Challenges Associated With Interfacing Computed Tomography to a Picture Archiving and Communication System at the Baltimore Veterans Affairs Medical Center—A Historical Perspective

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The interfacing of digital image acquisition modalities to the picture archiving and communication system (PACS) plays a major part in the conversion from a traditional film-based radiology practice to one that relies almost entirely on soft-copy reading. The Baltimore Veterans Affairs Medical Center (VAMC) is one of the first filmless hospitals in the world. Since 1993, it has used computed tomography (CT) scanners connected to a commercial PACS to provide digitized patient images for filmless reading. Over the years, the evolution of Digital Imaging and Communications in Medicine (DICOM) standards, advances in networking technologies, and enhancements in PACS and hospital information system (HIS) software have greatly improved this system's robustness and patient/study identification accuracy. The result has been a major increase in productivity.

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IN ORDER TO DISPLAY a digital image produced by an acquisition modality on a diagnostic picture archiving and communication system (PACS) workstation, the following sequence of steps must be executed:

- (1) The images have to be acquired by the modality.
- (2) The correct patient name, patient identification, and accession number have to be assigned to the images.
- (3) The images have to be transmitted to the PACS.
- (4) The images have to be associated with the corresponding patient and study on the PACS.
- (5) The images have to be processed by the PACS and placed on the file servers.
- (6) The images have to be sent to the PACS workstation.
- (7) The images have to be displayed correctly on the PACS workstation.
- (8) The images need to be of diagnostic quality.

Several different technologies have to work together to make this sequence happen. A breakdown at any step along this path will require manual intervention, introduce the possibility of error, and dramatically reduce the productivity of the PACS. To maintain an efficient operation, it is

essential that all of these steps be performed correctly.

Over time, this process has become more automated, thereby reducing the possibility of human error. Hardware improvements have provided better performance with increased robustness. The Digital Imaging and Communications in Medicine (DICOM) standard has developed services to fill gaps found in the workflow of the filmless radiology department.

COMPUTED TOMOGRAPHY PIXEL VALUES

Computed tomography (CT) scanners are a little more complicated than most imaging acquisition modalities to interface to a PACS because there are many different ways to represent their pixel values. CTs generate a series of images that are measured in Hounsfield units, where air has the value $-1,000$, water has the value 0 , and bone has a larger positive value, but always less than $3,000$. The DICOM¹ images coming from a CT scanner typically have 512×512 12-bit resolution and can have their pixel values specified in at least three different ways: (1) signed integer—actual Hounsfield units; (2) unsigned integer—Hounsfield units shifted by $1,000$, so that they are in the 0 to $4,000$ range; and (3) unsigned integer—Hounsfield units shifted by $33,792$ ($2^{15} + 2^{10}$), so that they are in the $33,792$ to $37,792$ range.

The DICOM data elements rescale intercept ($0028,1052$) and rescale slope ($0028,1053$) are used to convert these stored values to Hounsfield

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units, using the following formula: Hounsfield Unit = (Rescale Slope * Stored Value) + Rescale Intercept. The area surrounding an axial image may be represented by a special value called a pad, a value not contained in the native image. Typical pad values for a CT are $-32,768$ (-2^{15}) and $-8,192$ (-2^{13}). Overlay information may also be present in the high order pixel bits or in separate planes.

In practice, some early PACS systems could not handle the DICOM images output by the CTs. Companies, like DeJarnette Research Systems, Inc (Towson, MD), developed protocol conversion boxes that could receive a CT image, massage it into a canonical form (like numerically shifting signed stored pixel values to unsigned ones), and send it to the PACS. These DICOM conversion boxes have been an immense aid to the early PACS developers.

NETWORKING CT SCANNERS

A CT scanner sends images to a PACS using the DICOM Storage Service over the Transmission Control Protocol/Internet Protocol (TCP/IP) network. A reliable physical network connection is required between the CT and the PACS.

In a local area network configuration, Ethernet is almost universally used as the physical medium that connects modalities to PACS. For the sake of reliability, there should be a minimum number of components in the path between the CT and the PACS. Ideally, there is only one, a central network hub connecting the CT and the PACS. In practice, however, there may be many more components—media converters, protocol converters/DICOM reformatters, cascaded switches, multiport repeaters, bridges, routers, etc—all of which may fail and lower the reliability of the overall network connection.

Ethernet was originally designed to operate at 10 mb/s over a single shared coaxial cable. Network problems were frequently encountered when several modalities at the same time tried to send images over the same 10 mb/s shared Ethernet segment.

