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An Ontology-based Framework for Authoring and Executing Clinical Practice Guidelines for Clinical Decision Support Systems

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ABSTRACT

Clinical Practice Guidelines (CPG) are used by healthcare practitioners to standardise clinical practice and to provide evidence-based healthcare. However, due to the paper-based nature of CPG they are under-utilised at the point-of-care. In this paper we present our CPG-based Clinical Decision Support System (CDSS) development framework – CPG-EX. This offers the functionality to (i) *model* a CPG in a computer-interpretable format; and (ii) *execute* the modelled CPG based on patient data to deliver CPG-mediated recommendations in line with the patient's conditions. We have taken a Semantic Web approach and employ ontologies to model the CPG knowledge and proof engines to execute the CPG. CPG-EX comprises three different ontologies, namely CPG ontology, Domain ontology and Patient ontology, that interact at a semantic level to represent the entire disease-specific knowledge. We have developed a forward-chaining CPG execution engine that executes the set of CPG decision-rules using JENA (a semantic web framework for JAVA) reasoning to provide patient-specific CPG-mediated recommendations. We also implemented an automated justification tree generation module that provides the inference trace for the solution in order to assist practitioners in understanding the rationale for the proposed recommendations. A working prototype of our CPG-based CDSS was constructed using an international guideline for ordering radiological investigations. This was tested using a number of real-life clinical cases and both the recommendations and their justifications were validated by medical practitioners.

INTRODUCTION

Despite the proliferation of disease-specific Clinical Practice Guidelines (CPG) their utilisation in healthcare settings, especially at the point-of-care, is low[1]. Barriers to the poor utilisation of CPGs in the care delivery process are manifold and can be broadly categorised along three dimensions:

- **Operational issues** that concern the accessibility and usability of the paper-based CPGs in a timely manner at the point-of-care

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- **Behavioural issues** that involve the perception of health professionals towards the notion that CPGs tends to restrict or constrain their practices of patient care as per their judgment
- **Technical issues** that involve the development of practical computer-based methods to both model the disease-specific knowledge encapsulated within the CPG and execute the modelled CPG to provide CPG-mediated and patient-specific recommendations for healthcare professionals.

Lately, there has been an upsurge in efforts to optimise the use of CPGs, especially to support and standardise clinical decisions by healthcare professionals. A popular approach, at the operational and technical levels, towards the operationalisation of CPGs is to model them in a computer-interpretable format[2] and then incorporate the modelled CPGs within computer-based Clinical Decision Support Systems (CDSS)[3,4]. The disease-specific CDSS can then be deployed within a healthcare setting to:

- Execute the CPG at the point of care
- Guide healthcare practitioners to make evidence based decisions, actions and recommendations
- Standardise the delivery of care at a particular healthcare setting
- Collect all necessary and relevant patient data.

The development of CPG-based CDSS is a challenging activity as it involves (i) *Computerising* the paper-based CPG into a computer interpretable and executable format. This involves the modelling of the disease-specific knowledge inherent within a CPG and representing it in a semantically unambiguous formalism. The modelling exercise identifies the key concepts, the relationships between the concepts, the decisional elements and the consequences of these decisions, the data elements; (ii) *Specifying* a functional and executable workflow of the CPG that entails interactions between the different CPG elements and the corresponding actions and interventions; (iii) *Abstracting* the clinical decision logic inherent within a CPG in terms of medically salient and executable logic-based decision rules; (iv) *Executing* the computerised (or modelled) CPG based on both acquired and inferred patient information, to recommend patient-specific recommendations; and (v) *Justifying* the recommendations suggested by the CDSS to establish a degree of 'trust' in the output of the CDSS.

Typically, the development of CDSS involves a tedious and challenging knowledge engineering process that is geared towards the accumulation of disease-specific knowledge from expert health professionals. CPGs are a validated source of disease-specific knowledge that is based on best evidence and designed to assist clinical decision-making[5]. We propose that CPGs can serve as a validated, evidence-driven knowledge-base for CDSS (targeting a specific disease), thereby circumventing the knowledge engineering problem faced during the development of CDSS.

