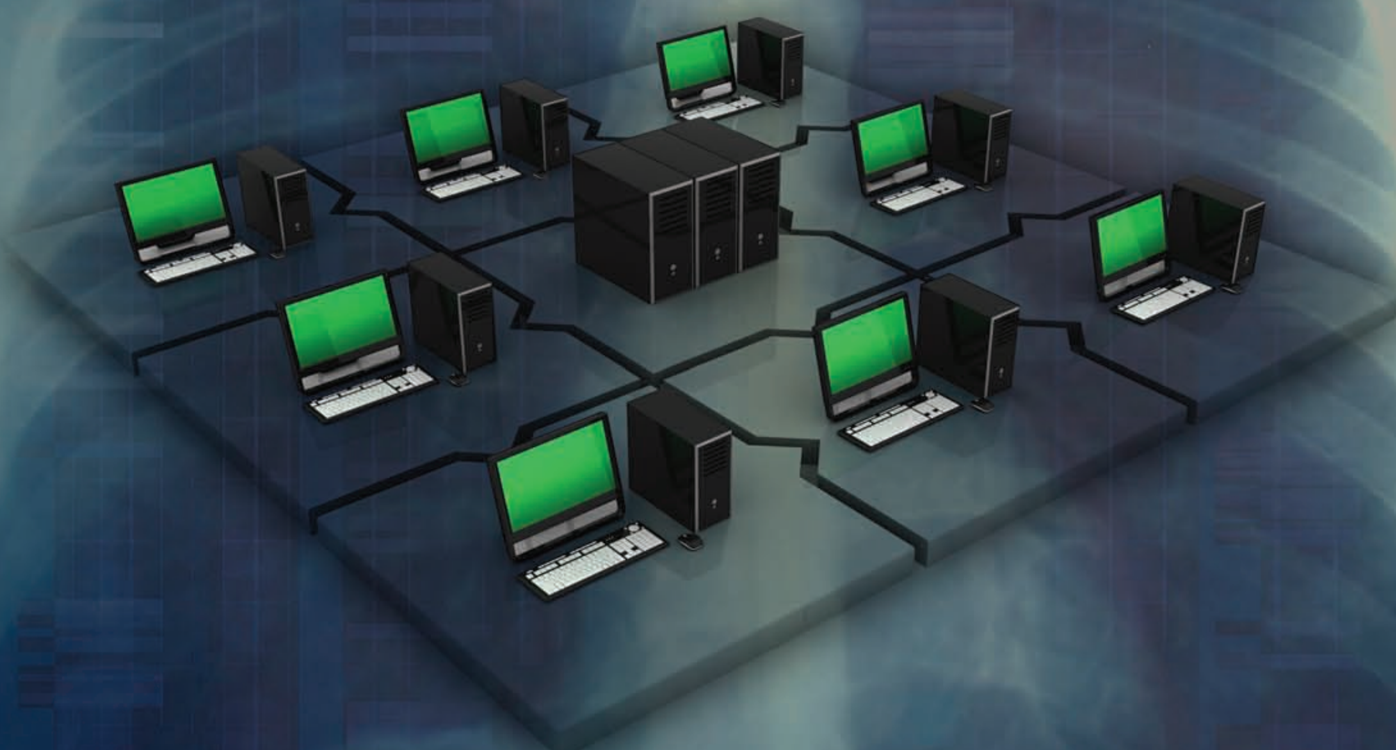
IMAGING IN MEDICAL DIAGNOSIS AND THERAPY

William R. Hendee, Series Editor

# Informatics in Medical Imaging




Edited by

George C. Kagadis

Steve G. Langer



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*To my son Orestis who has blessed me with love, continuously challenging me to become a better person, and my wife Voula who stands by me every day.*

*To George Nikiforidis and Bill Hendee for their continuous support and dear friendship.*

**George C. Kagadis**

*Of course I want to thank my mother (Betty Langer) and wife Sheryl for their support, but in addition I would like to dedicate this effort to my mentors . . .*

*My father Calvin Lloyd Langer, whose endless patience for a questioning youngster set a good example.*

*My graduate advisor Dr. Aaron Galonsky, who trusted a green graduate student in his lab and kindly steered him to a growing branch of physics.*

*My residency advisor, Dr. Joel Gray, who taught science ethics before that phrase became an oxymoron.*

*And to my precious Gabi, if her father can set half the example of his mentors, she will do well.*

**Steve G. Langer**

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# Contents

# Series Preface

Advances in the science and technology of medical imaging and radiation therapy are more profound and rapid than ever before, since their inception over a century ago. Further, the disciplines are increasingly cross-linked as imaging methods become more widely used to plan, guide, monitor, and assess the treatments in radiation therapy. Today, the technologies of medical imaging and radiation therapy are so complex and so computer-driven that it is difficult for the persons (physicians and technologists) responsible for their clinical use to know exactly what is happening at the point of care, when a patient is being examined or treated. The persons best equipped to understand the technologies and their applications are medical physicists, and these individuals are assuming greater responsibilities in the clinical arena to ensure that what is intended for the patient is actually delivered in a safe and effective manner.

The growing responsibilities of medical physicists in the clinical arenas of medical imaging and radiation therapy are not without their challenges, however. Most medical physicists are knowledgeable in either radiation therapy or medical imaging, and are experts in one or a small number of areas within their discipline. They sustain their expertise in these areas by reading scientific articles and attending scientific talks at meetings. In contrast, their responsibilities increasingly extend beyond their specific areas of expertise. To meet these responsibilities, medical physicists periodically must refresh their knowledge of advances in medical imaging or radiation therapy, and they must be prepared to function at the intersection of these two fields. How to accomplish these objectives is a challenge.

At the 2007 annual meeting of the American Association of Physicists in Medicine in Minneapolis, this challenge was the topic of conversation during a lunch hosted by Taylor & Francis Publishers and involving a group of senior medical physicists (Arthur L. Boyer, Joseph O. Deasy, C.-M. Charlie Ma, Todd A. Pawlicki, Ervin B. Podgorsak, Elke Reitzel, Anthony B. Wolbarst, and Ellen D. Yorke). The conclusion of this discussion was that a book series should be launched under the Taylor & Francis banner, with each volume in the series addressing a rapidly advancing area of medical imaging or radiation therapy of importance to medical physicists. The aim would be for each volume to provide medical physicists with the information needed to understand the technologies driving a rapid advance and their applications to safe and effective delivery of patient care.

Each volume in the series is edited by one or more individuals with recognized expertise in the technological area encompassed by the book. The editors are responsible for selecting the authors of individual chapters and ensuring that the chapters are comprehensive and intelligible to someone without such expertise. The enthusiasm of volume editors and chapter authors has been gratifying and reinforces the conclusion of the Minneapolis luncheon that this series of books addresses a major need of medical physicists.

*Imaging in Medical Diagnosis and Therapy* would not have been possible without the encouragement and support of the series manager, Luna Han of Taylor & Francis Publishers. The editors and authors, and most of all I, are indebted to her steady guidance of the entire project.

**William R. Hendee**
*Series Editor*
*Rochester, Minnesota*

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# Preface

The process of collecting and analyzing the data is critical in healthcare as it constitutes the basis for categorization of patient health problems. Data collected in medical practice ranges from free form text to structured text, numerical measurements, recorded signals, and imaging data. When admitted to the hospital, the patient often experiences additional tests varying from simple examinations such as blood tests, x-rays and electrocardiograms (ECGs), to more complex ones such as genetic tests, electromyograms (EMGs), computed tomography (CT), magnetic resonance imaging (MRI), and position emission tomography (PET). Historically, the demographics collected from all these tests were characterized by uncertainty because often there was not a single authoritative source for patient demographic information, and multiple points of human-entered data were not all in perfect agreement. The results from these tests are then archived in databases and subsequently retrieved (or not—if the "correct" demographic has been forgotten) upon requests by clinicians for patient management and analysis.

For these reasons, digital medical databases and, consequently, the Electronic Health Record (EHR) have emerged in healthcare. Today, these databases have the advantage of high computing power and almost infinite archiving capacity as well as Web availability. Access through the Internet has provided the potential for concurrent data sharing and relevant backup. This procedure of appropriate data acquisition, archiving, sharing, retrieval, and data mining is the focus of medical informatics. All this information is deemed vital for efficient provision of healthcare (Kagadis et al., 2008).

Medical imaging informatics is an important subcomponent of medical informatics and deals with aspects of image generation, manipulation, management, integration, storage, transmission, distribution, visualization, and security (Huang, 2005; Shortliffe and Cimino, 2006). Medical imaging informatics has advanced rapidly, and it is no surprise that it has evolved principally in radiology, the home of most imaging modalities. However, many other specialties (i.e., pathology, cardiology, dermatology, and surgery) have adopted the use of digital images; thus, imaging informatics is used extensively in these specialties as well.

Owing to continuous progress in image acquisition, archiving, and processing systems, the field of medical imaging informatics continues to rapidly change and there are many books written every year to reflect this evolution. While much reference material is available from the American Association of Physicists in Medicine (AAPM), the Society for Imaging Informatics in Medicine (SIIM) Task Group reports, European guidance documents, and the published literature, this book tries to fill a gap and provide an integrated publication dealing with the most essential and timely issues within the scope of informatics in medical imaging.

The target audience for this book is students, researchers, and professionals in medical physics and biomedical imaging with an interest in informatics. It may also be used as a reference guide for medical physicists and radiologists needing information on informatics in medical imaging. It provides a knowledge foundation of the state of the art in medical imaging informatics and points to major challenges of the future.

