Using GEM-encoded Guidelines to Generate Medical Logic Modules

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Abstract

Among the most effective strategies for changing the process and outcomes of clinical care are those that make use of computer-mediated decision support. A variety of representation models that facilitate computer-based implementation of medical knowledge have been published, including the Guideline Elements Model (GEM) and the Arden Syntax for Medical Logic Modules (MLMs). We describe an XML-based application that facilitates automated generation of partially populated MLMs from GEM-encoded guidelines. These MLMs can be further edited and shared among Arden-compliant information systems to provide decision support. Our work required three steps: (a) Knowledge extraction from published guideline documents using GEM, (b) Mapping GEM elements to the MLM slots, and (c) XSL transformation of the GEM-encoded guideline. Processing of a sample guideline generated 15 MLMs, each corresponding to a *conditional* or *imperative* element in the GEM structure. Mechanisms for linking various MLMs are necessary to represent the complexity of logic typical of a guideline.

Introduction

Over the past decade, a major global initiative has been undertaken to develop, disseminate, and implement clinical practice guidelines. Several studies have shown that simply creating and disseminating guidelines does not necessarily result in behavior changes on the part of practitioners or changes in health outcomes for their patients (1, 2). Among the most effective strategies for changing the process and outcomes of care are those that make use of computer-mediated decision support (3-5).

A variety of representation models to facilitate computer-based implementation of medical knowledge have been published (6-8), including the Guideline Elements Model (GEM) (9) and the Arden Syntax for Medical Logic Modules (MLMs) (10). In the Arden Syntax, each MLM contains sufficient knowledge to make a single medical decision. Knowledge bases that are composed of independent rules, formulae, or protocols are most amenable to being represented using the Arden Syntax. On the other hand, GEM is a model for representing practice guidelines, which are knowledge bases that contain complex logic requiring coordination among multiple recommendations.

In this paper, we describe an eXtensible Markup Language (XML)-based application that facilitates automated generation of partially populated MLMs from GEM-encoded guidelines.

GEM

GEM is a guideline document model based on XML (11) that stores and organizes the heterogeneous knowledge contained in practice guidelines. The GEM Document Type Definition (DTD) is being balloted by the American Society for Testing and Materials E31.25 committee as a standard for representation for guideline documents. GEM is intended to facilitate translation of natural language guideline documents into a format that can be processed by computers. It is a multi-level hierarchy of more than 100 discrete elements in nine major branches – Identity, Developer, Purpose, Intended Audience, Target Population, Method of Development, Testing, Review Plan, and Knowledge Components. The elements are basic units of information that store data and define structure by virtue of their position in the hierarchy of the document. Knowledge components section of the hierarchy (Figure 1) stores and categorizes the recommendations that constitute the essence of practice guidelines.

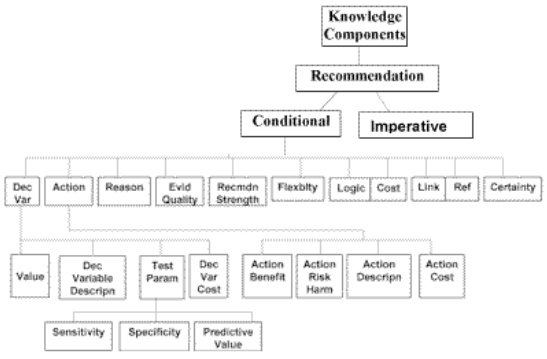

Figure 1: A portion of the Knowledge Components section of the GEM hierarchy

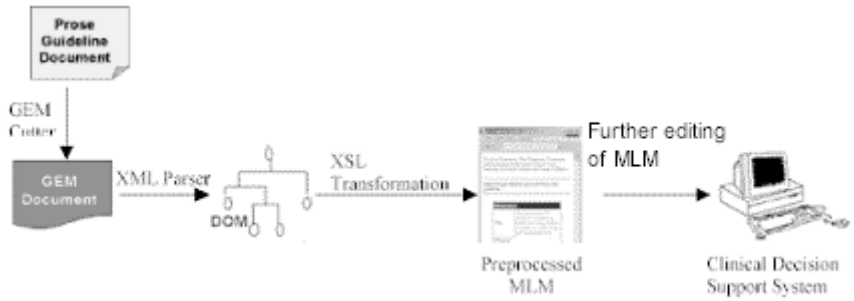

Figure 3: An overview of the process for generating partially populated MLMs from a GEM-encoded guideline

