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An Ontology for PACS Integration

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An ontology describes a set of classes and the relationships among them. We explored the use of an ontology to integrate picture archiving and communication systems (PACS) with other information systems in the clinical enterprise. We created an ontological model of thoracic radiology that contained knowledge of anatomy, imaging procedures, and performed procedure steps. We explored the use of the model in two use cases: (1) to determine examination completeness and (2) to identify reference (comparison) images obtained in the same imaging projection. The model incorporated a total of 138 classes, including radiology orderables, procedures, procedure steps, imaging modalities, patient positions, and imaging planes. Radiological knowledge was encoded as relationships among these classes. The ontology successfully met the information requirements of the two use-case scenarios. Ontologies can represent radiological and clinical knowledge to integrate PACS with the clinical enterprise and to support the radiology interpretation process.

KEY WORDS: Ontologies, semantic models, knowledge representation, knowledge sharing and reuse, PACS, systems integration, workflow, Protégé, Web Ontology Language (OWL), Transforming the Radiologic Interpretation Process (TRIP)

INTRODUCTION

Effective radiology workflow in a filmless, electronic environment requires knowledge about the structure and content of diagnostic imaging studies. This knowledge can be used in image-display protocols and decision support systems to improve clinical performance. Such knowledge also can enable more efficient operations by providing operational logic and by improving interoperability with enterprise information systems through the use of common semantics. We explored whether knowledge of the structure and content of radiology workflow could be encoded using the construct of an ontology.

An ontology describes a set of classes ("terms" or "entities") and the relationships among them. The word "ontology" has been used to describe constructs with degrees of structure ranging from simple taxonomies, to metadata schemes, to logical theories. An ontology formally defines a set of terms that describe and represent a domain. It also defines attributes ("slots") for those terms and relationships of various types among those terms.[1–3]

Ontologies are usually expressed in a frame language or logic-based language, so that detailed, accurate, consistent, sound, and meaningful distinctions can be made among the classes, attributes, and relations. Ontologies can be created and stored in human-readable form. In addition, they can be processed in computer applications that need to access and share information in a particular domain. Some systems perform reasoning using the ontologies and thus provide advanced services

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to intelligent applications such as conceptual search and retrieval, decision support, speech and natural language understanding, knowledge management, intelligent databases, and electronic commerce. Ontologies can support advanced services such as intelligent software agents and knowledge management tools.

The relationships in an ontology make explicit the meaning of the terms they associate.[2] Capturing such meaning is vital for intelligent computer applications, particularly those involved in integrating diverse and complex information such as medical data. By defining relationships among classes in an ontology, we can build a variety of types of hierarchies. For example, the "is–a" (subsumption) relation defines the relationship between a more specific class and a more general one; for example, the class "chest x-ray" is a specific type of "radiographic procedure." By displaying all classes that have "is–a" relationships, we create a subsumption hierarchy. Similarly, the "part–of" (component) relation indicates that one class is a part of another class. By displaying all classes that have "part–of" relationships, we create a component hierarchy.

In this manuscript, we introduce the ontology formalism as an approach to represent radiological procedural knowledge for picture archiving and communication systems (PACS) integration. This project was undertaken in response to the Transforming the Radiologic Interpretation Process (TRIP) initiative.[4] Our work seeks to use knowledge encoded in an ontology to improve the delivery and utilization of radiological images to aid in the interpretation process. One can create large and complex ontology models that describe numerous and diverse radiology classes (procedures, anatomy, diagnoses, etc.) and contain rich relationships among these classes. In this manuscript, we present an ontology in a limited radiology domain that captures the knowledge needed to integrate the flow of information within the process of diagnostic radiology and the broader clinical enterprise. This ontology offers a flexible, extensible, and human-readable knowledge base that can be used by PACS and other medical enterprise computer systems for a variety of applications.

MATERIALS AND METHODS

To demonstrate the feasibility of creating and using an ontology for PACS integration, we explored a limited domain in radiology, namely, radiographic and computed tomographic (CT) imaging of the chest. The ontology was built to include pertinent anatomy, clinical indications, imaging procedures, procedure steps, and diagnoses. The knowledge sources used to construct the ontology are described in Table 1. The model's hierarchically organized classes represented generalized classes such as imaging procedures, procedure steps, and image characteristics. The slots (or "attributes") of the classes contained information about the classes, including pointers to other classes.

