COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE 112 (2013) 580–598

journal homepage: www.intl.elsevierhealth.com/journals/cmpb

Application of probabilistic and fuzzy cognitive approaches in semantic web framework for medical decision support

Elpiniki I. Papageorgiou[a,*], **Csaba Huszka**[b], **Jos De Roo**[b], **Nassim Douali**[c], **Marie-Christine Jaulent**[c], **Dirk Colaert**[b]

[a] Department of Computer Engineering, Technological Educational Institute of Central Greece, 3rd Km Old National Road Lamia-Athens, 35100 Lamia, Greece
[b] Agfa HealthCare NV, Moutstraat 100, B-9000 Gent, Belgium
[c] INSERM UMR_S 872, Eq 20, Medicine Faculty – Pierre and Marie Curie University (Paris 6), France

ARTICLE INFO

Article history:
Received 15 February 2012
Received in revised form
15 July 2013
Accepted 17 July 2013

Keywords:
Knowledge representation
Bayesian networks
Fuzzy cognitive maps
Decision support

ABSTRACT

This study aimed to focus on medical knowledge representation and reasoning using the probabilistic and fuzzy influence processes, implemented in the semantic web, for decision support tasks. Bayesian belief networks (BBNs) and fuzzy cognitive maps (FCMs), as dynamic influence graphs, were applied to handle the task of medical knowledge formalization for decision support. In order to perform reasoning on these knowledge models, a general purpose reasoning engine, EYE, with the necessary plug-ins was developed in the semantic web. The two formal approaches constitute the proposed decision support system (DSS) aiming to recognize the appropriate guidelines of a medical problem, and to propose easily understandable course of actions to guide the practitioners. The urinary tract infection (UTI) problem was selected as the proof-of-concept example to examine the proposed formalization techniques implemented in the semantic web. The medical guidelines for UTI treatment were formalized into BBN and FCM knowledge models. To assess the formal models' performance, 55 patient cases were extracted from a database and analyzed. The results showed that the suggested approaches formalized medical knowledge efficiently in the semantic web, and gave a front-end decision on antibiotics' suggestion for UTI.

1. Introduction

Extensive medical guidelines are produced by medical committees in order to support physician in his/her decision making process, helping him/her which relevant therapy is proper to be applied to patient [1–3]. However because of the sheer volume and the rigid structure of such guidelines, it is very difficult for the physician to apply and strictly follow the workflow presented by such guidelines. It seems to be a challenge for decision support to create a computerized system that dynamically guides the physician through the workflow [4]. Besides, the need to adjust general guidelines to individual circumstances is becoming the future goal of medical research.

* *Corresponding author*. Tel.: +30 2231060255; fax: +30 2231093345.
E-mail addresses: epapageorgiou@teilam.gr (E.I. Papageorgiou), jos.deroo@agfa.com (C. Huszka), csaba.huszka@agfa.com (J. De Roo), nassim.douali@crc.jussieu.fr (N. Douali), dirk.colaert@agfa.com (D. Colaert).
0169-2607/$ – see front matter
http://dx.doi.org/10.1016/j.cmpb.2013.07.008

In our approach, we follow these principles by trying to model medical knowledge, while keeping its main characteristics of uncertainty in focus. From this necessity, we decide to use dynamic solutions (such as dynamic networks) rather than just follow the classical way of medical knowledge modeling with static structures such as decision trees. So, BBNs and FCMs, because of their natural dynamic properties, are selected to support modeling, knowledge integration of clinical practice guidelines and decision support in medicine.

Previous studies have shown that probabilistic networks and fuzzy logic based methodologies have been proposed for medical decision support [5–11]. Leibovici et al. tried to model bacterial infections by suggesting a causal probabilistic network for optimal treatment of these infections [5]. Kao and Li also proposed an optimal treatment model for bacterial infections with fuzzy information using influence diagrams [8]. These diagrams were used simultaneously for diagnostic reasoning and treatment planning, too [7,9,10]. On the other hand, FCM methodologies have been proved to be efficient medical approaches as far as decision-making and support are concerned [12–17].

