Documenting the Information Content of Images

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A standards-based message and terminology architecture has been specified to enable large-scale open and non-proprietary interchange of imaging-procedure descriptions and image-interpretation reports providing semantically-rich linkage of linguistic and non-linguistic information. The DICOM Structured Reporting Supplement, now available for trial use, embodies this interdependent message/terminology architecture. A DICOM structured report object is a self-describing information structure that can be tailored to support diverse clinical observation reporting applications by utilization of templates and context-dependent terminology from an external message/terminology mapping resource such as the SNOMED DICOM Microglossary (SDM), HL7 Vocabulary, or Terminology Resource for Message Standards (TeRMS).

INTRODUCTION

Effective large-scale interchange of semantically-rich imaging-procedure descriptions and image-interpretation reports requires a standards-based architecture that integrates explicit semantic structure and context-dependent content. This paper describes a data-interchange architecture that combines a generic template-driven message design with a context-dependent controlled terminology. The model provides appropriate identification and descriptive structure for documentation of observational and historical data in accordance with the principles of the American College of Radiology Standard for Communication in Diagnostic Radiology.[1] The architecture is specified in proposed extensions of the following data-interchange standards: the Digital Imaging and Communications in Medicine (DICOM) Standard[2] and the Systematized Nomenclature of Human and Veterinary Medicine (SNOMED)[3] for use in biomedical imaging. The design strategy is to couple a highly-adaptive, *mapping-resource-aware* message specification with a context-dependent *message-standard-aware* controlled-terminology resource that is designed specifically to serve the message-standard. By substitution of different templates of specialty terminology from an external message/terminology mapping resource, such as the SNOMED DICOM Microglossary (SDM)[4,5] or Health Level Seven (HL7) Vocabulary[6], a generic message specification, such as the DICOM Visible Light[7] or Structured Reporting[8] Standard, can be reconfigured efficiently and explicitly for diverse clinical or operational contexts. This *interdependent-message/terminology architecture* accelerates the development of domain-specific data-interchange specifications by increasing the expressiveness of message-standards, such that they are adaptable to a wider range of applications without re-ballot. Externalization of the controlled-terminology resource from the message-standard facilitates distributed development of domain-specific content and data-models.[9,10] Although originally developed for DICOM and SNOMED, the architecture could provide similar operational benefits in other message-standard or object-request-broker environments.[11]

MESSAGE/TERMINOLOGY ARCHITECTURE

The major components of the interdependent message/terminology architecture are: 1) a domain information model, 2) a set of adaptive mapping-resource-aware message specifications, and 3) a message-standard-aware controlled-terminology mapping resource. All of these components have been implemented in the biomedical imaging domain. The *domain information model* provides high-level semantic context for the message standard and the controlled-terminology. The *message standard* provides one or more transaction-oriented semantic data models. The *message/terminology mapping resource* provides context-dependent templates and value-sets for the message standard. The message/terminology architecture provides the following semantic functionality: 1) Context-dependent constraint of data-element value-sets; 2) context-dependent constraint of relationship-types (or modifier properties); and 3) preservation of the original semantic context at the time of encoding.[4]

Domain Information Model

The Structured Reporting Domain Information Model[8] (SRDIM) illustrated in Figure 1 is a semantic-network developed by object-oriented analysis. The SRDIM evolved from the Information System - Imaging System (ISIS) Context Model.[8,10] The SR DIM depicts the real-world entities that are most significant in the ISIS Interface.[8,10] Information-object definitions (IODs) based on the SR DIM are specified in the DICOM Modality Worklist Service-Object Pair (SOP) Class,[2,10] Performed Procedure Step SOP Class,[12] Visible Light Image SOP Class,[7] Waveform SOP Class, and Structured Interpretation SOP Class.[8] The SR DIM is also used in corresponding parts of the European CEN/TC 251 Medical Image Communication (MEDICOM) Standard,[13] the Japanese Type 2 Medical Image Processing System Standard,[14] and the Image Save and Carry Standard[15].

