Enhancing the Expressiveness and Usability of Structured Image Reporting Systems

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Abstract

We have implemented a structured reporting system for medical imaging that replaces dictation and transcription by allowing radiologists and other imaging professionals to select imaging findings from medical lexicons. The system uses an imaging-specific information model called a Description Set to organize selected terms in a relational database. The system's expressiveness for reporting is enhanced by its ability to codify uncertainty about imaging observations and to represent explicit causal and associational relationships among imaging findings. The system promptly and automatically generates a text report that referring physicians are accustomed to receiving. Because the image report information is stored in a fully coded fashion, it can be used to provide real-time decision support to radiologists, to transmit coded imaging data to electronic patient record systems, to measure and improve radiologists' performance, and to index images by content.

Introduction

The overall goal of this research is to build a structured reporting system that will replace the current dictation and transcription processes for medical imaging. We focus here on the system's information model, and its ability to capture uncertainty and logical relationships that have not been captured in most previous reporting systems.

Motivations for the Proposed Work

The system is motivated by the need to improve the clarity of communication among radiologists and referring physicians, and to improve the quality of radiologist's interpretations. There are several shortcomings of the current process of medical image interpretation, including:

1. *Transcribed preliminary reports often are not available in a timely fashion.* 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 turn-around time [1].
2. *Transcription has a significant error rate.* One study of 4871 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 [2].
3. *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].
4. *A text report has limited utility for subsequent decision support and practice management.* Natural language processing systems, while promising [4], have not yet achieved levels of accuracy sufficient for many clinical and management tasks.
5. *Transcription services are costly.* Transcription services typically drain 3 to 6 percent of radiology practice revenues.

Accordingly, there is a need for systems that capture coded, structured information about image content, while enabling prompt report signature as part of normal radiology work flow.

In the sections that follow, we will briefly review 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 (e.g., [5-7]). However, these systems have not been widely adopted, primarily because many past systems suffered from a limited ability to express uncertainty and relationships between findings. Prior systems typically used static report templates, and employed insufficient computing power. Recent evidence indicates that structured reporting systems 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 al [9] found that only 88 of 1,297 statements (6.8%) could not be made in a structured reporting system for gastrointestinal endoscopy. Of the unexpressable statements, about half could be expressed after only minor additions or modifications to the knowledge base. Recent research demonstrates 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 uncertainty about findings and relationships between findings has substantial appeal.

User Interface Design

A number of researchers have examined the overall design of user interfaces [13] and the effect of the breadth and depth of menu-based choices on usability [12]. The Pen-Ivory Project [14] is particularly relevant to our work because it focused specifically on the needs of physicians who were selecting terms from a large medical lexicon. In addition, Pen-Ivory's interface employed newer interface elements, such as tab sheets, radio buttons, check boxes, and palettes. Results from that system show that the shortest times to select terms from a lexicon were achieved by paging through fixed palettes of terms. We used these principles in the design of our interface.

System Architecture

The structured reporting system is implemented in the Delphi Developer Suite (Inprise, Scotts Valley, CA), an object-oriented, component-based programming environment that provides a hierarchical library of visual components for developing client-server software. A web-based interface is not currently practical due to radiologists' need for a dynamic interface that responds immediately to their input. However, an interactive version of the system's reports can be delivered using web-based methods.

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 exam to be reported, the *Terminology Server* sends terms pertinent to the anatomic region under study and the imaging modality employed to the *Graphical User Interface*. The radiologist selects imaging terms from the *Graphical User Interface* to describe the findings and conclusions appropriate for the examination. The *Graphical User Interface* sends these selections to the *Imaging Report Knowledge Base*, which is a relational database organized according to the information model described below. As the findings are selected, the *Report Generator* constructs a report in real-time, using modifications of text-generation techniques originally developed in the mid-70s [15]. The *Decision Support* module uses the selected terms to automatically construct a differential diagnosis, which can be provided as optional advice to the radiologist in real-time.

Underlying Information Model

The image-specific notion of a *Description Set* serves as a simple information model for imaging reports. Each Description Set is intended to represent a single imaging finding and embodies the three key features of an elemental finding on an imaging examination:

1. the location of the finding on the imaging study (e.g., "on the corner of the lateral view" or "on the post-contrast images");
2. the anatomic location of the finding (e.g., "in the apex of the left lung" or "in the anterior mediastinum"); and
3. the finding itself (e.g. "moderate congestive heart failure" or "a single large mass").