In this paper we present our CPG-based CDSS development framework, named CPG-EX, that offers the functionality to (i) *model* a CPG in a computer-interpretable format; and (ii) *execute* the modeled CPG based on patient data to deliver CPG-mediated recommendations in line with the patient's conditions. For CPG modeling we take a model-centric approach and represent the CPG knowledge using ontologies. For CPG execution we use logic-based reasoning to select the relevant CPG recommendations based on given patient data. We propose to leverage the Semantic Web approach to develop the CPG modeling and execution functionalities of CPG-EX. In this paper, we present a prototype of our CPG-EX framework to model and illustrate it in practice using an international guideline devised to aid clinicians in ordering radiology investigations.

FUNCTIONAL DESIGN OF CPG-EX

We believe that Semantic Web technology offers an interesting approach to both model and execute CPGs, and in turn develop CPG-based CDSS. The Semantic Web purports the semantic modelling and markup of knowledge in terms of formal definitions of domain concepts, explicit representation of relationships between concepts and any logical constraints between the concepts and relationships[6]. The semantically modelled knowledge can then be reasoned over using proof engines employing logic-based reasoning methods to infer 'trusted' solutions. Therefore, the design of CPG-EX is guided by Semantic Web technologies. The two main functions of CPG-EX are:

- *CPG modelling* that allows the transformation of a paper-based CPG into a formal representation that can be executed by computer-based CDSS
- *CPG execution* that allows operationalisation of the modelled CPG to derive patient-specific CPG-based recommendations

CPG Modelling

CPG modelling entails the representation of a paper-based CPG in terms of a formal and expressive knowledge-model that provides (i) an in-depth understanding of the clinical procedures, addressed by the guideline; and (ii) a precise and unambiguous description of the guideline. CPG modelling is pursued through two main approaches: (i) Document-Centric approach that entails the mark-up of the CPG, as per a document modelling language such as XML (extensible markup language), to generate a semi-formal model of the CPG. Guideline Element Model (GEM) is a prominent document-centric CPG mark-up language[7] that characterises the CPG using over 100 different mark-up tags; (ii) Model-Centric approach aims to generate a knowledge-model of the CPG, using a formal model description language, that entails classes, relationships between classes and decision rules that operate over instances of the classes and relationships. Model-based approaches provide a semantically rich expressivity of the CPG knowledge and are hence preferred whenever CPG execution is also desired. Typical model-based CPG representations include GLIF[8], GUIDE[9], and Proforma[10].

For CPG modelling we follow the model-centric approach and in line with the Semantic Web framework we model all the domain-specific knowledge using specialised ontologies. Ontology-based CPG modelling is pursued by other CPG representations formalisms such as GLIF[8], HELEN[3], SAGE[4], EON[11] and PROforma[10].

To capture the entire knowledge resources needed for the CDSS to provide CPG-based recommendations we developed three independent, yet conceptually and functionally interoperable, ontologies [12] using Protege[13]:

I. *CPG Ontology* that models the computerised structure of the CPG. The rationale for the CPG ontology is driven by our belief that to model the knowledge components of a CPG, we first need to understand (and model) the underlying knowledge representation structure of the CPG; hence the need to develop the CPG ontology. We model the CPG using the Guideline Element Model (GEM) structure, and therefore our CPG ontology is based on the GEM DTD (Document Type Definition)[7].

II. *Domain Ontology* that models the medical knowledge encapsulated within the CPG. The Domain Ontology represents both the concepts described in a CPG and the relationships between these concepts. The domain ontology not only standardises the domain concepts but also captures the decision logic inherent within the descriptions of the CPG and allows for writing logical decision-rules that relate patient/disease-specific conditions to corresponding actions/recommendations.

