Research Topics in Computer-Interpretable Guidelines

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***Abstract*—This paper describes some lines of research of the Knowledge Engineering group at Universitat Jaume I, which investigates the construction of knowledge-based systems with an emphasis on practical applications. In particular, the paper presents a selection of research lines in the context of Computer-Interpretable Guidelines, a topic in which the group has specialised over the last years.**

***Index Terms*—Knowledge Engineering, Clinical Decision-Support Systems, Clinical Practice Guidelines, Computer-Interpretable Guidelines**

I. Introduction: Knowledge Engineering group at Universitat Jaume I

This paper describes the main research activities of the Knowledge Engineering (KE) group at Universitat Jaume I. The group investigates the construction of knowledge-based systems, with a special emphasis on practical applications in the field of Medicine. The KE group was founded in 2003 as a result of the consolidation of research activities initiated in collaboration with groups of other universities and research centers at European level, in the framework of the EU projects Protocure I and II [1], [2]. Among the medical applications, the KE group has been working for a long time on decision-support systems developed from Clinical Practice Guidelines. Another topic the KE group has payed attention to is the quality assurance of knowledge-based systems in general, and of clinical decision-support systems in particular. The group is also interested in knowledge representation in different fields (e.g. Medicine, Enterprise) and using different approaches (e.g. rule-based, ontologies, business process models).

II. Context: Computer-Interpretable Guidelines

In the field of Medicine, the KE group has specialised for some time now in Clinical Practice Guidelines (CPGs) and their counterpart in electronic format, the so-called Computer-Interpretable Guidelines (CIGs). According to the most recent definition, CPGs are "statements that include recommendations intended to optimize patient care that are informed by a systematic review of evidence and an assessment of the benefits and harms of alternative care options" [3]. Research has demonstrated that CPGs have the potential to improve the quality and outcomes of healthcare. To achieve these benefits, CPG recommendations should be made available to clinicians where and when they are needed [4]. Although this can be done using CPGs in text form, there is consensus that the most effective way is by converting them to a computer-interpretable format [5]. Thus, CIGs can be defined as electronic versions of CPG documents to be executed as part of decision-support systems.

CPGs are developed using methods that incorporate principles of *Evidence-Based Medicine* and consensus recommendations made by panels of experts, in the context of a specific clinical condition. As for their appearance and structure, CPGs are more or less lengthy documents describing neatly and in detail the recommended diagnostic and therapeutic interventions. CPGs often include tables summarising the key recommendations as well as flowcharts structuring the interventions, for ease of reference. The information provided in summary tables usually includes the class of recommendation, the level of evidence and the supporting literature reference(s). As an illustration of CPG documents, the reader is referred to e.g. the 2012 ESC guidelines for the diagnosis and treatment of acute and chronic heart failure [6].

CIGs have been an active topic in the Artificial Intelligence (AI) in Medicine field for over 20 years. The emergence of CIGs was motivated by the interest in making CPG recommendations available to clinicians in an easier and immediate way, as opposed to CPG documents. In a review work, Peleg identifies a total of 8 research themes in the CIG area [4]:

1) Representation languages
2) Acquisition and specification methodologies
3) Integration with Electronic Health Record (EHR) systems and with workflow systems
4) Verification & validation
5) Execution engines and other CIG-related tools
6) Exception and error handling
7) Maintenance
8) Sharing and reuse

The KE group has been involved in projects related to several of the above themes, concretely: verification & validation, acquisition and specification, sharing and reuse, and

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interoperability with EHR systems. Besides, the group has wide experience in CIG modelling using the PROforma representation language [7]. The following sections briefly describe a selection of the lines of research in which the group has been recently working, and the ongoing projects.

