Vaidurya – A Concept-Based, Context-Sensitive Search Engine For Clinical Guidelines

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Abstract

A major problem in the effective use of clinical guidelines is fast and accurate access at the point of care. Thus, we are developing a digital electronic guideline library (DeGeL) and a set of tools for incremental conversion of free-text guidelines into increasingly machine-comprehensible representations, which support automated application. Even if guidelines are represented in electronic fashion, care providers need to be able to quickly retrieve the guidelines that best fit the clinical situation at hand. We describe Vaidurya*, a search and retrieval engine that exploits the hybrid nature of guideline representation in the DeGeL architecture. Vaidurya can use not only free-text keywords, but also multiple semantic indices along which the guidelines are classified, and the mark up of guidelines in DeGeL, using the semantic roles of one or more guideline-representation languages. Search results are displayed and browsed using the* VisiGuide *tool. Preliminary evaluation of Vaidurya in a standard information-retrieval task and a large guideline repository is encouraging; formal evaluation is under way.*

Keywords: Information Retrieval, Medical Informatics, clinical guidelines, context-sensitive search, Digital Libraries.

Introduction

Clinical practice guidelines (CPGs) are a powerful method for standardizing the quality of medical care [1]. CPGs are a set of schematic plans for management of patients who have a particular clinical condition (e.g., insulin-dependent diabetes).

Unfortunately, most CPGs are represented in free text, whether in paper or in an electronic format. Paper-based CPGs are relatively inaccessible to care providers at the point of care, while the free-text electronic format provides little support for automated retrieval of the CPGs potentially most applicable to the patient at hand, especially when the user is not an expert in the relevant clinical domain. The free-text format also provides no support for automated application of the guideline.

Several representation formats, or *CPG ontologies*, have been proposed in order to represent clinical guidelines in a structured or even machine-comprehensible fashion. Examples include ONCOCIN [2], EON [3], Asgaard [4], PROforma [5], and GLIF [6]. However, most guidelines are still only in various free-text formats.

The DeGeL Architecture

The main hurdle preventing fast conversion of free-text CPGs into machine-comprehensible formats is that expert physicians cannot program using the syntax of the current CPG specification languages, while programmers and knowledge engineers do not understand the clinical semantics of the CPGs. However, text-based representations also have benefits: They are useful for search and retrieval of relevant CPGs, although a formal representation is necessary for machine execution. Thus, in our view, expert physicians should be transforming free-text guidelines into structured, semantically meaningful representations, while knowledge engineers should be converting marked-up segments into a formal, expressive, executable language.

To gradually convert CPGs into a machine executable target representation, we have developed a distributed architecture, the *Digital Electronic GuidelinE Library*, (**DeGeL**) [10,11] and a set of web-based software tools for incremental conversion of CPGs into multiple CPG-specification representations (Figure 1). (Currently, full specification of procedural aspects is provided only for the Asbru ontology, although specification and retrieval of declarative roles are supported for any ontology.)

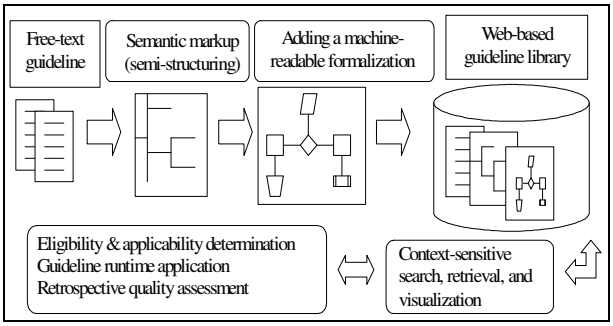

Figure 1- Gradual conversion of free-text guidelines to an executable format in the DeGeL architecture

The DeGeL architecture uses a CPG semantic-markup tool, **Uruz**, which combines the expertise of both the expert physician and knowledge engineer to incrementally convert free-text CPGs into a machine-executable format (see Figure 1).

The output of Uruz is a *hybrid representation* of a CPG which, for each CPG, contains one or more of the following three formats:

- *Structured Text* –text fragments assigned to top-level Asbru (or another target ontology) semantic *knowledge-roles,* such as *intentions*, *effects*, and the procedural *plan body*.
- *Semi-formal Asbru* – further specification of the structured text towards the formal representation, performed by the knowledge engineer and expert physician
- *Formal Asbru* – the final step of the conversion process, performed by the knowledge engineer, resulting with the CPG converted to a machine executable format

Marking Guidelines in the DeGeL Architecture

Each CPG in the DeGeL library eventually undergoes a *semantic mark up* process, in which the CPG's text is labeled by one of the available ontologies implemented in DeGeL (such as Asbru or GEM). The mark up is made by dragging a text segment from a source CPG (original textual representation) to a relevant element in the chosen ontology. The text can then be further modified or extended. The markup is performed mainly by a domain expert. Domain experts are organized by groups, with a corresponding permission model for search and editing [11]. The markup process's main goal is to assist the knowledge engineer in transforming the CPG into a formal machine-comprehensible format, such as full Asbru. these segments of the text representing the relevant context are good for accurate retrieval operations.

