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Ontological semantic inference based on cognitive map

Heejung Lee [a], Soon Jae Kwon [b,*]

[a] Department of Applied Systems, Hanyang University, Seoul 133-791, Republic of Korea
[b] Department of Business Administration, Daegu University, Kyong San 712-714, Republic of Korea

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ABSTRACT

Cognitive map is a well-known approach to model the dynamics of qualitative systems, and has been studied and used in various fields, such as psychology, education, engineering, and management. Although the validity and usefulness of cognitive maps has been proven in many fields, and a considerable number of cognitive maps have been built during the last decade, cognitive map construction and use was just one-off event. In addition, the high degree of cognitive complexities in large cognitive maps makes it difficult for others to understand and exploit the pre-defined cognitive map in another similar domain problem.

In this paper, an ontological semantic inference method, which combines the cognitive map and semantic influence, is proposed. This approach reuses a pre-defined cognitive map and provides an ontological semantic inference mechanism in decision making environments by reducing the degree of cognitive complexities in a large cognitive map.

1. Introduction

The integration of research on cause and effect inference from cognitive science, econometrics, epidemiology, philosophy, and statistics is critical in the complex decision making process, since causality is the most basic way of knowing if one state of affairs causes another (Meier, 2001). Causality helps a decision maker to predict the future, achieve goals based on actions, and explain why some phenomena have happened. In most cases, however, causes and effects are related by a rather broad probability distribution that purely mechanistic causation, the inference of causality, is not easily obtained. Recently, knowledge-based approaches using formal reasoning to infer causality from natural texts were attempted by an automatic causality extraction prototype (Kaplan & Berry-Rogghe, 1991). Other researchers attempted to extract causality from narrative-style texts by applying machine learning techniques without knowledge-based inferencing (Cole, Roya, Valtorta, & Huhns, 2006; Girju, 2003; Khoo, Chan, & Niu, 2000; Khoo, Kornfilt, Oddy, & Myaeng, 1998).

Among the logic-based implementation of causality inference mechanisms, rule-based methods are the most common type. Rule-based methods generally constitute the knowledge-base of an expert system in the form of IF–THEN rules or Horn Clause Logic. The traditional formal inference approach is conducted at the logical system, composed of propositions and inference rules (Burns, Winstead, & Haworth, 1989; Godo & Rodríguez, 2002; Martínez-Béjar, Cadenas, Shirazi, & Compton, 2009; Muro-Medrano, Banares, & Villarroel, 1998; Murray & Rosenthal, 1987; Shan, Liu, Qu, & Ren, 2005). These inference rules define new propositions which are derived from previously established ones. Considerable related work was done in the early 80s and 90s on the use of production rules for the decision making process (Rychener, 1988; Sriram, 1997; Tong & Sriram, 1992).

On the other hand, a cognitive map is a knowledge representing and reasoning method that offers a powerful and flexible framework to cope with the types of complicated problems for which analytical techniques are inadequate (Axelrod, 1976; Kosko, 1986; Miao, Liu, Siew, & Miao, 2001). The cognitive map is an essential tool for inferencing the fundamental causal relationships in a complex system, including diagnosing root causes of a problem (Evans, 2005), identifying critical control points, and formulating strategy (Kaplan & Norton, 2004). Furthermore, knowledge systems defined as cognitive maps can be connected and propagated to other maps if we can find the cause and effect links from one to another.

To coordinate a complex decision making process effectively, a cognitive map needs to be defined at an abstraction level, and control the semantic inference mechanism in the decision making process. However, few attempts have been made to develop the semantic framework that considers these semantic relations based on existing cognitive maps. The principal question in this paper, is therefore, how to combine the cognitive map and the semantic inference to improve propagated semantic relations in the decision making process, especially to explore opportunities for reducing the degree of cognitive complexities in large cognitive maps that

* Corresponding author. Tel.: +82 10 2722 8757.
E-mail address: kwonsj72@gmail.com (S.J. Kwon).

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are difficult to exploit and understand. This paper focuses on modeling a semantic hierarchy, namely ontology, and defining the semantic inference based on constructed ontologies, given a pre-defined cognitive map.

The outline of the paper is as follows: Section 2 provides the basic concepts of a cognitive map and an ontology. Section 3 proposes semantic inference methods based on a cognitive map. Section 4 shows a practical case study and concluding remarks are given in Section 5.

2. Theoretical background

2.1. Concept

A concept can be a single word such as ''price'' or ''customer'', or a phrase such as ''customer relationship management''. The word ''concept'' is used with different meanings in different situations or communities. Seiler (2001) discussed a great variety of concept theories, and elaborates on his approach in twelve aspects which are briefly described as: concepts are cognitive acts and knowledge units, concepts are categories but subjective theories, concepts are not generally interlinked in the sense of formal logic, concepts are domain specific and often prototypical, concepts are knowledge units that refer to reality, concepts are analogous patterns of thoughts, concepts are principally conscious but their content is seldom fully actualized in consciousness, concepts can be implicitly and explicitly actualized, concepts are languages as medial systems, concepts have motivational and emotional qualities, concepts have a history and go through a development processes, and concept formation is not a formalizable automatism.