III. Research lines

A. Interoperability between CIG and EHR systems

1) Biomedical problem and its impact: To be effective, CIG systems must be integrated within clinical information systems. The interoperability with the EHR is the main obstacle hindering this integration. On the side of the EHR the main problem is the heterogeneity of clinical data sources, which may differ in used data models, schemas, naming conventions and level of detail. On the side of CIGs the issue is that used data is often at a level of abstraction much higher than that of the clinical data in the EHR (the so-called "impedance mismatch").

The potential impact of interoperability solutions providing access to EHR data from CIG systems can be huge for healthcare quality. Additionally, applications related to the secondary use of EHR data, e.g. in clinical research, can benefit from the same kind of solutions.

2) Research team(s): The KE group first worked in this line of research in collaboration with the Instituto de Aplicaciones de las Tecnologías de la Información y de las Comunicaciones Avanzadas (ITACA), Universitat Politècnica de València, and with clinical collaborators from the Oncological Institute at Hospital Provincial de Castellón [8], [9]. In a different case study, the same teams worked with the Departamento de Informática y Sistemas, Universidad de Murcia, and with clinical experts from the Fundación para la Formación e Investigación Sanitaria of Murcia [10].

3) Approach: The approach seeks to solve the interoperability problems between CIG and EHR systems using generic EHR architectures, concretely openEHR archetypes (standardised information models for specific clinical concepts). It can be summarised in the following steps (see also Figure 1):

- An appropriate integration archetype (or archetypes) must be designed for the data/concepts used in the CIG
- It must be ensured that the CIG includes references to this archetype in the parts where interactions with the EHR are required
- It must be ensured that the connection with the EHR through the integration archetype is feasible, which implies the definition of a series of mappings between the elements of the archetype and the data elements of the EHR

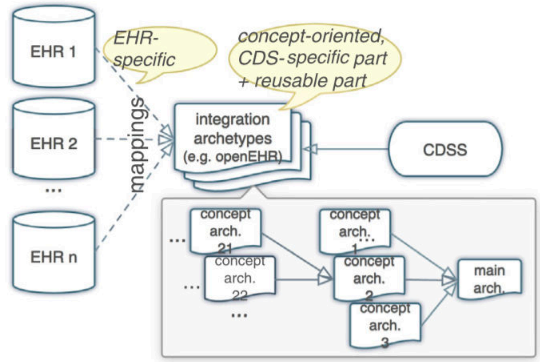

Fig. 1. Linking a CIG system to different EHR systems (extracted from Fig. 4 by Marcos *et al.* [9]).

B. Utilisation of workflow patterns in the acquisition of CIG procedural knowledge

1) Biomedical problem and its impact: CPGs are difficult to understand and formalise, because they are aimed at clinicians with specialised background knowledge. Moreover, CPGs are often composed of sets of procedures with logical gaps or contradictions. On the other hand, CIG representation languages provide a wide range of modelling constructs tailored to the different knowledge types found in CPGs (procedures, decision criteria, abstract concepts, etc.). This makes CIG languages poorly accessible and understandable for clinicians, in general. As result of these factors, CIG knowledge acquisition is usually carried out by joint teams made up of clinical and IT experts. This line of work seeks to facilitate the initial phases of knowledge acquisition of CIGs, by providing procedural patterns in a notation that can be further refined into different target CIG languages.

The use of patterns can reduce modelling time and enable stakeholders to communicate more precisely and in a less ambiguous way, with consequent benefits. Besides, a faster modelling can serve to translate CPG recommendations almost immediately to a CIG system that can be used at the point of care, which would have a positive impact on healthcare quality.

2) Research team(s): This work was carried out jointly by the KE group and the Institute of Software Technology & Interactive Systems, Vienna University of Technology [11].

3) Approach: The overall idea was to provide a series of procedural patterns in a notation (1) that is intuitive for clinicians and (2) that can be easily refined into different CIG languages. For the patterns, the so-called workflow control patterns, which are frequent task (and control) structures identified in the fields of workflow systems and business process modelling, were used. As implementation-independent notation for the description of the patterns, the BPMN notation was chosen. The most important result was the analysis of the adequacy of workflow control patterns for the representation of CPG procedural knowledge, and the identification of additional patterns, using a sample of CPG texts [11].