An initial version was crafted as a semantic network using the Network-based Ontology (NEON) software suite — a Web-based environment for creating, viewing, and updating semantic network models.[5] The ontology was subsequently migrated to Protégé,[6,7] a widely used system for development and use of ontologies. The Web Ontology Language (OWL) — a format for representation of semantic information developed by the World Wide Web Consortium[8]—was used as the interchange language. The Protégé system is able to import and export

Table 1. Knowledge sources that serve as components of the ontology

Acronym	Resource name; responsible organization	Knowledge type	Description	References
DICOM	Digital Imaging Communication in Medicine; National Equipment Manufacturers Association	Digital imaging standard	DICOM specifies the format for transmission of image and imaging-study information.	[15,23,24]
FMA	Foundational Model of Anatomy; University of Washington	Ontology	FMA defines anatomical concepts and their relationships for the Digital Anatomist project.	[25–27]
IHE	Integrating the Healthcare Enterprise; Radiological Society of North America and Health Information Management Systems Society	Standards integration profiles	IHE is not a standard, but rather a set of agreed-upon integration profiles that specify how to use existing standards. In particular, our ontology incorporates the perform grouped procedure integration profile.	[15,28]
MA	*Merrill's Atlas of Radiographic Positions and Radiologic Procedures*; Ballinger et al.	Reference text	Printed reference of radiographic positioning	[9]

ontologies using OWL. The ontology was accessed either through the graphical user interface or through the Protégé application programming interface (API) using Java or a scripting language such as Python and could be accessed remotely through the Internet. The ontology could be saved as a "flat" text file or in Extensible Mark-up Language (XML) format.

We explored the utility of the model with two scenarios requiring integrating information at the PACS workstation ("use cases") that applied different aspects of the ontology. In the first scenario, we tested use of the model to determine completeness of radiology examinations. In this scenario, the radiologist is interpreting studies at the PACS workstation and wants to determine if each study contains the appropriate images and series of images for that study. The radiologist wants to ensure that all the images required have been acquired before reporting each study.

In the second scenario, we used it to identify appropriate reference ("comparison") images. In this scenario, the radiologist interpreting images on the PACS workstation sees an abnormality on the frontal radiographic view of the chest that is not seen on the lateral view, and the radiologist wants to quickly retrieve all other frontal views of the chest on this patient to determine if this abnormality was visible before.

In both of the use cases, we evaluated the capability of our ontology to provide the necessary information required to meet the information requirements of these two scenarios. The evaluation was conducted by compiling the list of information items needed to satisfy the scenario, and determining whether that information was contained in the ontology, as well as how that information would be located in the ontology.

RESULTS

Ontology of Radiology Procedure Information

Our ontology of radiology procedure information incorporated a total of 138 classes. The top-level classes are shown in Figure 1. The ontology is organized as a taxonomy, in which classes ("child classes") that are subsumed by another class (the "parent class") have an "is–a" relationship to the parent class; as such, the child class inherits properties from its parent. For example, the class Radiology Imaging Procedure Step is a Radiology Procedure Step, which, in turn, is a Radiology Information Model Entity (Fig. 1). There are 52 Radiology Procedure Step classes. There are 22 Acquisition classes, 22 Radiographic Position classes, and 5 Modality classes.

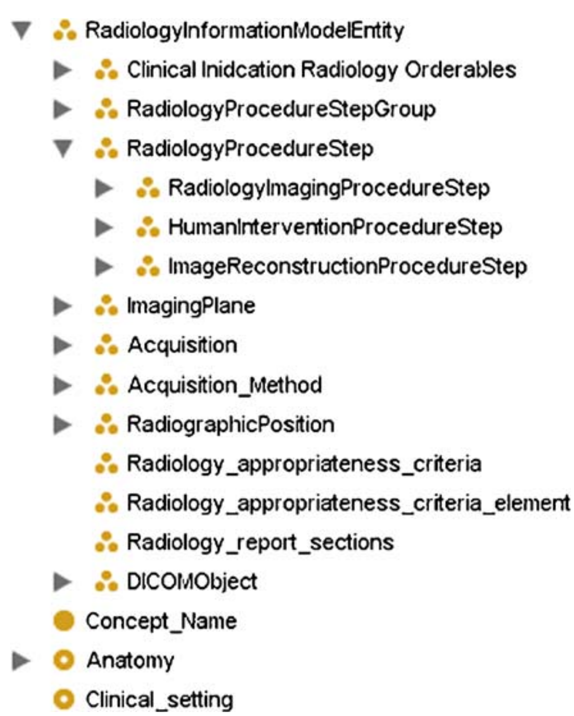

Fig 1. Top-most classes in ontology of radiology procedure information. A screen capture of the ontology in the Protégé ontology editor is shown. The top-most class, Radiology Information Model Entity, subsumes all other classes, which have an "is–a" relationship to their parents. The ontology is shown as a tree as demonstrated in this figure, with child classes shown indented and below the parent classes.

The ontology contained relationships to represent information such as *radiographic position*, *acquisition method*, *imaging plane*, the anatomy that a procedure includes (the *visualizes* relationship), and *radiographic projection* (Fig. 2). The ontology included attributes on classes to specify information such as the name of a class, its definition, and class-specific information such as "Procedure Step ID" (Fig. 2). The current ontology's knowledge of chest imaging incorporates 19 children of the Radiology Procedure Step Group class.

