Title
Building Blocks for a Clinical Imaging Informatics Environment

Journal
Journal of Digital Imaging, 27(2)

ISSN
0897-1889

Authors
Kohli, Marc D
Warnock, Max
Daly, Mark
et al.

Publication Date
2014-04-01

DOI
10.1007/s10278-013-9645-0

Building blocks for a clinical imaging informatics environment

Marc D Kohli, MD[1]
Paul G. Nagy, PhD[2]
Max Warnock[2]
Mark Daly, BS[2]
Christopher Toland[2]
Chris Meenan, BS[2]

1 – Department of Radiology, Indiana University School of 550 University Blvd Indianapolis, IN 46202

2 - From the Department of Diagnostic Radiology and Nuclear Medicine, University of Maryland School of Medicine, 22 S. Greene St., Baltimore, MD. Address correspondence to P.G.N. (pnagy@umm.edu).

Phone: (410) 328-6301
Fax: (410) 328-0641

Index Terms: software reuse, HL7, DICOM, Mirth, open-source, imaging informatics, informatics

Abstract

Over the past 10 years, imaging informatics has been driven by the widespread adoption of radiology information and picture archiving and communication and speech recognition systems. These three tools are intuitive to most radiologists as they replicate familiar paper and film workflow. So what is next? The next generation of applications will be built with moving parts that work together to satisfy advanced use cases without replicating databases and without requiring fragile, intense synchronization from clinical systems.

We provide blueprints for addressing common clinical, educational, and research related problems. This paper is the result of identifying common components in the construction of over two dozen clinical informatics projects developed at the University of Maryland Radiology Informatics Research Laboratory. The systems outlined are intended as a strong foundation rather than an exhaustive list of possible extensions.

Background

Software reuse is a philosophy that makes stored information more accessible and flexible, facilitating creation of novel uses of existing data. Before examining software reuse within healthcare, we present online-travel an example of the higher-level integration that we strive toward. Travel web pages integrate pricing and availability information not only from airlines, as well as hotels and rental cars. Travel web sites also present a single interface for payment transactions, sending your payment (likely aggregated with other travelers) on to each individual airline, hotel and rental car companies.

Contrast the online travel agent experience with the interpretation process for a CT scan. In many cases, radiologists have separate passwords to access the computer system, PACS, dictation system, and even the electronic medical record. Integrating all of these disparate systems can require extensive expertise, money, and time. We aim to describe a set of inexpensive tools that can be reused to facilitate integration at lower cost. We will first describe two important terms – standards and interfaces, and then move on to describing the building blocks themselves – single sign on, HIPAA logging, honest broker, interface engine, report warehouse, context integration and web portal, distributed knowledge management, workflow engine, issue tracking and management. In our discussion we outline use cases where the reusable components can be combined to offer advanced functionality: easily creating research cohorts, facilitating just-in-time learning, and business intelligence using quality dashboards.

Methods

Technical Standard

Technical standards define the message structure for two computer systems to communicate. This is analogous to two people agreeing that they will use English in their conversations. Some standards go a step further and define an interface, which is the mechanism for the actual exchange of information. After two people have settled on English, they may agree to use e-mail, sms, or a voice phone to transfer information. For the most part, standards specify the message to be exchanged, and interfaces specify the mechanism to exchange the message.

Returning to the travel web page example, when you place a search request the travel company sends a message to a variety of airlines, hotels, and car rental companies. Each company returns a message to the web page that is aggregated into what you see as a search result. After you make a purchase, the travel site sends another message with purchase and payment information on to the vendor. Finally, after receiving payment the airline will send the travel web page confirmation that the transaction is complete.

For this approach to work, airline X and the travel site decide have to agree on two things – what information will be exchanged (the standard), and how it will be transferred (the interface).

