Enhancing the Expressiveness of Structured Reporting Systems

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The overall goal of this research is to build a structured reporting system that reduces the cost, delays, and inconvenience associated with conventional dictation and speech recognition systems. We have implemented such a structured reporting system for radiology that replaces current dictation and transcription processes by allowing radiologists and other imaging professionals to select imaging findings from a medical lexicon. The system uses an imaging-specific information model, called a "description set," to organize selected terms in a relational database. Unique features of the knowledge representation that enhance its expressiveness include its ability to codify uncertainty about an imaging observation and to represent explicitly the logical relationships among imaging findings. In addition, the system does not require the user to fill in "blanks" in a static text template. Instead, it allows entry of terms in arbitrary order and uses automated text-generation techniques to create a text report that referring physicians are accustomed to receiving. In parallel, the system also produces a multimedia report that the referring physician can use as a quick reference. Unlike the results of conventional dictation or speech recognition, each finding is coded in a relational database for later information processing. Thus, the structured report database can be used to index images by content, to provide real-time decision support, to enhance radiologists' performance, to conduct exploratory clinical research, and to transmit imaging report data to computer-based patient record systems.

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OUR EFFORT TO BUILD A structured reporting system for medical imaging addresses several scientific issues, including the development of knowledge representation methods for imaging findings and their logical relationships, and the dynamic construction of user interfaces from lexicons and visual components. We focus here on the knowledge representation, and its ability to capture the uncertainty and the logical relationships that typically have not been captured in previous reporting systems.

MOTIVATIONS FOR THE PROPOSED WORK

The system is motivated by the needs of both research and clinical care. Assessing the relationship between imaging results and patient outcome is critical to the evaluation of new and existing medical imaging technology. Yet this relationship is difficult to discern unless the imaging results can be recorded with precision and clarity. Likewise,

there are several clinical shortcomings of the current process of medical image interpretation, including:

1. *Transcribed preliminary reports often are not available in a timely fashion.* Transcription adds an additional step to the process. Report distribution is often via paper or facsimile, rather than more efficient electronic modes.
2. *Transcriptionists have a significant error rate.* One study of 4,871 radiology reports found that 33.8% of reports required post-transcription editing by radiologists, with nearly 6% of the corrected errors having a potentially significant effect on patient care.¹
3. *Report signature causes additional delays.* One radiology practice reported that only two thirds of reports were finalized and signed within 24 hours, despite a comprehensive program targeted at improving report turnaround time.²
4. *The text report is frequently vague, incomplete, or inaccurate.* One systematic analysis of 8,426 chest x-ray reports found as many as 14 different terms to describe a single common abnormal finding, and 23 synonyms for reporting the presence of a finding.³
5. *A text report has limited utility for subsequent practice analysis and outcomes measurement.* Natural language processing systems, while promising,⁴ have not yet achieved levels of accuracy sufficient for many clinical and management tasks.
6. *Transcription services are costly.* Transcription services typically drain 3% to 6% percent of radiology practice revenues.

Accordingly, there is a need for systems that can capture clear, structured information about the

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content of images for later analysis and distribute it efficiently, while maintaining current clinical work patterns.

In the subsections that follow, we will evaluate the relevant existing scientific knowledge and describe the architecture and operation of the reporting system we have constructed in an attempt to achieve these goals.

PREVIOUS STRUCTURED REPORTING SYSTEMS

Structured reporting systems have been a source of interest and experimentation for decades.⁵⁻⁷ However, these systems have not been widely adopted, primarily because existing systems suffered from limited expressiveness, static "fill-in-the-blanks" interfaces, and insufficient computing power. More recent evidence indicates that structured reporting systems, enhanced by newer computing hardware and knowledge representation techniques, are increasingly acceptable to radiologists, referring physicians, and other medical professionals.⁸

Structured reporting systems for endoscopy have been tested at several sites, perhaps because the limited anatomic coverage of endoscopy requires less system flexibility and terminological scope. For example, Moorman et al⁹ found that only 88 of 1,297 statements (6.8%) could not be made in a structured reporting system for gastrointestinal endoscopy. Of those unexpressable statements, about half could be expressed after only minor additions or modifications to the knowledge base. Recent research has demonstrated the feasibility of similar structured reporting systems for specific imaging examinations.^{10,11} Thus, the development of a structured reporting system that can capture and express both finding uncertainty and relationships between findings has substantial appeal.