The Arden Syntax

The Arden Syntax for Medical Logic Modules (MLMs) is a standard for representing medical knowledge for clinical decision support (10). MLMs have been used to generate contraindication alerts, management suggestions, data interpretations, treatment protocols, and diagnosis scores.

```
Maintenance:
  title:          Screen for hypokalemia with digoxin therapy;;
  filename:       hypokalemia_and_digoxin;;
  version:        1.06;;
  institution:    Columbia-Presbyterian Medical Center;;
  author:         George Hripcsak, M.D.;;
                  (hripcsa@cucis.columbia.edu);;
  specialist:     George Hripcsak, M.D.;;
  date:           1993-09-17;;
  validation:     production;;
Library:
  purpose:        Warn the health care provider of hypokalemia
                  in the setting of digoxin therapy.;;
  explanation:    Whenever a serum or whole blood potassium
                  value is stored, it is checked for hypokalemia
                  (less than 3.3).;;
  keywords:       hypokalemia; digoxin; arrhythmia;;
  citations:      1. International Committee of Medical Journals.
                  NEJM 1991:324:424-8;;
  links:          CTIM-1.14.5;;
Knowledge:
  type:           data-driven;;
  data:           K:=read last {serum potassium} where it
                  occurred before now;;
  priority:       50;;
  evoke:          potassium_storage;;
  logic:          If K>=3.3 then conclude false; endif;;
  action:         write "This patient has hypokalemia in the
                  setting of digoxin therapy..."
  urgency:        50;;
End:
```

Figure 2: A sample Medical Logic Module from the library of MLMs at the web site http://www.cpmc.columbia.edu/arden/

An MLM is composed of a number of slots grouped into three categories: maintenance, library, and knowledge. The maintenance category contains descriptive information about the MLM (its title, author, version, etc.). The library category provides descriptions of the purpose of the MLM as well as index keywords to facilitate searching. The knowledge category of an MLM includes slots such as evoke (the conditions under which the MLM becomes active), logic (tests some condition and then concludes true or false), and action (action produced when the logic slot concludes true). Figure 2 displays a sample MLM that warns the health care provider of hypokalemia in the setting of digoxin therapy.

Methods

Generation of an MLM from knowledge contained in a guideline requires three steps: (a) Knowledge extraction, (b) Mapping GEM elements to the MLM slots, and (c) XSL transformation (XSL-T) (12) of the GEM document to produce a partially populated MLM.

Figure 3 provides an overview of the steps used in our application. The substrate for generating MLMs is a published guideline document. The product of this process is an XML file that contains GEM-encoded knowledge from the practice guideline. This GEM file is parsed into memory, creating an XML Document Object Model (DOM), which, in turn, can be operated upon by XSL-T. XSL-T queries the DOM tree to extract components of guideline text pertinent to generating an MLM. The outcome of this process is a list of partially populated MLMs. These MLMs can be further edited and shared among Arden-compliant information systems to provide decision support.

(a) Knowledge Extraction

The American Academy of Pediatrics (AAP) guideline on the diagnosis, treatment, and evaluation of the initial urinary tract infection in febrile infants and young children (13), was marked up as an XML document according to the GEM Document Type Definition (DTD) using GEM Cutter. GEM Cutter is

a GEM-specific XML editor, developed at the Yale Center for Medical Informatics (available at http://ycmi.med.yale.edu/GEM).