Returning to the travel example, imagine the difficulty and confusion that would result if airline X wanted to send information in a different format from airline Y, and airline Z. If the travel industry got together and defined a common format for exchanging availability, and price information, it would be much easier for the travel web site to integrate a new airline into their search. It would also be easier for a new airline to buy software to interface with the travel web site. When computer applications outside medicine talk to each other, eXtensible Markup Language (XML) is a common platform to describe messages, and hypertext transfer protocol (http) is a common interface.

Another analogy is submission of a manuscript for review. The journal sets standards about the format that they will accept (Acrobat, Word, Rich Text File, etc). The submitter must be able to save their manuscript in this format. The journal publisher also provides the interface for exchanging the manuscript. Common interfaces for manuscript submission include e-mail and uploading to a web page or FTP server. In other words, both parties must agree on a standard (.doc files), and an interface (web, ftp, email). In the next section we will examine standards and interfaces common within healthcare.

Healthcare Standards and Interfaces

Imaging informatics deals primarily with two standards: Health Level Seven (HL7), and Digital Imaging and Communication in Medicine (DICOM). We will briefly describe uses for these two standards and briefly address some inherent limitations.

In healthcare, many silos of information have developed over time. Traditionally, the electronic medical record (EMR) contains registration data, insurance and billing data, as well as nursing data, and result data from lab systems. The radiology information system (RIS) contains scheduling information, as well as radiology reports, and many timestamps that can be useful to evaluate workflow. The EMR and RIS both use HL7 as the main standard for communication which comes with a significant limitation - there is no mechanism to request a piece of information via HL7. The RIS cannot request information on a patient from the EMR like the travel site can request flight information from an airline. This is a significant disadvantage that is a barrier to designing systems that integrate data from multiple healthcare systems. One avenue to solve this challenge is by exposing web services on your healthcare system (EMR, RIS, PACS, etc). What this means is that in addition to using HL7, the system provides a second standard using an http interface that is able to respond to a query and return information dynamically. Another historical challenge is that systems that support healthcare have traditionally focused on electronically replicating paper-based workflow. This has led to a patient-centric electronic workflow, with relatively little progress on easy to use tools that support aggregation of data across multiple patients.

When it comes to imaging, another important standard is Digital Imaging and Communication in Medicine (DICOM). DICOM, in contrast with HL7 does provide a mechanism for dynamic querying. Another important distinction between DICOM and HL7 is that DICOM defines not only the information to be exchanged; it also defines the interface to be used (storage class provider, and storage class user). When dealing with electronic systems, security and privacy must always be balanced with ease of use. The DICOM protocol indicates that both the server and the client machines (storage class provider and storage class user) have prior knowledge of each other in an end-to-end one-to-one fashion. This can be a significant limitation when trying to design high-availability systems with multiple servers that function as one.

DICOM and HL7 are two standards that are most frequently encountered in a radiology department in the United States. There are several other standards for exchanging healthcare information, which are common outside the US. In the next section we will begin to describe several of the reusable components that we have found useful in imaging informatics.

Reusable components for Imaging Informatics

Vendor supplied RIS and PACS solutions have been refined to the point where they excel at providing core functionality, however, most RIS and PACS systems do not offer the kind of flexible platform that allows development of novel applications such as business intelligence, flexible report searching, or issue tracking. Our goal is to describe some of the systems that are commonly needed to create an environment that supports informatics innovation, with an emphasis on reuse and web services.

Single Sign On

It is unlikely that anyone reading this article lacks experience with password overload. Many institutions struggle with multiple PACS, SR systems, and EMRs each with separate passwords. Single sign on is a concept where multiple independent computer systems all rely on a centralized storage mechanism for passwords. Using single-sign-on technology, users can change their password once with this change propagated throughout multiple systems. Single sign on becomes critically important when standard 6 month password resets are required.

There are several technologies available for single sign on. Two mechanisms that we have successfully employed are Lightweight Directory Access Protocol (LDAP) and Central Authentication Service (CAS). LDAP service can be provided by a variety of tools including the free open-source OpenLDAP[1] server. Microsoft Active Directory can also be configured to communicate with external non-microsoft applications via LDAP[2]. CAS was originally developed at Yale and is a free open-source web-based application[3]. CAS is best used for authentication for web-based applications.