USER INTERFACE DESIGN

Although a number of researchers have examined the effect of breadth and depth of menu-based choices,¹² and the overall design of user interfaces,¹³ the Pen-Ivory Project is particularly relevant to our work because it focused specifically on the needs of physicians who were selecting terms from a large lexicon. In addition, their interface employed newer interface elements, such as tab sheets, radio buttons, check boxes, and palettes. Their results showed that the shortest times to enter

terms from a vocabulary were achieved with paging through fixed palettes. We used these principles as guidelines in the design of our user interface. Poon et al¹⁴ also found that search times were shorter when all terms were available in the interface, but their terminology was relatively small, and demand-loading of additional terms was slow. For medical imaging, the subset of terms is manageable in size because the number of concepts required for each report is constrained by the anatomic region under study and by the imaging modality used.

Our reporting system was implemented for radiology practices in part because they typically apply a single imaging modality (eg, magnetic resonance imaging or computed tomography) to a specific anatomic region (eg, brain, knee), making automated interface generation and reporting computationally tractable.

In the sections below, we will describe the system components and demonstrate their current operation.

SYSTEM ARCHITECTURE

The structured reporting prototype was implemented using the Delphi Developer Suite (Inprise, Scotts Valley, CA), an object-oriented, component-based programming environment that provides a hierarchical library of visual components for use in programmatic interface generation. The modularity of the design will facilitate a shift to web-based technology, including the use of extensible markup language (XML) and web-based interfaces as these languages and their object-oriented development environments mature.¹⁰

Figure 1 shows the design of the structured reporting system in detail. The operation of the system can be summarized briefly as follows. Based on the type of imaging examination to be reported, the "interface builder" constructs a "graphical user interface" from a set of visual components and terms from a "terminology server." The terminology server provides terms pertinent to the anatomic region under study and the imaging modality employed. By interacting with a graphical user interface, the radiologist selects imaging terms to signify the findings and conclusions appropriate for the examination. The graphical user interface sends these selections to the "text report generator," which constructs a text report in real-time. The text report generator sends the terms that

describe the findings and conclusions to an "imaging report knowledge base," which is organized as a relational database.

UNDERLYING KNOWLEDGE REPRESENTATION

The system's knowledge representation is based on the image-specific information model called a "description set." A description set is intended to represent the three key features of an elemental finding on an imaging examination: (1) the location of the finding on the imaging study (eg, "on the corner of the lateral view," "on the postcontrast images," or "on image 12 of series 3"); (2) the anatomic location of the finding (eg, "in the apex of the left lung," "in a branch of the left pulmonary artery," or "in the anterior mediastinum" and (3) the finding itself (eg, "moderate congestive heart failure," "a single large mass," or "an ill-defined consolidation").

Each of the above three components of a description set is composed of a "primary term" and a set of "modifying terms" from the structured terminology. Thus, the phrase "a single large mass" could be specified by the primary term "mass" and the modifier terms "single" and "large." The phrase "in the apex of the left lung" could be represented by the term "lung" and the modifier terms "apex" and "left." The phrase "on the corner of the lateral view" could be specified by the term denoting "lateral-view" with the modifier term "corner." The combination of primary and modifying terms provides additional richness of expression, and is compatible with the notion of compositional terminologies and with the notion of terms and modifiers

in a recently proposed structured reporting standard for imaging.¹⁵

REPRESENTING RELATIONS AND UNCERTAINTY

In previous structured reporting systems, methods to represent the uncertainty of findings and to capture the logical relationships among findings have been limited or absent. To address this problem, we have augmented the notion of a description set to allow entry of logical relationships among findings. These additions allow the selection of terms signifying logical relationships (eg, "caused-by," "associated-with"), then allow any combination of currently selected findings to be chosen as the parameters of that relationship. For example, the user can select the "due-to" logical relationship, "congestive heart failure" as one finding, and "pleural-effusion" as the other. This logical relationship would be translated as: "The pleural effusion is due to congestive heart failure."