The book content is grouped into six sections. Section I deals with introductory material to informatics as it pertains to healthcare. Section II deals with the standard imaging informatics protocols, while Section III covers healthcare informatics based enabling technologies. In Section IV, key systems of radiology informatics are discussed and in Section V special focus is given to operational issues in medical imaging. Finally, Section VI looks at medical informatics issues outside the radiology department.

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# Editors

**George C. Kagadis, PhD** is currently an assistant professor of medical physics and medical informatics at University of Patras, Greece. He received his Diploma in Physics from the University of Athens, Greece in 1996 and both his MSc and PhD in medical physics from the University of Patras, Greece in 1998 and 2002, respectively. He is a Greek State Scholarship Foundation grantee, a Fulbright Research Scholar, and a full AAPM member. He has authored approximately 70 journal papers and had presented over 20 talks at international meetings. Dr. Kagadis has been involved in European and national projects, including e-health. His current research interests focus on IHE, CAD applications, medical image processing and analysis as well as studies in molecular imaging. Currently, he is a member of the AAPM Molecular Imaging in Radiation Oncology Work Group, European Affairs Subcommittee, Work Group on Information Technology, and an associate editor to *Medical Physics*.

**Steve G. Langer, PhD** is currently a codirector of the radiology imaging informatics lab at the Mayo Clinic in Rochester, Minnesota and formerly served on the faculty of the University of Washington, Seattle. His formal training in nuclear physics at the University of Wisconsin, Madison and Michigan State has given way to a new mission: to design, enable, and guide into production high-performance computing solutions to implement next-generation imaging informatics analytics into the clinical practice. This includes algorithm design, validation, performance profiling, and deployment on vended or custom platforms as required. He also has extensive interests in validating the behavior and performance of human- and machine-based (CAD) diagnostic agents.

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# I

# Introduction to Informatics in Healthcare

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# 1

# Ontologies in the Radiology Department



Dirk Marwede
*University of Leipzig*

Ontologies have become increasingly popular to structure knowledge and exchange information. In medicine, the main areas for the application of ontologies are the encoding of information with standardized terminologies and the use of formalized medical knowledge in expert systems for decision support. In medical imaging, the ever-growing number of imaging studies and digital data requires tools for comprehensive and effective information management. Ontologies provide human- and machine-readable information and bring the prospective of semantic data integration. As such, ontologies might enhance interoperability between systems and facilitate different tasks in the radiology department like patient management, structured reporting, decision support, and image retrieval.

## 1.1 Ontologies and Knowledge Representation

There have been many attempts to define what an ontology is. Originally, in the philosophical branch of metaphysics, an *ontology* deals with questions concerning the existence of entities in reality and how such entities relate to each other. In information and computer science, an ontology has been defined as a body of formally represented knowledge based on a conceptualization. Such a conceptualization is an explicit specification of objects, concepts, and other entities that are assumed to exist in some area of interest and the relations that hold among them (Genesereth and Nilsson, 1987; Gruber, 1993). Similarly, the term *knowledge representation* has been used in artificial intelligence, a branch of computer science, to describe a formal system representing knowledge by a set of rules that are used to infer (formalized reasoning) new knowledge within a specific domain.

Besides different definitions, the term ontology nowadays is often used to describe different levels of usage. These levels include (1) the definition of a common vocabulary, (2) the standardization of terms, concepts, or tasks, (3) conceptual schemas for transfer, reuse, and sharing of information, (4) organization and representation of knowledge, and (5) answering questions or queries. From those usages, some general benefits of ontologies in information management can be defined

- To enhance the interoperability between information systems
- To transmit, reuse, and share the structured data
- To facilitate the data aggregation and analysis
- To integrate the knowledge (e.g., a model) and data (e.g., patient data)

## 1.2 Ontology Components

### 1.2.1 Concepts and Instances

The main component of ontologies are *concepts* also called classes, entities, or elements. Concepts can be regarded as "unit of thoughts," that is, some conceptualization with a specific meaning whereas the meaning of concepts can be implicitly or explicitly defined. Concepts with implicit definitions are often called *primitive* concepts. In contrast, concepts with explicit definitions (i.e., *defined* concepts) are defined by relations to other concepts and sometimes restrictions (e.g., a value range). Concepts or classes can have *instances*, that is, individuals, for which all defined relations hold true. Concepts are components of a knowledge model whereas instances populate this model with individual data. For example, the concepts *Patient Name* and *Age* can have instances such as *John Doe* and *37*.

### 1.2.2 Relations

Relations are used to link concepts to each other or to attach attributes to concepts. Binary relations are used to relate concepts to each other. The hierarchical organization of concepts in an ontology is usually based on the *is_a* (i.e., is a subtype of) relation, which relates a parent concept to a child concept (e.g., "inflammation" *is_a* "disease"). The relation is also called *subsumption* as the relation subsumes *sub*-concepts under a *super*-concept. In the medical domain, many relations express structural (e.g., anatomy), spatial (e.g., location and position), functional (e.g., pathophysiological processes), or causative information (e.g., disease cause). For example, structural information can be described by partonomy relations like *part_of* or *has_part* (e.g., "liver vein" *part_of* "liver"), spatial information by the relation *located_in* (e.g., "cyst" *located_in* "liver"), or *contained_in* (e.g., "thrombus" *contained_in* "lumen of pulmonary artery"), and functional information by the relation *regulates* (e.g., "apoptosis" *regulates* "cell death"). Attributes can be attached to concepts by relations like *has_shape* or *has_density* (e.g., "pulmonary nodule" *has_shape* "round").

A relation can be defined by properties like transitivity, symmetry/antisymmetry, and reflexivity (Smith and Rosse, 2004; Smith et al., 2005). For example, a relation $R$ over a class $X$ is *transitive* if an element $a$ is related to an element $b$, and $b$ is in turn related to an element $c$, then $a$ is also related to $c$ (e.g., "pneumonia" *is_a* "inflammation" *is_a* "disease" denotes that "pneumonia" *is_a* "disease"). Relational properties are mathematical definitions from set theory, which can be explicitly defined in some ontology or representation languages (Baader et al., 2003; Levy, 2002).

### 1.2.3 Restrictions and Inheritance

Beside formal characteristics of relations, further logical statements can be attached to concepts. Such logical expressions are called restrictions or axioms, which explicitly define concepts. Basic restrictions include *domain* and *range* restrictions that define which concepts can be linked through a relation. Restrictions can be applied to the filler of a relation, for example, to a value, concept, or concept type and depend on the representation formalism used. In general, restrictions are commonly deployed in large ontologies to support reasoning tasks for checking consistency of the ontology (Baader et al., 2003; Rector et al., 1997). *Inheritance* is a mechanism deployed in most ontologies in which a child concept inherits all definitions of the parent concept. Some ontology languages support mechanism of multiple inheritance in which a child concept inherits definitions of different parent concepts.

## 1.3 Ontology Construction

The construction of an ontology usually starts with a *specification* to define the purpose and scope of an ontology. In a second step, concepts and relations in a domain are identified (*conceptualization*) often involving natural language processing (NLP) algorithms and domain experts. Afterwards, the description of concepts is transformed in a formal model by the use of restrictions (*formalization*) followed by the *implementation* of the ontology in a representation language. Finally, *maintenance* of the implemented ontology is achieved by testing, updating, and correcting the ontology. Many ontologies today, in particular controlled terminologies or basic symbolic knowledge models, do not support formalized reasoning. In fact, even if not all ontologies require reasoning support to execute specific tasks, reasoning techniques are useful during ontology construction to check consistency of the evolving ontology.

In most ontologies, concepts are precoordinated which means that primitive or defined concepts cannot be modified. However, in particular within large domains like medicine, some ontologies support postcoordination of concepts which allows to construct new concepts by the combination of primitive or defined concepts by the user (Rector and Nowlan, 1994). Postcoordination requires strict rules for concept definition to assure semantic and logical consistency within an ontology.

## 1.4 Representation Techniques

The expressivity of ontology languages to represent knowledge ranges from informal approaches with little or no specification of the meaning of terms to formal languages with strict logical definitions (Staab and Studer, 2009). In general, there is a tradeoff between logical expressivity of languages and computational efficiency, thus the appropriate ontology language or representation formalism needs to be chosen with regard to the domain of interest and the intent of the ontology.

