Evolution of a Filmless Digital Imaging and Communications in Medicine-Conformant Picture Archiving and Communications System: Design Issues and Lessons Learned Over the Last 3 Years

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This presentation describes our experience and lessons learned over the first 3 years of developing and operating a filmless picture archiving and communications system (PACS) for all computed tomography (CT), magnetic resonance (MR), ultrasound, and nuclear medicine studies in our hospital. The PACS conforms to the Digital Imaging and Communications in Medicine (DICOM) standard and includes a sophisticated Worldwide Web (WWW)-based interface to complement the regular DICOM services. The PACS has undergone many design modifications from its inception, which have addressed performance, functionality, support, and maintenance issues. The lessons we have learned through making these modifications are described here and may prove to be helpful to anyone planning to deploy a PACS of their own.

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THIS PRESENTATION describes our experience in developing a picture archiving and communications system (PACS) conforming to the Digital Imaging and Communications in Medicine (DICOM) standard and how it has evolved over the past 3 years during which films have been eliminated in ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), and nuclear medicine. In late 1995, we decided to develop and implement our own ultrasound mini-PACS.¹ The success of this system, both financially and clinically, and the confidence we gained technically, led to the decision (in mid-1996) to extend the project to include CT and MRI.

A key difference between this new system and the ultrasound PACS was our new found commitment to follow the DICOM standard, version 3.0 (see: <http://www.nema.org/nema/medical/dicom/>). In February of 1997, after 5 months of development (10 person-months), the PACS was implemented

and films were eliminated entirely in CT and MRI. By virtue of working directly with the users of the PACS, the development team has been guided by the experience of working in a clinical environment where there is no permitted recourse to film. Consequently, the total reliance of our users on the PACS has served to highlight weaknesses and design flaws, yielding many insights that have helped to guide its evolution.

Having 3 years of experience in developing, implementing, and supporting a truly filmless PACS has yielded the almost unique opportunity to candidly share the lessons we have learned, including what we believe to be our mistakes and triumphs. In so doing, we hope to convey an understanding of PACS that will be useful to those who may soon be implementing a PACS of their own, whether from a commercial vendor or not.

METHODS

The PACS itself employs a distributed design with specialized "servers" dedicated to the acquisition of images from the scanners; archival; retrieval; database management, and provision of several worldwide web (WWW)-based utilities. Detailed descriptions can be found in Cox et al.² Every server runs the LINUX operating system (see: <http://www.fsf.org/home.html>). For our initial implementation of the PACS at the Montreal General Hospital, we elected to purchase eight dual-monitor Unix-based diagnostic review workstations from a commercial vendor. Until only recently, there was no link to a radiology or hospital information system (HIS). The link that is now in place has greatly benefited the PACS in ways that we describe later.

Owing to the complexity of the DICOM standard and our limited resources, we chose to employ the DICOM Central Test Node (CTN) software developed by the Mallinckrodt Institute of Radiology, which, like LINUX, is freely available (see: <http://www.erl.wustl.edu/DICOM/ctn.html>). We chose to employ the same public domain database as the CTN software, called mini-SQL (see: <http://www.Hughes.com.au/>). We have modified the CTN software extensively and have employed mini-SQL to support many new applications peripheral to the PACS. A detailed description of these modifications is beyond the scope of this presentation, but they have been necessary to make the software more robust and support our multiserver distributed design. Several of these modifications are described below.

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0897-1889/99/1202-1053\$10.00/0*

RESULTS AND DISCUSSION

Reliability and robustness in the PACS have been our primary concerns. At the beginning, most effort was spent resolving communication and data format problems on two DICOM "gateways" that had been purchased for a pair of our non-DICOM-conformant CT scanners. Over the following weeks, autorouting was introduced, and the Query/Retrieve service on our servers was modified to address some reliability and speed issues.

During this time, our WWW Server continued to be refined while being introduced to clinicians throughout our hospital. Fifteen new PCs and eight paper printers were added in strategic locations to address complaints that existing computers were inadequate and that some areas lacked image access altogether. Feedback from the clinicians subsequently focussed on miscellaneous image display considerations, including how best to select image window widths and levels (ie, brightness and contrast settings) for display purposes.

