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Ontology-driven diagnostic modeling

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Abstract

The paper presents a concept of diagnostic network models. This class of models consists of statement networks in which nodes represent statements concerning an object. The advantages of such models were enumerated and, in particular, their usefulness in collaborative research on knowledge acquisition was emphasized. Furthermore, not only the significance of dictionaries of statements contents, but also the purposefulness of supporting the development process of the models in question through definition of ontology referring to the studied objects was discussed.

Keywords: Statement network; Knowledge representation

1 Introduction

The purpose of diagnostic studies is to formulate diagnoses describing the current condition of an examined object. A number of classes of the studied objects may be considered. The classes may include technical objects (e.g., machines), processes (e.g., chemical ones), systems (e.g. social ones), medical examination objects, and many more. The research area that deals with methods and techniques of diagnostic studies is referred to as diagnostics. To simplify further considerations, this paper will focus on technical diagnostics only in which a technical condition of an object is understood as a general 'health condition' of this

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object with its current defects, wear, fatigue failures, etc.

Diagnoses are formulated based on the available data concerning the design and operation of an object as well as its history, where such data may be inaccurate and/or incomplete. An operating object is observed via signals, and sets of values of signal features make up observation results. There exist diverse inference methods concerning the object condition that base on quantitative and/or qualitative models of the object [1]. These models may be analytical or heuristic ones representing experts' knowledge. In order to give a diagnosis, values of selected features of observed signals may be compared with values determined on the basis of models.

Diagnostic symptom models are a particular class of models. They are based on sets of characteristic values of signal features occurring simultaneously with specific conditions of an object. These values constitute the symptoms of the object condition. The purpose of the symptom models is to set up classification tasks.

While evaluating the diagnostic models it should be emphasized that, in a number of applications, they may not be considered as cause-and-effect models, because as a rule only limited sets of signals may be observed as well as the complete set of potential causes is not known. In general this allows only for development of associative models proving co-occurrence of selected causes and their observable resulting effects.

The literature concerning diagnostic methods is broad, and for a considerable number of described methods, examples of their efficient applications are known [1]. However, when assessing the current knowledge level, one needs to consider the insufficient number of acknowledged solutions allowing for acquisition and aggregation of knowledge originating from various sources, particularly, the knowledge obtained independently from a variety of experts. This paper aims at presenting a set of selected actions that, eventually, will facilitate aggregation and accumulation of diagnostic knowledge.

2 Network model

A concept of network is applied in numerous fields of models development. Network models presented in a form of graphs consisting of nodes and branches spread over them are an interesting class of diagnostic models. In a set of nodes, one may distinguish, among others, between input and output nodes. The values of input nodes of a model representing information about an object as well as about its operation and condition are available as a result of observation of the object. They are the input data for inference process concerning the condition of the object. The values of the output nodes, on the other hand, represent data on the condition of the object as a result of inference process, i.e., the process of formulating a diagnosis.

Branches of a model represent domain and diagnostic knowledge. They allow for propagation of changes in the values of network nodes. Changes in the values of input nodes result in changes in the values of output nodes. One observes a variety of diagnostic network models. Models already in use manifest different manners of defining and interpreting nodes and branches, where the Bayesian models may be considered to be the most popular.

Models with nodes representing statements constitute an interesting class of network models in which a statement becomes information on acknowledgment of an expression stating the observed facts or representing an opinion. A statement s may be presented in a form of a pair

$$s = \langle\, c(s), b(s)\, \rangle, \tag{1}$$

where $c(s)$ is a statement content, and $b(s)$ is a statement value. The statement content is a logical sentence, i.e., a declarative expression which is always either true or false. The statement value defines, e.g., a degree of belief in truthfulness of the statement content. Numerous interpretations of this value are possible [2], which result in different definitions of branches in the diagnostic model. The so-called intuitionistic statement networks [3] offer a considerable number of practical applications. In these networks, a value $b(s)$ of each statement s is an ordered pair that consists of a degree of belief in truthfulness of a statement content $p(s)$, and a degree of belief in lack of truthfulness of a statement content $n(s)$

$$b(s) = \langle\, p(s), n(s)\, \rangle \quad \text{for} \quad p(s), n(s) \in [\,0\,,1\,]\,. \tag{2}$$

The values $p(s)$ and $n(s)$ are also referred to as evaluations of positive and negative information. Within the theory of intuitionistic fuzzy sets [4] it is assumed that

$$p(s) + n(s) \in [\,0\,,1\,]\,, \tag{3}$$

and it is not assumed that

$$p(s) + n(s) = 1.0\,. \tag{4}$$

Considering (2), the value $b(s)$ of an unrecognized statement s, i.e., a value of the statement not recognized as true or false, takes the following form

$$b(s) = \langle\, 0, 0\, \rangle\,. \tag{5}$$

This, among others, allows to record information on the statement value being unknown. Furthermore, condition (3) enables identification of inconsistent results of inference process.