Health Insurance Portability and Accessibility Act (HIPAA) logging

Nearly all healthcare systems contain protected health information (PHI) and therefore require user authentication, and audit tracking. In the case of enterprise systems such as HIS, RIS, and PACS each application is historically left to it’s own devices to handle and manage these critical tasks. As noted in the prior section, this has made single-sign-on difficult to achieve in the typical radiology department. Auditing becomes even more difficult as every system must be queried individually to see an enterprise-wide audit trail. Returning to our travel example this is similar to searching every airline, every rental car shop, and every hotel individually to be able to see the whole picture. Only a few HIPAA log systems have been described in the literature [4,5] and an IHE profile that gives guidelines on implementation of an auditing solution [6].

A centralized HIPAA audit log was developed in-house. It was designed and implemented to be a high-availability, scalable system that exposes web services to a multitude of other applications.

Honest Broker

With the introduction of HIPAA the need to access de-identified patient information, while preserving patient context between heterogeneous systems has become paramount in performing medical research. An honest broker integrates with existing clinical databases and scrubs identifiable attributes, providing a dataset that includes Research IDs generated by the broker. This allows researchers to mine data flexibly without navigating the Institutional Review Board (IRB) process. Creating a unique patient ID that can ultimately be traced back to identifiable information given proper IRB clearance decreases a significant barrier to research, and improves the ability to share data across institutions. Several of these systems have been described in the literature [7-11].

Interface Engine

HL7 interfaces have historically been very expensive and have required custom programming to implement. Frequently this custom development can cost $10,000 per interface. Because of these high costs, many institutions implement in-house interface engines to pass HL7 messages between clinical systems. Interface engines provide many benefits to closed-loop HL7 interfaces including the ability to redirect messages on-the-fly, cache messages, as well as providing needed backup and archiving capabilities. While there are many available interface engines, we have found success with the free open-source Mirth Connect [12]. In our use cases, Mirth serves as an end point for HIS and RIS HL7 feeds, that are then saved to a database or sent on to another application via web services.

Report Warehouse

There are several use cases commonly encountered in today's radiology department that can benefit from a report warehouse. For instance, a centralized report database can be used to generate reports on resident productivity for the ACGME, and hospital credentialing. Report warehouses can also be used to examine attending physician productivity. Currently, many departments handle these requests by running reports on the RIS and aggregating data in spreadsheets. This mechanism carries several limitations including the reliance on an inflexible proprietary reporting structure with a steep learning curve, as well as the inability to examine data in near-real or real-time. Additionally, running a complicated report on the RIS database during clinical hours can cause unacceptable performance declines resulting in delay of clinical work. Many approaches to data warehousing radiology reports have been published [13-15]. The report warehouse itself utilizes several of the reusable components as demonstrated in Figure 1.

Context Integration and Portal

The ability to automatically view the same patient or exam in two different systems is called context sharing, and is critically important to adoption of systems that extend PACS and RIS. For radiologists, the most important context is usually either a patient or an exam. Our experience has shown that adding context sensitive buttons to the PACS is a good design to follow for one or two integrated applications. However, as the number of context-aware integrations grew, we built a context portal. Rather than having seven separate buttons, we built a web page that dynamically generates context-specific links based on the currently opened examination in the PACS workstation (see Figure 2).