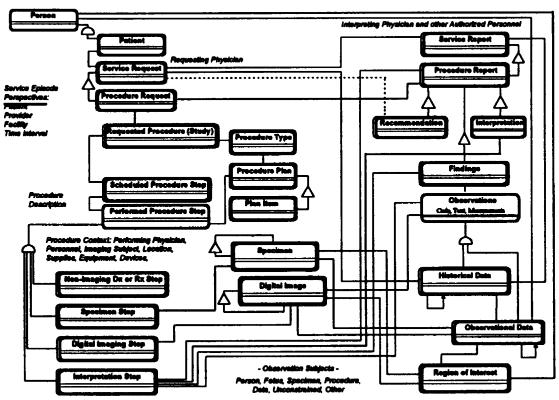

Figure 1. Structured Reporting Domain Information Model. Semi-circles represent "generalization-specialization" relationships. Triangles represent "part-whole" relationships. For more explanation of representation conventions, see Coad and Yourdon.[16]

The SR Entity Relationship (ER) Model[8] (Figure 2) depicts the subset of SR DIM entities specified by the proposed SR standard to support interpretation data interchange.

Mapping-Resource-Aware Message Specifications. Three first-generation mapping-resource-aware DICOM Standards (i.e. the X-ray Angiography SOP Class, the revised Nuclear Medicine Image SOP Class, and the revised Ultrasound Image SOP Class) were approved in 1995.[2] Two second-generation mapping-resource-aware DICOM Standards were released in 1997 for trial use. The second-generation Standards, Supplement 15: Visible Light (VL) Image for Endoscopy, Microscopy, and Endoscopy[7] and Supplement 23: Structured Reporting (SR)[8] fully utilize the message/terminology architecture. Each

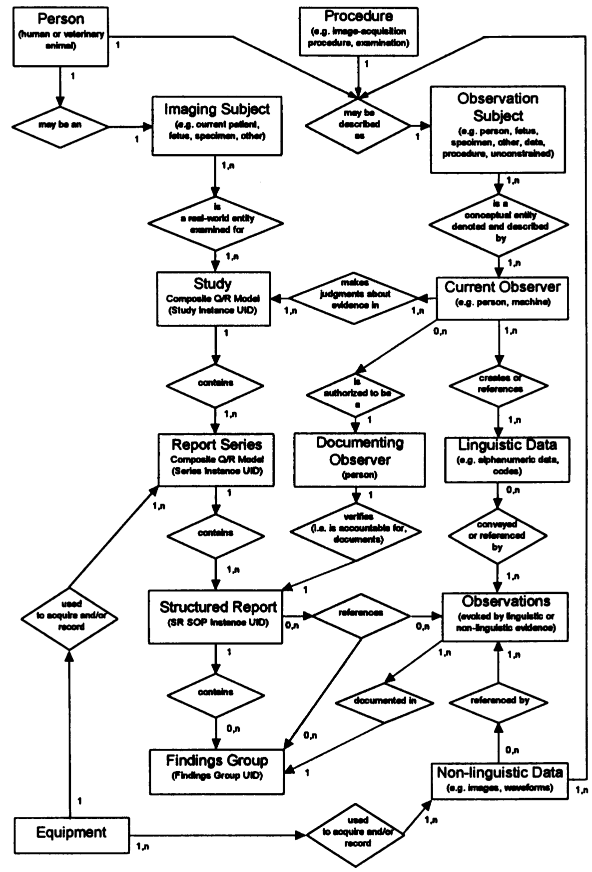

Figure 2. The Structured Reporting (SR) Entity Relationship model. Semantic network depicting the real-world entities in the scope of the DICOM Structured Reporting specification.

supplement specifies a generic, adaptive mapping-resource-aware message-template for a family of specialized message-types. The VL Standard supports visible-light images. The generic VL message may be tailored to serve of any number of specialized VL imaging modalities (e.g. gastrointestinal endoscopy, bronchoscopy, cystoscopy, arthroscopy, laparoscopy, surgical microscopy, photography) by application of context-specific controlled terminology templates from the SNOMED DICOM Microglossary (SDM). The proposed SR Standard supports image-interpretations and other types of reports. Domain-specialization is accomplished with explicit semantics (i.e. explicit name/value-pair associations) and no loss of specificity.