First knowledge representation languages include *semantic networks* and *frame-based* approaches. Semantic networks represent semantic relations among concepts in a graph structure (Sowa, 1987). Within such networks, it is possible to represent logical description, for example existential graphs or conceptual graphs. Frame-based systems use a *frame* to represent an entity within a domain (Minsky, 1975). Frames are associated with a

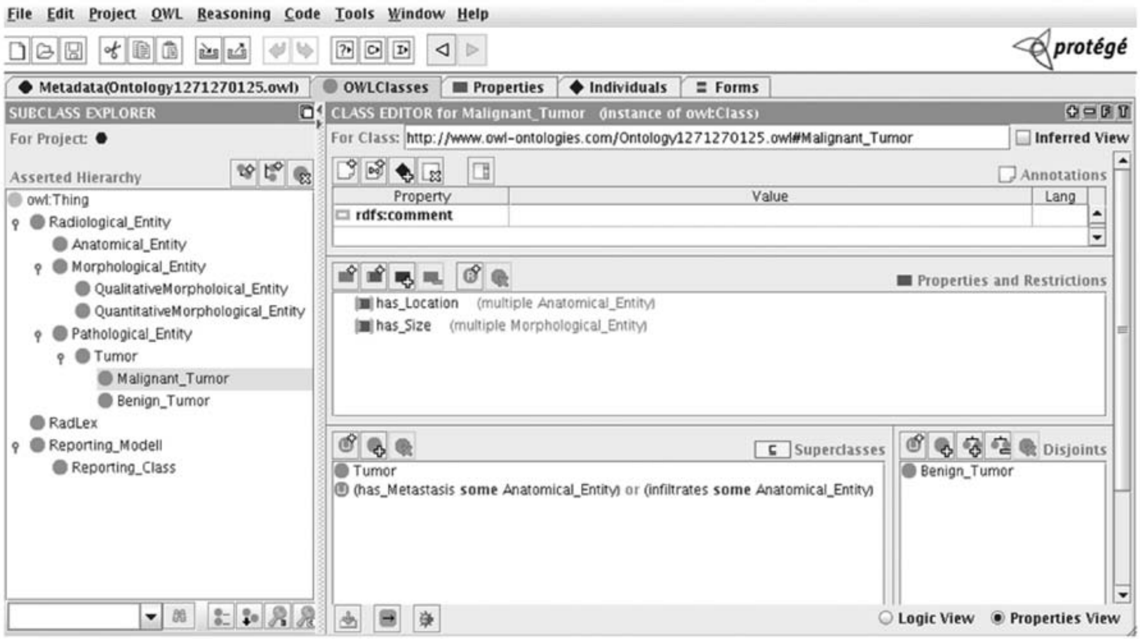



**FIGURE 1.1** Definition of concepts in a frame-based ontology editor with OWL support (Protégé OWL).

number of *slots* that can be filled with *slot values* that are also frames. Protégé is a popular open-source ontology editor using frames, which is compatible to the open knowledge base connectivity protocol (OKBC) (Noy et al., 2003).

*Description logics* (DLs) are a family of representation languages using formal descriptions for concept definitions. In contrast to semantic networks and frame-based models, DLs use formal, *logic*-based semantics for knowledge representation. In addition to the description formalism, DLs are usually composed of two components—a terminological formalism describing names for complex descriptions (T-Box) and a assertional formalism used to state properties for individuals (A-Box) (Baader et al., 2009).

The resource description framework (RDF) is a framework for representing information about resources in a graph form. The Web Ontology Language (OWL), an extension of RDF, is a language for semantic representation of Web content. OWL adds more vocabulary for describing properties and classes, that is, relations between classes (e.g., disjointness), cardinality (e.g., "exactly one"), equality, richer typing of properties, characteristics of properties (e.g., symmetry), and enumerated classes.* OWL provides three sublanguages with increasing expressivity and reasoning power: *OWL Lite* supports users primarily concerned with classification hierarchies and simple constraints, *OWL DL* provides maximum expressiveness while retaining computational completeness, and *OWL Full* has maximum expressiveness and the syntactic freedom of RDF with no computational guarantees. Today, some frame-based ontology editors provide plug-ins for OWL support combining frame-based knowledge models with logical expressivity and reasoning capacities (Figure 1.1).

## 1.5 Types of Ontologies

Medicine is a very knowledge intensive area with a long tradition in structuring its information. First attempts focussed on the codification of medical terminology resulting in hierarchical organized controlled vocabularies and terminologies, for example, the International Classification of Disease (ICD). The introduction of basic relations between entries in different hierarchies resulted in more complex medical terminologies like the Systematized Nomenclature of Medicine (Snomed) (Spackman et al., 1997). However, in recent years, complex knowledge models with or without formal reasoning support have been constructed like the Foundational Model of Anatomy (FMA) (Rosse and Mejino, 2003) or the Generalized Architecture for Languages, Encyclopaedias, and Nomenclatures in Medicine (GALEN) (Rector and Nowlan, 1994).

### 1.5.1 Upper-Level Ontologies

A top- or upper-level ontology is a domain-independent representation of very basic concepts and relations (objects, space, time). In information and computer science, the main aim of such an ontology is to facilitate the integration and interoperability of domain-specific ontologies. Building a comprehensive upper-level ontology is a complex task and different upper-level ontologies have been developed with considerable differences in scope, syntax, semantics, and representational formalisms (Grenon and Smith, 2004; Herre et al., 2006; Masolo et al., 2003).

* http://www.w3.org/TR/owl-features/

Today, the use of a single upper-level ontology subsuming concepts and relations of all domain-specific ontologies is questioned and probably not desirable in terms of computational feasibility.

### 1.5.2 Reference Ontologies

In large domains like medicine, many concepts and relations are foundational in the sense that ontologies within the same or related domain use or refer to those concepts and relations. This observation has led to the notion of *Foundational* or *Reference Ontologies* that serve as a basis or reference for other ontologies (Burgun, 2006). The most-known reference ontology in medicine is the Foundational Model of Anatomy (FMA), a comprehensive ontology of structural human anatomy, consisting of over 70,000 different concepts and 170 relationships with approximately 1.5 million instantiations (Rosse and Mejino, 2003) (Figure 1.2). An important characteristic of reference ontologies is that they are developed independently of any particular purpose and should reflect the underlying reality (Bodenreider and Burgun, 2005).

### 1.5.3 Application Ontologies

Application ontologies are constructed with a specific context and target group in mind. In contrast to abstract concepts in upper-level ontologies or to the general and comprehensive knowledge in reference ontologies, concepts and relations represent a well-defined portion of knowledge to carry out a specific task. In medicine, many application ontologies are used for decision support, for example, for the representation of mammographic features of breast cancer. Those ontologies are designed to perform complex knowledge intensive tasks and to process and provide structured information for analysis. However, most application ontologies thus far do not adhere to upper-level ontologies or link to reference ontologies that hamper the mapping and interoperability between different knowledge models and systems.

## 1.6 Ontologies in Medical Imaging

Medical imaging and clinical radiology are knowledge intensive disciplines and there have been many efforts to capture this knowledge. Radiology departments are highly computerized environments using software for (1) image acquisition, processing, and display, (2) image evaluation and reporting, and (3) image and report archiving. Digital data are nowadays administered in different information systems, for example, patient and study data in Radiology Information Systems (RIS) and image data in Picture Archiving and Communication Systems (PACS).

Within radiology departments, knowledge is rather diverse and ranges from conceptual models for integrating information from different sources to expert knowledge models about diagnostic conclusions. A certain limitation of information processing within radiology departments today is that even if images and reports contain semantic information about anatomical and pathological structures, morphological features, and disease trends, there is no semantic link between images and reports. In addition, image and report data are administered in different systems (PACS, RIS) and communicated using different standards (DICOM, HL7), which impair the integration of semantic

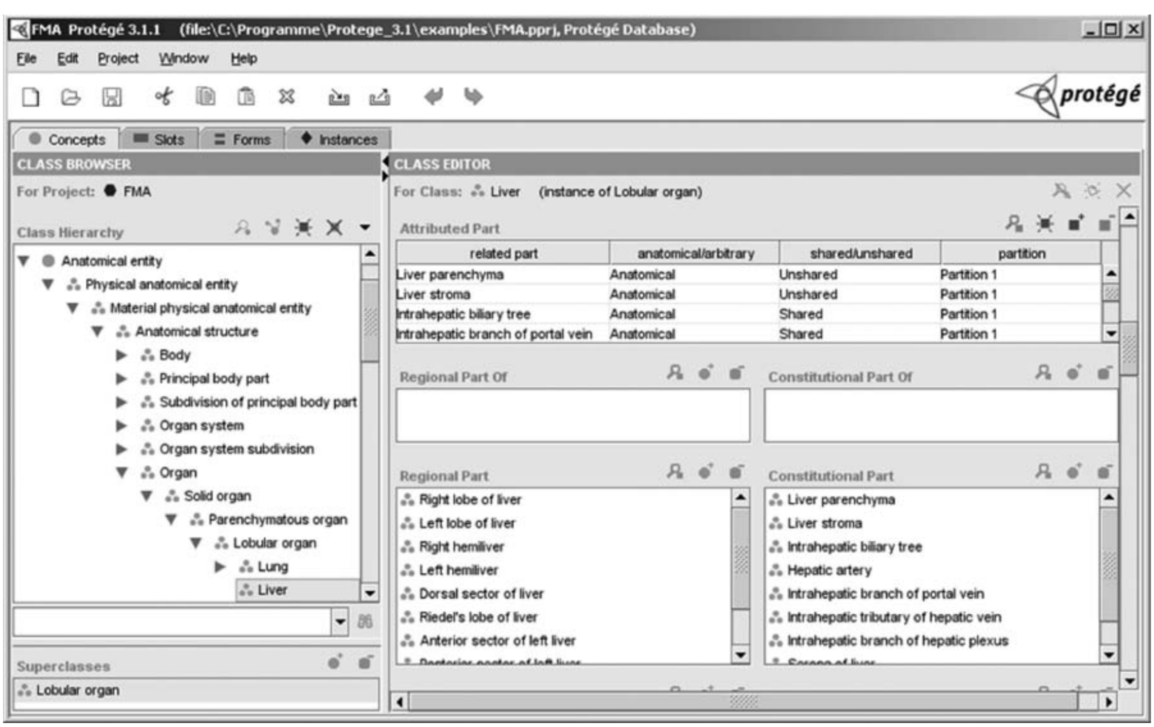



**FIGURE 1.2** Hierarchical organization of anatomical concepts and symbolic relations in the Foundational Model of Anatomy (FMA).

radiological knowledge models and the interoperability between applications.