The DeGeL Meta-Ontology and Semantic Axes

The DeGeL library represents CPGs using a meta-ontology format [10]. Ontology independent elements, such as documentary details and semantic classification indices, are common to every CPG, regardless of the lower-level ontology, such as Asbru, used to present the CPG's details.

To classify guidelines, mainly for purposes of efficient retrieval, seven semantic axes are implemented in DeGeL. Each Axis represents a major clinical aspect. Axes include (1) *symptoms and signs* (e.g., hypertension), (2) *diagnostic findings* (e.g., blood cells count, electrocardiogram), (3) *disorders* (e.g., ischemic heart disease, malignant neoplasm), (4) *treatments* (e.g., antibiotic therapy , abdominal surgery), (5) bo*dy systems and regions*, or a relevant CPG classification (6) *guideline types* (e.g., screening, prevention), and (7) *guideline specialties* (e.g., radiology, internal medicine).

Each Axis is implemented as a hierarchical tree of sub axes. Each CPG is indexed along one or more semantic axes, such as Disorders (e.g., malignant skin melanoma), Guideline specialties (e.g., oncology), etc.

The Vaidurya Search Engine

A major current focus is on the retrieval of CPGs as a valuable tool to improve the adoption and integration of CPGs at the point of care, as part of the evidence based medicine approach. Electronic CPG repositories, such as the National Guideline Clearinghouse (NGC) [8] provide access to electronic CPGs in a free-text or semi-structured format.

We introduce in this paper **Vaidurya**, a powerful search and retrieval tool, which we use currently mostly for search within a guideline library. Vaidurya uses three types of search: (1) free-text search, using standard key terms; (2) *concept-based search*, which we call also *external search*, which uses a semantic–axes structure that indexes guidelines, a structure that exists in the DeGeL library (and to some extent, also in the NGC repository), and (3) *context-sensitive search*, which we call also *internal search*, which exploits the semantic markup performed on guidelines in the DeGeL library. Internal search focuses on searching for key terms only in the context of the text that exists within the scope of a particular ontology-specific semantic knowledge role. (A natural implementation is searching for text within specific XML elements, although other representation formats are potentially possible).

The Vaidurya Search and Retrieval Model

Concept Based Search in Vaidurya

Multiple digital libraries are indexed in a hierarchical structure; examples include the known web portal Yahoo and the NGC library [8]. These sites allow browsing through the categories in the hierarchical structure, starting from the root of the categories tree, and ending at the most specific category, located at the leaves. The NGC web site has two main Axes based on MeSH[13]: *Disorders* and *Therapies*.

Thus, part of the Vaidurya search model includes optional specification in the query of one or more semantic axes or subaxes, and logical operators defining the relations between the axes. The *concept search query* is thus a collection of constraints represented by chosen sub axes and the logical relations between them: conjunction or disjunction..

Context-Sensitive Search in Vaidurya

The context-sensitive search exploits the markup process that a CPG goes through in URUZ. Each marked up CPG in DeGeL is represented within the target ontology selected for it by the URUZ user, implemented as an XML structure that depends on the structure of the target ontology..

To implement the Concept-Based Search and the Context-Sensitive Search, we defined two properties for each element in a guideline representation ontology, *Search Type* and *Search Scope*. These properties, or *aspects*, define the way an element will be indexed, queried and retrieved (Table 1).

Table 1 – Search Type definitions

Search Type	Description	Querying Options	Relevance measure
Free Text	An element containing a free text content.	Keywords with disjunction or conjunction logic operator.	Metric
Text Value	An element that may contain only a single fixed string value.	Requested string values with disjunction being the only possible relation.	Boolean
Text Multiple Value	An element containing one or more fixed string values.	Requested string values with conjunction, disjunction relations.	Boolean
Date	An element that its content represents a calendar date.	A date constraint using operators such as '>' or '>=' etc.	Metric
Integer	An element that its content represents an integer value.	An integer constraint using operators such as '>' or '>=' etc..	Metric
Semantic Index	An element represents the conceptual classification of the guideline	Requested concepts using conjunction, disjunction operators between indices.	Boolean
Unsearchable	An element that doesn't have content or its content is irrelevant for search.	No query.	Not relevant.

