

# Building Blocks for a Clinical Imaging Informatics Environment

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Published online: 9 October 2013  
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**Abstract** Over the past 20 years, imaging informatics has been driven by the widespread adoption of radiology information and picture archiving and communication and speech recognition systems. These three clinical information systems are commonplace and are intuitive to most radiologists as they replicate familiar paper and film workflow. So what is next? There is a surge of innovation in imaging informatics around advanced workflow, search, electronic medical record aggregation, dashboarding, and analytics tools for quality measures (Nance et al., *AJR Am J Roentgenol* 200:1064–1070, 2013). The challenge lies in not having to rebuild the technological wheel for each of these new applications but instead attempt to share common components through open standards and modern development techniques. 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. The purpose of this paper is to identify building blocks that can position a practice to be able to quickly innovate when addressing 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 mere foundation rather than an exhaustive list of possible extensions.

**Keywords** Software reuse · HL7 · DICOM · Mirth · Open-source · Imaging informatics · Informatics

## 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 as an example of the higher-level integration that we strive toward. Travel web pages integrate pricing and availability information from airlines, hotels, and rental cars, reaching across numerous corporate structures. 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.

In contrast to 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 requires 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, Health Insurance Portability and Accessibility Act (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 used cases where we have combined the components to offer advanced functionality.

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## 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 server 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 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 must agree on two things—what information will be exchanged (the standard) and how it will be transferred (the interface).

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 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 the new airline to buy software to interface with travel vendors. When computer applications outside medicine talk to each other, Javascript object notation (JSON) is a common standard, and hypertext transfer protocol (http) is a common interface.

Another analogy is submission of a manuscript for review. Journals set standards for 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 (.docx files) and an interface (web, ftp, e-mail). 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 [1]. 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 limits integration of 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 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 but also the interface to be used (e.g., 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 the two standards that are most frequently encountered in a radiology department in the USA. There are several other standards for exchanging healthcare information, which are common outside the USA. 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. 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

Password overload is likely to be common among every reader of this article. 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, every 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 [2] server. Microsoft Active Directory can also be configured to communicate with external nonmicrosoft applications via LDAP [3]. CAS was originally developed at Yale and is a free open-source web-based application [4]. CAS is best used for authentication for web-based applications.

### Health Insurance Portability and Accessibility Act 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 its 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 [5, 6] and an IHE profile that gives guidelines on implementation of an auditing solution [7].

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 [8–12].

### Interface Engine

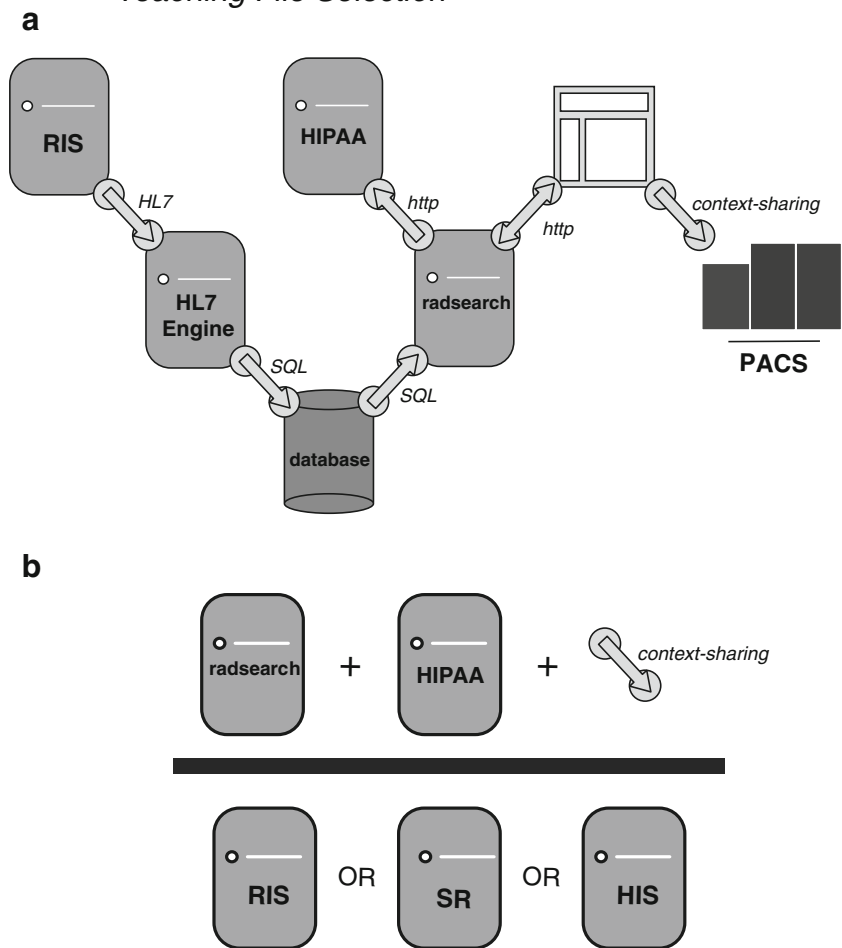
HL7 interfaces have historically been very expensive and have required custom programming to implement. Frequently this custom development can cost \$10,000 per interface. Because of these high costs, many institutions implement in-house interface engines to pass HL7 messages between clinical systems. 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 [13]. 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