## 1.7 Foundational Elements and Principles

### 1.7.1 Terminologies in Radiology

In the past, several radiological lexicons have been developed such as the Fleischner Glossary of terms used in thoracic imaging (Tuddenham, 1984; Austin et al., 1996), the Breast Imaging Reporting and Data System (BIRADS) (Liberman and Menell, 2002), and the American College of Radiology Index (ACR) for diagnoses. As those lexicons represented only a small part of terms used in radiology and were not linked to other medical terminologies, the Radiological Society of North America (RSNA) started, in 2003, the development of a concise radiological lexicon called RadLex© (Langlotz, 2006).

RadLex was developed to unify terms in radiology and to facilitate indexing and retrieval of images and reports. The terminology can be accessed through an online term browser or downloaded for use. RadLex is a hierarchical, organized terminology consisting of approximately 12,000 terms grouped in 14 main term categories (Figure 1.3). Main categories are *anatomical entity* (e.g., "lung"), *imaging observation* (e.g., "pulmonary nodule"), *imaging observation characteristic* (e.g., "focality") and *modifiers* (e.g., "composition modifier"), *procedure steps* (e.g., "CT localizer radiograph") and *imaging procedure attributes* (e.g., modalities), *relationship* (e.g., is_a, part_of), and *teaching attributes* (e.g., "perceptual difficulty"). Thus far, the hierarchical organization of terms represents *is_a* and *part_of* relations between terms.

RadLex can be regarded as a hierarchical, organized, standardized terminology. RadLex thus far does not contain formal definitions or logical restrictions. However, evolving ontologies in radiology might use RadLex terms as a basis for concept definitions and different formal constructs for specific application tasks. In this manner, RadLex has been linked already to anatomical concepts of the Foundational Model of Anatomy to enrich the anatomical terms defined in RadLex with a comprehensive knowledge model of human anatomy (Mejino et al., 2008).

### 1.7.2 Interoperability

Ontologies affect different tasks in radiology departments like reporting, image retrieval, or patient management. To exchange and process the information between ontologies or systems, different levels of interoperability need to be distinguished (Tolk and Muguira, 2003; Turnitsa, 2005). The *technical* level is the most basic level assuring that a common protocol exists for data exchange. The *syntactic* level specifies a common data structure and format, and the *semantic* level defines the content and meaning of the exchanged information in terms of a reference model. *Pragmatic* interoperability specifies the context of the exchanged information making the processes explicit, which use the information in different systems. A *dynamic* level ensures that state changes of exchanged information are understood by the systems and on the highest level of interoperability, the *conceptual* level, a fully specified abstract concept model including constraints and assumptions is explicitly defined.


**FIGURE 1.3** RadLex online Term Browser with hierarchical organization of terms (left) and search functionality (right).

## 1.8 Application Areas of Ontologies in Radiology

### 1.8.1 Imaging Procedure Appropriateness

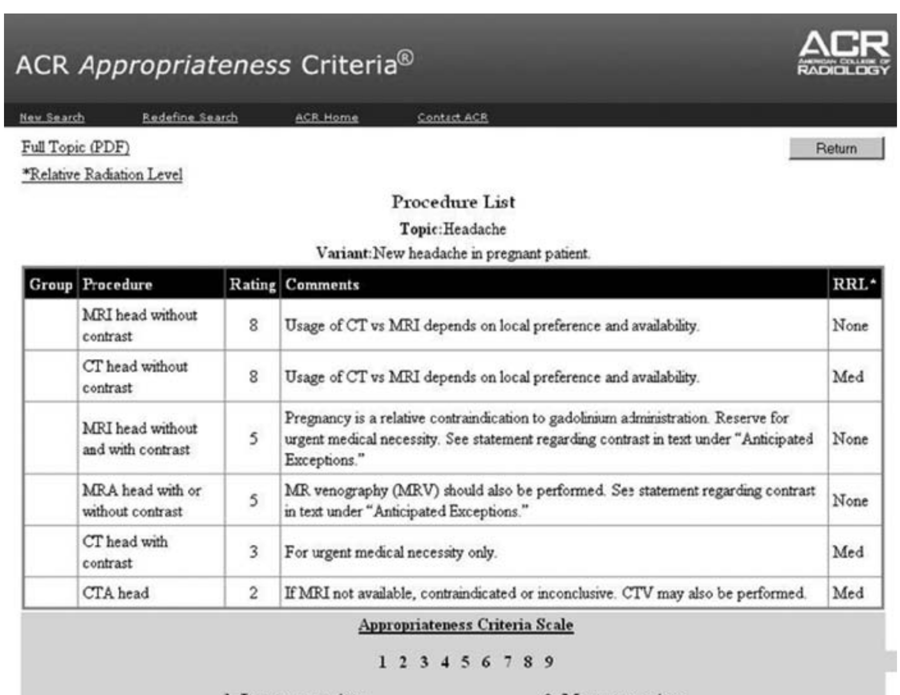
Medical imaging procedures are performed to deliver accurate diagnostic and therapeutic information at the right moment. For each imaging study, an appropriate imaging technique and protocol are chosen depending on the medical context. In clinical practice, this context is defined by the patient condition, clinical question (indication), patient benefit, radiation exposure, and availability of imaging techniques determining the appropriateness of an imaging examination. During the 1990s, the American College of Radiology (ACR) has developed standardized criteria for the appropriate use of imaging technologies, the ACR Appropriateness Criteria (ACRAC).

The ACRAC represent specific clinical problems and associated imaging procedures with an appropriateness score ranging from 1 (not indicated) to 9 (most appropriate) (Figure 1.4). The ACRAC are organized in a relational database model and electronically available (Sistrom, 2008). A knowledge model of the ACRAC and online tools to represent, edit, and manage knowledge contained in the ACRAC were developed. This model was defined by the Appropriateness Criteria Model Encoding Language (ACME), which uses the Standard Generalized Mark-Up Language (SGML) to represent and interrelate the definitions of *conditions*, *procedures*, and *terms* in a semantic network (Kahn, 1998). To promote the application of appropriate criteria in clinical practice, an online system was developed to search, retrieve, and display ACRAC (Tjahjono and Kahn, 1999). However, to enhance the use of ACRAC criteria and its integration into different information systems (e.g., order entry), several additional requirements have been defined: a more formal representation syntax of clinical conditions, a standardized terminology or coding scheme for clinical concepts, and the representation of temporal information and uncertainty (Tjahjono and Kahn, 1999).

### 1.8.2 Clinical Practice Guidelines

"Clinical practice guidelines are systematically developed statements to assist the practitioners and patient decisions about appropriate healthcare for specific circumstances" (Field and Lohr, 1992). In the 1990s, early systems emerged representing originally paper-based clinical guidelines in a computable format. The most popular approaches were the GEODE-CM system for guidelines and data entry (Stoufflet et al., 1996), the Medial Logical Modules for alerts and reminders (Barrows et al., 1996; Hripcsak et al., 1996), the MBTA system for guidelines and reminders (Barnes and Barnett, 1995), and the EON architecture (Musen et al., 1996) and PRODIGY system (Purves, 1998) for guideline-based decision support. As those systems differed by representation technique, format, and functionality, the need for a common guideline representation format emerged.

In 1998, the Guideline Interchange Format (GLIF), a representation format for sharable computer-interpretable clinical practice guidelines, was developed. GLIF incorporates functionalities from former guideline systems and consists of three abstraction levels, a conceptual (human-readable) level for medical terms as free text represented in flow charts, a computable level with an


ACR *Appropriateness* Criteria®

New Search Redefine Search ACR Home Contact ACR

Full Topic (PDF)

*Relative Radiation Level

Return

**Procedure List**

**Topic:** Headache

**Variant:** New headache in pregnant patient.

| Group | Procedure | Rating | Comments | RRL* |
|---|---|---|---|---|
| | MRI head without contrast | 8 | Usage of CT vs MRI depends on local preference and availability. | None |
| | CT head without contrast | 8 | Usage of CT vs MRI depends on local preference and availability. | Med |
| | MRI head without and with contrast | 5 | Pregnancy is a relative contraindication to gadolinium administration. Reserve for urgent medical necessity. See statement regarding contrast in text under "Anticipated Exceptions." | None |
| | MRA head with or without contrast | 5 | MR venography (MRV) should also be performed. See statement regarding contrast in text under "Anticipated Exceptions." | None |
| | CT head with contrast | 3 | For urgent medical necessity only. | Med |
| | CTA head | 2 | If MRI not available, contraindicated or inconclusive. CTV may also be performed. | Med |

**Appropriateness Criteria Scale**

**1 2 3 4 5 6 7 8 9**

**1=Least appropriate** **9=Most appropriate**

**FIGURE 1.4** Online access to the ACRAC: Detailed representation of clinical conditions, procedures, and appropriateness score.

expressive syntax to execute a guideline, and an implementation level to integrate guidelines in institutional clinical applications (Boxwala et al., 2004). The GLIF model represents guidelines as sets of classes for guideline entities, attributes, and data types. A flowchart is built by *Guideline_Steps*, which has the following subclasses: *Decision_Step* class for representing decision points, *Action_Step* class for modeling recommended actions or tasks, *Branch_Step* and *Synchronization_Step* classes for modeling concurrent guideline paths, and *Patient_State_Step* class for representing the patient state. In addition, the GLIF specification includes an expression and query language to access patient data and to map those data to variables defined as decision criteria.

In summary, computer-interpretable practice guidelines are able to use diverse medical data for diagnoses and therapy guidance. Integration of appropriate imaging criteria and imaging results in clinical guidelines is possible, but requires interoperability between information systems used in radiology and guideline systems. However, the successful implementation of computer-interpretable guidelines highly depends on the complexity of the guideline, the involvement of medical experts, the degree of interoperability with different information systems, and the integration in the clinical workflow.

