

Article ■

Development of an Ontology to Model Medical Errors, Information Needs, and the Clinical Communication Space

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Abstract Medical errors are common, costly and often preventable. Work in understanding the proximal causes of medical errors demonstrates that systems failures predispose to adverse clinical events. Most of these systems failures are due to lack of appropriate information at the appropriate time during the course of clinical care. Problems with clinical communication are common proximal causes of medical errors. We have begun a project designed to measure the impact of wireless computing on medical errors. We report here on our efforts to develop an ontology representing the intersection of medical errors, information needs and the communication space. We will use this ontology to support the collection, storage and interpretation of project data. The ontology's formal representation of the concepts in this novel domain will help guide the rational deployment of our informatics interventions. A real-life scenario is evaluated using the ontology in order to demonstrate its utility.

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Introduction

The Institute of Medicine's report on medical errors served to alert patients and providers alike to a challenge that we are all called to address.¹ Adverse events (AEs) in hospitalized patients are common. The Institute of Medicine estimated that 44,000 to 98,000 deaths occur each year as a result of medical errors. Using the lower number, deaths due to medical errors constitute the seventh leading cause of death in the United States.

Several studies have examined the types of errors that result in AEs.²⁻⁴ Many are preventable (75-80% of omission errors). Most adverse drug events (ADE's) occurred at the stage of ordering (56%), administration (34%), transcription (6%), and dispensing (4%). These errors were all classified as *cognitive errors*, as

opposed to accidents (such as a slip of a scalpel). Overall, 28% were deemed preventable. Clearly there is room for improvement.

Leape⁶ and Reason⁷ have suggested that the mechanisms of cognitive errors can be categorized as slips or mistakes (see table of Figure 3). Leape described "latent" errors which come about as the result of poor system design, and are not preventable by humans. Systems failures predispose to slips and mistakes. Leape et al conducted a prospective cohort study⁸ in which the authors detected 16 different types of systems failures. The most common errors were due to inadequate dissemination of drug knowledge (29%), and to inadequate availability of information about the patient (18%). All seven of the most frequent errors had in common *impaired access to information*.

Impaired access to clinical information is a common problem. In a seminal study,⁹ Covell et al assessed physicians' self-reported information needs. The infor-

mation needs were met only 30% of the time. Interestingly, physicians were observed to rely on communication with other health care workers more often (53%) than they used paper-based resources (27%).

The information-seeking behaviors of nurses was evaluated in a study by Corocoran-Perry and Graves.¹⁰ The predominant reason for seeking information of all types was direct patient care. Information about medications was the most frequently occurring category of domain information sought. Moreover, the most frequently used information source was other nurses. Spath and Buttlar's study of the information and research needs of acute-care clinical nurses also supported the fact that nurses most often seek information from other nurses and that they use the library only rarely to obtain the information needed for patient care decisions.¹¹

Coiera performed observational studies to assess communication patterns in a clinical setting.^{12,13} He noted the *high mobility* of the physicians, that the hospital was an *interrupt-driven* environment, that workers were members of *teams* and that there tended to be a *synchronous-bias* among the workers. That is, the workers preferred face-to-face or direct contact for all of their communication.¹² Communication with colleagues appeared to be the primary route of gathering information. However, a person was successfully contacted only 74% of the time for all the pages sent. The author recommended using "wireless" technology to address the mobility issue, a message board with some form of acknowledgement for tasks, a role-based database like a Yellow Pages, attaching an "urgency" to task requests, and improved collaboration among team members.¹³

Despite the emergence of "communication" as an important concept in the information needs literature, clinical communication has received inadequate attention as a source of medical errors. Leape found that at least 5% of systems failures were directly attributable to "interservice communication problems."⁸ Wilson et al found that communication errors were much more common than errors attributable to inadequate skill.¹⁴ Another study of primary care physicians found that nearly 50 percent of errors were associated with communication difficulties.¹⁵

In a recent Viewpoint piece in *JAMIA*,¹⁶ Coiera proposed a novel model for understanding the dynamics of clinical communication. First, he asserted that the clinical communication space accounts for the major part of information flow in health care. Second, he

created a model in which a communication task can be viewed along a continuum of "common ground". This implies that if two communicating bodies share common knowledge, then communication should proceed smoothly (and vice versa). Third, he noted that the knowledge required to complete a future communication task is either predictable or unpredictable. In the case where the knowledge required is unpredictable and there is little common grounding, he advocates high-bandwidth interventions that involve *conversation*. In the case where the knowledge required to complete a communication task is predictable, he advocates pre-emptive grounding through some *computational* means.

