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Fuzzy theory approach for temporal model-based diagnosis: An application to medical domains

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Summary

Objective: The aim of this work is to provide a theoretical framework which is sufficiently expressive to describe temporal evolution of diseases, and also to propose a diagnostic process for building explanations of patient's observed temporal evolution based on these disease descriptions.
Background: Model-based diagnosis (MBD) tackles the problem of troubleshooting systems by starting from a description of their structure and function (or behaviour). It is in this area where the use of deep causal models, as part of MBD systems, has shown its greater efficiency over classical rule based systems. From its beginnings, the temporal dimension was considered as an important component in MBD, since it makes it possible to define the dynamic behaviour. Several approaches have been proposed to represent time in MBD, enabling the representation of temporal concepts and relations, as well as the use of temporal reasoning mechanisms.
Methodology: We first propose a temporal behavioural model (TBM), which allows us to capture the dynamics underlying temporal evolution of diseases and to include contextual information. Contextual information is required to model how contextual factors change the temporal evolution of diseases. The temporal component is modelled by fuzzy temporal constraints networks (FTCN), which makes the representation of quantitative and qualitative imprecise temporal information possible. We also provide a diagnostic process, which is based on a temporal adaptation of classical cover and differentiate method.
Results: The TBM and diagnostic process proposed provides a unique framework which addresses three problems not dealt with together so far: (a) the inclusion of contextual information, (b) the expressivity of the solution provided, and (c) the evaluation of the diagnostic hypotheses. This proposal demonstrates that the FTCN

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formalism provides mechanisms sufficiently expressive to cope with the intrinsic imprecision in the description of diseases' temporal evolution. The explanation generated provides the user with a complete picture of the temporal evolution of diseases and its causal links, thus allowing the appearance of repeated instances of the same disease through time. Mechanisms are provided which evaluate the credibility of alternative hypotheses, based on possibility theory. A prototype is presented along with a knowledge acquisition tool that guides medical experts in the model building process.
Conclusions: In this paper, we propose a model that tightly couples methods from MBD area with constraint-based temporal reasoning techniques. The proposed model allows us to model complex contextual relationships in a compact way as well as providing solutions expressive enough to be used for decision support purposes. The solution provided conforms a causal network entailing the abnormal observations, including pathophysiological and etiological states. Furthermore, different instances of the same diagnostic hypotheses, located at different time instants, are also possible in the final solution. Finally, we provide an analysis of related and future works.

1. Introduction

Since the early days of Artificial Intelligence, the design of intelligent systems for medical diagnosis has been one of the most prolific areas. Deep causal models have been pioneered in this area, showing the advantages of modelling domain knowledge in this way and in contrast to the classical rule-based systems [1]. During the last decade, research in this area has paid increasing attention to the use of deep causal models, especially if they are considered as integrated in model-based diagnostic (MBD) techniques, which have proved their efficiency in the design of intelligent diagnostic systems [2].

MBD tackles the problem of troubleshooting systems by starting from a description of their structure and function (or behaviour) [3]. From its beginning, the temporal dimension was considered as an important component in MBD (especially in medical domains if it is considered as part of patient monitoring), since it makes the definition of the dynamic behaviour possible. This is especially important in Artificial Intelligence in Medicine which has shifted its research interest from static consultation systems to dynamic ones, which capture the patient's evolution over time better [4,5]. It is in the Intensive Care Unit (ICU) where temporal dimension is the key element in diangosis. However, the inclusion of the temporal dimension in MBD has increased the complexity of the diagnostic process. Different formalisms have been proposed to represent time in MBD, ranging from totally qualitative approaches [6,7], based on Allen's interval logic [8], to totally quantitative approaches [5,9—11]. An exhaustive review of temporal MBD (TMBD) can be seen in [3], together with a general characterization for TMBD at knowledge level.

Despite the intense research activity in this area, there are three issues that have still not been analysed together: (a) the interaction between contextual knowledge and behavioural models, (b) evaluation of hypotheses, and (c) the structure of the explanation provided. Contextual knowledge can be defined as knowledge, which plays the role of premises instead of consequences of some hypotheses. In most MBD proposals, contextual knowledge is modelled as preconditions in the antecedents of temporal formulas defining causal relations between diseases and their associated findings [3,12]. However, there are situations in which a certain combination of contextual factors may modify the normal evolution of a disease. These modifications may range from a simple change in the causal relations between the diseases and a given finding, to removing a causal relation or adding a new one. This kind of contextual knowledge is not easy to model using the classical TMBD approaches. The other two issues are related to the capacity of the diagnostic process to be integrated in the decision making process. In this sense, the solution must include all the information required for justification purposes and not be limited to the presentation of a set of hypotheses. It would be also desirable to include a hypothesis evaluation process which takes into account medical information, such as that provided by evidence-based medicine (EBM) [13].

In this paper, a TMBD approach, which provides solutions to the issues outlined above, is proposed. The proposed model is based on the definition of temporal patterns. These temporal patterns cap-