### 1.8.3 Order Entry

In general, computer-based physician order entry (CPOE) refers to a variety of computer-based systems for medical orders (Sittig and Stead, 1994). For over 20 years, CPOE systems have been used mainly for ordering the medication and laboratory examinations; however, since, some years, radiology order entry systems (ROE) are emerging, enabling physicians are to order the image examinations electronically. CPOE and ROE systems assure standardized, legible, and complete orders and provide data for quality assurance and cost analysis.

There is no standard ROE system and many systems have been designed empirically according to the organizational and institutional demands. Physicians interact with the systems through a user interface, which typically is composed of order forms in which information can be typed in or selected from predefined lists. The ordering physician specifies the imaging modality or service and provides information about the patient like signs/symptoms and known diseases. Clinical information is usually encoded into a standardized terminology or classification schema like the International Classification of Diseases (ICD). Some systems incorporate the decision support in the order entry process, providing guidance for physicians which imaging study is the most appropriate (Rosenthal et al., 2006). There is evidence that those systems might change the ordering behavior of physicians and increase the quality of imaging orders (Sistrom et al., 2009).

Knowledge modeling of order entry and decision support elements is not trivial as relations between clinical information like signs and symptoms, suspected diseases, and appropriate imaging examinations are extensive and frequently complex. However, as standardized terminologies are implemented in most order entry systems and criteria for appropriate imaging have been defined, an ontology or knowledge model for the appropriate ordering of imaging examinations can be implemented and possibly shared across different institutions.

## 1.9 Image Interpretation

### 1.9.1 Structured Reporting

Structured reporting of imaging studies brings the prospect of unambiguous communication of exam results and automated report analysis for research, teaching, and quality improvement. In addition, structured reports address the major operational needs of radiology practices, including patient throughput, report turnaround time, documentation of service, and billing. As such, structured reports might serve as a basis for many other applications like decision support systems, reminder and notification programs, or electronic health records.

General requirements for structured reports are a controlled vocabulary or terminology and a standardized format and structure. Early structured reporting systems used data entry forms in which predefined terms or free-text was reported (Bell and Greenes, 1994; Kuhn et al., 1992). For the meaningful reporting of imaging observations, some knowledge models were developed to represent statements and diagnostic conclusions frequently found in radiology reports (Bell et al., 1994; Friedman et al., 1993; Marwede et al., 2007). However, integrating a controlled vocabulary with a knowledge model for reporting imaging findings in a user-friendly reporting system remains a challenging task.

In fact, the primary candidate for a controlled vocabulary is RadLex, the first comprehensive radiological terminology. There is some evidence that RadLex contains most terms present in radiology reports today, even if some terms need to be composed by terms from different hierarchies (Marwede et al., 2008). In 2008, the RSNA defined general requirements for structured radiology reports to provide a framework for the development of best practice reporting templates.* Those templates use standardized terms from RadLex and a simple knowledge representation scheme defined in extensible mark-up language (XML). Furthermore, a comprehensive model for image annotations like measurements or semantic image information has been developed using RadLex for structured annotations (Channin et al., 2009). In this model, annotations represent links between image regions and report items connecting semantic information in images with reports. Storage and export of annotations can be performed in different formats (Rubin et al., 2008).

Structured reporting applications today mainly use data entry forms in which the user types or selects terms from lists. Those forms provide static or dynamic menu-driven interfaces, which enable the radiologist to quickly select and report items. However, a promising approach to avoid distraction during review is to integrate speech recognition software into

* http://www.rsna.org/informatics/radreports.cfm

structured reporting applications (Liu et al., 2006). Such applications might provide new dimensions of interaction like the "talking template," which requests information or guides the radiologist through the structured report without interrupting the image review process (Sistrom, 2005).

### 1.9.2 Diagnostic Decision Support Systems

In radiology departments, diagnostic decision support systems (DSS) assist the radiologist during the image interpretation process in three ways: (1) to perceive image findings, (2) to interpret those findings to render a diagnosis, and (3) to make decisions and recommendations for patient management (Rubin, 2009). DSS systems are typically designed to integrate a medical knowledge base, patient data, and an inference engine to generate the specific advice.

In general, there are five main techniques used by DSS: *Rule-based reasoning* uses logical statements or rules to infer knowledge. Those systems acquire specific information about a case and then invoke appropriate rules by an inference engine. Similarly, *symbolic modeling* is an approach which defines knowledge by structured organization of concepts and relations. Concept definitions are explicitly stated and sometimes constrained by logical statements used to infer knowledge. An *artificial neural network* (ANN) is composed of a collection of interconnected elements whereas connections between elements are weighted and constitute the knowledge of the network. ANN does not require defined expert rules and can learn directly from observations. Training of the network is performed by presenting input variables and the observed dependent output variable. The network then determines internodal connections between elements and uses this knowledge for classification of new cases. *Bayesion Networks*—also called probalistic networks—reason about uncertain knowledge. They use diverse medical information (e.g., physical findings, laboratory exam results, image study findings) to determine the probability of a disease. Each variable in the network has two or more states with associated probability values summing up to 1 for each variable. Connections between variables are expressed as conditional probabilities such as sensitivity or specificity. In this manner, probabilistic networks can be constructed on the basis of published statistical study results. *Case-based Reasoning* (CBR) systems use knowledge from prior experiences to solve new problems. The systems contain cases indexed by associated features. Indexing of new cases is performed by retrieving similar cases from memory and adapting solutions from prior experiences to the new case (Kahn, 1994).

Applications concerned with the detection of imaging findings by quantitative analysis are called computer-aided diagnosis (CAD) systems. Those systems frequently use ANN for image analysis and were successfully deployed for the detection of breast lesions (Giger et al., 1994; Huo et al., 1998; Jiang et al., 1999; Xu et al., 1997), lung nodules (Giger et al., 1994; Xu et al., 1997) (REF DOI), and colon polyps (Yoshida and Dachman, 2004). DSS systems concerned with the diagnosis of a disease were developed at first for the diagnosis of lung diseases (Asada et al., 1990; Gross et al., 1990), bone tumors in skeletal radiography (Piraino et al., 1991), liver lesions (Maclin and Dempsey, 1992; Tombropoulus et al., 1993), and breast masses (Kahn et al., 1997; Wu et al., 1995). In recent years, applications have been developed using symbolic models for reasoning tasks (Alberdi et al., 2000; Rubin et al., 2006) and a composite approach of symbolic modeling and Bayesian networks for diagnostic decision support in mammography (Burnside et al., 2000).

Even if all techniques infer knowledge in some manner, symbolic modeling and rule-based reasoning approaches conform more precisely to what is understood by *ontologies* today. As inferred knowledge often is not trivial to understand by the user, those approaches tend to be more comprehensible to humans due to their representation formalism. In fact, this is besides workflow integration and speed of the reasoning process, one of the most important factors affecting the successful implementation of DSS systems (Bates et al., 2003).

### 1.9.3 Results Communication

#### 1.9.3.1 DICOM-Structured Reporting

The use of structured reporting forms reduces the ambiguity of natural language reports and enhances the precision, clarity, and value of clinical documents (Hussein et al., 2004). DICOM-Structured Reporting (SR) is a supplement of the DICOM Standard developed to facilitate the encoding and exchange of report information. The Supplement defines a document architecture for storage and transmission of structured reports by using the DICOM hierarchical structure and services.

An SR document consists of *Content Items,* which are composed of name/value pairs. The name (concept name) is represented by a coded entry that uses an attribute triplet: (1) the code value (a computer readable identifier), (2) the code scheme designator (the coding organization), and (3) the code meaning (human-readable text). The value of content items is used to represent the diverse information like containers (e.g., headings, titles), text, names, time, date, or codes. For specific reporting applications and tasks, SR templates were developed, which describe and constrain content items, value types, relationship types, and value sets for SR documents.

By the use of content items, text strings or standardized terms can be used to encode and interrelate the image information. For example, a mass can be described by properties like margin or size, which is achieved by relating content items through the relationship *has_properties*. In this manner, a structured report represents some kind of knowledge model in which image findings are related to each other (Figure 1.5).

