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A Semantic Web Based Framework for Modeling Clinical Practice Guidelines to Develop Clinical Decision Support Systems

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Abstract

In this paper we present a Semantic Web based framework for the computerization and execution of Clinical Practice Guidelines via a Clinical Decision Support System (CDSS). Our framework involves multiple ontologies to represent different CPG, domain and patient knowledge. We have developed a tool to specify the CPG's decision logic as decision-rules that are executed via a proof-engine to derive patient specific recommendations. We provide a justification tree of the reasoning process to explain to the user the CPG-mediated recommendations suggested by the CDSS.

Keywords:

Clinical Practice Guidelines, knowledge management, Decision Support System, Semantic Web, ontologies

Introduction

Clinical Practice Guidelines (CPG) are systematically developed disease-specific recommendations to assist clinical decision-making in accordance with the best evidence [1]. However, the uptake of CPG is rather minimal in actual healthcare settings due to a range of behavioral, operational and technical issues. Indeed, CPG can be more effectively used if they are computerized and incorporated within Clinical Decision Support Systems (CDSS) that are available at the point-of-care[2].

In our work, we take a knowledge management approach to computerize CPG and develop a CPG-based CDSS. We apply the Semantic Web framework [3] to (i) Computerize a CPG by semantically representing disease-specific knowledge inherent within a CPG, whilst specifying the relationships and interactions between the key CPG elements to realize a functional and executable CPG plan; (ii) Transform the decision logic inherent within a CPG into executable logic-based decision rules; (iii) Execute the computerized CPG based on patient information, in order to provide CPG-mediated, patient-specific recommendations; and (iv) Justify the CDSS's recommendations by providing CPG-based explanations. The Semantic Web purports the semantic modeling and markup of knowledge, its properties and its relations using well-defined semantics such as formal definitions of terms, ontological definitions of domain concepts and resources. The semantically modeled knowledge can then be operationalized via proof engines employing logic-based reasoning methods to infer 'trusted' solutions.

In this paper we present a Semantic Web based framework for developing CDSS. The key elements of our framework are (a) modeling the CPG knowledge and (b) executing the CPG knowledge. To model the entire working environment and knowledge essential to derive a CPG-based recommendation, we developed three unique ontologies as follows: (i) A CPG Ontology that models the computerized structure of the CPG. We model the CPG using the Guideline Element Model (GEM) [4] structure, and therefore our CPG ontology is based on the GEM DTD; (ii) A Domain Ontology, in OWL, that models the CPG's medical knowledge; and (iii) A Patient Ontology that models the patient in terms of various health information. We used Protégé [5] to develop all the ontologies.

Our CDSS is divided into two main modules, namely CPG Encoding Module and CPG Rule Authoring and Execution Module. The CPG Encoding Module is used to encode the text-based CPG into the CPG ontology and to annotate the decision variables and logic structures inherent within the CPG. Both the CPG Ontology and the Domain Ontology are used for CPG encoding. The CPG Rule Authoring and Execution Module is used to define the decision logic rules in a CPG and to execute them based on patient data. A novel feature of our CPG Execution Module is that it provides an automated justification trace of inferred recommendations. Figure 1 shows the architecture of our Semantic Web based CDSS.