Within such a network, expert knowledge is represented in a form of necessary and sufficient conditions which are introduced as inequalities between statement values. These inequalities are assigned to given directed branches of the network. The role of the network is to iteratively follow the state of its equilibrium. The network itself may be used as a dynamic one. The main advantage offered by the intuitionistic statement network is dynamic assessment of a degree of conditional inconsistency of statement values in the network, which facilitates identification of incorrect data and/or mistakes made at the stage of network development. For more comprehensive discussion concerning the structure and role of intuitionistic statement networks with both their advantages and disadvantages look into [3,5].

3 Development of diagnostic model

An increasing number of cases where application of diagnostic techniques is required resulted in a growing interest in methods of development of diagnostic models. At the initial stage of developing a diagnostic model, one needs to consider its complexity. Simple models may be developed as heuristic models which base on knowledge of a single author. In a number of applications, however, one needs to introduce extended models basing on knowledge derived from various knowledge domains, thus developing them by a single author becomes a hard or even infeasible task.

Within a network model, one observes a possibility to consider a complete set of its branches as a family of subsets of branches which, while being spread over selected corresponding nodes of the model, constitute partial diagnostic models. It is not required that these subsets of branches be disjunctive. This approach makes it possible to independently develop partial models by a number of authors and, subsequently, to merge the obtained models into one main model. It allows for dividing one complex task of model development into a set of tasks that can be realized independently by a number of experts. This, in turn, denotes that there is no need to organize collaborative activities of one team of these experts, which otherwise would be indispensable in the case of development of one complete complex model. What is more, development of simple partial models reduces the range of required verification studies, and facilitates, to a large extent, not only the processes of their validation, but also allows to develop numerous versions of partial models for the purpose of tests, comparisons and potential aggregation.

Aggregation of partial models may become difficult for some categories of networks which require negotiation of these models. This difficulty does not occur in intuitionistic statement networks which allow for merging complex networks as a result of concurrent application of a set of independently constructed subnetworks. Of course merging of such partial models is reasonable only if their authors use a shared set of nodes.

4 Dictionary of statement contents

It is assumed that research related to development of diagnostic models for a defined class of objects is conducted independently by various research teams that apply intuitionistic statement networks. To ensure that the teams' research results may be compiled, the models in question should use the same shared sets of nodes. This implies that, at the initial stage of research, the mentioned teams should define the commonly shared set of statement contents which may be assigned to nodes. Such a set shall be further referred to as a dictionary of statements contents.

During development of a network model with nodes representing statement (1), statement contents $c(s)$ may include simple declarative sentences. In complex models a use of such simple sentences leads to a considerable number of nodes and, as a result, to a large number of branches representing the model. An alternative approach consists in considering a model in which statements contents occur in a form of *the object x belongs to the class M_i*, where x denotes the studied object or its fragment. The class M_i is referred to as a class of patterns of these objects. It determines a group of objects that operate in specific conditions, are in a defined technical condition, and are sources of observed signals. This is equivalent to studying statements contents occurring in a form of complex logical expressions. As a result, it allows for a considerable reduction of the number of nodes and branches of a model. Such an approach requires the application of supporting tools, particularly when it involves a number of research teams.

5 Ontology

Research to be carried out by a number of teams requires particular agreement on the terminology to be used. It needs to be emphasized that assuming a shared set of concepts and their corresponding terms is not sufficient. It is essential to agree on and define the meanings of these concepts because they may be subject to numerous interpretations. The process of defining a meaning may be realized as a process of ontology designing.

The term 'ontology' has various meanings of itself. For hundreds of years it has been considered one of the fundamental areas of philosophy. In the last decades, this term has been used in computer science as formal naming and definition of entities of a given domain [6, 7]. Ontology defines a coherent set of concepts of a selected knowledge domain as well as relations occurring between these concepts. Complex concepts are defined based on simple ones. The concepts determined in this manner are assigned to their terms whose set constitutes vocabulary belonging to the considered domain. Among the many languages facilitating recording of an ontology one needs to emphasize the OWL language family (Web Ontology Language). The OWL language (published in 2004) and its extended version OWL 2 (published in 2009) are declarative languages whose specifications have been confirmed as a standard by W3C (World Wide Consortium) [8]. The basic elements that make up a description of ontology in the OWL languages include individuals, properties, classes and annotations.

Individuals represent real and abstract objects of the studied domain. They are interpreted as instances of classes and, furthermore, may be defined independently of the classes.

Properties are binary relations. One distinguishes between object properties connecting pairs of individuals, and data type properties connecting individuals with data values. These relations require that their domains and their ranges be determined. Properties may be both transitive and symmetric, and may be accompanied by reverse properties. The nature of properties may be manifested by the suffixes of their terms. The most frequent suffixes include *has* and *is*. The properties approximate slots known from languages representing frames-based knowledge.