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

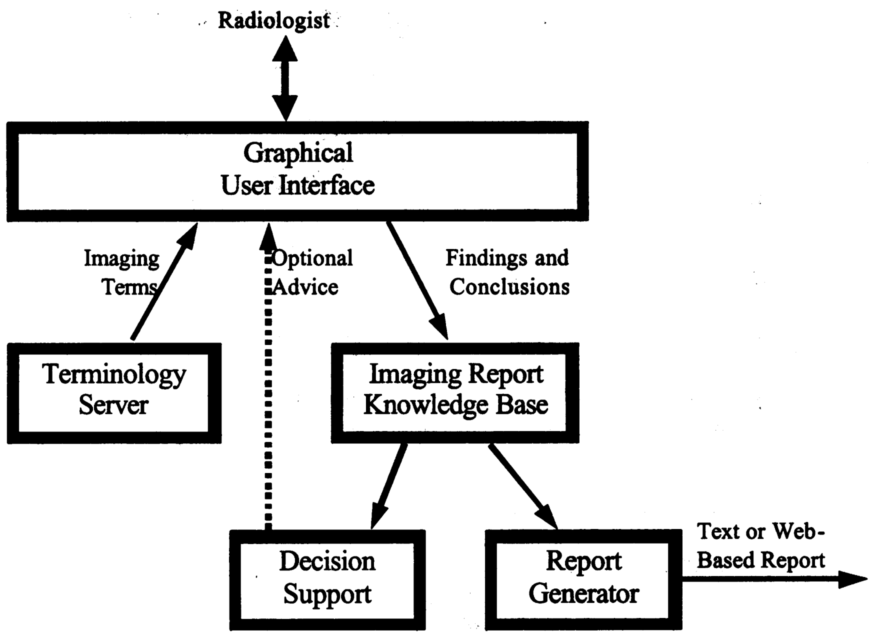

Figure 1: The architecture of the proposed structured image reporting system. Boxes represent computational components; arrows represent the flow of information.

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 compositional terminologies, such as SNOMED (College of American Pathologists, Northfield, IL) and with a new structured reporting standard [16].

Representing Relations and Uncertainty

In previous structured reporting systems, methods to represent the *uncertainty* about findings and to capture *relationships* among findings have been limited or absent. To address this problem, the system allows entry of logical relationships among Description Sets. The user can select (under the "Associations" tab in Fig. 2) from a variety of terms signifying logical relationships (e.g., CAUSED-BY, ASSOCIATED-WITH). The parameters of those relationships are chosen from the currently active Description Sets. For example, the user can select the DUE-TO logical relationship, CHF as one finding, and PLEURAL-EFFUSION as the other. The system's Report Generator translates this causal relationship into the following sentence: "The pleural effusion is due to CHF."

Because radiologists often wish to report uncertain findings, each Description Set is augmented with an integer to represent the uncertainty of the finding on a Likert-type scale, with "1" representing definite presence of the finding, and "7" representing definite absence of the finding. (See *Confidence* panel in Figure 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 radiologists; (2) it contains a limited number of categories so as not to overwhelm the user; and (3) it incorporates the representation of negation.

System Operation

The system's user interface is shown in Figure 2. A panel at the top of the screen allows "housekeeping" information to be shown for each