Structured Reporting Specification. The DICOM SR protocol can support any report structure. The proposed SR standard defines a semantically-rich conceptual model for interpretation-data interchange, integrating *alphanumeric*, *time-based waveform*, and *bit-mapped-array* data-types. The specification supports full documentation of the data-acquisition procedures (e.g. imaging procedure, electro-physiologic examination) that produce non-linguistic evidence (e.g. image, waveform) and the services (e.g. physical examination, historical interview, interpretation procedure) that produce linguistic evidence.

SR specifies a mechanism to denote important features of non-linguistic evidence (i.e. structures visible in an image; regions of an electrocardiogram tracing; named-regions of a person or specimen) and create explicit semantic links to text, codes, or measurements that explain them. The association is made with *coordinates (of waveforms and images)* and *relationships* that convey not only the reported facts, but the observational knowledge that underlies observer judgments, without the use of "burned in" annotations or bit-mapped overlays. Thus, any number of annotations may be associated with one original image or waveform. This concise, open, semantically-rich integration of linguistic and non-linguistic findings may be of great benefit for education, training, and outcomes-measurement.

Figure 3 illustrates the layout of reports, findings, and observations in the SR conceptual model. Observations are computer-processable, atomic representations of judgments (findings) made by a human observer or by expert-system software. They may include pointers to the evidence that evoked them. Each observation item conveys one class of information (e.g. text, code, quantitative measurement, image, coordinates).

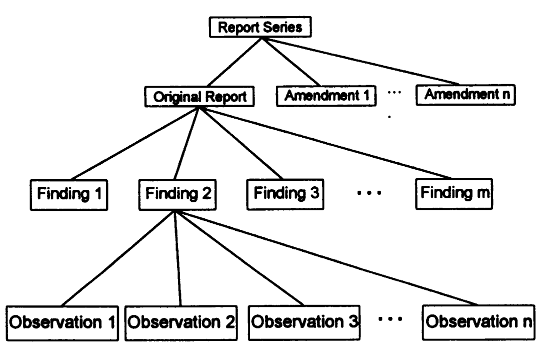

Figure 3. Structured-report layout.

The Report Series depicted in Figure 3 contains a family of related reports including one original report and any number of amendments. A report consists of one or more findings-groups that contain one or more observations. Figure 4 depicts the DICOM SR conceptual schema in more detail. All observations within a single findings group share a common *category*, *observer*, *subject*, and *procedure*.

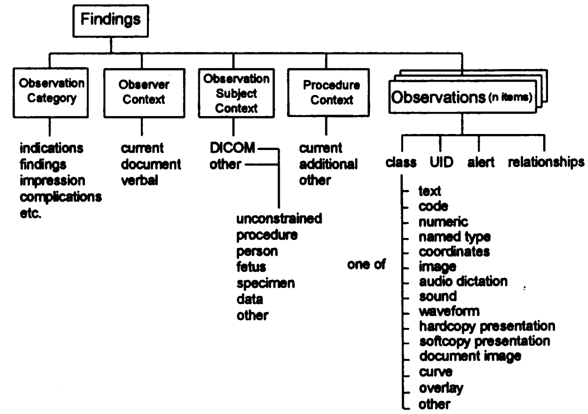

Figure 4. Structured-report Findings Layout.

Free text utterances, categorical codes, or numeric measurements may be conveyed by-value or may be denoted by reference. Bit-mapped arrays (e.g. images, overlays) or time-dependent data (e.g. waveforms, sound, audio dictation, curves) and other objects are denoted by reference. An observation item has a unique identifier (UID) and may be tagged with an alert flag if clinically indicated. The observer may define relationships between observations. For example: a text label and any number of appropriate measurements or SNOMED codes could be linked to the image-coordinates that denote the perimeter of a mass -- identifying the lesion precisely and unambiguously -- and indexing the visual (non-linguistic) evidence for retrieval along with the observer judgments that define it.