Radiology procedures consist of a number of individual procedure steps. Radiology orderables, requested procedures, and reports apply to groups of procedure steps that comprise them; thus, Radiology Orderable, Radiology Requested Procedure, Radiology Reportable, and Radiology Billable are children of Radiology Procedure Step Group (Fig. 1). The hierarchical organization of the ontology reflects the varying granularity in classes related to radiology procedures and how they are ordered, performed, and billed. The Radiology Orderable class denotes typical medical orders for imaging procedures and includes subclasses such as CXR (chest radiography) and Contrast-enhanced CT Chest. The Requested Procedure class describes more specifically the imaging procedure to be performed; for example, the orderable CXR is mapped to the requested procedure Chest Radiography PA and Left Lateral. The Radiology Reportable and Radiology Billable classes are used to aggregate imaging procedures for the purposes of reporting and billing, respectively.

The Radiology Procedure Step class represents the individual tasks that are performed in the course of carrying out a radiology imaging examination. An imaging procedure, therefore, is a series of individual procedure steps, usually to be carried out in a particular order. For example, the ontology contains radiology procedures such as Chest PA Step, Chest Left Lateral Step, CT Chest Scout AP Step, and CT Chest Axial Routine Step.

The ontology captured all of the information describing radiological procedures that we sought to represent and simultaneously provided machine-interpretable and human-readable presentations of the information. The detailed information about individual classes was stored as attributes (slots) in the ontology (Fig. 2). For example, the radiological procedure step for Chest PA (Chest PA Step) included details such as the acquisition method, imaging plane, radiographic position, and page reference to *Merrill's Atlas of Radiographic Positions and Radiologic Procedures*.[9] Similarly, the radiological procedure Chest PA and Left Lateral contained the name of the requested procedure and the radiology procedure steps needed to perform that procedure.

The Procedure Step class has two main subclasses: Imaging Procedure Step and Human Intervention Procedure Step. An imaging procedure step describes an image acquisition procedure performed using an imaging device. A "human intervention" is a nonimaging procedure step, such as the injection of contrast material; these procedure steps may be independent of the imaging modality being employed. The Imaging Procedure Step class is further divided by imaging modality; subclasses include X-ray Procedure Step and CT Procedure Step. One difference between these two procedure step classes is that the X-ray Procedure Step class was designed to include a slot for a page reference to *Merrill's Atlas*. The CT Procedure Step does not have that slot, but has instead a slot for local institutional CT protocol information. CT procedure steps specify the acquisition of scout (planar) images, axial images, helical images, and reformatted images.

Every Radiology Orderable is mapped to a Radiology Requested Procedure, which is mapped, in turn, to one or more Radiology Requested Procedure Steps. For example, the orderable CXR is mapped to the single requested procedure Chest Radiography PA and Left Lateral, which is mapped, in turn, to the two procedure steps, Chest PA and Chest Left Lateral.

The reader will note that all of the imaging procedures and steps are modeled in the ontology as "classes": the hierarchical relationships among them are described by their superclass–subclass relationships. Thus, the generalized relationships among the various classes are inherited by the specific instance.

Enablement of Use Cases by the Ontology

Our ontology contained the information needed by our two use-case scenarios. In addition, because the information is in machine-interpretable