Search Type

The Search Type aspect characterizes the type of an ontology element for the purposes of a search engine. The search-type aspect caters for varying ontologies and for additional ones which DeGeL might need to handle in the future. In order to add a new ontology, one has to define the *Search Type* of each ontology element. Table 1 describes, for each Search Type, its definition and properties.

Search Scope

Since CPGs are represented in DeGeL within different hierarchical ontologies, an element in an ontology tree may have descendents. These might need to be searched as well.

Table 2 – Search Scope definitions

Search Scope	Description
None	No search at that element nor at its descendents - elements that don't contain any content, and their descendents' contents aren't relevant to them.
Search-Self	Search the element without descendents
Only-Children	No search at that element, search only its descendents.
Children-Included	Search both that element and its descendents.

Sometimes there are elements that function as headers and don't have any content; these elements may sometimes use their descendents' contents when being queried. Using an element's descendents will be relevant only when its descendents are of the same *Search Type* as the element and when its descendents contents are semantically relevant and have a retrieval value to the element. Thus, the *Search Scope* aspect has several possible values (Table 2).

It is possible to query an element's descendents and score-up the result to the queried element. Using the Search Scope approach allows broadening the query when appropriate, and taking advantage of the descendents' contents, a crucial option within a library such as DeGeL, since CPGs are often in the process of being marked up and the elements' contents aren't necessarily instantiated--possibly because they weren't marked-up yet.

The Hybrid Query Model

Vaidurya offers a highly variable query structure, in which both very simple and highly sophisticated queries can be built. A query may contain constraints limiting the search in a sub group of CPGs that are indexed by requested semantic axes, such a query defines the logic relations between the sub axes and the axes conjunction or disjunction. The query may include also ontology elements that are of different search *types*; each element can be queried according to its type, as described at Table 1.

Querying options

There are two main CPG entities implemented currently in DeGeL: Free Text, or *guideline source* (*GLS*) – represents a source guideline; *marked-up guideline* (*GLM*) - represents a marked up guideline that was created by the URUZ tool, based

on one or more GLSs. A third entity we are currently adding is a guideline represented in a full structured representation, for example Asbru. Currently there are two main search options (1) search for a GLS based on the Source ontology, an ontology containing mainly documentation elements describing the source guideline, and (2) search for a GLM using the meta-ontology, which contains, among other elements, compulsory documentation elements that describe the GLM. One of the meta-ontology elements is the ontology by which the guideline was marked up. Each kind of search retrieves the relevant guideline entity. A *query* is a set of constraints on the requested guideline, created by defining constraints on one or more ontology elements. The constraints on each ontology element differ according to its *SearchType*.

The Vaidurya Query Interface

The current Vaidurya full-query interface is shown in Figure 2. The interface enables users to form a query using all the elements of the guideline. However, our experience indicates that offering a user *all* of the elements and semantic axes produces an overloaded, complicated query interface. Furthermore, there is a variety of user types for such a search engine: general practitioners, patients, nurses, medical students, physicians at different specialty levels and knowledge, etc. Different users require different levels of complexity in the interface. Thus, we built a *query-interface generation tool* that enables us to offer different user types different levels of complexity of the query interface, from a simple basic text box to a complex interface. The results returned by Vaidurya are displayed by **VisiGuide** (Figure 3), a sophisticated viewer, which enables users to browse the retrieved guidelines, including their contents and the classification of the returned results. VisiGuide can display any guideline ontology given to it as an XML file.