In this project, the domain ontology models the EU Radiation Protection 118 Referral Guideline for Imaging (RPG)[14]. Radiological investigations are routinely used by clinicians to aid patient diagnosis and management. However investigations are frequently ordered inappropriately and in addition the most suitable investigation is often not ordered e.g. a CT (Computed Tomography) scan may be ordered when a plain X-Ray is sufficient. The RPG provides guidance on whether a radiological investigation is likely to provide useful information for a specific clinical problem, the most suitable imaging modality to be used, the radiation dose associated with an individual imaging modality and the evidence for any recommendations given. The RPG Domain

Table 1. *Example of a Recommendation from EU Radiation Protection 118 – Referral Guideline for Imaging*

Clinical Problem	Investigation (Dosage)	Recommendation (Grade)	Comments
Headache: Chronic (A7)	XR skull, sinus, C spine (I) CT (II) or MRI (0)	Not indicated routinely (B)	Radiology of little use in the absence of focal signs or symptoms. Some exceptions for specialists or if evidence of raised intracranial pressure, posterior fossa or other signs

Ontology[15] is mainly divided into three categories of concepts: *Clinical Problems*, *Investigations* and *Recommendations*. All distinct clinical problems are represented as instances of respective clinical problem classes. These classes are arranged as sub-classes under the class Clinical Problem. Investigations are radiological procedures reported in the RPG and are represented similar to the Clinical Problems shown in Table 1. For a given clinical problem one or more investigations may be recommended. Recommendations are treatments based on investigations and clinical problems. Each recommendation is represented along with the evidence grade to support the recommendation. An *indicated* recommendation signifies that the investigation is likely to provide information that can contribute to the diagnosis and treatment of the patient. Conversely, a *not indicated routinely* recommendation emphasises that the investigation is extremely unlikely to provide any information that will assist the clinician in patient management

III. Patient Ontology that models the patient in terms of various health information parameters that may constitute the longitudinal medical record of the patient. The instances of the patient ontology determine the patient's health profile which is subsequently used to 'fire' the necessary decision-rules to yield patient-specific recommendations based on the CPG.

CPG Execution

CPG execution involves the selection of relevant and correct recommendations from the modelled CPG based on patient-data. CPG execution is pursed through a CPG execution engine that employs a variety of execution methods including: (i) logic-based reasoning; (ii) workflow engineering and (iii) graph based algorithms. In line with the Semantic Web framework we pursue CPG execution using proof-engines that employ logic-based reasoning over the knowledge represented through the various ontologies. We use the JENA reasoning engine for executing CPG decision logic on patient cases, and generating CPG-mediate recommendations.

ARCHITECTURE OF CPG-EX

Architecturally, CPG-EX is divided into two main modules:

- *CPG Encoding Module*
- *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 given patient clinical data. A novel feature of our CPG Execution Module is that it provides an automated justification trace of inferred recommendations. This is to inform practitioners, who

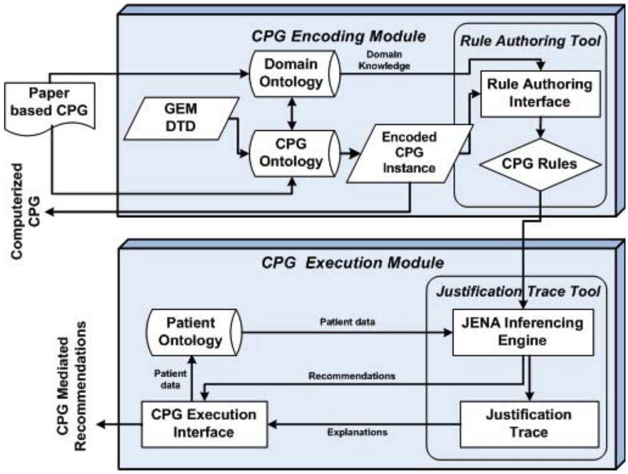

Figure 1. *System Design of our Clinical Decision Support System (CDSS)*
CPG= Clinical Practice Guideline, DTD= Document Type Definition, GEM =Guideline Element Model.

operate on the recommendations, the rationale for the recommendations. Figure 1 shows the architecture of our Semantic Web based CPG-EX.