Distributed Knowledge Management

Early in the history of the World Wide Web, pages were initially static, and were generated using an editor such as notepad or other dedicated HTML editor. Frequently, editing was restricted to a single person, or a group of people with high level access to the server. The next iteration and improvement was using the combination of a database and a web application (like ASP, .NET, PHP, or Ruby on Rails) to generate content dynamically. Eventually people realized that the combination of a database and a web application could allow development of tools that support distributed knowledge management – like content management systems (Drupal, Plone, Joomla), or a wiki (mediawiki, dokuwiki). Both of these types of systems empower users to add, suggest, or edit content. This effectively lowers the burden on a centralized editor who now only needs to evaluate and approve content, rather than author everything by hand. Documentation of processes and development has always been, and always will be a pain, distributed knowledge management can spread responsibility between users, lessening impact and improving information timeliness and quality. The concept of a wiki has been spreading throughout biomedical science. As of March 2009 there are already 12 publications from 2009 indexed by PubMed [16-26] regarding or mentioning use of a wiki.

Workflow Engine

PACS and RIS worklists that show new studies to be dictated demonstrate a common use case for a workflow engine. However, there are many situations throughout the modern radiology department where the PACS and/or RIS workflows are not sufficient. Take for example a report that is marked dictated in the PACS where there is a problem with the report in the RIS. In a PACS-driven workflow with voice recognition, the radiologist is unaware of the problem and need for mediation. In our environment, we use a custom workflow engine to build web-based worklists that link directly to studies in the PACS. These worklists can be built for other purposes not currently supported by vendor RIS and PACS solutions such as reviewing preliminary interpretations by residents in a systematic fashion, and facilitating peer-review processes.

Issue Tracking/Management

Many IT departments have realized the benefit of issue tracking and management. However, this concept has taken longer to catch hold in radiology departments. Our approach was to develop an issue tracking tool that is flexible and can be integrated into existing clinical systems [27]. Prior to implementing the issue tracking tool, issues were recorded with a heterogenous set of mostly paper-based tools that were difficult to aggregate or audit and were frequently misplaced or lost entirely. With the new focus on practice quality improvement (PQI) by the American Board of Radiology (ABR) and the Accreditation Council of Graduate Medical Education (ACGME), our issue tracking application has provided metrics for several PQI projects.

Discussion

Creation of Cohorts for Research

Imagine being able to quickly identify how many patients have been seen in the past year with autoimmune pancreatitis, and how many of those have an MRI. This type of data mining can be performed prior to embarking down the lengthy institutional review board (IRB) process, saving valuable research time.

Further, if an honest broker is in place, researchers may be able to access individual cases without prior IRB approval. Additionally, de-identifying data sets by hand takes significant time and can be error prone.

Just-in-time learning

Imagine the ability for one of your radiologists or residents faced with a tough case of right lower quadrant pain to quickly find 10 cases of acute appendicitis, and browse through several examples. A searchable electronic report warehouse provides the fodder for an automatically updated teaching file that can provide decision support at the point-of-care. Further, faculty can use the electronic report warehouse for spontaneous ad-hoc teaching sessions at the viewbox. Cases of uncommon disease processes can be quickly located and accessed.

Business Intelligence

One important aspect of running a successful radiology department is the ability to proactively monitor processes throughout the enterprise. Graphical dashboards are one tool that can facilitate proactive monitoring [28-31].

For instance, many departments still struggle to comply with the 2008 JCAHO patient safety goals for reporting of critical test results [32]. In the absence of a dedicated result delivery system, a report-searching tool can be useful to identify and monitor delivery of critical results. If the search process can be automated, statistics regarding critical result delivery can easily be added to a graphical dashboard.

Conclusion

While RIS and PACS have become adept at replacing paper and film workflow, the full advantages of digital images, reports, and orders have yet to be realized. We have described a set of reusable components that can be combined to begin to leverage the wealth of digital information that is routinely generated in the RIS and PACS. These components can be combined to satisfy advanced use cases for decision support, quality improvement, and research.