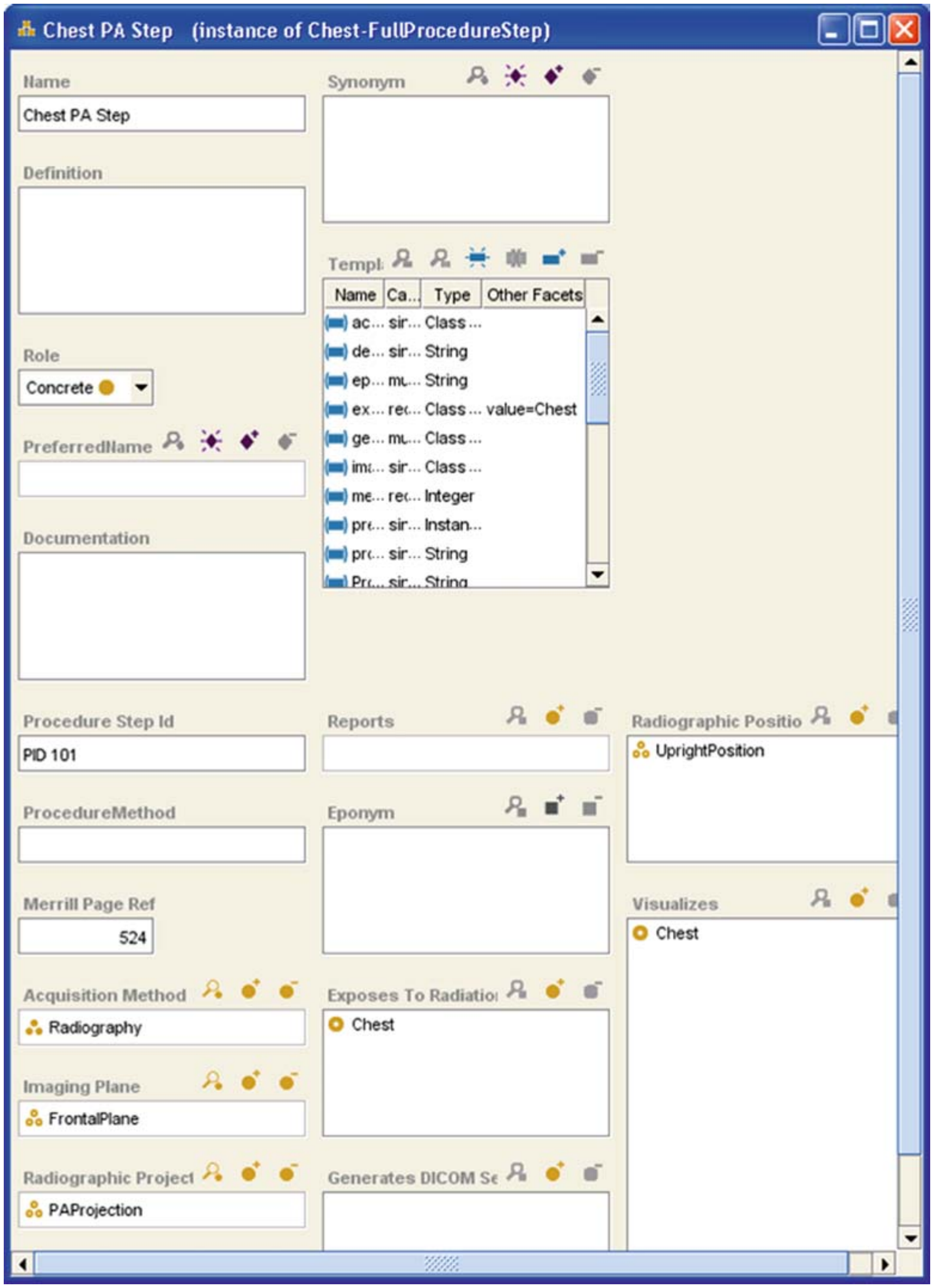

Fig 2. Ontology frame for the Chest PA radiology procedure step. This class has many attributes, specifying the information that describes details of this procedure step, such as the acquisition method, imaging plane, radiographic position, and page in *Merrill's Atlas* where the details of this procedure step are described.

format and can be accessed through the Protégé API, it would be possible to create a computer program to implement these scenarios as applications within the PACS workstation to assist radiologists in their work. The ontology integrated the necessary diverse knowledge about radiology procedures that would be required to develop such applications.

Scenario 1: Determining Radiology Examination Completeness. In this scenario, the radiologist is interpreting studies at the PACS workstation and wants to determine if each study contains the appropriate images and series of images for that study. The radiologist wants to ensure that all the images required have been acquired before reporting each study. In the first part of the scenario, the radiologist has an exam designated “CXR” to be read on the PACS workstation, and this study has only a single PA image. Our ontology supported the ability to assess exam completeness using a few lookups in the ontology (Fig. 3). First, the radiologist could look up the exam orderable corresponding to the study to be interpreted (“CXR;” Fig. 3A) to find the requested procedure that should be performed to fulfill that orderable (“Chest PA and Left Lateral;” Fig. 3B). Next, by looking at the requested procedure class in the ontology, the radiologist could determine the images that should be acquired (two images, a “Chest PA” and a “Chest Left Lateral;” Fig. 3C). Consequently, the radiologist could determine that the CXR study on the PACS system is incomplete, missing a left lateral chest view, avoiding the mistake of reporting an incomplete study. The radiologist could also determine that the images to be interpreted on the PACS workstation meet the technical requirement of the exam that was ordered by looking at the detailed specifications of the procedure steps associated with those images. For example, the radiologist could confirm that the images to be interpreted comprise two images, a PA and left lateral projection of the chest (Fig. 3D; also see Fig. 2).