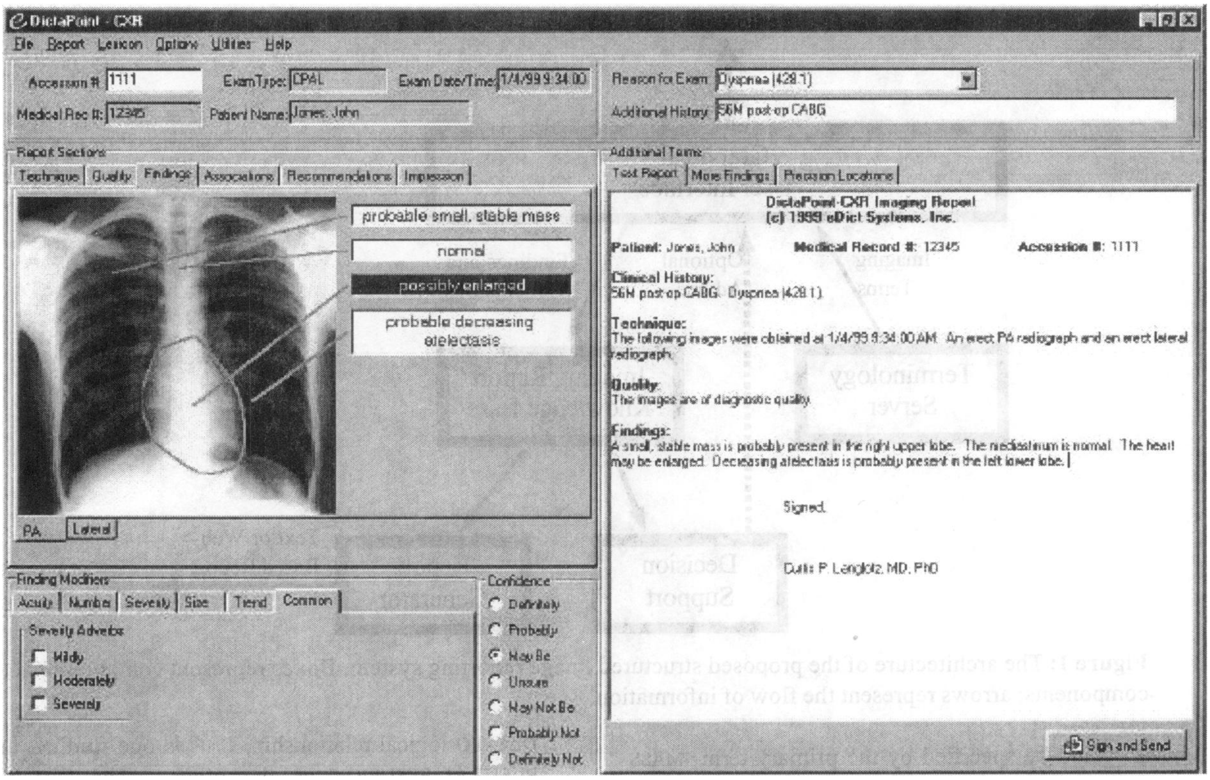

Figure 2: The reporting system's user interface. The top panel is for "housekeeping" items. The left panel is for selecting anatomic terms. The right panel shows the text report as it is generated, and can be used to select uncommon finding terms and modifier terms.

exam, such as exam type, date and time, accession number, and clinical history. At the right of the screen, the text report is displayed in real-time as terms are selected from the interface.

When the user selects an anatomic region, the most common terms for that region appear in a popup menu. For example, when the user clicks on the lung, the menu of common findings includes atelectasis, congestive heart failure (CHF), consolidation, edema, mass, normal, pnuemonia, and pneumothorax. Since radiology reports consist mostly of imaging findings linked to anatomic locations, most findings can be entered by selecting a finding from that menu. For less common findings, the *More Findings* tab on the right can be used to select less common terms and modifiers, using fixed palettes of check boxes.

Preliminary Evaluation

A preliminary evaluation was conducted on a convenience sample of 10 abnormal chest X-ray reports from patients in a medical intensive care unit. The reports were selected to include reports with a large number of findings but were also screened so that they did not contain any rare findings not present in the system's lexicon. The system was used to enter these pre-existing reports, not to enter reports de novo while interpreting imaging examinations. The time for report entry was recorded with a stopwatch. Because the experiment was conducted in ideal laboratory conditions on a small select sample of reports, the results are representative of the best possible results that might be obtained in an actual clinical setting. Table 1 displays the timing results in comparison to a similar timing study comparing conventional dictation and a speech recognition system [17].

Reporting Mode	Report Creation Time (minutes)
Structured reporting	0.60
Conventional dictation	0.87*
Speech recognition	1.27*

Table 1: Reporting times for various reporting methods. Time needed for editing and other clerical tasks is excluded. (*adapted from [17])

Summary

This paper describes the notion of a Description Set, an information model for image reporting that facilitates the capture, processing, and storage of structured, coded imaging reports. This information model enhances the expressiveness of structured image reporting systems because it allows the capture and explicit representation of uncertainty about findings and of logical relationships between findings. Preliminary data suggest that structured reporting systems like this one may provide reporting speeds comparable to conventional dictation. The resulting fully-coded report facilitates real-time decision support for radiologists, radiology practice management, indexing of images by content, and transmission of coded imaging report data to computer-based patient record systems.

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