Acknowledgements

Figure 1

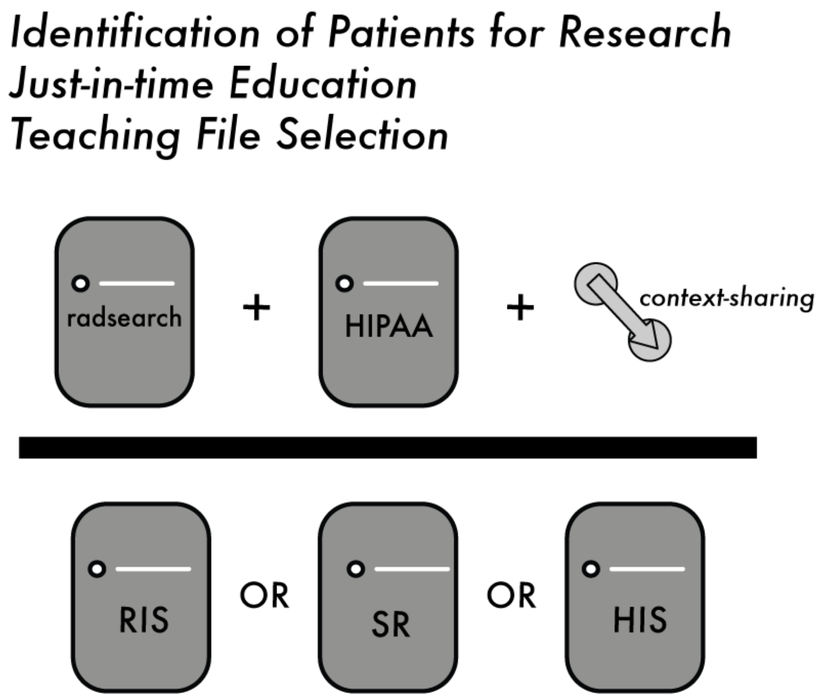


Figure 2a