For the second part of the scenario, the radiologist has an exam, “Contrast-enhanced (CE) CT with Chest CT Angio,” on the PACS that contains a scout, axial noncontrast, axial postcontrast, and sagittal maximum intensity projection (MIP)

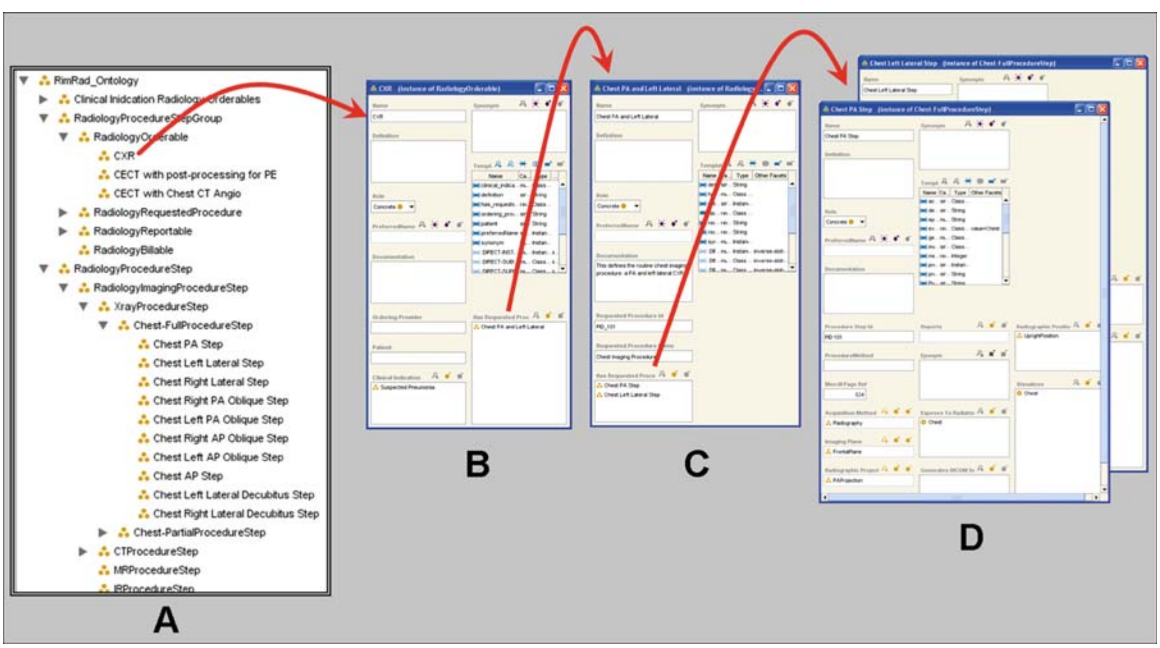

Fig 3. Using the ontology of radiology procedures to determine whether all necessary images have been acquired for a study to be interpreted at the PACS workstation. This information is identified as follows: (A) look up the exam orderable (“CXR”), (B) determine the requested procedures needed to fulfill that orderable (“Chest PA and Left Lateral”), and finally (C) identify the images that are acquired in that requested procedure (“Chest PA” and “Chest Left Lateral”). The radiologist can also determine that images to be interpreted on the PACS workstation actually meet the technical requirement of the exam that was ordered by looking at the detailed specification of the procedure steps associated with those images (D; also see Fig. 2).

series. To determine whether this study is complete, the radiologist could find the orderable, CECT with Chest CT Angio, in the ontology and immediately determine that two procedures, Chest CECT and Chest CT Angio, would have been performed. The ontology shows that the Chest CECT contains a scout chest, an axial series (noncontrast CT), a contrast agent injection, and finally another axial series (contrast-enhanced CT). The ontology also demonstrates that the Chest CT Angio should contain a CECT, sagittal reformations, off-axis coronal reformations, and curved planar reformations. Thus, the radiologist can recognize that the exam on the PACS is missing two series of reformations and is not yet ready for interpretation.

Scenario 2: Finding and Aggregating Similar Images. In this scenario, the radiologist interpreting images on the PACS workstation sees an abnormality on the frontal radiographic view of the chest that is not seen on the lateral view, and the radiologist wants to quickly retrieve all other frontal views of the chest on this patient to determine if this abnormality was visible before. The ontology was able to support the ability of the PACS display manager to selectively retrieve all frontal view images of the chest. Each image in the PACS is part of a radiology procedure (series) from which it was acquired. All classes in the ontology under Radiology Procedure Step could be searched for those which have a Frontal Plane value for the Imaging Plane slot (in other words, those radiology procedure steps that are acquired in the frontal imaging plane; Fig. 2). The ontology revealed that three chest imaging procedures, Chest PA Step, Chest AP Step, and Chest CT Scout AP, are frontal views of the chest. The PACS display manager could use this information to find whether the patient has images from these types of radiology procedures as a simple lookup from the archive of studies for that patient (Fig. 4). In this scenario, the radiologist would be able to directly retrieve images for the patient from a Chest PA, a Chest AP, and a chest CT procedure without having to manually cull through the list of imaging studies for that patient on the PACS workstation.