CPG Encoding Module
The literature highlights a number of CPG encoding formalism that although are able to encode a CPG yet are unable to execute the encoded CPG in conjunction with a patient's case. Given that we aim to execute the CPG we developed a CPG encoding tool that transforms the CPG in an electronic format that can be executed by our CPG execution (reasoning based) engine. The CPG encoding module handles (a) CPG and Domain ontologies in order to model the CPG; and (b) Rule authoring to write decision rules capturing the CPG decision logic.

Domain Ontology
The Domain Ontology for the RPG[15] is mainly divided into three categories of concepts:

- Clinical Problems
- Investigations
- Recommendations

All distinct clinical problems are represented as instances of respective clinical problem classes. These classes are arranged as sub-classes under the class Clinical Problem. Investigations are radiological procedures in RPG and represented in RPG Domain Ontology similar to the Clinical Problems. For a given clinical problem, one or more investigations are recommended. Recommendations are treatments based on investigations and clinical problems. Each recommendation is represented

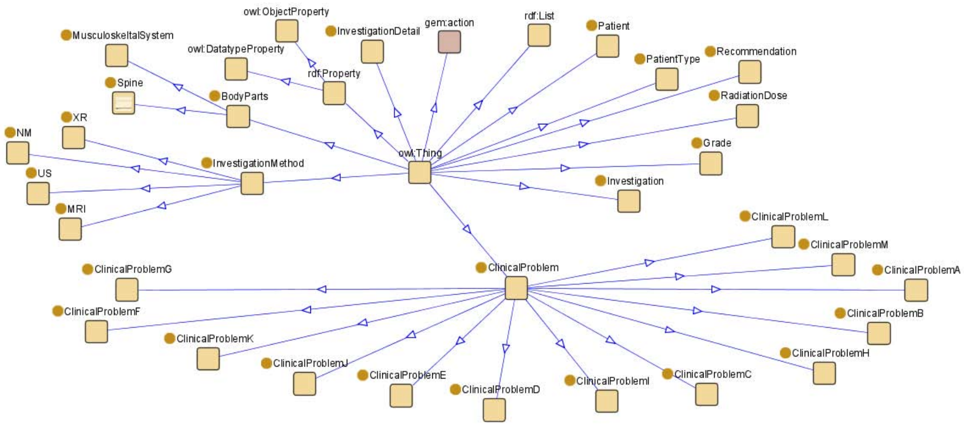

Figure 2. *Class Hierarchy in the RPG Ontology*

MRI = Magnetic Resonance Imaging. Nm = Nuclear Medicine, US = Ultrasound, XR= X-ray.

along with the grade of its evidence. An indicated recommendation is most likely to contribute to the diagnosis and treatment, while an investigation that is not routinely recommended emphasises that the investigation is unlikely to provide any information that will aid management. Figure 2 shows a fragment of the Domain Ontology.

CPG Ontology

We developed the *CPG Ontology* based on the GEM DTD[7] using an Ontology Editor Protégé[13]. The main CPG knowledge is represented in the *Knowledge Component*