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 Accreditation Council of Graduate Medical Education (ACGME) compliance 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 a proprietary reporting structure with a steep learning curve as well as the inability to examine data in a timely fashion. Running a complicated report on the RIS database during clinical hours can cause unacceptable performance declines resulting in a delay of clinical work. Many approaches to data warehousing radiology reports have been published [14–16]. The report warehouse itself utilizes several of the reusable components as demonstrated in Fig. 1.

**Fig. 1** Depicts the connections between systems and the standards used at each step

*Identification of Patients for Research  
Just-in-time Education  
Teaching File Selection*



**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 extends 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 Fig. 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 the 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. Documentation of processes and development has always been and always will be difficult, and distributed knowledge management can spread responsibility between users, lessening impact and improving information timeliness and quality. Use of wikis has been spreading throughout biomedical science. As of March 2009, there were 12 publications indexed by PubMed

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

**Fig. 2** Depicts an example of a context portal used to integrate several applications with a PACS client

[17–27] regarding or mentioning the use of a wiki. In 2012, there were 231.

### 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 [28]. Prior to implementing this tool, issues were recorded with a heterogeneous set of paper-based tools that had critical limitations. Many were difficult to aggregate or audit and were frequently misplaced or lost entirely. With the increased focus on practice quality improvement (PQI) by the American Board of Radiology (ABR) and the ACGME, our issue-tracking application has provided metrics for several PQI projects.

### Discussion

University of Maryland has used these building blocks to create an agile environment where we were able to address opportunities quickly. The University of Maryland began implementing Six Sigma quality management efforts in 2005. The purpose of Six Sigma is to enable frontline employees to be able to identify quality issues, understand the problem through data-driven methodologies, and engineer rapid innovative solutions. Individuals from the front line lead projects working with physicians, and administration, usually for 3–6 months.

The building blocks allowed the informatics lab to support these quality efforts through configuring components as opposed to building each from the ground up. Below is a list of component combinations and how they were applied to