(b) Mapping GEM Elements to MLM Slots

MLM constructs were mapped to corresponding elements in the GEM hierarchy (Table 1). As anticipated, some of the slots in the Arden Syntax had no corresponding GEM element. These slots specify information unrelated to the health knowledge in the MLM such as institution-specific information or information concerning MLM knowledge base maintenance and version control. These slots include Mlmname, Arden Syntax version, version, institution, author, specialist, date, and validation in the maintenance category; keywords in the library category; and type, data, priority, and urgency in the knowledge category.

Arden Syntax	**GEM Element**
Maintenance	
Title	<conditional>
Library	
Purpose	<objective>
Explanation	<reason> <evidence.quality> <recommendation.strength>
Citations	<citation>
Links	<reference>
Knowledge	
Evoke	<decision.variable> decision.variable/<value>
Logic	<logic>
Action	<action>

Table 1: Mapping GEM elements to the Arden Syntax

(c) XSL Transformation

Based on the GEM-MLM mapping, a customized XSL stylesheet was designed. A variety of XSL-T methods were used to selectively extract text components relevant to an MLM from the guideline. The following example (Figure 4) demonstrates a method that was used to test the content of a GEM element *objective*. The *objective* element of GEM corresponds with the slot named 'purpose' in the library category of an MLM (Table 1). If the objective of the guideline was not specified, then the phrase "not available" is displayed; otherwise the text stored in the *objective* element will be retrieved and displayed as the content of the 'purpose' slot in the resultant MLM.

```
<xsl:choose>
        <xsl:when test="//objective[.='']">
                <B>Not available</B>
        </xsl:when>
        <xsl:otherwise>
                <xsl:value-of select="//objective" />
        </xsl:otherwise>
</xsl:choose>
```

Figure 4: Example of an XSL-T method

Results

Sample Guideline: An Analysis

Using this application, 15 Medical Logic Modules were generated from the AAP guideline on the management of the urinary tract infection (13) (figure 5). Examination of published guidelines indicates that guideline recommendations are stated in two different formats that require different considerations for implementation. *Conditional* recommendations define activities that are applicable only under specific circumstances; they can usually be understood as IF…THEN statements. On the other hand, *imperative* recommendations are broadly applicable to the target population of the guideline. In a conditional, the IF clause defines one or more *decision variables* that must be satisfied, i.e., the value for the variable must be matched with real world data, for the THEN clause – the recommended *action* to trigger. In an *imperative*, the recommended action is termed a *directive* to avoid confusion. The *conditional* and *imperative* elements are intended to store the actual text of the guideline's advice in a sentence form.

Each *conditional* and *imperative* element in the GEM-encoded guideline generated one MLM. In the MLMs generated from the *conditional*, each *decision variable* under that conditional generated one line in the *evoke* slot of the MLM and each *action* generated one line in the *action* slot of the MLM. In addition, the *id* attributes of the decision variables such as *dv1*, *dv2* and the *id* attributes of the action such as *a1*, *a2* were also displayed in the MLM. These attributes may be used to fill the *logic* slot of the MLM, for example, IF [(dv1 or dv2) and dv3]….THEN (a1 and a2). In the MLMs generated from the *imperative* component of the guideline, the evoke slot displays the inclusion criteria for the guideline and the *action* slot displays the value of each *directive*. In addition, the values of the elements *reason*, *evidence.quality* and *recommendation.strength* are displayed in the explanation slot of each MLM. The title slot of the

MLM is derived from the text content of the corresponding *conditional* or *directive* element.