In philosophy, concepts can be understood as the basic units of thought, and a concept is constituted by a pair, *extent* and *intent*. The extent is the set of all objects which belong to the concept, and the intent is the set of all attributes which are valid for all the objects of the extent (Wagner, 1973). Concepts can only matter in relationships with many other concepts, such *as* subconcept-superconcept relations. Being a subconcept of a superconcept means that the extent of the subconcept is contained in the extent of the superconcept, which is equivalent to, the intent of the subconcept contains the intent of the superconcept (Ganter, Stumme, & Wille, 2005).

2.2. Cognitive maps

A cognitive map is a visual representation of an influence network between concepts (Tolman, 1948). A cognitive map is composed of three fundamental elements: a collection of nodes, directed arcs between the nodes, and causality coefficients associated with an edge. The nodes represent concepts describing the problem domain with text, the arcs indicate relationships between the concepts, or the way one concept affects another one, while the causality coefficients specify an influence of a causal connection, and can be represented by a numeric or a symbolic value. Possible influence forms are as follows: the simplest symbolic form such as '' + '', ''−'', ''0''; a real value in the interval [−1,+1]; a fuzzy value such as ''more'' or ''some''.

The cognitive map describes the expert's knowledge of causal relationships among factors of a given problem. The validity and usefulness of cognitive maps has been proved in various fields, including administrative science (Eden & Ackermann, 1989; Eden, Jones, & Sims, 1979), software operations support (Nelson, Nadkarni, Narayanan, & Ghods, 2000), distributed network decision process modeling (Zhang, Wang, & King, 1994), geographical information systems (Liu & Satur, 1997; Satur & Liu, 1999), negotiation support for users in e-commerce (Lee & Kwon, 2006), avatar design (Lee & Kwon, 2008), decision analysis (Zhang, Chen, & Bezdek, 1989), business process redesign (Kwahk & Kim, 1999), and problem solving systems in which many relevant factors are causally interrelated with one another (Eden & Ackermann, 1989; Eden & Jones, 1980; Eden et al., 1979; Klein & Cooper, 1982; Lee & Kim, 1997; Montazemi & Conrath, 1986; Park & Kim, 1995).

Since the cognitive map describes experts' perceptions about the subjective world rather than objective reality, the challenge is to explore multiple cognitive maps from experts, and then incorporate them into a single collective cognitive map (Scavarda, Bouzdine-Chameeva, Goldstein, Hays, & Hill, 2006). Widely used approaches in practice for constructing cognitive maps are brainstorming and focus group interviews. Formal brainstorming to create a cognitive map is accomplished through a structured group workshop by allowing every participant to contribute his or her own ideas to the final cognitive map (Bryson, Ackermann, Eden, & Finn, 2004; Delbecq, Van de Ven, & Gustafson, 1975; Evans, 2005; Hegedus & Rasmussen, 1986; Novak, 1998). In focus group interviews for capturing cognitive maps, qualitative and open-ended questions are posed to experts (Eden, 1988; Nelson, Nadkarni, Narayanan, & Ghods, 2000), in which the interview process follows either a deductive (Newstead, Handley, Harley, Wright, & Farrelly, 2004), or an inductive approach (Del et al., 2005).

2.3. Ontology

The word ontology refers to a particular theory of the nature of being or existence, and is used with different meanings in different applications (Gruber, 1993; Guarino & Giaretta, 1995). Gruber (1993) originally defined an ontology as an ''explicit specification of a conceptualization'', Borst (1997) defined an ontology as a ''formal specification of a shared conceptualization'', and Studer, Benjamins, and Fensel (1998) merged these two definitions stating an ontology is a ''formal, explicit specification of a shared conceptualization'' This definition provides several characteristics of an ontology as a specification of domain knowledge, that is, formality, explicitness, being shared, conceptuality, and domain specificity. The following are some explanations: *formality* ensures that ontology is expressed in a well-defined way and provides formal semantics, an ontology captures knowledge *explicitly* to make it accessible for machines, an ontology reflects a *shared* agreement on a domain conceptualization among people of the same interest, an ontology states knowledge in a *conceptual* way in terms of symbols that represent concepts and their relations, and the specification in an ontology are limited to knowledge about a particular *domain* of interest. Therefore, an ontology specifies the semantics of terminology systems of a domain of interest and the meanings of domain data formally and explicitly, thereby providing a shared understanding of a domain of interest to support communication among human beings and applications.

One main advantage of ontologies is the ability to support the sharing and reuse of formally represented knowledge by explicitly stating concepts, relations, and axioms in a domain. Therefore, ontologies have been applied by many researchers to model knowledge for information sharing among applications, and to boost knowledge reuse. Over the last few decades, ontology-based applications have been expanding and maturing, coming from wide-ranging fields such as knowledge acquisition and knowledge-based systems (Abecker, Bernardi, Maus, Sintek, & Wenzel, 2000; Abecker, Bernardi, & van Elst, 2003; Abecker et al., 2003), ontologies for formal representations of biological systems (Stevens, Goble, Baker, & Brass, 2001; Stevens, Goble, & Bechhofer, 2000), semantic portals of cultural heritage (Hyvönen & Mäkelä, 2006; Hyvönen, Salminen, Kettula, & Junnila, 2004), and ontology-based recommender systems (Lee, Chun, Shim, & Lee, 2006;