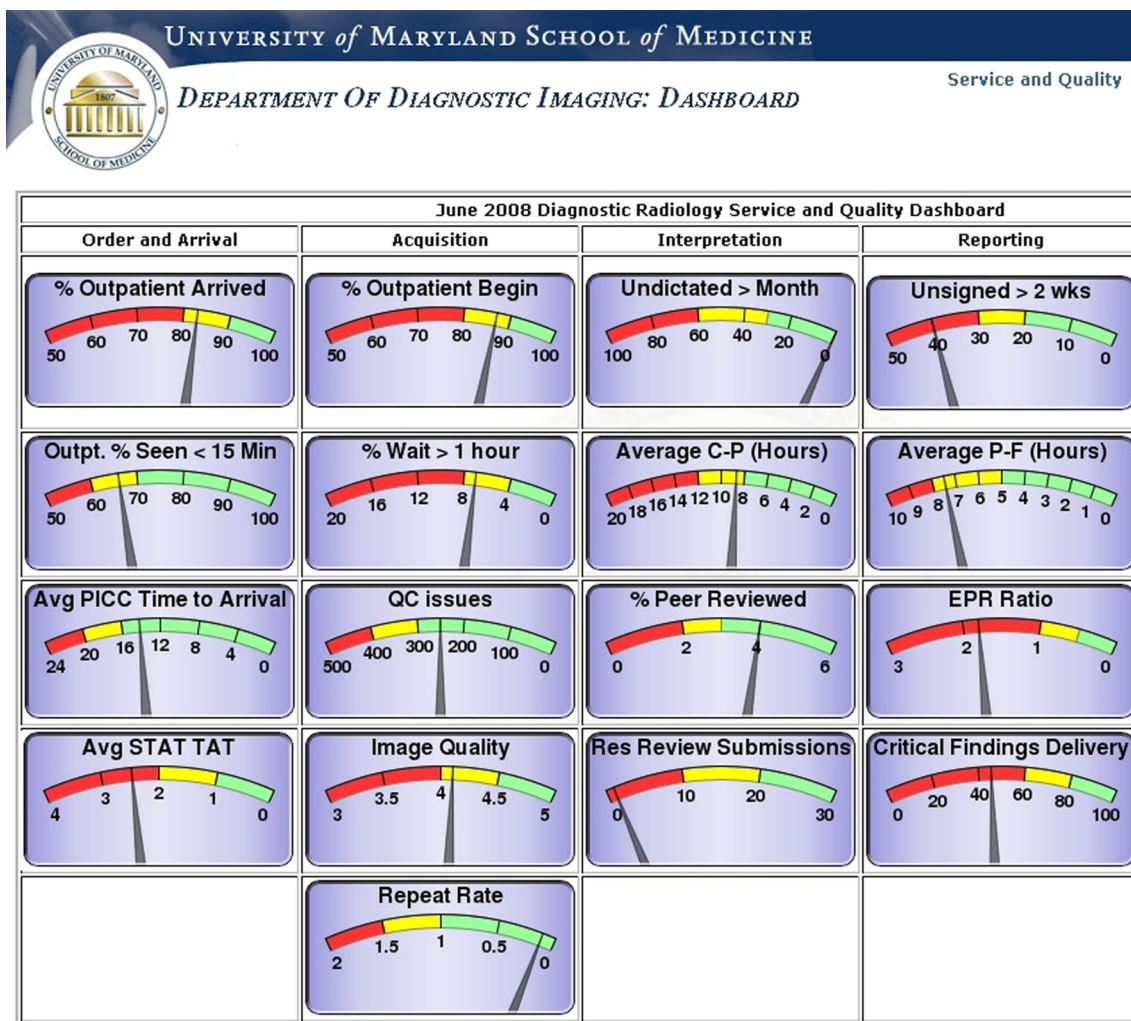


Fig. 3 Example of a dashboard for a radiology department

address clinical problems. These examples represent a few out of many possibilities of combinations to solve various problems.

#### Radtracker

Point-of-care radiologist submitted quality control with built-in technologist alerting [28]. We used clinical context integration to allow radiologists from the PACS to automatically launch an issue-tracking tool that alerted technologists to issues and communicated back to radiologists as they were resolved.

#### Radiologist Peer Review

We were able to customize a peer review system for our radiologists by combining several pieces. On the back end, we used the Report Repository to build select random cases and provide the reports to the radiologist for review. On the front-end, we used the clinical context integrator to sync the

PACS to the images as well as a workflow engine to manage the review process. PHI access was logged to the HIPAA logging system.

#### Report Search

We created radiologist differential diagnosis and report-searching capabilities, opening instant access to 10 years of radiology reports. This was accomplished by combining the HL7 listener feeding the Report Repository with a PACS-integrated clinical context web tool. The reports were keyword indexed using off-the-shelf open-source components, providing a commonly understood google-like interface. PHI access was logged to the HIPAA logging system.

#### Resident Discrepancy Reporting

We created a visualization tool that made it easy for residents to compare preliminary and finalized reports. We used the workflow engine to create a review list of cases that met a

threshold for changes. This was coupled with the context integration to allow the resident to be able to pull the case in PACS for review. PHI access was logged to the HIPAA logging system.

### 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 [29–32].

For instance, many departments still struggle to comply with the 2008 JCAHO patient safety goals for reporting of critical test results [33]. 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 (see Fig. 3).

### 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.

**Acknowledgments** We acknowledge Micah Adams, MS for providing diagram support.

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