To unify the representation of radiological findings, a model integrating UMLS terms, radiological findings, and DICOM SR has been proposed (Bertaud et al., 2008). This is a promising approach to standardize and integrate the knowledge about imaging observations and their representation in structured format. However, as DICOM SR defines only few relations and allows basic constrains on document items, its semantic and logical expressivity is limited. In future applications, the use

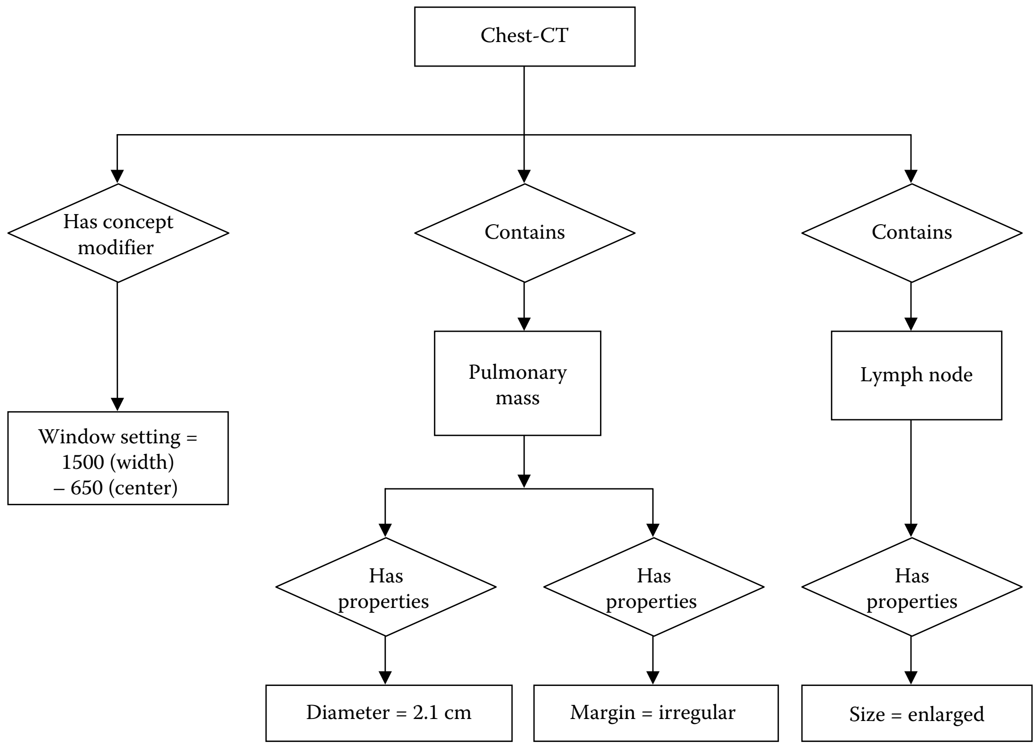



**FIGURE 1.5** DICOM Structured Reporting Tree.

of a standardized radiological lexicons like RadLex and a more expressive representation formalism might increase the usefulness of structured reports and allows interoperability and analysis of imaging observations among different institutions.

#### 1.9.3.2 Notification and Reminder

Notification and reminder systems track clinical data to issue alerts or inform physicians (Rubin, 2009). In radiology, such systems can be used to categorize the importance of findings and inform physicians about recommended actions. These systems facilitate the communication of critical results by assuring quick and appropriate communication (e.g., phone or email). In addition, systems can track the receipt of a message and send reminders if no appropriate action is taken. Communication and tracking of imaging results often are implemented in Web-based systems that have shown to improve the communication among radiologists, clinicians, and technologists (Halsted and Froehle, 2008; Johnson et al., 2005). As the primary basis for notification and reminder systems are imaging results, standardized terminologies and structured reports seem to be very useful as input for such systems in the future. However, definition of criteria for notification and reminder systems might benefit from ontologies capturing knowledge about imaging findings, clinical data, and recommended actions.

### 1.9.4 Semantic Image Retrieval

The number of digitally produced medical images is rising strongly and requires efficient strategies for management and access to those images. In radiology departments, access to image archives is usually based on patient identification or study characteristics (e.g., modality, study description) representing the underlying structure of data management.

Beginning in 1980, first systems were developed for querying images by content (Chang and Fu, 1980). With the introduction of digital imaging technologies, content-based image retrieval systems were developed using colors, textures, and shapes for image classification. Within radiology departments, applications executing classification and content-based search algorithms were introduced for mammography CT images of the lung, MRI and CT images of the brain, photon emission tomography (PET) images, and x-ray images of the spine (Muller et al., 2004).

Besides retrieving the images based on image content determined by segmentation algorithms or demographic and procedure information, the user often is interested in the context, that is, the meaning or interpretation of the image content (Kahn and Rubin, 2009; Lowe et al., 1998). One way to incorporate context in image retrieval applications is to index radiology reports or figure captions (Kahn and Rubin, 2009). Such approaches are encouraging if textual information is mapped to concept-based representations to reduce equivocal image retrieval results by lexical variants or ambiguous abbreviations.

Current context-based approaches for image retrieval use concepts like imaging technique (e.g., "chest x-ray"), anatomic region or field of view (e.g., "anterioposterior view"), major anatomic segments (e.g., "thorax"), image features (e.g., "density"), and findings (e.g., "pneumonia") for image retrieval. However, for a comprehensive semantic image retrieval application, a knowledge model of anatomical and pathological structures displayed on images and its image features would be desirable. For many diseases, however, image features are not unique and its presence or combination in a specific clinical context produces lists of possible diagnoses with different degrees of certainty. In this regard, criteria for diagnoses inferred from images are often imprecise and ill-defined and considerable intra- and interobserver variation is common (Tagare et al., 1997).

There have been some efforts to retrieve images based on semantic medical information. For example, indexing images by structured annotations using a standardized radiological lexicon (RadLex) allow the user to store such annotation together with images. Such annotations than can be queried and similar patients or images can be retrieved on the basis of the annotated information (Channin et al., 2009). Other approaches use automatic segmentation algorithms and concept-based annotations to label image content and use those concepts for image retrieval (Seifert et al., 2010).

### 1.9.5 Teaching Cases, Knowledge Bases, and E-Learning

There is a long tradition of collecting and archiving images for educational purposes in radiology. With the development of digital imaging techniques and PACS, images from interesting cases can be easily labeled or exported in collections. In recent years, many systems have been developed to archive, label, and retrieve images. Such systems often provide the possibility to attach additional clinical information to images or cases and share teaching files through the Web like the Medical Image Resource System (MIRC) (Siegel and Reiner, 2001). Today, many departments possess teaching archives that are continuously populated with cases encountered in the daily work routine. In fact, various comprehensive teaching archives exist on the Web providing extensive teaching cases (Scarsbrook et al., 2005).

One major challenge in the management of teaching files is the organization of cases for educational purposes. Most teaching archives label cases by examination type (e.g., "MRI"), body region (e.g., "abdominal imaging"), and diagnoses (e.g., "myxoid fibrosarcoma") using text strings. Even if many archives represent similar cases, such systems deploy their own information and organizational model and contain non uniform labels. One important aspect in usability and interoperability of teaching archives is the use of a standardized terminology and knowledge model for organization and retrieval of cases together with a strict guideline for labeling cases. An ontology- or concept-based organization of semantic image content would empower users to query cases by explicit criteria like combination of morphological features and classify cases according to additional attributes like analytical or perceptual difficulty.

The use of electronic educational material is called e-learning and many Web-based applications have been developed to present medical images together with additional educational material electronically. Most implementations deploy a learning management system to organize, publish, and maintain the material. Such systems usually encompass registration, delivery and tracking of multimedia courses and content, communication and interactions between students/residents and educators, and testing (Sparacia et al., 2007). Some e-learning applications for radiology are in use and such systems would certainly benefit from concept-based organization of semantic image content. In this way, cases and knowledge in existing teaching archives could be re-used within e-learning applications and interpretation and inference patterns frequently encountered in radiology could be used for the education of students and residents.

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# 2

# Informatics Constructs




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## 2.1 Background

### 2.1.1 Terms and Definitions

*Actor:* In a particular Use Case, Actors are the agents that exchange data via Transactions, and perform operations on that data, to accomplish the Use Case goal (Alhir, 2003).

*Class:* In programming and design, the class defines an Actor's data elements, and the operations it can perform on those data (Alhir, 2003).

*Constructs:* Constructs are conceptual aids (often graphical) that visually express the relationships among Actors, Transactions, transactional data, and how they inter-relate in solving Use Cases.

*Informatics:* Medical Informatics has been defined as "that area that concerns itself with the cognitive, information processing, and communication tasks of medical practice, education, and research, including the information science and the technology to support these tasks" (Greenes and Shortliffe, 1990). More broadly, informatics is a given branch of knowledge and how it is acquired, represented, stored, transmitted, and mined for meaning (Langer and Bartholmai, 2010).

*Object:* An Object is the real world instantiation of a Class with specific data.

*Ontology:* A specification of a representational vocabulary for a shared domain of discourse—definitions of classes, relations, functions, and other objects (Gruber, 1993). Another way to consider ontology is the collection of content terms and their relationships that are agreed to represent concepts in a specific branch of knowledge. A common example is HTTP (Hypertext Transfer Protocol), which is the grammar/protocol used to express HTML (Hypertext Markup Language) content on the World Wide Web.

*Protocol:* Protocols define the transactional format for transmission of information via a standard Ontology among Actors (Holzmann, 1991).

*Transactions:* Messages that are passed among Actors using standard Protocols that encapsulate the standard terms of an Ontology. The instance of a communication pairing between two Actors is known as an association.

*Use Case:* A formal statement of a specific workflow, the inputs and outputs, and the Actors that accomplish the goal via the exchange of Transactions (Bittner and Spence, 2002).

### 2.1.2 Acquired, Stored, Transmitted, and Mined for Meaning

As defined above, the term "Informatics" can be applied to many areas; bioinformatics concerns the study of the various scales of living systems. Medical Imaging Informatics, the focus of this book, is concerned with the methods by which medical images are acquired, stored, viewed, shared, and mined for meaning. The purpose of this chapter is to provide the background to understand the constituents of Medical Imaging Informatics that will be covered in more detail elsewhere in this book. After reading it, the reader should have sufficient background to place the material in Chapters 1 (Ontology), 3 (HL7), and 4 (DICOM) in a cohesive context and be in a comfortable position to understand the spirit and details of Chapter 5 (IHE, Integration of the Healthcare Enterprise).

As will ultimately become clear, the goal of patient care is accomplished via the exchange of Transactions among various Actors; such exchanges are illustrated by a variety of constructs, consisting of various diagram types. These diagrams are ultimately tied rendered with the content Transactions, Protocols, and Actors that enable the solution of Use Case scenarios.