Fortunately, there have been three major improvements in Ethernet in the 1990s. The first was the introduction of Ethernet switches, which replaced the original “all the devices on a single coaxial cable” linear topology with a “each device on its own cable connected to a switch” star topology,

and allowed multiple sessions to operate simultaneously through a switch at 10 mb/s. The second major improvement was the media transition from clumsy 50-ohm coax cable to unshielded twisted pair (UTP). These ubiquitous UTP cables connect both the image acquisition modalities and DICOM Storage Providers to the same switch in the wire closet, and eliminate the need for many of the previously used intervening media conversion components. The third improvement was in the area of speed, first to 100 mb/s switched Fast Ethernet, and then the development of 1,000 mb/s switched Gigabit Ethernet. Today, at the end of the decade, with structured wiring codes and faster networking equipment available, the networks can much more reliably handle the volume of data required for imaging.

DICOM MODALITY WORKLIST SERVICE

In order for a DICOM digital image to be associated with the proper patient and study, its header must contain the correct HIS/RIS patient and study identification information. For this reason, the VA requires the patient name, patient identifier (social security number), and study accession number to be supplied in each DICOM image header. Image producing modalities need to be provided with this data prior to performing the study so that it can be placed into the image headers.

The following three steps must be performed in order to ensure that DICOM images have the proper patient name, patient identifier, and accession number so that they can be correctly associated with the corresponding patient and study:

- (1) The patient and study order information from the hospital information system/radiology information system (HIS/RIS) must be entered into the PACS.
- (2) The same patient and study order information from the HIS/RIS must be entered into the modality.
- (3) The same patient and study information must be copied into the image headers to correctly identify them when they are sent to the PACS.

DICOM automates this “second step” by allowing an image producing device to query a Modality Worklist service provider to obtain the patient and study order information (Fig 1). VistA (the VA’s hospital information system) sends the patient and

Fig 1. PACS modality interface.

study information for each order to the PACS. VistA also maintains a list of all imaging orders that are active on the HIS/RIS so it can provide the DICOM Modality Worklist service.

The modality can query the VistA Modality Worklist provider to obtain information about the study to put into the image header. When the study's images are sent to the PACS, they will exactly match the corresponding patient and study on the PACS and will be correctly incorporated into the PACS database. The PACS then sends the images to the VistA image management system for incorporation into the VA's in-house electronic patient record, which makes them available for display at every clinical workstation in the institution (Fig 2).²⁻⁵

The VA has published a Modality Interface DICOM Conformance Requirements document, which specifies the necessary DICOM services that image acquisition equipment must use to interface to PACS.⁶ The Healthcare Information and Management Systems Society (HIMSS)/Radiological Society of North America (RSNA) collaborative effort, "Integrating the Healthcare Enterprise Technical Framework," states a similar set of requirements for modalities.⁷

Fig 2. VistA DICOM PACS and modality interface.

CT CONFIGURATION HISTORY AT THE BALTIMORE VAMC

Since June 1993, the Baltimore VAMC has operated a pair of CT scanners connected to their General Electric (GE, Milwaukee, WI) PACS. These modalities and the associated network have since undergone several major changes (Table 1).

Initial Configuration

While both of the original GE and Picker (Marconi, Cleveland, OH) units were capable of transmitting DICOM image objects, the GE PACS initially was not able to communicate via DICOM. (The system had originally been developed by Siemens Gammasonics, Inc (Hoffman Estates, IL), and used the proprietary Siemens PACSNET protocol instead.) DeJarnette DOS-based ImageShare 910s were required to translate the DICOM image objects generated by the CTs into PACSNET objects that were sent to the Modality Interface Unit of the PACS. The ImageShare also converted the Picker PQ-2000 pixel data from the actual signed Hounsfield units into the unsigned integer values (0 to 4,000), as required for display on the MacIntosh (Apple, Cupertino, CA) PACS workstations (Fig 3).

A bidirectional ACR-NEMA Version 2.0 text and image interface between the VAs HIS and the GE PACS was placed into operation. This allowed patient demographic information and all orders and reports to be sent to the PACS. Also, all images could be sent from the PACS to the VA system. By providing the PACS with the correct patient and study information in a timely manner, this interface

Table 1. Data Configuration

Date	Configuration
June 1993	Initial Configuration—GE High Speed Advantage and Picker PQ-2000 CTs with DeJarnette 910s sending images via shared Ethernet to the PACS
October 1993	VistA American College of Radiologists (ACR)—National Electrical Manufacturers Association (NEMA) Version 2.0 Interface to PACS placed into operation
1996	Replaced original 2 DeJarnette ImageShare 910s with two ImageShare 1000s
Spring 1998	Replaced original 2 CTs with a Picker PQ-5000 and a Picker PQ-6000
Summer 1998	Started using Modality Worklist on PQ-5000
Fall 1998	Replaced Cabletron Hub with Cisco Catalyst 5500 Ethernet Switch

Fig 3. Initial CT configuration—1993.

has proven to be a key element in the success of the PACS. However, the patient and study information had to be manually entered by the operator at the CT scanner console. This step was a major source of human error.