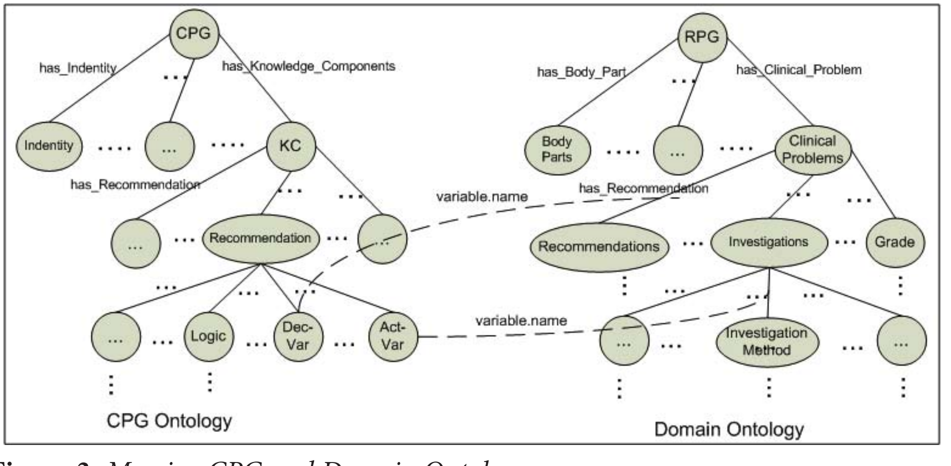

Figure 3. *Merging CPG and Domain Ontology*

CPG = Clinical Practice Guideline, KC= Knowledge Component, RPG = Radiology Practice Guideline class in the CPG Ontology as they describe the procedural, conditional or imperative knowledge. We defined the *Recommendation* class, within the knowledge component, to describe the recommended actions (see Figure 3). The recommendations are classified as being either imperative or conditional and represented as classes within the Recommendation class. Imperative recommendations found in the CPG are applicable to the entire eligible population. The conditional recommendations describe the clinical conditions/scenarios that demand specific actions. These clinical conditions and actions are represented by *decision.variable* and *action.variable* classes, respectively. The decision.variable and action.variable classes model the structure and type of a decision or action step in the CPG. We also made use of the property *logic* in conditional/imperative recommendations to define the decision logic of conditional/imperative recommendations based on the conditions for the various actions.

In our work, we merged two inter-related ontologies for representing CPG knowledge (Figure 3). The first ontology, i.e. the CPG Ontology, models the structural knowledge of the CPG, whereas the second ontology, Domain Ontology, represents the underling CPG knowledge in terms of medical concepts and their relationship. We established semantic mapping between the atomic entities of the candidate ontologies. Two such atomic entities were: (i) the *decision.variable* from the CPG Ontology; and (ii) a property from the Domain Ontology that explains that *decision.variable*. This mapping of the ontology nodes (a *decision.variable* instance and its related property in the Domain Ontology), in the two ontologies was achieved through a new property named *variable.name* that served as the bridge between the two ontologies. The property *variable.name* belongs to the *decision.variable* class, which represents the structure and type of a *decision.variable* in the encoded CPG, whereas the property *variable.name* merges each *decision.variable* instance with a

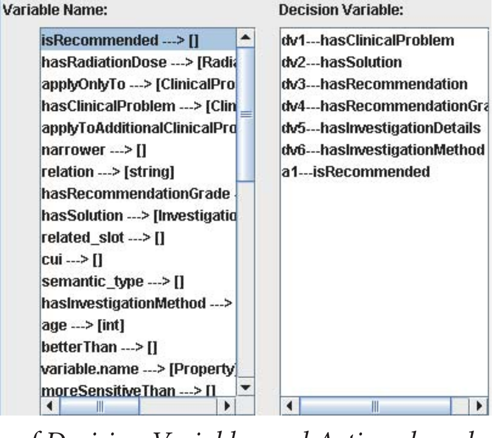

Figure 4. *Annotation of Decision Variables and Actions based on RPG Domain Ontology*

property from the Domain Ontology that describes the operational details of the *decision.variable*. Each *decision.variable* instance with a property *variable.name* is annotated with a property from the Domain Ontology.

Figure 4 demonstrates the semantic annotation of decision variables *dv1 ... dv6* and action variable *a1* to represent the inherent logic of the recommendation shown in Table 1. For example, decision variable *dv1* is annotated with a property *hasClinicalProblem* in the RPG Domain Ontology, where the property value describes various clinical problems in a RPG test-case. Similarly *dv2 … dv6* are annotated and describe one or more investigations along with their recommendations and recommendation grades based on clinical problems. Action variable *a1* is annotated with a property *isRecommended*, where the property value represents the list of investigations along with their methods and recommendations with along their grades.

Patient Ontology

The patient ontology mirrors an Electronic Patient Record and models a patient in terms of various health information and patient clinical situations. The patient ontology allowed us to generate standardised descriptions of a patient, which in turn serve as patient *instances* used to execute the decision logic of the CPG to derive CPG-mediated recommendations/actions.