## 2.2 Acquired and Stored

When either humans or machines make measurements or acquire data in the physical world, there are several tasks that must be accomplished:

a. The item must be measured in a standard, reproducible way or it has no benefit.
b. The value's magnitude and other features must be represented in some persistent symbolic format (i.e., writing on paper, or bits in a computer) that has universally agreed meanings.
c. If the data is to be shared, there must be a protocol that can encapsulate the symbols and transmit them among humans (as in speech or writing) or machines (electromagnetic waves or computer networks) in transactions that have a standard, universally understood, structure.

### 2.2.1 Data Structure and Grammar

#### 2.2.1.1 HL7

The Health Level 7 (HL7) standard is the primary grammar used to encapsulate symbolic representations of healthcare data among computers dealing in nonimaging applications (Henderson, 2007). It will be covered in detail in Chapter 3, but for the purposes of the current discussion it is sufficient to know just a few basic concepts. First, that HL7 specifies both events and the message content that can accompany those events. Second, some aspects of HL7 have strictly defined allowed terms, while other message "payloads" can have either free text (i.e., radiology reports) or other variable content. Consider Figure 2.1.

Finally, HL7 transactions can be expressed in two different protocols: the classical HL7 format (versions V2.x), which relies on a low-level networking protocol called TCP/IP (see Section 2.3), is exemplified in Figures 2.1 and the new XML format (for HL7 V3.x) is shown in Figure 2.2.

#### 2.2.1.2 DICOM

While HL7 has found wide acceptance in most medical specialties, it was found insufficient for medical imaging. Hence in 1993, the American College of Radiology (ACR) and National Electrical Manufacturers Association (NEMA) collaborated to debut DICOM (Digital Imaging Communications in Medicine) at the Radiological Society of North America annual meeting. DICOM introduced the concept of Service–Object Pairs, which relates for certain object types what services can be applied to them (i.e., store, get, print, display). DICOM is also much stronger "typed" then HL7, meaning that specific data elements not only have fixed data type that can be used, but fixed sizes as well.

(a)


```
MSH|^~\&|RIMS|MCR|IHE-ESB|MCR|20101116103737||ORM^O01|1362708283|P|2.3.1||||||||
PID||2372497|03303925^^^^MC~033039256^^^^CYCARE~AU0003434^^^^AU|03-303-925^^^^MC~03-303-925-
6^^^^CYCARE~AU0003434^^^^AU|TESTING^ANN^M.^^^||19350415|F||||||||||||||||||||
PV1||O|^^^^ROMAYO|||||||||||||||||||||||||||||||||||||||||||||| ORC|SC|429578441-1^MSS|429578441-
1^RIMS||NW||^^^201011161100^^NORM|||10181741^CLEMENTS^IAN^P||10181741^CLEMENTS^IAN^P|E2X-
REC||||||^^^| OBR|0001|429578441-1^MSS|429578441-1|07398^Chest-- PA \T\ Lateral^RIMS|NORM||||||||testing
interface to PCIL||^^^^N Chest-- PA \T\ Lateral|10181741^CLEMENTS^IAN^P||429578441-1|429578441-
1|07398||201011161037||CR||||||| |||&&&||||||||||07398^Chest-- PA \T\ Lateral^RIMS^^^|
ZDS|1.2.840.113717.2.429578441.1^RIMS^Application^DICOM|
Z01|NW|201011161037|0055|||MCRE3|201011161037|201011161100|N||
```


(b)


```
MSH|^~'&|RADIOLO|ROCHESTER|ESB||20101110072148||ORU^R01|1362696376|P|2.3.1|||||
PID|||06004163||Fall^Autumn^E.^^^||19720916|F|||||||||||||||||
PV1||O|RADIOLOGY^||||||||||||||||||||||||||||||||||||||||||||
OBR|||429578288-2|07201^CT Head
wo^RRIMS|||201011100720|201011100721||||||201011100721||10247131^BRAUN^COLLEEN^M^^^^PERSONI
D||SMH|SMHMMB|429578288-3|N|201011100721||CT|F||^^^^^^R||||testing|99999990^RADIOLOGY
STAFF^BRAUN^^^^^PERSONID|||10247131|
OBX|1|TX|07201^CT Head wo^RRIMS|429511111|{\rtf1\ansi \deff1\deflang1033\ {\fonttbl{\f1\fmodern\fcharset0
Courier;}{\f2\fmodern\fcharset0 Courier;}} \pard\plain \f1\fs18\tx0604\par ||||||P|
OBX|2|TX|07201^CT Head wo^RRIMS|429511111|10-Nov-2010 07:20:00  Exam: CT Head wo\par ||||||P|
OBX|3|TX|07201^CT Head wo^RRIMS|429511111|Indications: testing\par ||||||P|
OBX|4|TX|07201^CT Head wo^RRIMS|429511111|ORIGINAL REPORT - 10-Nov-2010 07:21:00   SMH\par
||||||P|
OBX|5|TX|07201^CT Head wo^RRIMS|429511111|test\par ||||||P|
OBX|6|TX|07201^CT Head wo^RRIMS|429511111|Electronically signed by: \par ||||||P|
OBX|7|TX|07201^CT Head wo^RRIMS|429511111|Radiology Staff, Braun 10-Nov-2010 07:21 \par }||||||P|_
```


**FIGURE 2.1** (a) Health Level 7 consists of messages, whose transfer is initiated by messages and events. This figure shows an Order. (b) This is the resulting OBX message that contains the content (a radiology report in this case from a CT).

#### 2.2.1.3 XML

The eXtensible Markup Language (XML) is an extension to the original HTML (Hypertext Markup Language) that was invented by Tim Berners-Lee in the early 1990s (Berners-Lee and Fischetti, 1999). It differs from HTML (Figure 2.3) in that in addition to simply formatting the page's presentation state, it also enables defining what the content of page elements are. In other words, if a postal code appeared on the Web page, the XML page itself could wrap that element with the tag "postal-code." By self-documenting the page content, it enables computer programs to scan XML pages in a manner similar to a database, if the defined terms are agreed upon.

### 2.2.2 Content

While a protocol grammar defines the structure of transactions, the permitted terms (and the relationships among them) are defined by specific ontologies. It is the purpose of a specific ontology to define the taxonomy (or class hierarchies) of specific classes, the objects within them, and how they are related. The following examples address different needs, consistent with the areas they are tailored to address.

```
<Labrs3P00 T=" Labrs3P00">
    < Labrs3P00.PTP T="PTP">
        <PTP.primePrsnm T="NM">
            <fmn T="ST"> Jones </fmn>
            <gvn T="ST"> Tim </gvn>
            <mdn T="ST"> H </mdn>
        </PTP.primePrsnm>
    < /Labrs3P00.PTP>
    <Labrs3P00.SI00_L T="SI00_L">
        <SI00_L.item T="SI00">
            <SI00.filrOrdId T="IID">LABGL110802< /SI00.filrOrdId >
            <SI00.placrOrdID T="IID">DMCRES387209373</SI00.placrOrdID>
            <SI00.Insnc0f T="MSRV">
                <MSRV.unvSvcId T="CE">18768-1<.MSRV.unvSvcId>
                < MSRV.svcDesc T="TX">Cell Counts< /MSRV.svcDesc>
            </SI00.Insnc0f>
            <SI00.SRVE_L T="SRVE_L">
                <SRVE_L.item T="SRVE">
                    <SRVE.name T="CE">4544-3</ SRVE.name>
                    <SRVE.svcEventDesc T="ST">Hematocrit</SRVE.svcEventDesc>
                    <SRVE.CLOB T="CLOB">
                        <CLOB.obsvnValu T="NM">45< /CLOB.obsvnValu >
                        <CLOB.refsRng T="ST">39-49< /CLOB.refsRng >
                        <CLOB.clnRvlnBgmDtm T="DTM">199812292128</CLOB.clnRvlnBgmDtm >
                    </SRVE.CLOB>
                    <SRVE.spcmRcvdDtm T="DTM">199812292135</SRVE.spcmRcvdDtm >
                </SRVE_L.item>
            </SI00.SRVE_L>
    < Labrs3P00.SI00_L>
</Labrs3P00>
```


**FIGURE 2.2** HL7 is available in two formats; the version 2.x in wide use today is expressed in the format shown in Figures 2.1. The HL7 V3.0 is encoded in XML as seen here; note this sample explicitly states it contains laboratory values.

#### 2.2.2.1 SNOMED

Developed in 1973, SNOMED (Systemized Nomenclature of Medicine) was developed by pathologists working with the College of American Pathologists. Its purpose is to be a standard nomenclature of clinical medicine and findings (Cote, 1986). By 1993, SNOMED V3.0 achieved international status. It has 11 top level classes (referred to as "axis") that define: anatomic terms, morphology, bacteria/viruses, drugs, symptoms, occupations, diagnoses, procedures, disease agents, social contexts and relations, and syntactical qualifiers. Any disease or finding may descend from one or more of those axes, for example, lung (anatomy), fibrosis (diagnosis), and coal miner (occupation).

#### 2.2.2.2 RadLex

While SNOMED addressed the need for a standard way to define illness and findings with respect to anatomy, morphology, and other factors, RadLex seeks to address the specific subspecialty needs of radiology. Beginning in 2005, the effort started with six organ-based committees in coordination with 30 standards organizations and professional societies (Langlotz, 2006). In 2007, six additional committees were formed to align the lexicon along the lines of six modalities; the result is now referred to as the RadLex Playbook.