We also found that the ontology's capability for query extends beyond our initial predefined scenarios. For example, if the radiologist wished to retrieve all supine images of the chest on a patient, this would be the same query to the ontology, but with the additional restriction on patient position, and, in this case, two image series would be retrieved (Fig. 4). Thus, the knowledge encoded in the ontology can inform a PACS display manager and enable it to recognize pertinent radiological attributes about images, such as the view, patient position, and anatomy imaged. This information could be used by the PACS display manager to show other frontal projection images of the chest for comparison.

DISCUSSION

We sought to build an ontology of radiological procedures and explore its impact on PACS integration. The current study provides proof-of-concept for the use of ontologies to integrate PACS with other enterprise information systems. The current ontology described generalized classes in a modular and extensible knowledge base. The model applied open-source software tools, recognized standards, and the interrelationships among standards. The model fulfilled the knowledge requirements of two scenarios requiring integration of information at the PACS workstation.

Ontologies can simplify application development. In currently available PACS workstations, the functionality demonstrated by our test scenarios would require custom software for each application, and future applications would be no easier to implement than the initial applications. In contradistinction, an ontology model would require a single software application; new applications could be created by extending the ontology's content, without necessarily requiring additional software. Thus, an ontology provides an extensible foundation to create new applications and to cover broader radiology domains.

Our study was limited by the lack of comprehensive evaluation and the lack of implementation of software to apply the ontology. There are clearly other possible scenarios against which the ontology could have been evaluated besides the two described above. The scope of our ontology was limited to thoracic imaging; real-world applications would require the scope of the ontology to be expanded. In particular, one would need to expand the ontology to accommodate cross-sectional imaging modalities. Ontologies