As part of a larger project designed to assess the impact of wireless computing on medical errors, we have begun to study the way in which medical errors, information-seeking behavior and clinical communication interact. We have conducted a series of preliminary studies in the form of surveys, focus groups and observational studies, the results of which are reported elsewhere.¹⁷

This paper reports on our efforts to build an ontology that captures the concepts discussed above. We realized early in the process that no formal representation of these topics existed in one package. Therefore, the study group lacked a common language to discuss project design and data coding. In an effort to "re-use" knowledge, our ontology extends some of the existing semantic definitions in the UMLS Semantic Network. We incorporate Coiera's model of the "Communication Space" and Leape's description of "Human Error" and "Systems Failures." We developed the conceptual schema using the conceptual graph notation defined by Sowa.¹⁸ The purpose of creating the ontology is to support the design of the larger study's interventions, to clarify the coding of the resulting data, to support the development of a database to house the data, and to facilitate the interpretation of the data. An example of instantiating the conceptual schema is provided.

Methods

Requirements for a formal knowledge representation of the domains were derived from a series of discussions with the project members. Stakeholders present for the meetings included informaticians, physicians, nurses, and cognitive psychologists. Discussion of the required characteristics of the ontology resulted in the following goals:

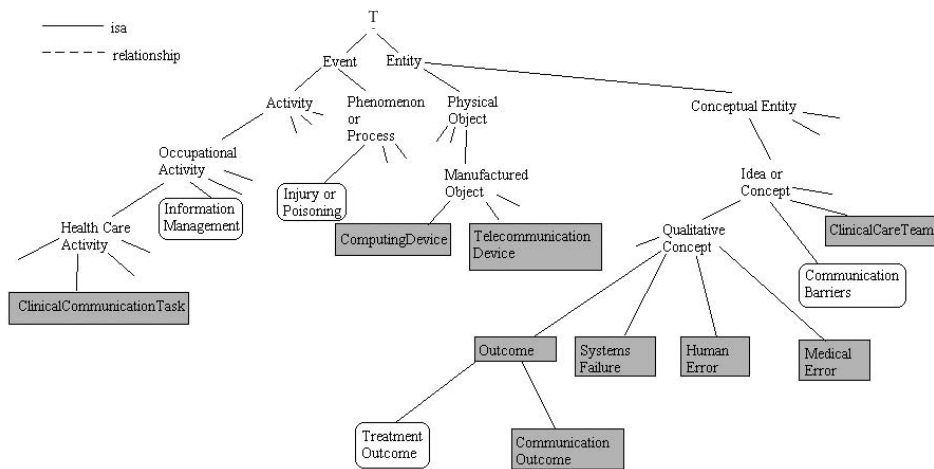


Figure 1 Extending UMLS with new concepts: High-level concepts important to the novel domain—an extension of UMLS Semantic Network²⁰ (New concepts are in boxes. Concepts already represented in the UMLS are in rounded boxes). T = Universal Type¹⁸

- Broad content coverage of concepts in the three major domains (medical errors, information needs, communication space)¹⁹
- Re-use of available ontologies (if possible)
- A flexible, logical schema using accepted representation rules (conceptual graphs)
- Formal definitions¹⁹
- Allow polyhierarchical structure¹⁹
- Design should support task analysis at multiple levels of granularity¹⁹

A literature review of the three main domains was completed using MEDLINE to search for relevant articles. Some of the terms that were searched included the following: “ontology, taxonomy, vocabulary, classification, errors, communication, coordination, collaboration, information needs.” The concepts obtained from the literature review were evaluated by the project members for utility and validity in an ad hoc fashion. A systematic review of the refined concepts and semantic relations was conducted in the UMLS Metathesaurus and Semantic Network to assess content coverage of the refined concepts.²⁰ Required, new, high-level concepts were defined in relation to existing concepts in the UMLS and added to the new resulting ontology.

Once the new required concepts were defined, a conceptual schema was created using conceptual graph notation. Then, an iterative process of refinement involving project members ensued resulting in the final ontology.

Two basic assumptions were made:

- 1) There is no instance in which coordination of care takes place in the absence of communication.

- 2) There is no instance in which clinical information exchange occurs in the absence of clinical communication.

To determine the potential utility of the ontology, we selected a clinical scenario elicited in one of our focus groups. The instantiation of the ontology with the scenario is shown in the results section.

Results

Out of 245 potentially usable concepts (those that contained the words “error, communication, information, coordination, adverse, or outcome” in MRCON), the UMLS contained 4 high-level concepts that were relevant to the novel domain. They are depicted as rounded boxes in Figure 1. The new concepts that serve as the junction between pre-defined concepts in UMLS and the rest of the extended ontology for the novel domain are depicted as dark boxes in Figure 1.