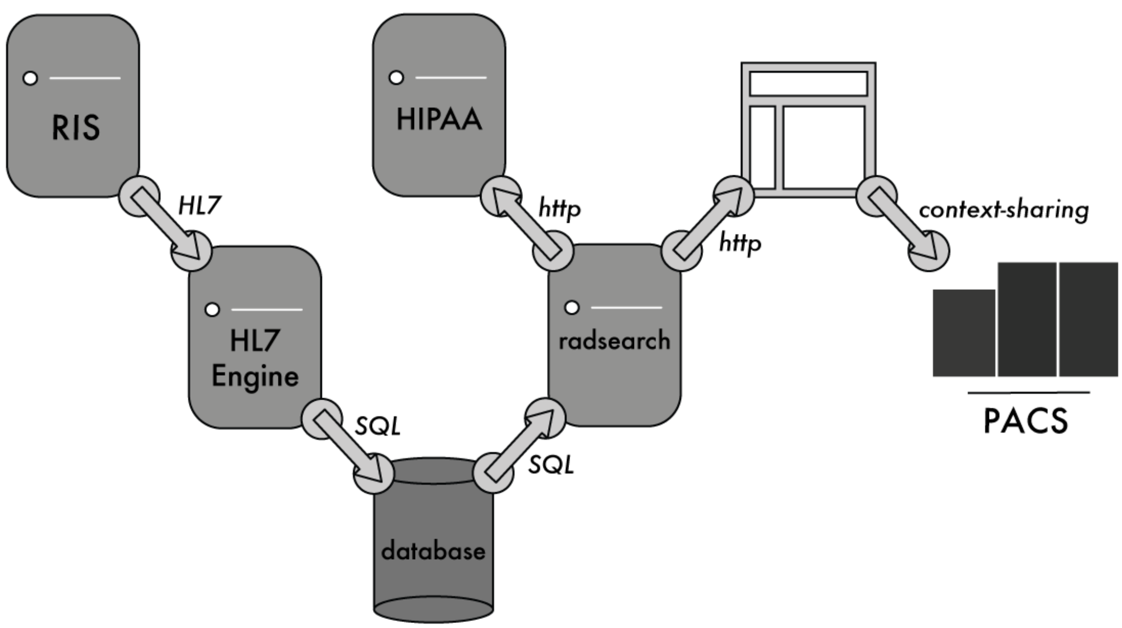
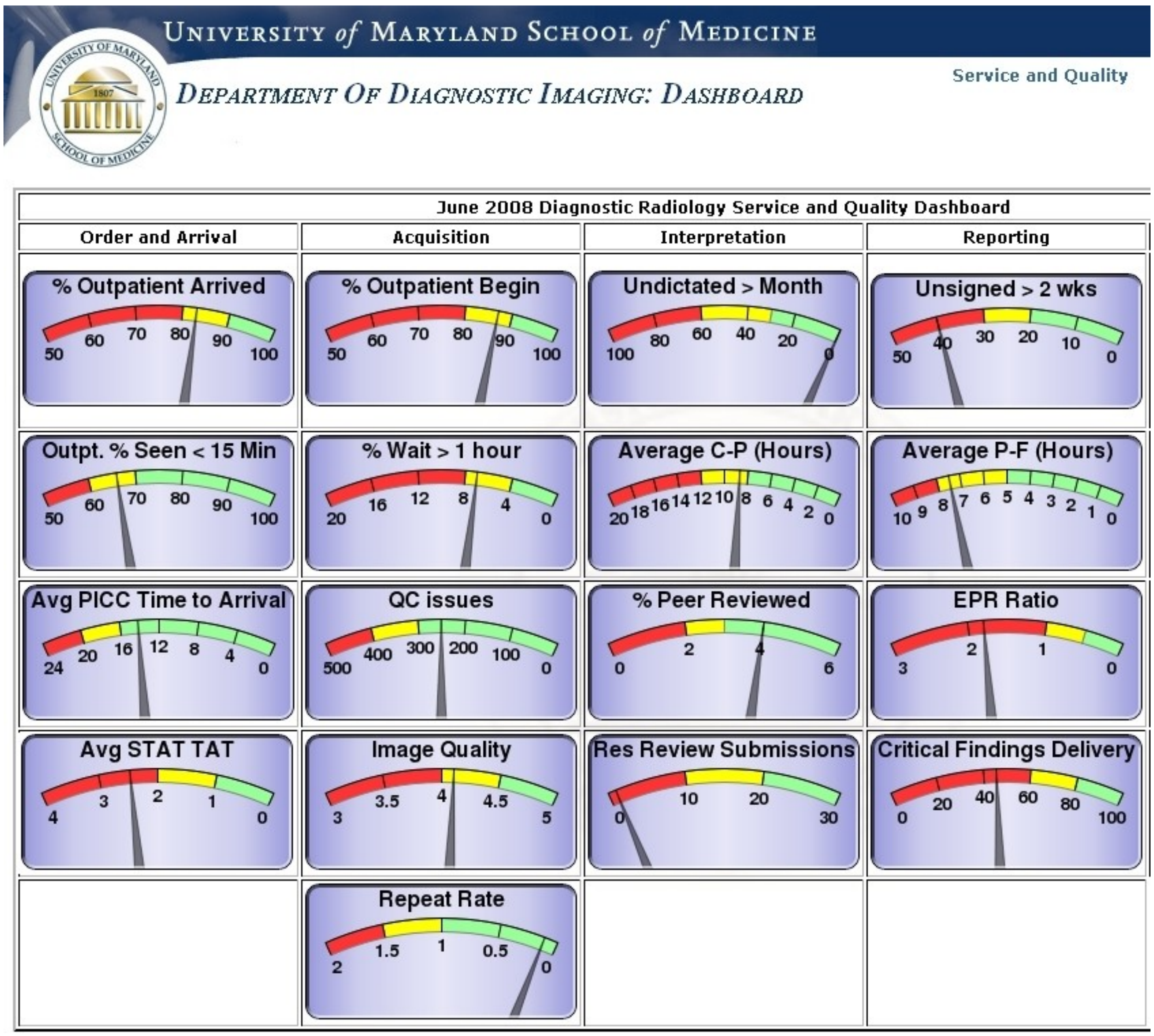


