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Three-way concept learning based on cognitive operators: An information fusion viewpoint ☆

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ABSTRACT

The theory of three-way decisions is to consider a decision-making problem as a ternary classification one which is realized by the acceptance, rejection and non-commitment. Recently, this theory has been integrated with formal concept analysis in two different ways: constructive and axiomatic methods. The constructive method is to define certain three-way concepts in a formal context to support three-way concept analysis, while the axiomatic one is to characterize general three-way concepts by axioms so as to perform three-way concept learning. Nevertheless, there are similarities between the constructive and the axiomatic methods. In fact, both three-way concept analysis induced by the constructive method and three-way concept learning induced by the axiomatic one are realized by incorporating the idea of ternary classification into the design of extent or intent of a concept. However, their information fusion abilities need to be improved since neither of them is able to deal with large or multi-source data effectively. Motivated by this problem, our paper is to reconsider three-way concept learning based on cognitive operators from the perspective of information fusion. That is, the parallel computing techniques of learning three-way concepts are developed for large and multi-source data. Specifically, for large data, the relationship between the global granular concept and the local ones is first clarified, and then it is employed to design an information fusion algorithm. For multi-source data, the whole evaluation function used to induce three-way decisions is established by aggregating the results obtained in each single-source data, and three-way concept learning is made by constructing lower and upper approximation concepts. Finally, we conduct some numerical experiments to evaluate the effectiveness of the proposed parallel computing algorithms.

1. Introduction

The theory of three-way decisions was proposed by Yao [65], and it has attracted much attention in recent years. For example, Yao [66,67] elaborated how to make three-way decisions in the real world and what is the superiority of three-way

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decisions compared to other decision-making techniques. What is more, he [68] also illustrated the cognitive advantages of three-way decisions from various aspects. Following his work, many researchers have further studied this theory to meet different requirements. For instance, Yang and Yao [59] put forward multi-agent three-way decisions based on the decision-theoretic rough set. Deng and Yao [4] discussed the problem of approximating a fuzzy set from the viewpoint of decision-theoretic three-way decisions. Hu [11] gave a novel investigation of three-way decisions from the perspective of multi-granulation three-way decisions space. Liang et al. [28] extended the three-way decisions model with linguistic assessment and adopted multi-attribute group decision making to optimize the useful parameters. Liu et al. [32] employed the decision-theoretic rough set to make three-way investment decisions. Now, this theory has been applied in many fields such as concept analysis [40,41], concept learning [23], recommender system design [74], face recognition [27], spam e-mail filtering [14], and so on [12,71,76].

Concepts are well known to be the fundamental units of human cognition in philosophy [48], and they are often used to identify a real-world concrete entity or describe a perceived-world abstract subject [49]. Until now, scholars have developed a variety of concepts to meet all kinds of requirements of knowledge discovery in the real world. For example, Wang [48] put forward abstract concepts for the purpose of knowledge and software modeling. Wille [53] proposed formal concepts to make data analysis of a formal context. Düntsch and Gediga [7] presented property-oriented concepts to apply qualitative data analysis. Yao [62,63] defined object-oriented concepts to support rough data analysis. Wang and Liu [50] combined rough set with AFS algebra to perform fuzzy concept analysis. Li et al. [25] discussed approximate concepts to analyze incomplete information. Moreover, Qi et al. [40,41] used the theory of three-way decisions to construct three-way concepts for three-way concept analysis. In fact, approximate concepts and three-way concepts are similar to each other since the intension part of an approximate concept designed as a nested pair is equivalent to that of a three-way concept designed as an orthopair [5,6].

Concept learning is a classical problem and it has become a hot topic in recent years. Generally speaking, it needs a learner to distinguish the categories which possess concept-relevant features from the ones which do not possess concept-relevant features. For studying this problem, researchers have developed many effective learning methods such as queries [1], version spaces [9,36], Bayesian program learning [22], set approximation [24,26], cloud model [51], cognitive systems [56,57], and so on [2,44]. According to different data types, concept learning can be discussed for structured data, semi-structured data, or even unstructured data. Note that, generally speaking, techniques are required to translate semi-structured data and unstructured data into the corresponding structured forms before we can make concept learning. In addition, it deserves to be mentioned that concept learning can be investigated from the abstract, brain and machine levels, and Yao [64] stated that three different levels may be analyzed independently. On the other hand, attention should also be paid to the fact that the results obtained from any level are useful to the study of the other two.

Among the existing concept learning methods, we are more interested in those based on cognitive operators [23,26,35,56, 57] because they can allow us to simulate human thought processes (e.g. perception, attention and remembering something) by analyzing the cognitive mechanism, constructing cognitive computing system and performing cognitive processes.

Recently, the theory of three-way decisions has been integrated with concept learning methods based on cognitive operators for supporting three-way concept learning [23]. It should be pointed out that different from the three-way concept analysis induced by the constructive method [40], three-way concept learning was induced by the axiomatic method. More specifically, three-way concept analysis is to define certain three-way concepts in a formal context for meeting the certain type of requirements of data analysis, while three-way concept learning is to characterize general three-way concepts by axioms so as to allow more wide applications. Nevertheless, there are similarities between three-way concept analysis and three-way concept learning. For instance, both of them were realized by incorporating the idea of ternary classification into the design of extent or intent of a concept. However, although both of them can support three-way decisions in the real world, their information fusion abilities need to be improved since neither of them is able to deal with large or multi-source data effectively. Motivated by this problem, this study is to reconsider three-way concept learning based on cognitive operators from the perspective of information fusion (the case of three-way concept analysis can be done in a similar manner). That is, the parallel computing techniques of learning three-way concepts are developed for large and multi-source data. Concretely, for large data, we clarify the relationship between the global granular concept and the local ones to design an information fusion algorithm. For multi-source data, the whole evaluation function used to induce three-way decisions is established by aggregating the results obtained in each single-source data, and then three-way concept learning is performed by constructing lower and upper approximation concepts.

The rest of this paper is organized as follows. Section 2 introduces the related work on three-way idea in formal concept analysis. Section 3 recalls some basic notions related to three-way concept learning based on cognitive operators. Section 4 discusses three-way concept learning methods for large data. Section 5 investigates the issue of three-way concept learning for multi-source data. Section 6 conducts some numerical experiments to evaluate the effectiveness of the proposed parallel computing algorithms. The paper is then concluded with a brief summary and an outlook for further research.

2. Related work on three-way idea in formal concept analysis

In this section, we review the related work on three-way idea to make readers well understand the development of this novel idea in formal concept analysis.