In a previous study, Cheah and co-workers presented the advantages and limitations of FCMs and BBNs and proposed an FCM-BBN conversion process. Based on the comparison results, FCM has been shown to be simpler, more intuitive, more high-level and user-friendly, whereas BBN has been shown to be more expressive, powerful, formal and sound mathematically [18]. In their suggested methodology, BBN were constructed by FCM that acquires knowledge from domain experts. The results showed that the BBN constructed by FCM is similar, based on reasoning results, to the BBN constructed directly by specifying conditional probability tables of BBNs. The main potential of the cognitive map to Bayesian network conversion process is the reduction of knowledge acquisition time and effort [18,19].

The undertaken work is focused on knowledge representation and reasoning, using probabilistic and cognitive processes, implemented in semantic web framework, because an explicit knowledge with a clear semantic meaning is needed. The Notation3 [20.21] was selected as an open and semantic web language to implement the directed influence networks.

The primary objectives of the paper is to point out the construction, reasoning and usefulness of BBNs and FCMs implemented in N3 for medical knowledge modeling and decision support. A general purpose EulerSharp reasoning engine, (EYE [22]) and the necessary plug-ins which can perform the reasoning on these knowledge models were also developed to accomplish the objectives of this study. Both techniques were formalized in semantic web for modeling and reasoning processes, providing the advantages and disadvantages of each one for medical treatment suggestions, thus to drive our future work in a technical unification of them, to overcome the limitations of each one, and proposing a more efficient DSS method.

Our effort is focused on a decision support system (DSS), moving beyond classical clinical pathways. The application of probabilistic and fuzzy cognitive networks for DSS creates a path dynamically, based on the current and constantly changing clinical information of the patient, the environment and the guidelines.

The problem of urinary tract infection (UTI) in adult community, which is a common medical problem, was selected as a proof-of-concept example to examine the proposed approach. The problem of handling imprecision and uncertainty in the assignment of UTI treatment was tackled through the combined use of dynamic graphs and semantic web approaches. The therapy theories for UTI were formalized using the BBN and FCM formalisms and used by the DSS. The inference was performed by the general purpose First Order Logic reasoning engine EYE, which is released as open source software. The simulations of 55 real patients that were performed using the system implementation provide therapy recommendations for these patients. The results of both approaches emerged high accuracy for the examined cases as they were in fully agreement with the treatment guidelines. A comparative analysis between both proposed approaches was accomplished. The validation results showed that using probabilistic networks and fuzzy cognitive maps in semantic web framework is reliable and efficient for decision support tasks.

Seven more sections are included in this paper. Section 2 provides the main aspects of modeling medical knowledge using probabilistic and fuzzy cognitive maps, formalized in semantic web. Section 3 provides BBN and FCM built-ins and plug-ins in notation3. Section 4 describes the decision support theories in N3, whereas in Section 5 the development of DSS for UTI treatment is described. Validation analysis and comparison on the proof-of-concept decision support problem are both presented in Section 6, whereas the discussion and deriving conclusions are summarized in the last two sections.

2. Modeling medical knowledge

Medical knowledge modeling starts with a standard procedure, by defining the problem to be modeled (as a domain) and all variables that represent it. Such modeling follows a goal-driven, need-oriented approach, meaning that each model will serve a certain purpose and is custom-made. Two basic models can be identified for the medical DSS. These are the diagnostic and therapeutic model.

Medical knowledge can be represented in several ways. Perhaps, the most commonly used is the clinical pathway (clinical guideline). It is quite easy and handy for the physician to use such guideline, because it provides a simple decision tree algorithm that could be followed in the diagnostic or therapeutic path to aid conclusions. The decision tree approach has some main limitations/disadvantages such as the possibility of duplication with the same sub-tree on different paths, the limitation to one output per attribute, and the inability to represent tests that refer to two or more different objects. Even a small change in input data can occasionally cause large changes in the decision tree. The absence of dynamicity in decision trees makes them a second choice for decision support tasks in the field of medicine.

Moreover, many guidelines are not so easy to be used in daily practice, due to the complexity of clinical cases and guideline itself, as physicians have to consider a large number of small chunks of information spread over large text