Figure 2 depicts our representation of Coiera’s communication model. We defined Coiera’s “task space” to be equivalent to the concept “Health Care Activity” in the UMLS. Three definitions are required to interpret this part of the schema:

- 1) CommonGround is the amount of common knowledge shared between the initiator and receiver at the time of a given communication task.
- 2) GroundType is defined as “shifting” if it is *hard to predict ahead of time how much knowledge needs to be shared* during a communication task.
- 3) GroundType is defined as “solid” if it is *predictable that a communication task requires a large amount of shared knowledge*.

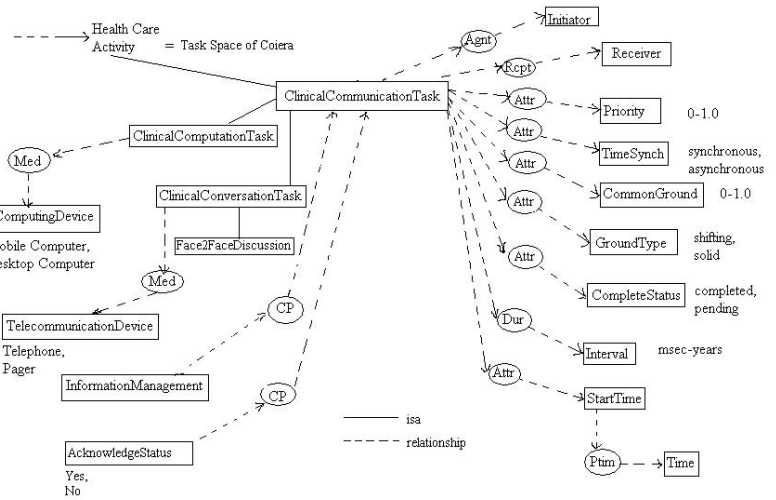


Figure 2 Conceptual Schema for Communication Space: Denoted using Conceptual Graphs. Boxes are Concepts, Ovals are Relationships. Possible values for the concepts are depicted next to the box containing the concept.

Abbreviation	Meaning	Source
Agt	Agent	Sowa ¹⁸
Attr	Attribute	Sowa ¹⁸
Chre	Characteristic	Sowa ¹⁸
CM	Complicates	UMLS Semantic Network ²⁰
CP	Conceptual_Part_Of	UMLS Semantic Network ²⁰
Dur	Duration	Sowa ¹⁸
Med	Medium	Sowa ¹⁸
Ptim	PointInTime	Sowa ¹⁸
Rept	Recipient	Sowa ¹⁸
T	Universal Type	Sowa ¹⁸

Figure 3 depicts our representation of Leape’s model of Human error and systems failures. The reader should note that we have tried to model Leape’s view that medical errors are a *combination* of human factors and systems factors. Additionally, we believe that communication barriers can also contribute to the development of medical errors.

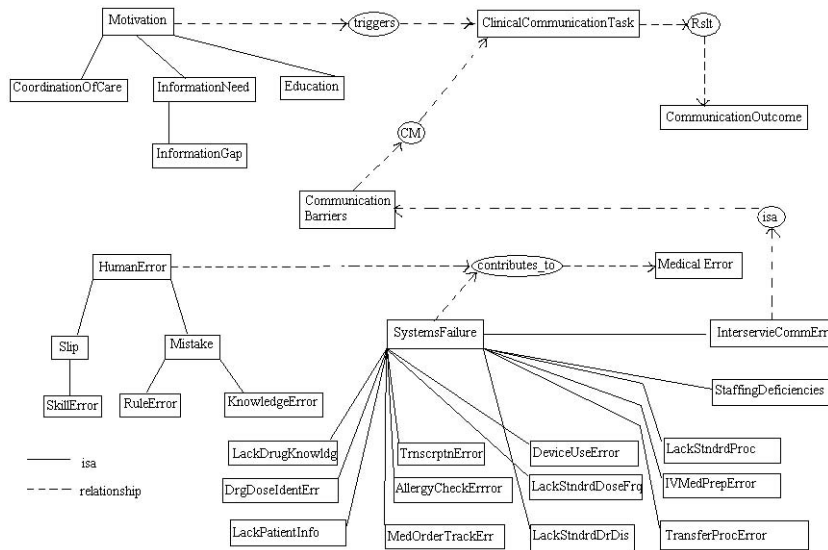
Table 1 demonstrates the instantiation of the conceptual schema with a clinical scenario elicited in one of our focus groups.