Speed, in terms of database response time, image transmission, and retrieval from long-term archive, has been another concern for us that has motivated several design and algorithm modifications. Aside from upgrading our Radiology departmental network to 100 Mbit/s (switched) Ethernet, we have refined the software functions used for (DICOM) image transmission, and we increased the amount of on-line disk space (while also introducing loss-less data compression) to reduce the number of studies being retrieved manually from the long-term archive (ie, from CD).

As an academic centre, teaching and research workflows were also impacted. Without film, we lacked a convenient way to collect and document interesting cases. This need spawned the creation of our electronic Teaching File Server³ (see: <http://tf.rad.mgh.mcgill.ca>).

As the amount of data handled by the PACS grew and was archived to CD, the relative number of prior patient studies that were available on film decreased. Rather than burden the clerical staff with the task of retrieving and distributing these studies on the PACS, we developed a scheme to fully automate electronic prefetching. The result has proven to be faster and more reliable than the manual system.

While the speed of the PACS within Radiology was satisfactory, there arose some problems throughout the hospital. Access to images outside

when Radiology was obtained through our WWW Server, which was fed by several Modality Servers (via autorouting). Therefore, the capacity of the WWW Server to retain data on-line was limited to approximately 1 week, resulting in delays when older data were required. This was resolved by distributing WWW services to every server on our PACS, making access to the images immediate. Computational loads for WWW access became more evenly distributed, and the single network bottleneck was eliminated. Access via the WWW is now multiply redundant and the amount of data on-line has increased to over 3 months.

After 1 year of being filmless in CT and MRI, it became clear that our CD-based Retrieval Server was impractical. Nearly 90 CDs were loaded manually per day. Therefore, we acquired a digital linear tape (DLT) jukebox (two drives; 48 tapes; 35 GB uncompressed per tape) and developed the software needed to control its robotics. The PACS now preferentially selects the DLT system over the CD-based Retrieval Server whenever possible. An average of 25 CDs per day is now loaded manually by our clerical staff.

Automating the retrieval of archived data marked a milestone beyond which we have had few problems due to shortcomings in the design of the PACS. Recently, we introduced a link between our PACS and the HIS of our hospital. The link employs the Health Level Seven (HL7) standard to transmit orders for radiology examinations from the HIS to the PACS, then return the reports from the PACS to the HIS.

A new system has been developed on the PACS side that now attempts to link imaging studies with corresponding orders. In so doing, misentered patient information on the PACS is identified automatically. The data are subsequently corrected and rearchived. Previously, such errors often went unnoticed, resulting in studies that could be difficult to find or even become lost. A new radiology transcription application was also developed along with a worklist used by the radiologists to perform corrections. Both are WWW-based. The worklist has allowed us to eliminate the flow of paper reports between transcriptionists and radiologists. All preliminary reports are now corrected and "signed" by the radiologists via the WWW. Thus, report turnaround times have improved dramatically, and the workload on the transcriptionists has been reduced. This has allowed us to achieve our

goal of providing access to both images and reports through a single common interface (the WWW).

During the last 6 months, we have reexamined certain issues related to fault-tolerance in our PACS. We have eliminated every single-point-of-failure in our PACS (including the Master Database) and we have fully automated the recovery or circumvention process that is needed to survive almost every type of disaster (eg, system crashes, limited power failures, network faults, etc). The PACS has an extensive self-monitoring system that is integrated with email and pager services. Process logs are highly detailed to facilitate debugging, and every action performed by users of the WWW interface is logged, allowing audits and statistics to be generated. These systems were designed to facilitate support and maintenance, and to allow more time to be spent on the development side of the project.

Most recently, the PACS has been deployed throughout the University of Toronto Teaching Hospitals. Our development team has now doubled

in size with groups both in Toronto and Montreal. Although not by design, the initial deployment of the PACS was insufficient to support the numbers of users and imaging equipment that were connected. This effectively "stress-tested" the PACS and brought to light several new design flaws, mostly related to algorithm and database inefficiencies. These have been fixed and a new system has been introduced to facilitate enterprise-wide image retrieval on the PACS.⁴

CONCLUSION

The experience we have gained has allowed us to design a PACS that is flexible and highly economical. Being filmless has motivated the design of a sophisticated support system and yielded a PACS that is both scalable and fault-tolerant. The system will continue to evolve as the link with our HIS is exploited. Ultimately, we hope PACS will lead efforts throughout our institutions to more fully integrate patient-related information, facilitating access and improving patient care.

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