incoming ATDs/demographics and incoming orders from the HIS, bidirectionally interfaced to the digital dictation system (results), and interfaced to the PACS. The basic interfacing between RIS and PACS enables the automated pre-fetching of prior imaging data (according to user defined rules) every time the RIS receives a new order (from HIS), and also allows the display of current and prior RIS reports within the PACS application.

The development of the RIS interfaces was one of the most critical components of our PACS/RIS project. This task depends on the timely collaboration between different sections within the enterprise (at a minimum, the Radiology and Information Systems departments), as well as collaboration among internal staff, vendors, and support teams representing the different information systems. Early involvement of all these participating entities is essential for the timely development of the RIS interfaces. Other crucial steps within our RIS project included the building of the RIS database and development of the user interfaces (application screens). These tasks, in general, preceded the

development of the RIS interfaces and relied on the expertise provided by the enterprise staff and seasoned application developers. This is a great opportunity to analyze how processes are currently being handled within the enterprise and to improve on them. Just mimicking current paper-based processes in digital format may not adequately deliver improvements in data access, operational enhancements, and enrichment in the quality of radiologic services. This is clearly a unique opportunity that has to be recognized, studied, and harnessed by all participating entities. Again, early involvement of all stakeholders is critical. Finally, in addition to the database building and development of the RIS interfaces, all participating parties should also be involved, as early as possible, in the planning and execution of the HIS/RIS/PACS integration testing, parallel testing, and operational monitoring.

DIGITAL IMAGING NETWORK

The DIN is a redundant meshed network capable of gigabit processing with full-duplex 4-GB backbone and 32-GB backplane (Fig 1). It supports multiple protocols and virtual local area network

Fig 1. The DIN is a fully redundant meshed network capable of gigabit processing with full-duplex 4-GB backbone and 32-GB backplane. It supports multiple protocols, VLAN switching, redundant gigabit firewall, and VPN encryption. It connects to the main campus backbone via a gigabit up-link.

(VLAN) switching. The network design was created to address gigabit density and the expected high bandwidth requirements for image transfer and server aggregation. The engineered (but not yet deployed) data safety mechanisms include a redundant gigabit firewall, virtual private network (VPN) encryption, and the use of secure ID (authentication) servers. Operating procedures complement the deployed hardware and software security solutions. This local area network (LAN) connects to the NIH campus-wide fiber backbone via a gigabit up-link. For additional protection, a firewall sits between the imaging LAN and the campus fiber-distributed data interface (FDDI) backbone.

Other large academic medical centers and multisite hospitals may not need to deploy a dedicated LAN to support their PACS environment. These sites may leverage on their existing information systems resources, often including a campus-wide digital data network delivering 10/100 Mbp to all enterprise desktops, gigabit backbone, and associated security. If that is the case of your (lucky) site, then new networking efforts should be directed to optimizing network support for the PACS/RIS computer room. However, if the enterprise-wide network cannot handle imaging traffic, then basic network infrastructure needs to be deployed prior to layering out a digital imaging operation.

PICTURE ARCHIVAL AND COMMUNICATION SYSTEM

Once fully integrated with all acquisition systems, the PACS will embrace more than 40 different imaging modalities, including 13 magnetic resonance (MR), three computed radiography (CR), three computed tomography (CT), one digital radiography (DR), and eight ultrasound units, as well as five nuclear medicine cameras, three positron emission tomography (PET) scanners, two film digitizers, and angio and fluoro units. Current integration efforts include approximately 60% of our existing imaging modalities. Projected workload is around 5 TB of new imaging data per year (uncompressed). The PACS architecture consists of a central, high-volume, high-throughput Digital Imaging and Communication in Medicine (DICOM) data repository and distributed redundant array of inexpensive disks (RAID) servers employing fiber-channel technology for immediate delivery of recently acquired images. The PACS product line

includes 16 high-resolution multidisplay diagnostic workstations for primary interpretation, about 20 software licenses for clinical review, and a clustered web server that is capable of providing full-fidelity DICOM or user-defined compressed JPEG images to the entire enterprise. The web product allows secure, fast distribution of images and reports to clinicians and researchers inside (and outside) the NIH campus. The Web distribution piece, however, does not allow downloading entire studies (as DICOM) into a local disk for further processing. This functionality is limited to single, individual images. Although this may be adequate for publication purposes, it is often not enough for assisting in the creation of teaching files or fulfilling the needs of image processing groups.

PACS Subsystems

The PACS has several components that may be grouped into functional subsystems. To that effect, we have adopted a variation of the nomenclature specified by the Department of Defense³ functionally dividing the PACS into an image acquisition subsystem, a network/security subsystem, an archival/management subsystem, and a display/processing subsystem. Each of these subsystems is composed of several pieces of hardware and software, with some of these items spanning over multiple subsystems. With each subsystem performing as designed and properly interfacing to one another, one can obtain a high degree of system automation and robustness, and achieve better image management and better workflow. These features, in turn, have the potential to increase system accuracy, throughput, and, ultimately, improve patient care.