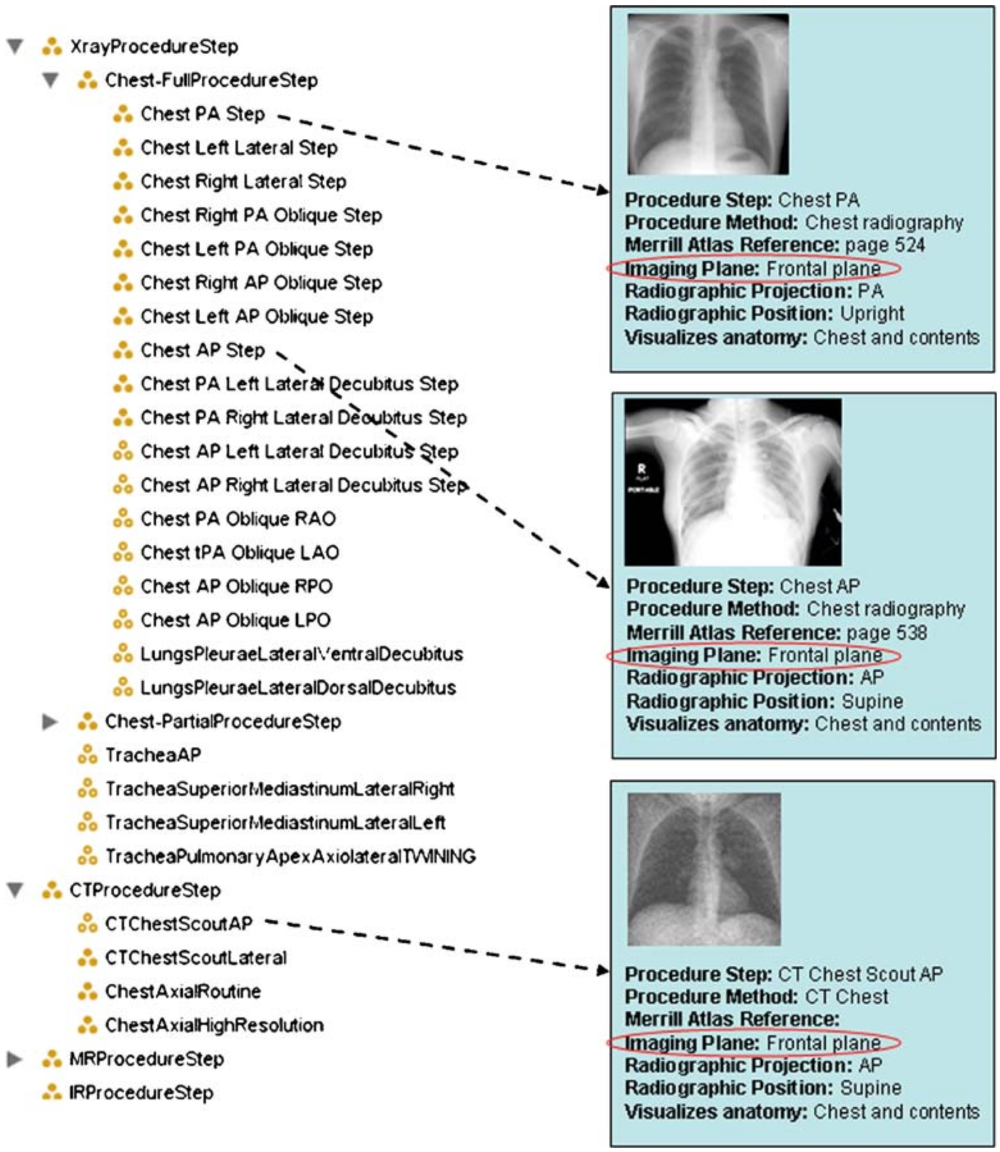

Fig 4. Using the ontology of radiology procedure information to find images from a patient taken in the same imaging plane. The classes in the Radiology Imaging Procedure Step hierarchy (Fig. 1) can be searched for those procedures that are acquired in the frontal plane (Chest PA Step, Chest AP Step, and CT Chest Scout AP; left side of the figure). Images in the PACS archive belong to particular series that correspond to these procedure classes in the ontology; accordingly, the chest PA, chest AP, and CT chest scout series could be retrieved by the PACS system. Thus, the ontology contains the information needed to inform the PACS manager which series to retrieve that contain frontal images of the chest (right side of figure).

implemented in biomedical software applications have shown value in terms of extensibility and reuse of knowledge.[10–12] Although the use cases we describe are quite simple, they were chosen to illustrate the principles of an ontology; by analogy, the ontology could support more complex scenarios. Our prototype ontology was intended as proof of concept, not as a functioning system.

It could be argued that our selection of the test cases used to evaluate the ontology was biased and affects our results. Our test cases were based on the content of the ontology; however, the ontology is a knowledge model that is not closely tied to the applications or test scenarios. The range of applications that the ontology can support is directly related to the information it

Table 2. Potential applications ("use cases")

Number	Use case	Description
1	Procedure selection	Help referring physicians select appropriate imaging procedures. Display indications and contraindications for imaging procedures; provide access to appropriateness criteria and clinical guidelines
2	Exam protocol selection	Select the appropriate procedure steps and imaging protocol to address the study's indications. Prefetch pertinent clinical data (e.g., serum creatinine, relevant clinical history, allergies)
3	Coding	Support automatic assignment of CPT-4 and ICD-9-CM codes for billing. Verify validity of CPT-4 codes for procedures performed. Link procedure code with valid indication(s)
4	Structured reporting	Create a predefined template that specifies the necessary information to be provided in the report. Create a textual summary of the performed procedure (views, scan parameters, etc.) for results reporting
5	Image retrieval and display ("hanging protocols")	Retrieve prior exams by identifying those containing similar anatomical regions and/or views. Automate display of current and prior image series based on image attributes: plane, type (projection, tomographic, 3D, 4D), and number and size of display device(s)
6	Diagnostic decision support and educational resources	Link to decision support tools such as computer-aided diagnosis systems, differential-diagnosis listings ("gamuts"), image libraries ("teaching files"), just-in-time learning resources, or other reference sources, based on the study's anatomy, indications, and/or imaging findings
7	Teaching file	Simplify the creation and indexing of teaching file cases
8	Quality improvement	Build database of clinical indications, procedures performed, and results for quality assurance and health services research

contains. There may well be scenarios for chest imaging for which the ontology lacks the necessary knowledge representation to support those scenarios. Such scenarios could be supported simply by modifying and extending the ontology. In fact, most ontology development efforts are iterative; they respond to the evolving needs of the applications and communities that use them.

Our current ontology, while limited in scope, can serve as a model for expansion to other domains and applications. Let us consider the "radiology round-trip" from referring physician to radiologist and back. A referring physician places an order for a radiological procedure, perhaps in an electronic medical record or other clinical information system. Typically, the order is then received by a radiology information system. The imaging protocol is determined either manually or automatically, and a technologist performs the appropriate imaging acquisition. In a PACS environment, the images are sent to the PACS from the imaging device. The images are displayed either on film or a workstation, and an interpretation is created by the radiologist. The interpretation is sent back to the referring physician, either electronically or on paper. The billing office must then read the report and code both the procedure actually performed and the diagnosis from the report. The information requirements needed to implement computer systems to automate these workflow processes are complex: they generally are embedded in the application code, and they are difficult to manage and extend. An ontology makes the information requirements explicit and readable. In addition, ontologies can be reused in many applications, which can streamline new application development.