Because the user might also wish to report that a finding is probably or possibly present, or that a finding is absent, each finding is augmented with an integer to represent the uncertainty of the finding on a 7-point Likert-type scale, with "1" representing certainty of finding presence, and "7" representing certainty of finding absence. (See *Confidence* panel in Fig 2.) This simple ordinal representation of uncertainty has several advantages: (1) it can be used for later construction of receiver-operating characteristic (ROC) curves to compare the diagnostic performance of readers; (2) it contains a small number of categories so as not to overwhelm the

Fig 2. The reporting system's user interface. The top panel is for demographic information and other "housekeeping" items. The right panel shows the text report as it is generated. The middle left panel is for selecting anatomic terms, and the bottom left panel is for selecting modifier terms.

user; and (3) it incorporates the representation of negation.

SYSTEM OPERATION

The system's user interface is shown in Fig 2. A panel at the top of the screen allows "housekeeping" data to be displayed for each examination, including exam type, date and time, accession number, and clinical history. At the right of the screen, a panel displays the text report in real-time as terms are selected from the interface. On the left panel, the user will select an anatomic location (and its corresponding term) from a schematic of the appropriate anatomic region. When an anatomic region is selected, the most common terms for that region appear in a pop-up menu. Most imaging terms are selected in that fashion, since radiology reports consist mostly of anatomic locations and common imaging findings. For less common findings, the *More Findings* panel on the right can be used to select additional finding terms, using a series of tab sheets, radio buttons, and check boxes.

Because the interface components are chosen

dynamically for each examination to be reported, the appearance of the interface in each panel is regenerated on the basis of the type of imaging exam and the reason for exam. To achieve this goal, the interface builder maintains database tables linking particular terms to specific types of imaging examinations. For example, the *Additional Findings* tab sheet shown on the right in Fig 2 allows selection of several terms corresponding to thoracic pathology that might be visible on conventional chest x-rays. If the next examination to be interpreted were a brain magnetic resonance image, the interface builder would automatically construct analogous interface elements for that tab sheet that correspond to the diseases and syndromes that can affect the brain. Several report sentences can be seen in the window at the right.

AUTOMATIC TRANSLATION OF TERMS

Although we recognize the value of adopting an existing terminology, such as SNOMED (College of American Pathologists, Northfield, IL) for our final system, we constructed our own simple hierar-

chical lexicon for chest radiology (using the desiderata outlined in Cimino et al¹⁶) for initial testing.

The methods for creating a text report from a description set are based on a set of translation techniques originally developed in the mid-1970s,¹⁷ and subsequently adapted by a variety of others for similar purposes. Text translations of each term set are constructed from a "translation schema" attached to each term. Special symbols in each schema signify where the translations of the term itself ("*T") and the modifier terms ("*M") should appear in the resulting text. Recursive calls to the translation routines provide the text for insertion. For example, the template for the "mediastinum" term (and other terms denoting anatomic location) is "in the *M *T." Thus, the term "mediastinum" with modifier terms "anterior" and "superior," translates to the phrase "in the anterior, superior mediastinum."

SUMMARY

These results illustrate the utility of an image-specific representation, called a description set, to capture, manipulate, and store the contents of imaging examinations. The system demonstrates two additional enhancements to the expressiveness of structured image reporting systems: the capture and explicit representation of uncertainty about findings and of logical relationships between findings. The architecture we describe facilitates (1) the dynamic and flexible creation a user interface from a lexicon, and (2) the real-time generation of acceptable text reports from imaging terms selected in arbitrary order. Structured reporting systems like this one can facilitate real-time decision support for radiologists, indexing of images by content, exploratory clinical research in medical imaging, and transmission of coded imaging report data to computer-based patient record systems.

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