The optional "*category*" in Figure 4 indicates the type of finding (e.g. indication, impression, complication). The "*observer*" section describes who is talking (e.g. physician, technologist, parent, spouse, author of a historical document). The identification of the observer may be inherited from a DICOM image or waveform object, or may be specified de novo. The "*observation subject*" is who or what the observer is talking about (e.g. the patient, fetus, specimen, or other entity being examined). If "DICOM", then the identification of the subject is inherited from the DICOM image or waveform being interpreted by the observer. If "other", then the subject is identified de novo by the observer. If "unconstrained", then the subject is not identified precisely. The "*procedure*" section identifies the data-acquisition procedure (e.g. imaging, electrophysiologic examination) that produced the non-linguistic evidence (e.g. image, waveform) or the service (e.g. physical examination, historical interview, interpretation procedure) that produced the linguistic evidence that evoked this observation. If "current", then the procedure is identified by attributes of the current requested procedure. In its simplest form, a procedure report would consist of one text observation made by an observer on evidence produced in the "current" procedure and with subject "unconstrained".

Message/terminology Mapping Resource. The SDM is a message/terminology Mapping Resource -- a database of context-dependent data element value-set specifications.[4] The aim of the SDM is to provide, in the words of Johnson and Gottfried "restrictions of word combination within the established word classes" that are needed for data interchange.[17] The SDM provides context-dependent mapping of specialty terminology from SNOMED to DICOM data elements. At the time of this writing, additional content is being added to the SDM from the Logical Observation Identifier Names and Codes (LOINC) vocabulary.[18] Since SNOMED and LOINC are fully represented in the Unified Medical Language System™ (UMLS) Metathesaurus of the United States National Library of Medicine,[19] the concepts mapped by the SDM are automatically included in the UMLS. The SDM database design includes fields for the Concept Unique Identifier (CUI), String Unique Identifier (SUI), Source Abbreviation (SAB), and Unique Identifier in the Source (SCD) of the UMLS.

The SDM database contains four types of tables: 1) the Context Group Summary Table (only one); 2) the Context Group Tables (many) 3) the Template Summary Table (only one); and 4) the Template Tables (many).[4,5] Context Groups specify context-dependent value-sets for DICOM data elements. Templates specify semantic networks for description of complex concepts such as image-acquisition context and anatomic frame-of-reference.

DISCUSSION

The message/terminology architecture: 1) enables specialization of generic message-templates for use in multiple clinical or operational contexts; 2) enables parallel, distributed development of terminology-content and message-models; 3) serves as a non-proprietary resource of context-specific content; 4) enables observers to express findings at any point along a continuum from free-text to discrete codes to complex semantic networks; 5) preserves observer knowledge as well as findings; and 6) permits full documentation of all historical and observational evidence considered in the formulation of diagnostic conclusions. Flexibility could have been achieved by relaxing semantic explicitness -- but only at the expense of selectivity in information-retrieval. Specialization of messages for various clinical applications could have been achieved through multiple narrowly-defined messages with embedded terminology. However, since the semantic capabilities of inflexible standards are fixed at the time of balloting, and since updates of message content require ballot, this strategy would have been costly and would have increased the risk of inconsistencies in the Standard.

CONCLUSION

Extraction of the information content of images requires domain knowledge or software designed to emulate human expertise. Documentation of the information content of images may require different degrees of granularity, different perspectives, and any number of references to external information depending on the clinical or operational context of the image interpretation. The necessary adaptability is present in the interdependent message/terminology architecture. The proposed *interpretation data interchange model* of the message/terminology architecture also improves the precision and reusability of interpretation findings -- making the information content of images more accessible to health care providers who are not primarily trained in diagnostic image interpretation.

The message/terminology architecture enables semantically-rich integration of linguistic and non-linguistic observational data. Observer knowledge can thus be shared along with observational data. The *encoding* model permits the observer to utilize the degree of encoding structure that is necessary in a given clinical situation. The *perceptual* model supports the wide variation in organization and detail that arise from the highly-subjective nature of the interpretation process. The controlled-terminology mapping resource provides context-dependent content that can be used to index diverse findings for selective retrieval. The *documentation* model of the message/terminology architecture provides appropriate identification and descriptive structure for documentation of observational and historical data in accordance with the principles of the American College of Radiology Standard for Communication in Diagnostic Radiology.[1] The interdependent message/terminology architecture accelerates the development of domain-specific data-interchange specifications by increasing the expressiveness of message-standards, such that they are adaptable to a wider range of applications without re-ballot. This is accomplished without compromising specificity or explicitness.

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