Figure 2b

Figure 2


Please note we still think you are referring to Accession # 1234. You will need to relaunch the "UM" button to change to a new case.
Education and Research
Add Study to Study-Stash
Add a study 1234 to the study-stash meta-data teaching file system
ResReview
Review resident's preliminary report
MyRSNA
Access online exhibits, journal articles, and a host of other features
Rad Search 2.0
Search the Radiology Report database
Clinical Tools
Power Chart
The hospital EMR
Undictated
Work List tool for undictated studies
DISPA Unread
A dashboard of studies in the many dispa systems
Radtracker QC
Add QC issue for accession # 1234
Bill 3D
Submit billing request for 3D reconstructions
ED Order Appropriateness Form
Chika's quality project on assessing ED order appropriateness
Surgical Followup Tracker
Tracking system for followup
Biopsy Request
Biopsy request approval form.
Communication and Information
Paging System (AMCOM)
The hospital paging service and directory
Findings Delivery
Tracking of critical and significant findings in the department
Raddash
The Departmental Statistical Analysis and Trending
Resident Wiki
Information for residents
UMMC Annual Image Quality Survey
Please fill out our Annual Survey form on the department's Image Quality. Survey ends March 20th.
Decision Support
Stat DX
A decision support tool for the residents
Yotta Look
Search for cases on the Internet
Gold Miner
Search for cases on the Internet
External Tools
Google
Search
YAHOO!
Search

Figure 3



UNIVERSITY of MARYLAND SCHOOL of MEDICINE
DEPARTMENT OF DIAGNOSTIC IMAGING: DASHBOARD
Service and Quality
June 2008 Diagnostic Radiology Service and Quality Dashboard
Order and Arrival
Acquisition
Interpretation
Reporting
% Outpatient Arrived
% Outpatient Begin
Undictated > Month
Unsigned > 2 wks
Outpt. % Seen < 15 Min
% Wait > 1 hour
Average C-P (Hours)
Average P-F (Hours)
Avg PICC Time to Arrival
QC issues
% Peer Reviewed
EPR Ratio
Avg STAT TAT
Image Quality
Res Review Submissions
Critical Findings Delivery
Repeat Rate

Bibliography

1. OpenLDAP, Main Page. at <http://www.openldap.org/>
2. Using ADSI, LDAP, and Network Management Functions With Active Directory. at <http://msdn.microsoft.com/en-us/library/ms806997.aspx>
3. Download CAS Server | Jasig Community. at <http://www.jasig.org/cas/download>
4. Liu, B.J., Zhou, Z. & Huang, H.K. A HIPAA-compliant architecture for securing clinical images. *J Digit Imaging* **19**, 172-180 (2006).
5. Gregg, B., D'Agostino, H. & Toledo, E.G. Creating an IHE ATNA-based audit repository. *J Digit Imaging* **19**, 307-315 (2006).
6. ATNA FAQ - IHE Wiki. at <http://wiki.ihe.net/index.php?title=ATNA_FAQ>
7. Boyd, A.D. et al. An 'Honest Broker' mechanism to maintain privacy for patient care and academic medical research. *Int J Med Inform* **76**, 407-411 (2007).
8. Silvey, S.A., Schulte, J., Smaltz, D.H. & Kamal, J. Honest broker protocol streamlines research access to data while safeguarding patient privacy. *AMIA Annu Symp Proc* 1133 (2008).
9. Boyd, A.D. et al. The "Honest Broker" method of integrating interdisciplinary research data. *AMIA Annu Symp Proc* 902 (2005).
10. Boyd, A.D. et al. The University of Michigan Honest Broker: A Web-based Service for Clinical and Translational Research and Practice. *J Am Med Inform Assoc* M2985 (2009).doi:10.1197/jamia.M2985
11. Liu, J. et al. Toward a fully de-identified biomedical information warehouse. *AMIA Annu Symp Proc* **2009**, 370-374 (2009).
12. Webreach, I. *Mirth*. (Webreach, Inc:).at <http://www.mirthproject.org/>
13. Rubin, D.L. & Desser, T.S. A data warehouse for integrating radiologic and pathologic data. *J Am Coll Radiol* **5**, 210-7 (2008).
14. Voet, T., Devolder, P., Pynoo, B., Vercruysse, J. & Duyck, P. Design and Implementation of an Open Source Indexing Solution for a Large Set of Radiological Reports and Images. *Journal of Digital Imaging* **20**, 11-20 (2007).
15. Wong, S.T. et al. Design and applications of a multimodality image data warehouse framework. *J Am Med Inform Assoc* **9**, 239-54 (2002).
16. Zhou, F. & Xu, Y. RepPop: a database for repetitive elements in Populus trichocarpa. *BMC Genomics* **10**, 14 (2009).
17. Wright, A. et al. Creating and sharing clinical decision support content with Web 2.0: Issues and examples. *J Biomed Inform* **42**, 334-346 (2009).
18. Seebregts, C.J. et al. The OpenMRS Implementers Network. *Int J Med*