Rule Authoring Sub-Module

Functionally, the Rule Authoring Sub-Module uses an encoded CPG (modelled by CPG Encoding module), and allows the user (a medical practitioners) to define the CPG's logical constructs as logic-based CPG rules using our 'simple' CPG Rule Syntax.

The Rule Authoring sub-module is designed to encapsulate the clinical decision making logic inherent within a CPG in terms of logical rules. Upon completion of the rule authoring process, we apply a rule transformation algorithm to transform

```
Logic := IF Decision_Variable_List THEN Action_Variable
       | Action_Variable
Decision_Variable_List := ⊄
                        | dv Rel Node, dv Rel Node, ….., dv Rel Node
Action_Variable := a Rel Node
Rel := < | <= | > | >= | =
Node  := ?             // variable
       | 'a literal'      // a plain string literal
       | Algebra
       | [dv1 dv2 ... dvn]
Algebra := Value
           | Value + Value
           | Value - Value
           | Value * Value
Value := dv | number     // dv must already been declared before
```

Figure 5. *CPG Rule Syntax*

```
Rule       :=   bare-rule .
            |   [ bare-rule ]
            |   [ ruleName : bare-rule ]
bare-rule :=    term, ... term -> hterm, ... hterm    // forward rule
            |   term, ... term <- term, ... term    // backward rule
hterm      :=   term
            |   [ bare-rule ]
term       :=   (node, node, node)           // triple pattern
            |   (node, node, functor)      // extended triple pattern
            |   builtin(node, ... node) //invoke procedural primitive
functor    :=   functorName(node, ... node)  // structured literal
node       :=   uri-ref                   // e.g. http://foo.com/eg
            |   prefix:localname         // e.g. rdf:type
            |   ?varname                 // variable
            |   'a literal'              // a plain string literal
            |   'lex'^^typeURI          // a typed literal
            |   number                   // e.g. 42 or 25.5
```

Figure 6. *JENA Rule Syntax*

the CPG rules into the JENA syntax so that they can be executed by the Execution Sub-Module that leverages the JENA inference engine[16]. The CPG and JENA rule syntax are discussed below.

Figure 5 shows the CPG syntax we have used to write rules in the *logic* element of CPG Ontology. Each rule is a *forward rule,* which has a list of decision variables (premises) and an action variable (conclusion) of the rule, followed by *IF* and *THEN*, respectively. In the decision variable list, each variable *dv* is an equality or inequality relation with either i) a variable, ii) a string, iii) a list of (already declared) decision variables or iv) an algebraic (binary) formula.

Figure 6 illustrates an informal description of the simplified JENA (text) rule syntax[16]. The "," separators are optional. The *functor* in an extended triple pattern is used to create and access structured literal values.

Example A: Below is an example of a rule written in JENA rule syntax. In it R is a rule written in CPG rule syntax to represent the recommendation shown in Table 1, where the annotations *dv1 – dv6* are used according to the concepts shown in Figure 4.

R = IF dv1=?, dv2=?,dv3=notIndicatedRoutinely, dv4=?, dv5=?, dv6=? THEN a1=[dv2 dv6 dv3 dv4]

Finally, the above CPG rule *R* is transformed into JENA syntax via rule transformation algorithm and shown as follows.

Transform (*R)* =

[conditional1: (?X2 rpg:hasClinicalProblem ?X1) , (?X1 rpg:hasSolution ?X3) , (?X3 rpg:hasRecommendation rpg:notIndicatedRoutinely) , (?X3 rpg:hasRecommendationGrade ?X4) , (?X3 rpg:hasInvestigationDetails ?X5) , (?X5 rpg:hasInvestigationMethod ?X6) -> (?X2 rpg:isRecommended List(?X3 ?X6 rpg:notIndicatedRoutinely ?X4))]