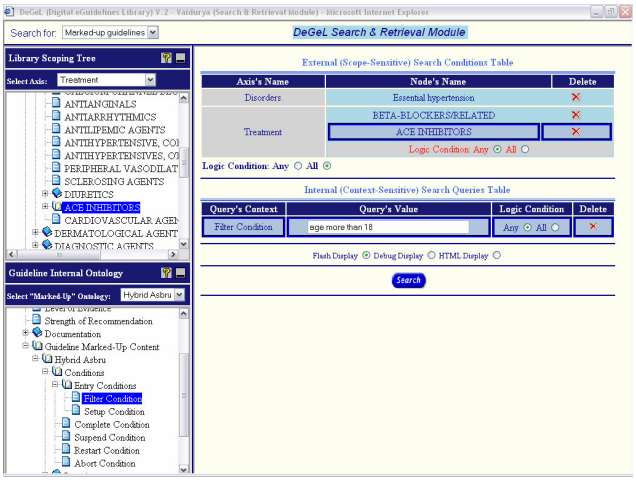

Figure 2 – The Vaidurya full-query interface

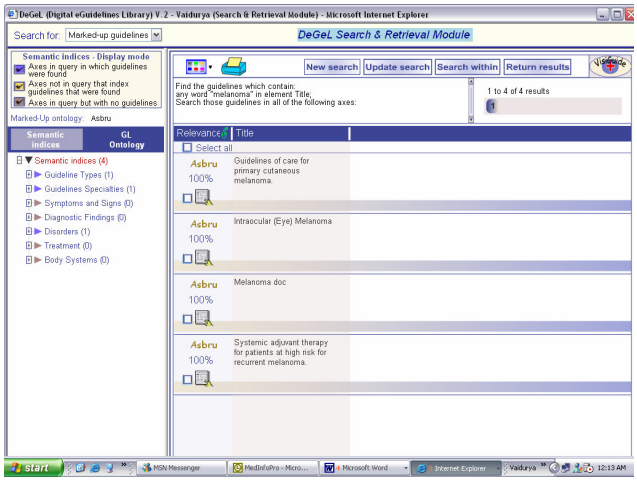

Figure 3 –Display of retrieved guidelines by VisiGuide

The Vaidurya Data Structures and Ranking Algorithm

A CPG is represented in our repository by its ID number and the ontology (e.g., GEM, Asbru) ID. Thus, each ontology element content, of any Search Type, is indexed as a *pair*. This scheme which differs from traditional textual databases represented by an *inverted file* of one dimension that represents the document free text [7]. The traditional method is a private case that would be implemented in our library as an ontology that has only one element of a *Free Text* search type. The pair consisting of document d and context c, $\langle d,c \rangle$, represents a multi-dimensional inverted file. Each pair represents a CPG's ontology element content, which is indexed according to its Search Type. When a query is processed and applied to the knowledge in the repository represented by the pairs (d,c) and its value, data structures that represent vectors and matrices are built, supporting the process of evaluating the CPGs relevance to the query and of ranking them.

Each *Search Type* element has a different importance in the ranking process. For example, a query constraint created on a date type element will contribute more than a Free Text constraint, that is because it is easier to express a date constraint properly than a Free Text constraint (which is expressed by words). Also, among the same search Type elements there are elements with content that is more or less obvious for retrieval; we implemented these differences by giving each *Search Type* a weight that represents its value in the ranking task, and the same for each ontology element.

Implementation of the search algorithm is based on basic linear operations. Let CM be a matrix in which one dimension is the CPGs and the second is a group of queried elements, or contexts, of the same *Search Type I*; for example all the elements that are chosen in a query from the *Free Text* search type. The value of each entry within CM represents the degree of matching of CPG d's content for context c. The number of the CM matrices is the number of the queried search types. Let qST be a vector that represents the elements of search type I and their weights, where each entry represents the weight of element c. Let $stRank_i$ be a vector which is a result of the matrix-vector multiplication of CM_i and qST_i, as in Equation 1:

$$stRank_i = CM_i \times \xrightarrow[qST_i]{} \quad (1)$$

After computing *stRanks* , we know the score each CPG had for each Search Type*i.* Let *STM* be a matrix of the unification of all the vectors $stRank_i$,; each entry $STM_{d,i}$ represents the score of a CPG *d* for the search type *I*; let *q* be the vector that represents the weights of each *search type.* Let *R* be the vector representing the rank of each CPG scored at the ranking process; each entry in the vector *R* is the final rank of a CPG. *R* is the result of the matrix-vector multiplication of the matrix *STM* and the vector *q*, as shown in Equation 2.

$$R = STM \times \xrightarrow[q]{} \quad (2)$$

Results

Initial testing of Vaidurya was performed using the TREC 6 collection [12], a benchmark collection of text documents and of queries and judgments on these documents. We then added queries regarding the NGC repository. Preliminary results are encouraging. A formal evaluation is underway. We are planning to mainly evaluate the concept-based and context-sensitive search methods on a CPGs repository.

Conclusions

The mark up process a CPG goes through in DeGeL gives us the outstanding opportunity to query using the context-sensitive methods. We had learned already that this querying approach allows more specific search that may limit the search and avoid irrelevant results which most of the search engines suffer from. The disadvantages are a complicated query that needs familiarity with an advanced query interface and time that users wouldn't often like to spend. The concept-based search allows limiting the search to a specific subset of the repository which increases the precision of the returned results; the potential disadvantage in this approach is the manual classification of a CPG in DeGeL, a subjective task that may harm the precision of the results.

Future Work

We are in the process of building a gold standard of queries that will be the base of the formal evaluation. Since the preliminary experiments had shown that the query interface, although powerful, is very overloaded, we are working on new interfaces that will be simpler and more user friendly. These interfaces will offer several versions customized by the user. We are developing also a semi natural-language search interface. Since the classification of each CPG is done by an expert and may be subjective, we are also developing an automatic classifier that will classify new CPGs along current axes, based on a given knowledgebase of classified CPGs.

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