Upgraded Shared Ethernet Architecture to Switched Ethernet Topology

The original architecture of the GE PACS used shared Ethernet as the medium for image acquisition. A single Ethernet segment was supported and all image acquisition traffic passed across it. The same Ethernet segment was used to send all of the images to the VA system. Understandably, the network was frequently overwhelmed with activity, and was the source of considerable intermittent network problems.

The Cabletron (Rochester, NH) hub was replaced by a Cisco (San Jose, CA) Catalyst 5500 switch running switched Ethernet (Fig 4). This greatly alleviated most of the network problems, since several simultaneous sessions could then go on independently. The DeJarnette ImageShare 910s were DOS-based systems, and were upgraded with a pair of DeJarnette ImageShare 1000s that were OS/2-

Fig 4. Interim CT configuration—1997.

Table 2. Items Retrieved by the Picker CT From the VistA Modality Worklist Provider

Tag	Element Name
(0008,0050)	Accession number
(0010,0010)	Patient name
(0010,0020)	Patient identifier
(0010,0030)	Date of birth

based. The functionality was unchanged, but performance improved.

Picker Replaces Old CTs With PQ-5000, PQ-6000, Which Support Modality Worklist

In 1998, the Baltimore VAMC purchased a pair of new Picker CTs to replace the old PQ-2000 and the old GE CT. They were both connected to the DeJarnette ImageShare 1000s as before.

At about this same time, GE installed their GE DICOM Gateway, which supports DICOM Storage as a provider. It was planned that the CTs would send their DICOM images directly to that unit, and thus eliminate the need for the ImageShare 1000s. However, this could not be achieved, the GE MacIntosh PACS workstations installed at the Baltimore VAMC could not correctly handle the Picker CTs signed pixel data. The ImageShare 1000s were still required.

The two new Picker CT Modalities were capable of supporting the DICOM Modality Worklist capability. The VistA Modality Worklist provider supplies patient and study data directly to the CT modalities.

The data items listed in Table 2 are retrieved by the Picker CT from the VistA Modality Worklist Provider for each study.

Since these data no longer has to be manually entered, the transcription error rate has been virtually eliminated (Fig 5).

Fig 5. Current CT configuration—1999.

CONCLUSION

A number of enhancements in multiple areas have been applied to the interface between CT scanners, the PACS, and the HIS/RIS at the Baltimore VAMC. These have resulted in major improvements in both productivity^{8,9} and accuracy in the CT section of the imaging department. Similar improvements were made during the same time frame at the Baltimore VAMC with Magnetic Resonance and Nuclear Medicine imaging.

In the future, we expect to see more precise use

of the Modality Worklist by the modalities. Accession Number and Requested Procedure ID queries should replace the currently used broad queries. This will narrow down the potential list of returned matches to a single individual request and further reduce the mistakes in study selection. We will also see more complete automation as the new DICOM Storage Commitment and Modality Performed Procedure Step services are implemented in the field. Hopefully, these services will further reduce the error rate and the need for human intervention.

REFERENCES

1. Digital Imaging Communication in Medicine (DICOM), NEMA Standards Publication PS 3 (1998). Washington, DC, National Electrical Manufacturers Association.
2. Dayhoff RE: VA's integrated imaging system: A multispecialty, hospital-wide image storage, retrieval and communication system, in Siegel EL, Kolodner RM (eds): *Filmless Radiology*. New York, NY, Springer, 1999
3. Kuzmak PM, Dayhoff RE: The Department of Veterans Affairs integration of imaging into the healthcare enterprise using the VistA hospital information system and Digital Imaging and Communications in Medicine. *J Digit Imaging* 11:53-64, 1998
4. Kuzmak PM, Dayhoff RE: Enabling technology: DICOM in the VA's hospital information system, in Siegel EL, Kolodner RM (eds): *Filmless Radiology*. New York, NY, Springer, 1999, pp 322-352
5. Kuzmak PM, Dayhoff RE: Success of HIS DICOM interfaces in the integration of the healthcare enterprise at the Department of Veterans Affairs, in *Medical Imaging 1999: PACS Design and Evaluation*. Proceedings SPIE, vol 3662, The International Society for Optical Engineering, Bellingham, WA, 1999
6. Oosterwijk H, Csipo D, Kuzmak PM, et al: Modality Interface DICOM Conformance Requirements, Version 1.2. <http://www.va.gov/oa&mm/busopp/formats.htm>, Sept 7, 1999
7. HIMSS & RSNA, Integrating the Healthcare Enterprise, IHE Technical Framework, Revision 3.0. <http://www.RSNA.org/IHE>, April 26, 1999
8. Reiner BI, Siegel EL, Hooper FJ, et al. A comparison of film based to filmless operation on CT technologists' productivity. *Radiology* 207:481-485, 1998
9. Reiner B, Siegel E, Kuzmak P, et al: Transmission failure rate for computed tomography examinations in a filmless imaging department. *J Digit Imaging* 13:79-82, 2000 (suppl 1)