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Extended evidential cognitive maps and its applications

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Abstract

Evidential cognitive maps (ECMs) are uncertain graph structure for describing causal reasoning through the cognitive maps (CMs) and Dempster–Shafer (D-S) theory, and utilize the basic probability assignments (BPAs) and intervals to denote connections among concepts and the state of concepts, respectively. ECMs have been proved effective and convenient in modeling those systems with both subjective and objective uncertainty. However, ECMs may get unreasonable results in system modeling when facing the problem of combining knowledge. To overcome the drawbacks of ECMs, we present extended evidential cognitive maps (EECMs) based on evidential reasoning (ER) theory, distance measure and convex optimization for the development of ECMs. In contrast with ECMs, in the EECMs, the default connections are redefined, a scheme of combining knowledge is established through the ER theory, and a convex-optimization-based approach is proposed for determining the weights of different EECMs. Both theoretical analysis and numerical examples indicate that EECMs not only develop ECMs, but also can overcome the limitations suffered by ECMs and other high-order cognitive maps including fuzzy grey cognitive maps (FGCMs), interval-valued fuzzy cognitive maps (IVFCMs) and intuitionistic fuzzy cognitive maps (IFCMs).

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1. Introduction

Cognitive maps (CMs) [1] and fuzzy cognitive maps (FCMs) [2] have enjoyed a broad and visible position in building up graph-oriented models representing mutual causal relationships among concepts. Up to now, there have been numerous studies emphasized on the analysis, development, and applications of both CMs and FCMs (see [3–21]). To enhance modeling capabilities of both CMs and FCMs, a series of generalizations have been introduced such as extended FCMs [3], dynamic CMs [10,11,13,20], and evolutionary fuzzy cognitive maps [6], just to mention several developments in the area of system modeling. To describe causal relationships more naturally in the process of system modeling, extended FCMs [3] were proposed including nonlinear membership functions, conditional weights, and time delay weights. To accurately reflect the uncertainty in the process of modeling, fuzzy grey cognitive maps (FGCMs) [4], intuitionistic fuzzy cognitive maps (IFCMs) [9] and interval-valued fuzzy cognitive maps (IVFCMs) [21], were introduced, which utilized information granularity (including grey values, interval-valued values and intuitionistic fuzzy numbers) to describe the state of concepts and causal relationships among them. Considering the importance of combining uncertain knowledge in the process of complex system modeling, evidential cognitive maps (ECMs) [8] were proposed, which not only describe the uncertain information of both causal relationships and the state of concepts through information granularity (including basic probability assignments (BPAs) and intervals), but also combine knowledge by Dempster–Shafer (D-S) theory [22].

As can be observed, the above generalizations have something in common, i.e., the state of concepts and the causal relationships among concepts are described in the form of information granules, especially intervals and some fuzzy sets. To establish a unified concept for most generalizations of both CMs and FCMs, granular cognitive maps (GCMs) were proposed and deeply discussed in [15,23]. As noticed in [15,23], the above-mentioned generalizations provide desirable additional freedom in the design of concepts and their causal relationships. This feature enables these maps to model highly complex problems from applications fields, such as business and industry. More information of CMs and FCMs may be found in [24]. However, the current studies of different forms of GCMs are still at an early stage. FGCMs, IFCMs and IVFCMs have not fully considered the problem of combining knowledge, especially determining the weights of different models. ECMs may generate unreasonable or incorrect results, since a number of issues have not been thoroughly addressed in modeling process including quantifying default connections, combining conflict knowledge and determining weights of different models.

To overcome the limitations of the aforementioned four high-ordered CMs, we present extended evidential cognitive maps (EECMs) based on evidential reasoning (ER) theory [25], distance measure and convex optimization for the development of ECMs. In comparison with those four high-ordered CMs, the main contributions of EECMs can be summarized as follows.

- We propose EECMs for the further development of ECMs. Compared with ECMs, EECMs redefine the default connections and develop an approach to quantify augmented connection matrices in the process of combining multiple models.
- We present a new scheme of combining knowledge based on ER theory in EECMs. Compared with the combining scheme in ECMs and FGCMs, the new scheme fully considers all the influence from every piece of knowledge. Meanwhile, the scheme can overcome