C. Transformation algorithms for the acquisition of CIG procedural knowledge

1) Biomedical problem and its impact: With a similar motivation (and potential impact) of that of the previous work, this line of research seeks to provide support for the refinement of CPG procedures from an initial specification in BPMN to an implementation in a CIG representation language, possibly different ones, in a (semi)automatic way (see Figure 2).

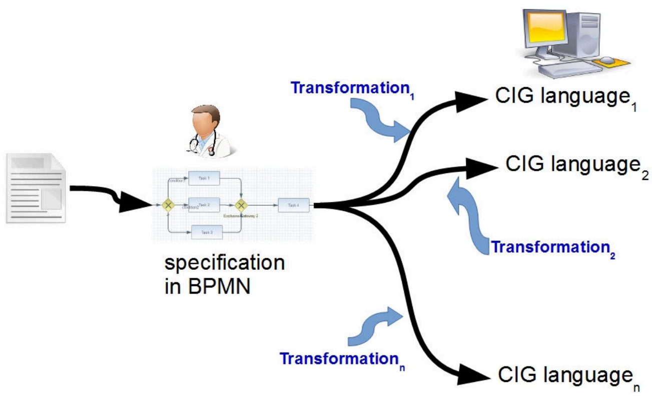

Fig. 2. Supporting the refinement of clinical process models into CIG models.

2) Research team(s): This work was carried out by the KE group, in collaboration with the Research Group on Artificial Intelligence, Universitat Rovira i Virgili, in some of its parts [12], [13].

3) Approach: As mentioned above, BPMN was used as notation for the specification of CIGs. As for the target CIG representation languages, PROforma [13] and SDA [12] were considered. In both cases the transformation algorithm follows a structure identification strategy, which focuses on certain structures of interest in the target language and identifies the source BPMN structures that correspond to the former ones. The algorithm works with source BPMN models/graphs which may contain sub-graphs, which typically occur in the case of CPGs.

IV. Ongoing work

Current research activities of the KE group are mainly dedicated to the CLIN-IK-LINKS project, *"Clinical Information and Knowledge Models for Linking Electronic Health Record and Clinical Decision Support Systems"*, funded by the Spanish Ministry of Economy and Competitiveness (reference TIN2014-53749-C2-1-R). The aim of this project is to enable interoperability of EHR and CDS systems in an effective and efficient way (research theme #3 in Peleg's review [4]). For this purpose, we investigate the combination and joint exploitation of the most advanced technologies for information, domain, and inference models. The project is carried out in collaboration with the Departamento de Informática y Sistemas, Universidad de Murcia, and with the company VeraTech for Health SL. Within this project, we are developing a platform for the configuration and execution of web services for clinical data transformation and reasoning processes [14]. The project also includes tasks addressing the execution of interoperable CIGs (combination of research themes #3 and #5 in Peleg's list).

Other ongoing research activities are related to CIG knowledge acquisition, and to CIG verification & validation (research themes #2 and #4 in Peleg's list). As a continuation of the work described in section III-C1, we are currently working on model transformation methods for CIGs using Model-Driven Engineering (MDE) tools. In connection with the verification & validation of CIGs, we are working on structural metrics that can be used to assess the quality of CIG model design (e.g. to detect certain maintainability issues), in line with what is done in the Software Engineering field.

V. Conclusions and outlook

The field of Medicine in general and the CPG/CIG area in particular present challenges and opportunities requiring new methods and techniques that can be addressed from an AI perspective. To take one example, the acquisition of knowledge of CPGs and the development of CIGs is usually tackled once the final CPG texts have been published. In this context, we are interested in the design of environments for knowledge management of CPGs, following the directives of medical organisations and taking into account the requirements for the further development of different types of support tools, CIGs or others.

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