Discussion

The primary goal of this study was to develop clear definitions for discussing what we feel is an emerging triad of concepts related to medical errors: Human/systems errors, information needs and clinical communication. As the reader can see, using the UMLS as a “starter kit” does not require a great deal of change in the UMLS Semantic definitions, despite the fact that there were so few related concepts in the UMLS to begin with (245, of which the vast majority were related to “adverse reactions to” a drug).

A direct benefit of developing this ontology is that our project members can now speak with one another about the concepts with “common ground”. Defining the concepts in the ontology also promotes the discovery of targets for interventions with informatics techniques. Since potential targets have formal definitions, hypotheses about how the targets might respond to intervention can be viewed in light of the target’s relationships with other concepts in the ontology. Consider the example scenario represented in Table 1. The interns we interviewed felt that interruptions by many people trying to sign out at once represented a barrier to accurate transfers of care. Additionally, they felt that the current medication list is often inaccurate. This process is modeled in Table 1. A possible intervention to improve the Sign-out process could be to automatically upload the current medications through some computational task. We could add the following relationship to the example in Table 1.

The ontology also provides for careful inspection of the Clinical Communication Task’s potential contribution to medical errors. It will allow the project members to resolve differences with regard to categorizing and coding data into a logical schema.



Classification of Human Performance: (Leape⁶—based on Rasmussen and Jensen)

1. **Skill-based:** thought and actions governed by preprogrammed instructions (schemata)
2. **Rule-based:** solutions to familiar problems governed by stored rules (if X, then Y)
3. **Knowledge-based:** used for novel situations requiring conscious, analytic processing and stored knowledge (synthetic)

Classification of Human Error:

1. **Slips:** errors of action
2. **Mistakes:** errors of conscious thought

Figure 3 Conceptual Schema for Information Needs and Errors. HumanError and SystemsFailure concepts derived from Leape.^{4,6} CM = complicates. Rslt = Result.

Finally, as an example of the utility of the formal definitions, we will discuss the potential of the ontology for hypothesis-generation. Consider the definitions of GroundType and CommonGround

mentioned above. Using the definitions also provided by the ontology, it is possible to extend Coiera’s model and generate the hypotheses shown in Table 2.

Table 1 ■

Example of Application of Conceptual Graph Schema to Clinical Scenario

Scenario:

Question: The Sign-out process to Night Float is another form of communication. Does it have any problems?

Answer: It’s variable.

Question: Give us an example.

Answer: Sign-out from people on call. It’s hard for them to listen to every person when they’re signing out.

Answer: The medication thing is a big issue. It is hard to remember to have that communication all the time. It would be great to have some way that the meds were listed, not by us, but by the pharmacy. . . .

Instantiation of the schema:

```
[CoordinationOfCare: SignOut] --> (triggers) -->
[ClinicalCommunicationTask: EndOfShiftSignOut]
--> (result) --> [CommunicationOutcome: TransferOfCare]
<-- (conceptual_part_of) <-- [InformationManagement: Current Medications]
<-- (conceptual_part_of) <-- [AcknowledgementStatus: Yes]
--> (agent) --> [Initiator: OnCallIntern]
--> (recipient) --> [Receiver: NightFloat]
--> (attribute) --> [TimeSynch: synchronous]
--> (attribute) --> [CommonGround: 0.3]
--> (attribute) --> [GroundType: Shifting]
--> (attribute) --> [CompleteStatus: completed]
--> (duration) --> [Interval: < 5, min>]
--> (attribute) --> [ StartTime]
--> (PointInTime) --> [Time: 21:00]
--> (isa) --> [ClinicalComputationTask: AutomaticMedSignOut]
--> (isa) --> [Face2FaceDiscussion: InternToIntern]
```

Table 2 ■

Predictions of the Types of Interventions that are Likely to be Successful. Extrapolated from Coiera’s Communication Model¹⁶

Predicted Characteristics of Clinical Communication Task		Suggested Intervention		Description of Intervention		
Ground Type	Common Ground	Cost During Task	Cost Prior to Task	Bandwidth During Task	Grounding Prior to Task	Favors
Shifting	0	High	Low	High	None	Conversation
Shifting	1	Low	Low	Low	None	Conversation or Computation
Solid	0	Medium	High	Medium	High	Computation
Solid	1	Low	Medium	Low	Medium	Computation

CONCLUSION

Medical errors are common, costly and preventable. They appear to occur in the setting of three major forces: Human/systems errors, information-seeking behavior, and clinical communication. It is possible to model this domain with an ontology that extends the concepts already contained in the UMLS. The ontology may provide a means of resolving coding disagreements, clarifying the role of communication in medical errors, development of a project database, targeting interventions, and promoting hypothesis-generation.

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