Table 2 presents a variety of potential applications of our ontology. The knowledge sources needed to realize these use cases are described in Table 3. Two future applications of our ontology would be to create a decision support application for referring physicians and to make reporting templates for radiologists. Decision support tools can encourage and improve evidence-based radiology practice. A number of recent articles have discussed what is lacking in radiology reporting.[13]

We believe that ontologies could have a larger role in the radiology community beyond specific applications such as what we have discussed in our current work. Specifically, ontologies may be advantageous in representing the information in integration profiles of the Integrating the Healthcare Enterprise (IHE) initiative. IHE promotes the

Table 3. Additional knowledge sources that can be integrated into an ontology for PACS integration

Acronym	Resource name; responsible organization	Knowledge type	Description	References
ACR-AC	American College of Radiology Appropriateness Criteria; American College of Radiology	Practice guideline	The ACR-AC rate the appropriateness of imaging procedures in various clinical settings.	[29–31]
CPT-4	Current Procedural Terminology, 4th edition; American Medical Association	Controlled vocabulary	CPT codes are used to specify the performed imaging procedures, particularly for billing purposes.	[32]
HL7	Health Level Seven; Health Level Seven, Inc.	Messaging standard	HL7 defines the formats of messages sent between healthcare enterprise systems, e.g., from order-entry system to radiology information system (RIS).	[33]
ICD-9-CM	International Classification of Diseases, 9th edition, Clinical Modification; World Health Organization	Controlled vocabulary	Diagnostic radiology procedures are assigned ICD codes to indicate the relevant diagnoses for billing. ICD codes are included in the UMLS Metathesaurus.	[34]
MeSH	Medical Subject Headings; National Library of Medicine	Taxonomy	MeSH concepts are used to categorize publications catalogued in MEDLINE; they are a component of the UMLS Metathesaurus.	[35,36]
RadLex	RadLex; Radiological Society of North America	Ontology	RadLex is a "lexicon for uniform indexing and retrieval of radiology information resources" that describes radiological procedures, anatomy, imaging findings, and diagnoses; under development.	[17]
SNOMED	Systematized Nomenclature of Medicine; College of American Pathologists	Ontology	Clinical terminology	[37,38]
UMLS	Unified Medical Language System; National Library of Medicine	Ontology	Metathesaurus	[39,40]

coordinated use of established standards, such as DICOM and HL7, to address specific clinical needs in support of optimal patient care.[14–16] An ontology can reduce the variation in interpretation of both DICOM and HL7 by further constraining the meaning of terms used in both standards.

The IHE initiative defines a model for radiology operations. Orders placed by clinicians are mapped to requested procedures, which are the units of work for the radiologist. The requested procedures are, in turn, mapped to scheduled procedure steps to be performed at the imaging modality. This information is very similar to the information in our radiology procedures ontology. Because our work suggests benefits of using the ontology related to our two scenarios, we believe that ontologies will be useful to represent the information in the IHE integration profiles.

To fully express the knowledge and interrelationships, semantic models such as ontologies can be developed to integrate imaging information systems into the broader clinical enterprise. The ability to encode knowledge about postprocessing images could simplify and accelerate the radiology interpretation process, which is a key goal of the TRIP initiative.[4] The principles we illustrate could be applied to systems other than PACS. In radiology, ontologies have been explored recently to represent and manage the terminology of the RadLex project.[17,18] By incorporating radiology procedural knowledge in an ontology framework, RadLex could help standardize the terminology and logistics of radiology workflow. The ontology described here complements the RadLex effort by defining the meaning of terms (often in relation to other lexicons) and the relationships between terms.

Although relatively unfamiliar in the radiological community, ontologies are quite common in biomedical research. Many biological databases use ontologies to describe their data and relate experimental results to biomedical knowledge.[19,20] Ontologies describe microarray experiment results[21] and organize, capture, and summarize clinical trial results.[22] The recent creation of the National Center for Biomedical Ontology (http://bioontology.org/) as part of the NIH Roadmap underscores the importance of ontologies in biomedicine. In general, ontologies have been valuable in knowledge-intensive and data-rich domains, attributes that certainly apply to radiology.

Most radiology systems are closed, use relational models or proprietary schemas, or have the application knowledge embedded in application code. Ontologies are beneficial because they are declarative and extensible, and they foster knowledge sharing and reuse. They can be used across radiology applications and provide consistent knowledge of the domain to diverse applications. An ontology thus packages knowledge into a computable format. Systems developers can decide how to best integrate that knowledge base into their products. The use of XML and other standards gives them the flexibility to do so in any number of ways.

In conclusion, we have created and successfully applied an ontology of procedural knowledge of thoracic radiology that serves as a proof of concept for the use of ontologies to integrate PACS with enterprise information systems. Ontologies contain the information that describes an application area. Although they are used in conjunction with computer applications, the ontologies themselves remain separate from those applications and can be reused and extended for new applications. We believe that there are many other ways in which ontologies will prove useful in radiology in the RadLex, IHE, and TRIP initiatives.

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