Maintenance	
Title	The presence of UTI should be considered in infants and young children 2 months to 2 years of age with unexplained fever
Library	
Explanation	Evidence Quality: strength of evidence: strong Recommendation Strength: **Not available**
Keywords	
Citations	Downs SM. Technical Report: Urinary Tract Infections in Febrile Infants and Young Children. Pediatrics 1999;103(4):e54
Links	**Not available**
Knowledge	
Evoke	**dv2** unexplained fever ;; **dv1** age 2 months to 2 years;;
Logic	
Action	**a1** The presence of UTI should be considered ;;
Urgency	
End:	

Figure 5: Sample components from one MLM generated from the UTI guideline

Discussion

This study demonstrates the feasibility of an application for automated generation of partially populated MLMs from a GEM-encoded guideline. We believe this process can facilitate guideline implementation by efficient transformation of guideline knowledge into a standardized sharable format.

The Arden syntax, having been written to divide knowledge into rules that represent individual clinical decisions, is not designed to link multiple rules that might fire in unpredictable patterns. Sherman et al. published a study demonstrating the use of intermediate states to improve the ability of the Arden Syntax to implement temporally complex care plans (14). They demonstrated that the knowledge contained in the practice guidelines and care plans could be successfully represented; however, the complexity and limitations of this approach have been evident. Implementing guideline knowledge using the MLMs will require defining and executing complex relationships not only among various MLMs but also among various rules within an MLM.

One advantage of our application is that once the customized XSL stylesheet has been designed to extract pertinent information from a guideline, it can generate MLMs from any GEM-encoded guideline without requiring additional programming or effort. If a new recommendation is added or revised in the guideline, a corresponding new MLM can be generated easily without having to reengineer the whole application.

A major issue in consistency relates to the atomization of concepts in GEM and mapping of those concepts to slots in an MLM. We believe that the level of granularity of an MLM corresponds not with a guideline recommendation but with individual conditionals and imperatives as defined in GEM. Therefore, one MLM should be generated for each *conditional* and *imperative* in the guideline. Each *conditional* may have multiple *decision variables* and *actions* and each *imperative* may have multiple *directives*. This is congruent with the "single rule, single decision" concept of the Arden.

GEM was developed with the intent of being a "more comprehensive" document model for knowledge representation of practice guideline (9). Research is underway to build applications and tools for guideline implementation and decision support using GEM. The Arden Syntax for MLMs has already been used to implement decision support systems both by academic centers and commercial vendors. Extending GEM to incorporate some constructs from the Arden Syntax such as priority (relative order in which MLMs should be evoked should several of them satisfy their evoke criteria simultaneously) and urgency (urgency of the action or message) may prove to be useful for guideline implementation applications. In addition, adding the 'keywords' construct to GEM may facilitate index searching of a library of GEM-encoded guidelines.

A major advantage of XML is the separation of the syntax from the semantics. Health Level Seven, the current home of the Arden Syntax, has been discussing the use of XML for modeling MLMs (Clinical Decision Support and Arden Syntax TC Meeting Minutes Fall Working Group Meeting, St. Louis, MO September 13 - 15, 2000). Although it will be relatively easy to model the maintenance and the library categories of the MLM, it may not be possible to represent the knowledge category of the MLM in XML using the current version of the Arden. GEM provides for detailed and multilayered abstraction of the knowledge contained in guidelines. GEM and Arden Syntax may complement each other in this respect and draw from each other's strengths.
XML markup of a guideline results in an intermediate, electronically processable document

that preserves the intent of the developers. GEM-encoded guidelines in XML format can be used by a variety of other applications. GEM-Q (15) is an XSL-based application designed to facilitate automated evaluation of guideline quality using published guideline rating instruments such as the Appraisal Instrument for Clinical Guidelines (16) and the Guidelines Quality Assessment Questionnaire (17). Since XML is an intrinsic part of the Web with presentation and parsing capabilities built into Web browsers, GEM-encoded guidelines can also be used to facilitate guideline dissemination on the Web. XML also provides easy capability for searching, indexing, and locating information. Therefore, applications can be built for GEM-encoded guidelines to interact with clinical databases to provide guideline-based decision support.

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