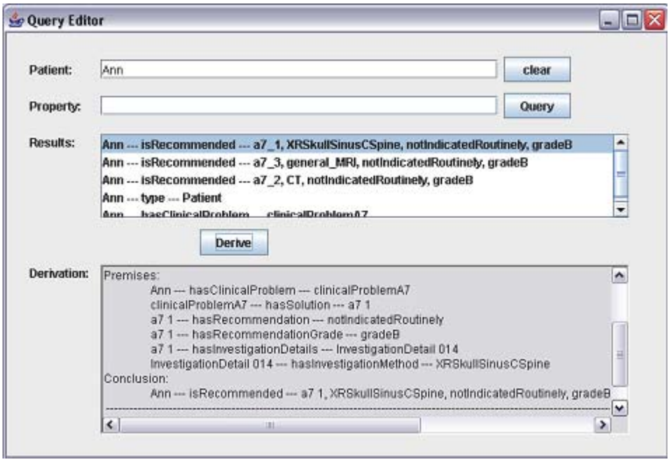

Figure 7. *Derivation Trace for Recommendations for a hypothetical patient Ann*

CPG Execution Module

The CPG Execution Module is designed to execute the CPG decision-rules, using patient data, to derive CPG-based recommendations. To achieve this functionality, we built two sub-modules namely, Execution Sub-Module and Justification Trace Sub-Module.

Execution Sub-Module

The Execution Sub-Module invokes the JENA inference engine[16] 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. The 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 patient scenario, encoded clinical knowledge in the Domain Ontology and CPG Ontology.

Justification Trace Sub-Module

The 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 process terminates, if all the premises are ground instances (known facts). Figure 7 shows the justification trace for the earlier presented RPG test-case.

CPG-EX IN ACTION

How the CPG-EX works in practice will now be briefly described. The sequence of actions are:

(i) A text-based CPG is input and pre-defined Domain Ontology and the Patient Ontology are loaded
(ii) The CPG is encoded in terms of the CPG Ontology and the Domain Ontology
(iii) The CPG rules are transformed to JENA rule syntax and passed to the JENA reasoning system
(iv) The execution engine reasons with the given patient instance and the CPG knowledge to infer CPG-mediated recommendations
(v) A justification trace of the inferred recommendations is generated to establish the physician's 'trust' in the recommendations offered by CPG-EX

The CPG-EX interface (Figure 8) is composed of three panels. On the left panel, the user can load a text-based CPG. The middle panel displays the CPG Ontology structure to enable the semantic annotation of the CPG using the CPG Ontology. The CPG Ontology panel further provides the following features to the user: (i) The *Duplicate Button* to duplicate selected tag/element in the CPG Ontology structure; (ii) The *Save Button* to save the CPG Ontology structure into a file in RDF/XML (Resource Description Framework/extensible markup) format; (iii) The *Run Button* to execute the CPG using a given patient instance; and (iv) The *Query Button* to generate a justification trace for a specific recommendation.

The right panel is used for assigning instances to each tag in the CPG Ontology. It consists of *Ontology Instances* text box, *Variable Name List* and a *Decision Variable List*. The Variable Name List displays all the properties stored in the Domain Ontology. The Variable Name List becomes active only when a *variable.name* tag (from CPG ontology) is selected. The user can select a variable name from the Variable Name List and assign it to a decision variable. The Decision Variable List shows the list of annotated decision variables associated with their variable names (as shown in Figure 4). The Query Button initiates a Query Window (as shown in Figure 7). The Query Window enables a user to query patient information and inferred recommendations. Furthermore, it allows the user to view the derivation trace for a specific inferred recommendation.