Inform **78**, 711-720 (2009).
19. Meenan, C., King, A., Toland, C., Daly, M. & Nagy, P. Use of a Wiki as a Radiology Departmental Knowledge Management System. *J Digit Imaging* (2009).doi:10.1007/s10278-009-9180-1
20. Kohli, M. & Bradshaw, J. What is a Wiki, and How Can it be Used in Resident Education? *Journal of Digital Imaging* doi:10.1007/s10278-010-9292-7
21. Hodis, E. et al. Proteopedia - a scientific 'wiki' bridging the rift between three-dimensional structure and function of biomacromolecules. *Genome Biol* **9**, R121 (2008).
22. Friend, S. & Schadt, E. Something wiki this way comes. Interview by Bryn Nelson. *Nature* **458**, 13 (2009).
23. Feltrin, E. et al. Muscle Research and Gene Ontology: New standards for improved data integration. *BMC Med Genomics* **2**, 6 (2009).
24. Demczuk, L., Gottschalk, T. & Littleford, J. Introducing information literacy into anesthesia curricula. *Can J Anaesth* **56**, 327-335 (2009).
25. Csosz, E., Mesko, B. & Fesus, L. Transdab wiki: the interactive transglutaminase substrate database on web 2.0 surface. *Amino Acids* (2008).doi:10.1007/s00726-008-0121-y
26. Cobus, L. Using blogs and wikis in a graduate public health course. *Med Ref Serv Q* **28**, 22-32 (2009).
27. Nagy, P., Warnock, M., Daly, M., Rehm, J. & Ehlers, K. Radtracker: a web-based open-source issue tracking tool. *J Digit Imaging* **15 Suppl 1**, 114-119 (2002).
28. Morgan, M., Branstetter, B., Mates, J. & Chang, P. Flying Blind: Using a Digital Dashboard to Navigate a Complex PACS Environment. *Journal of Digital Imaging* **19**, 69-75 (2006).
29. Nagy, P.G. et al. Informatics in Radiology: Automated Web-based Graphical Dashboard for Radiology Operational Business Intelligence. *Radiographics* (2009).doi:10.1148/rg.297095701
30. Nagy, P.G., Pierce, B., Otto, M. & Safdar, N.M. Quality control management and communication between radiologists and technologists. *J Am Coll Radiol* **5**, 759-65 (2008).
31. Morgan, M., Branstetter, B., Lionetti, D., Richardson, J. & Chang, P. The Radiology Digital Dashboard: Effects on Report Turnaround Time. *Journal of Digital Imaging* **21**, 50-58 (2008).
32. 2008 Critical Access Hospital National Patient Safety Goals | Joint Commission. at <http://www.jointcommission.org/PatientSafety/NationalPatientSafetyGoals/08_cah_npsgs.htm>