Image acquisition subsystem. The preferred way to interface imaging modalities to the PACS is through utilization of the DICOM standard. For those modalities that do not support the DICOM standard, video capturing or frame-grabbing technologies may offer an (inferior) alternative. Like film digitization, these secondary capture systems often degrade the image quality. At the NIH Clinical Center, all MRs, CTs, CRs, DRs, and PET scanners support a direct DICOM connection to the PACS. However, in the Ultrasound and Nuclear Medicine Sections, the DICOM connectivity to the main PACS is provided by local mini-PACS. These systems convert the original output generated by ultrasonic and nuclear cameras into the

DICOM format prior to sending data to the main PACS archive. The mini-PACS environment presents advantages related to image manipulation and display, however, it also adds the complexity of integrating yet another system into the overall digital imaging solution.

Another important feature of new imaging acquisition systems is the ability to communicate directly with the HIS/RIS systems, allowing electronic entry of patient and study information, as well as scheduling information directly into the scanners, a process known as DICOM modality worklist management. This process provides major workflow improvements—it reduces the number of data entry errors and time spent on corrections and system administration. Unfortunately, only a handful of our imaging systems currently support DICOM modality worklist. Another desirable function not widely available within our environment is support for DICOM performed procedure step.

Network and security subsystem. This subsystem was described in detail earlier. The size and configuration of the network is, in general, driven by the PACS architecture. At the NIH Clinical Center, a *centralized* architecture, using an *on-demand* image distribution method (described be-

low) has been adopted. Bandwidth requirements are high since all data must travel over the network at the time of request. To alleviate potential bottlenecks, one may compress the data prior to transmission and/or distribute data packets through multiple communication channels using fiber-channel technology, for example. A *distributed* network architecture could also have been adopted; however, we felt a distributed architecture is a better fit for *routed* image distribution methods where bandwidth requirements are smaller than for on-demand PACS.

Archival and management subsystem. As mentioned earlier, we adopted an on-demand image distribution with centralized architecture. The workflow under this configuration starts with images being sent from the imaging modalities to a (redundant) central database server, which in turn pitches data to the RAID. The data are then copied into a digital linear tape (DLT) library for long-term storage. Users located at any workstation can query the database server to immediately fetch (typically, under 2 seconds per study) any image in the system—either new data or pre-fetched studies. Users can also issue DICOM queries for data stored in the long-term archive (where typical

Fig 2. Workflow using an on-demand image distribution scheme with a centralized network architecture. (A) Images are acquired by imaging modalities, (B) sent to a redundant database server, and (C) associated RAID. (D) Data are copied into a DLT library for long-term storage. (E) Users located at any workstation can immediately fetch any study in the RAID system or issue DICOM queries to the long-term archive. Downstream data from RAID to the diagnostic workstations travel through parallel fiber channels drastically improving data delivery.

retrieval times are < 5 minutes). Figure 2 summarizes our workflow using an on-demand image distribution scheme with a centralized network architecture.

In addition to deploying the new archival and management subsystems, we also engaged in the migration of our homegrown DICOM data depository. This legacy system contains approximately 5.0 TB of DICOM data and a migration strategy has been devised achieving throughput of 0.3 sec/image. Although highly automated, this is still a time-consuming process. It does, however, provide the needed priors to our new PACS.

Display and processing subsystem. The diagnostic workstations are multiprocessor NT-based systems that can be used to select images for review, to view the images, to manipulate the data presented, and to document findings. The last action may or may not be performed at the PACS workstation depending on the degree of integration with the RIS and the digital dictation system or voice recognition system. Image selection can be accomplished by sorting a study list, or worklist, using patient information, date of study, accession number, modality, body part, etc. In highly integrated systems, a singular worklist is available for the PACS and RIS applications. In interfaced systems, like ours, worklists are updated between systems and a master patient list is maintained by the RIS. Images selected are displayed in the workstation monitors and several tools are available for image manipulation, annotation, magnification, etc. Pre-fetched priors used for comparison are also displayed according to user-selected hanging protocols. Basic image processing tools are available, including linear measurements, contrast, brightness, and thresholding. The current PACS workstations, however, are considered relatively poor in image processing features and do not include many desirable image processing routines. More re-

cently, PACS vendors started offering several image processing features as options to their systems, including 3D, maximum intensity projection (MIP), and registration of digital orthopedic templates.

CONCLUDING STATEMENTS

Our main goal with the NIH Clinical Center PACS/RIS project is to improve workflow. In particular, the timely delivery of radiologic images and reports to our clinicians and referring physicians. Additional goals include increased support for research activities within our large imaging research environment. These requirements impose serious demands on our operations, as well as on the hardware and software tools deployed. These systems must comply with industry-wide standards for clinical information systems such as HL-7 and DICOM; however, they must remain adaptable to a changing research environment with variable workload and diverse imaging protocols. At its current state, the NIH Clinical Center PACS/RIS provides an architecture for softcopy interpretation of imaging exams and supports the clinical imaging workload of the Clinical Center. The interfacing mechanism between PACS and RIS and HIS provides a continuous record of all radiologic-based care. Finally, the research efforts of the NIH clinicians and investigators are supported through the streamlined archival of all radiologic data, including tools to search and retrieve research data sets.

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