CPG Authoring involves extracting textual information of the text-based CPG (shown in the left panel of CPG-EX) and annotating them based on the classes and their properties in the CPG Ontology (shown in the middle panel of CPG-EX). The annotated text is assigned to the *Ontology Instance Text Box* (see right panel of CPG-EX) based on the classes/properties in the CPG Ontology. Rule Authoring is performed by defining decision rules in the logic tag of CPG ontology as follows:

Step 1: Select decision variables from the Decision Variable List, which represents the body (premises) of the rule and followed by *IF*;

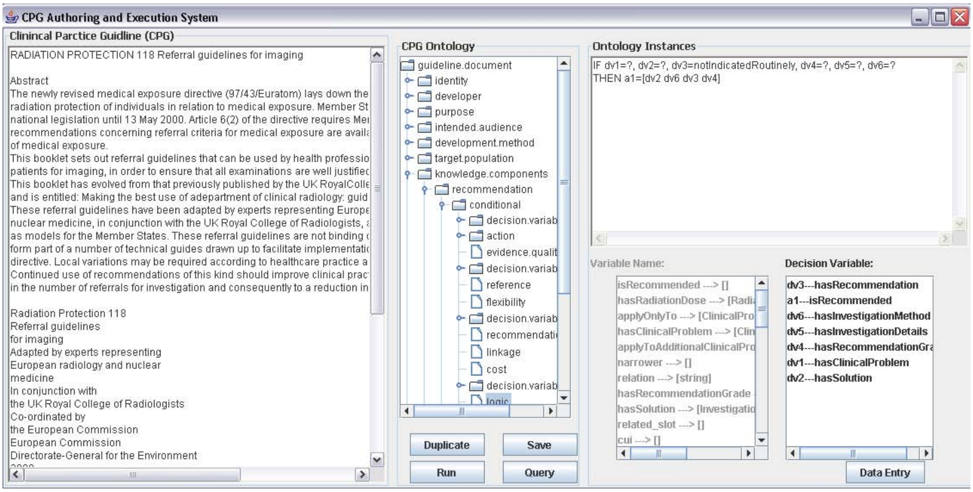

Figure 8. *The interface for the CPG-EX, showing the CPG text, CPG ontology and the CPG ontology instances*

Step 2: Select the action variable from the Decision Variable List, which represents the head (conclusion) of the rule and followed by *THEN*;

Step 3: For each decision variable and action variable in the rule, an equality/inequality relation can be defined with either a variable, a value, a binary algebraic formula, another decision variable or list of decision variables (see Example A and Figure 4).

The rule authoring steps for the CPG rule described in Example A can be traced and the outcome of each step is as follows:

Step # 1 & Step # 2: IF dv1, dv2, dv3, dv4, dv5, dv6 THEN a1

Step # 3: IF dv1=?, dv2=?,dv3=notIndicatedRoutinely, dv4=?, dv5=?, dv6=? THEN a1=[dv2 dv6 dv3 dv4]

Finally, we tested CPG-EX using the EU Radiation Protection 118 – Referral Guideline for Imaging. We used the pre-defined RPG Ontology[15], the Patient Ontology and the CPG Ontology to generate a series of CPG-mediated recommendations for the patient Ann (see Example A) as shown in Figure 7.

DISCUSSION

Computerisation of CPGs provides interesting opportunities to develop CDSS that provide evidence-guided recommendations. One advantage is that the CPG serves as a validated knowledge resource and allows CDSS developers to avoid the perennial knowledge engineering problem. By design, CPG follow 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 semantic web supports a logic-based framework that allows the semantic modelling of medical knowledge that can be used to provide a variety of knowledge-mediated services. In this paper, we have demonstrated the applicability of the semantic web to model CPG and leverage the CPG knowledge to develop ontology-based CDSS. We have presented a unique approach that features the integration of multiple ontologies to develop a CDSS. We demonstrated the integration of two ontologies, each representing the form and function of a CPG—the Domain Ontology describing the CPG function and the CPG Ontology representing the CPG structure. We have developed a simple CPG rule syntax that can be followed by medical practitioners to write clinical decision rules based on the logic inherent with a CPG. The CPG rules are then transformed into a much complex rule syntax to enable their execution in a powerful inferencing engine to infer recommendations and other information based on patient profiles. Our CDSS approach is quite generic and can be extended to other domains, provided the availability of a domain ontology. We tested our CPG-EX with a number of real-life clinical cases and both the recommendations and their justifications were validated by medical practitioners.

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