Classes represent concepts of the studied domain. They are organized into hierarchical structures in which an *is a* expression constitutes the most frequent attribute relation. In these structures, a class occurs as a generalization of its subordinate classes. For example, a class *Frictional-contact clutch* is a generalization of its subordinate class *Axial clutch*, where *Axial clutch* is a generalization of its subordinate classes *Disk clutch* and *Cone clutch*. There exists an *is a* relation between these classes. What is more, an inheritance of properties from superior classes comes into practice. Classes are interpreted as sets of individuals with shared properties. It is not assumed that classes are disjunctive, i.e., selected individuals may simultaneously belong to a number of classes. OWL allows for considering complex classes determined as intersections, unions as well as complements of other classes. Complex classes may occur in all of the places where simple classes may be observed as well. This, in turn, allows for definition of complex concepts.

Annotations include comments, remarks, links to sources, etc. They may be assigned to all elements of ontology description in a form of explanations. Annotations are not obligatory elements of the ontology description and bear no formal meaning, thus, they are omitted in inference process. Nonetheless, their frequent application is highly recommended.

6 Design of ontology

A set $\{M_i\}$ of classes of patterns which is required for a design of the above described dictionary of statements may be studied as a fragment of ontology that defines a complete hierarchical set of such classes. Ontology is a set of granules of knowledge that occur in a form of definitions concerning classes, properties, individuals and annotations. These definitions are further referred to as axioms in the OWL 2 language. The ontology assumes that all of its axioms are true. It is important to emphasize that this assumption concerns the process of inferring on the meanings of concepts specified by ontology only. In general this assumption is not valid, though, for a diagnostic model that applies statements obtained by means of ontology.

In order to design ontology, one needs adequate tools. Ontology editors are the basic tools. A frequently used ontology editor Protégé [9] was developed by the Stanford Center for Biomedical Informatics Research at the Stanford University School of Medicine as a free software. Also, tools in a form of reasoners that cooperate with editors are of great practical importance as well. They facilitate a formal validation of ontology under design, the validation consisting in verification of coherence of defined concepts, i.e., verification of coherence of ontology classes.

The studied ontology should include classes allowing for absorption of dictionaries of statements for the needs of diagnostic network models. Statements included in these dictionaries should facilitate picking up an object type, its operation conditions and object condition. It is often assumed that there is one main class for all remaining classes within a hierarchical structure of classes of ontology under construction. For example, in the Protégé editor, this main class is referred to as *Thing*. In the studied ontology, the *Thing* class should include, among other things, direct subclasses such as *Technical object*, *Conditions of operation*, *Technical condition*, *Defect*, *Wear*, *Signal*, *Symptom*, *Operation event*, *Operation history*. A set of these classes may be subject to extension or reduction depending on the type of the considered technical object as well as the needs of the developed diagnostic model.

7 Summary

The arguments concerning the advantages of diagnostic network models has been put forward. The use of intuitionistic statement networks as well as application of an adequate dictionary of statements contents allow for aggregation of independently developed individual diagnostic models. This, in turn, facilitates knowledge acquisition as a result of collaborative research. It was pointed out that development of a dictionary of statements may be supported by the application of tools devised for construction of ontology.

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References

[1] Korbicz J., Koscielny M., Kowalczuk Z., Cholewa W. (Eds.): *Fault Diagnosis: Models, Artificial Intelligence, Applications*. Springer-Verlag, Berlin Heidelberg 2004.

[2] Kacprzyk J., Pedrycz W., Eds.: *Handbook of Computational Intelligence*. Springer-Verlag, Berlin Heidelberg 2015.

[3] Cholewa W.: *Dynamical statement network*. In: Applied Non-Linear Dynamical Systems (J. Awrejcewicz, Ed.), Springer Proc. Mathematics Stat. **93**(2014), 351–361.

[4] Atanassov K.T.: *On Intuitionistic Fuzzy Sets Theory*. Springer Verlag, 2012.

[5] Cholewa W.: *Gradual forgetting operator in intuitionistic networks*. In: Proc. 7th IEEE Int. Conf. Intelligent Systems IS'2014, Springer Advances in Intelligent Systems and Computing **322**(2015), 613–620.

[6] Staab S., Studer R. (Eds.): *Handbook on Ontologies*. Springer-Verlag, Berlin Heidelberg 2009.

[7] Suarez-Figueroa M.C., Gomez-Perez A., Motta E., Gangemi A. (Eds.): *Ontology Engineering in a NeNetwork World*. Springer-Verlag, Berlin Heidelberg 2012.

[8] *OWL 2 Web Ontology Language*. Document Overview. W3C Recommendation. http://www.w3.org/TR/owl2-overview/ (accessed: 3 Nov. 2006).

[9] *Protégé. A free, open-source ontology editor and framework for building intelligent systems.* http://protege.stanford.edu (accessed: 14 Oct. 2016).