#### 2.2.2.3 ICD9

The International Statistical Classification of Diseases and Related Health Problems, better known as ICD, was created in 1992 and is now in its 10th version, although many electronic systems may still be using V9.0 (Buck, 2011). Its purpose is to classify diseases and a wide variety of signs, symptoms, abnormal findings, complaints, social circumstances, and external causes of injury or disease. It is used by the World Health Organization (WHO) and used worldwide for morbidity and mortality statistics. It is also often used to encode the diagnosis from medical reports into a machine-readable format that is used by Electronic Medical Record (EMR) and billing systems. The lexicon is structured using the following example: A00-B99 encodes infections and parasites, C00-D48 encodes neoplasms and cancers, and so on through U00-U99 (special codes).

## 2.3 Transmission Protocols

The previous section described two of the basic components of informatics constructs: symbols to encode concepts (ontologies) and grammars to assemble those symbols into standard messages. An analogy is helpful. Verbs, nouns, and adjectives form the ontology in speech. Subjects, predicates, and objects of the verb form the basis of spoken grammar. What is missing in both our healthcare messaging and speech example is a method to transmit the message to a remote "listener." The human speech solution to this challenge is writing and the printing press. The electronic analogs are computer transmission protocols.

### 2.3.1 TCP/IP

Transmission Control Protocol/Internet Protocol (TCP/IP) is a layering of concepts to enable the transmission of messages

```
<html>
<head>
<meta content="text/html;charset=lSO-8859-1 " http-equiv="Content-Type">
<title>html example</title>
<head>
<body>
<h1 style="text-align: center;">This is an Example of HTML formatting tags</h1>
<br>
The above part is bold and centered. This part is left-justified and
normal font size and weight<br>
<br>
This next. pan. is a table<br>
<br>
<table style="text-align: left; width: 100%;" border="1" cellpadding="2"
cellspacing="2">
<tbody>
<tr>
<td style="vertical-align: top;">1<br>
</td>
<td style="vertical-align: top;">3<br>
</td>
</tr>
<tr>
<td style="vertical-align: top;">2<br>
</td>
<td style="vertical-align: top;">4<br>
</td>
</tr>
</tbody>
</tab1e>
<br>
And this is the end of` this document.<br>
<br>
</body>
</html>
```

**FIGURE 2.3** HTML (Hypertext Markup Language) is a text markup language that informs the appropriate Web browsers (e.g., Firefox) how to render a page, but has no provision for encoding the content meaning of the page. By contrast, XML (as seen in Figure 2.2) adds the capability to express the meaning of the page content through the use of agreed upon "tags."

consisting of bits from one computer to another. The rules of the protocol guarantee that all the bits arrive, uncorrupted, in the correct order. The layers referred to are a result of the original formulations by the Internet Engineering Task Force (IETF) of what has come to be known as TCP/IP. Basically, if one starts at the physical layer (the network interface card), the naming convention is physical or link layer (layer one), Internet layer (layer two), transport layer (layer three), and the application layer (layer four) Request for Comment, RFC 1122–1123). Several years later, the International Standards Organization created the seven layer Open Systems Interconnect (OSI) model, which can lead to confusion if one does not know which system is being referenced (Zimmermann, 1980). For our purposes, it is sufficient to know that the further protocols discussed below ride on top of TCP/IP and rely on its guarantees of uncorrupted packet delivery in the correct order.

### 2.3.2 DICOM

Yes, DICOM again. This can be a point of some confusion, but DICOM is both an ontology and a protocol. Recall from Section 2.2.1.2 the concept of Service–Object Pairs. The objects are the message content (i.e., images, structured reports, etc.). The services are the actions that can be applied to the objects, and this includes transmitting them. The transactions that are responsible for network transmission of DICOM objects have names like C-MOVE and C-STORE. To facilitate the network associations among two computers to perform the transfer, the DICOM standard defines the process of *transfer syntax negotiation*. This process, between the server (service class provider or SCP in DICOM) and client (service class user or SCU), makes sure that the SCP can provide the required service, with the same kind of image compression, and in the right format for the computer processor on the SCU.

### 2.3.3 HTTP

Recall from Section 2.2.1.3 that Tim Berners-Lee invented HTML, the first widely used markup language to render Web pages in a Web reader. However, there remained the need to transfer such pages from server computers to the users that possessed the Web-reading clients (i.e., Internet Explorer or Firefox). The Hyper Text Transfer Protocol was invented to fill that role (RFC 2616). As alluded to earlier, HTTP is an application level protocol that rides on the back of the underlying TCP/IP protocol. Since its beginning, HTTP has been expanded to carry not just HTML-encoded patients, but XML content and other encapsulated arbitrary data payloads as well (i.e., images, executable files, binary files, etc.). Another enhancement, HTTPS (S is for secure), provides encryption between the endpoints of the communication and is the basis for trusted Internet-shopping stores (i.e., Amazon) to online (RFC 2818).

## 2.4 Diagrams

### 2.4.1 Classes and Objects

We have defined a step at a time the components which shall now come together in the informatics constructs generally referred to as diagrams. When one begins to read actual informatics system documentation (i.e., DICOM or IHE conformance statements), a typical point of departure is the Use Case. We will see examples of those in the next section, but for now it is useful to know that Use Cases leverage Actors, and Actors can be considered to be the equivalent of the Class as defined in computer science.

Recall from Section 2.1.1 that a Class defines an Actor's data elements, and the operations it can perform on those data. A simple real world example might be the class of temperature sensors. A temperature sensor may actually consist of a variety of complex electronics, but to the outside world, the Class "Temperature Sensor" only needs to *expose* a few items: temperature value, unit, and possess an address to a remote computer can access and read it. Optionally, it may also permit the remote reader to program the update interval.

Explicitly, the definition of the Temperature Session Class would look like this:

**Listing 2.1: A Textual Rendition of How One May Represent a Class in a Computer Language**

```
Class "Temperature Sensor" {
Value temperature
Value unit
Value update-interval
Value sensor-address
Function read-temp (address, temp)
Function set-interval (address, interval)
Function set-unit (address, unit)
}
```

The Class definition above specifies the potential information of a "Temperature Sensor"; a specific instantiation of a Class is referred to as an Object. The following shows this distinction.

**Listing 2.2: The Instantiation of a Class Results in an Object, Which Has Specific Values**

```
Object Sensor-1 is_class "Temperature Sensor" {
temperature 32
unit F
update_interval 5
address sensor1.site1.com
read-temp (address, temp)
set-interval (address, interval)
set-unit (address, unit)
}
```

One way to think of Actors in IHE (which will be discussed in detail in Chapter 5) is that the IHE documentation defines the Actor's Class behavior and a real-world device is an object level instantiation.

## 2.4.2 Use Cases

In Section 2.1, Use Cases were defined as a formal statement of a specific workflow, the inputs and outputs, and the Actors that accomplish the goal via the exchange of Transactions. A goal of this section is to begin to prepare the reader to interpret the IHE Technical Frameworks, which will be covered in Chapter 5. IHE specifies real world use cases (called Integration Profiles) encountered in the healthcare environment, and then offers implementation guidelines to implement those workflows that leverage existing informatics standards (DICOM, HL7, XML, etc.). As such, Sections 2.4.2.1 through 2.4.2.2 will delve into the specifics of a single Integration Profile, Scheduled Workflow. [*Note*: The concept may have presaged the term, but the first formal mention of Integration Profiles occurs in IHE Version 5.0, which curiously was the third anniversary of the IHE founding.]

### 2.4.2.1 Actors

A key strategy in IHE is that it defines Actors to have very low-level and limited functionality. Rather than describing the behavior of large and complex systems such as an RIS (Radiology Information Systems), the IHE model looks at all tasks that an RIS performs and then breaks out those "atomic" functions to specific Actors. To take a rather simple example, a Picture Archive and Communication System (PACS) is broken out into the following series of Actors: image archive/manager, image display, and optionally report creator/repository/manager. To begin to understand this process, we start with a diagram that depicts just the Actors involved in the Scheduled Workflow Integration Profile (SWF).

For reference, the actors are

a. *ADT*: The patient registration admission/discharge/transfer system.
b. *Order Placer*: The medical center wide system used to assign exam orders to a patient, and fulfills those orders from departmental systems.
c. *Order Filler*: The departmental system that knows the schedule for departmental assets, and schedules exam times for those assets.
d. *Acquisition Modality or Image Creator*: A DICOM imaging modality (or Workstation) that creates exam images.
e. *Performed Procedure Step Manager*: A central broker that accepts exam status updates from (d) and forwards them to the departmental Order Filler or Image Archive.
f. *Image Display*: The system that supports looking up patient exams and viewing the contained images.
g. *Image Manager/Archive*: The departmental system that stores exam status information, the images, and supports the move requests.

### 2.4.2.2 Associations and Transaction Diagrams

Figure 2.4a shows what Actors are involved in the Use Case for SWF, but gives no insight into what data flows among the Actors, the ordering of those Transactions, or the content. For that we add the following information shown below. For reference, the transactions are

a. *Rad-1 Patient Registration*: This message contains the patient's name, Identifier number assigned by the medical centers, and other demographics.
b. *Rad-2 Placer Order Management*: The Order Placer (often part of a Hospital Information System) creates an HL7 order request of the department-scheduling system.
c. *Rad-3 Filler Order Management*: The department system responds with a location and time for the required resources.

Rad-4 Procedure Scheduled:

a. *Rad-5 Modality Worklist Provided*: The required resource is reserved and the exam assigned an ID number.
b. *Rad-6 Modality Performed Procedure Step (PPS) in Progress*: The modality informs downstream systems that an exam/series is under way.