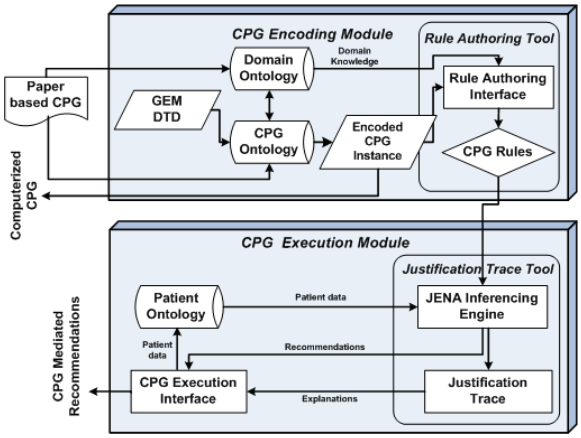

Figure 1- System Design of our CDSS

CPG Encoding Module

The CPG encoding module comprises two components: (a) a CPG representation formalism to convert the paper-based CPG into an electronic format; (b) a CPG ontology to model the structure of the CPG; and (c) a patient ontology to describe the characteristics of a patient. The *CPG Ontology* is based on the GEM DTD [4]. The *Patient Ontology* mirrors an Electronic Patient Record (EPR) and models a patient in terms of various health information and patient clinical situations.

CPG Rule Authoring and Execution Module

The CPG Rule Authoring and Execution module is designed to capture the CPG's clinical decision making logic in terms of logical rules—the logical rules were executed by a reasoning engine to derive CPG-based recommendations given a patient health record. To achieve the above functionality, we built three sub-modules namely, Rule Authoring Sub-Module, Execution Sub-Module and Justification Trace Sub-Module.

Rule Authoring Sub-Module uses the GEM encoded CPG to allow the user to identify the logical constructs within the CPG and define them as CPG (decision logic) rules using our CPG Rule Syntax. Upon completion of the rule authoring process, we apply a rule transformation algorithm to transform the CPG rules into the JENA syntax so that they can be executed the Execution Sub-Module that leverages the JENA inference engine [6].

Execution Sub-Module invokes the JENA inference engine to execute a CPG in order to infer recommendations based on patient profiles. We model instances from the Domain Ontology, CPG Ontology and Patient Ontology as RDF graphs, which serve as the knowledge base for JENA. JENA inference engine uses both the knowledge base and the CPG rule-set in a backward reasoning mode to infer CPG-mediated recommendations based on the given knowledge.

Justification Trace Sub-Module generates a justification trace of the rule execution to assist medical practitioners in understanding the logic behind the inferred recommendations. The justification derivation includes the linear representation of premises (facts) under which the JENA rules are satisfied and the conclusions based on those rules. The justification trace initiates with a derived patient recommendation (derived facts) from the JENA model (knowledge base) and generates facts which served as premises for deriving the patient recommendation, recursively.

The working of our CPG Authoring and Execution Module involves the following sequence of actions: (a) Input a text-based CPG and loads its pre-defined Domain Ontology and the Patient Ontology; (b) Encode the CPG in terms of the CPG Ontology and the Domain Ontology; (c) Specify the CPG (decision) rules. The CPG rules are transformed to JENA rule syntax and passed to the JENA reasoning system; (d) Execute the CPG based on a given patient instance to infer CPG-mediated recommendations; and (e) Justify the inferred recommendations through a justification tree.

Concluding remarks

The Semantic Web provides an interesting framework both for modeling and executing a CPG. Our Semantic Web based approach for CDSS development features the integration of multiple ontologies—we integrated two ontologies, each representing the form and function of a CPG—i.e. the *Domain Ontology* describing the CPG function and the *CPG Ontology* representing the CPG structure. We presented an intuitive CPG rule syntax that medical practitioners can use to write clinical decision rules from the CPG. We internally transformed the CPG rules into a complex rule syntax so that they can be executed via a inferencing engine to infer CPG based recommendations for a specific patient. Using our CDSS development approach we have developed two CDSS—i.e. (a) Breast Cancer Follow-up and (b) Imaging radiation protection—each based on a specific CPG.

The use of CPG in a CDSS not only provides an evidence based knowledge-base, but it relives CDSS developers from the perennial knowledge engineering problem. By design, CPG entail a decision logic that is structured in an algorithmic format that can be used to generate explicit symbolic clinical decision-support rules to suggest CPG-guided clinical recommendations. The knowledge management paradigm of the Semantic Web extends a logic-based framework to semantically model medical knowledge to provide a variety of knowledge-mediated services. Our CDSS approach is quite generic and can be extended to other medical problems.

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