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Three-way cognitive concept learning via multi-granularity

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ABSTRACT

The key strategy of the three-way decisions theory is to consider a decision-making problem as a ternary classification one (i.e. acceptance, rejection and non-commitment). Recently, this theory has been introduced into formal concept analysis for mining three-way concepts to support three-way decisions in formal contexts. That is, the three-way decisions have been performed by incorporating the idea of ternary classification into the design of extension or intension of a concept. However, the existing methods on the studies of three-way concepts are constructive, which means that the three-way concepts had been formed by defining certain concept-forming operators in advance. In order to reveal the essential characteristics of three-way concepts in making decisions from the perspective of cognition, it is necessary to reconsider three-way concepts under the framework of general concept-forming operators. In other words, axiomatic approaches are required to characterize three-way concepts. Motivated by this problem, this study mainly focuses on three-way concept learning via multi-granularity from the viewpoint of cognition. Specifically, we firstly put forward an axiomatic approach to describe three-way concepts by means of multi-granularity. Then, we design a three-way cognitive computing system to find composite three-way cognitive concepts. Furthermore, we use the idea of set approximation to simulate cognitive processes for learning three-way cognitive concepts from a given clue. Finally, numerical experiments are conducted to evaluate the performance of the proposed learning methods.

1. Introduction

Three-way decisions are one of the important ways in solving decision-making problems. Their key strategy is to consider a decision-making problem as a ternary classification one labeled by acceptance, rejection and non-commitment [60]. Up to now, substantial contributions have been made to the development of the theory of three-way decisions from various aspects. For instance, Yao [58] discussed the induction of three-way decision rules using the classical and decision-theoretic rough set models, and he also expounded the superiority of three-way decisions from the perspective of miss-classification cost [59]. Yang and Yao [53] employed the decision-theoretic rough set to model multi-agent three-way decisions. Deng and Yao [6] proposed a three-way approximation of a fuzzy set by means of the two

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parameters in the fuzzy membership function. Hu [9] established axiomatic approaches for three-way decisions and their corresponding spaces. Liang and Liu [19] built three-way decisions for the purpose of solving single-period and multi-period decision-making problems under intuitionistic fuzzy environment. Liu et al. [51] derived three-way decisions from investment decision-making problem for maximizing profit. In addition, three-way decisions have been applied to spam e-mail filtering [12], cost-sensitive face recognition [18], recommender system design [65], clustering analysis [67], and so on [68].

Cognitive computing is known as a computer system modeled on the human brain [42]. Its main purpose is to simulate human thought processes (e.g. perception, attention and learning) by computers. Cognitive learning is the function used to simulate cognitive processes such as the operations of thinking and remembering something. Generally speaking, cognitive learning can be viewed as a mathematical tool for the realization of cognitive computing. Moreover, both cognitive computing and cognitive learning have absorbed many novel methods from psychology, information theory and mathematics in the process of their development [41].

A concept, generally constituted by its extension and intension parts, is the basic unit of human cognition in philosophy [41], and is commonly used to recognize a real-world concrete entity or model a perceived-world abstract subject [42]. Up to now, many types of concepts such as abstract concepts [41], Wille's concepts [46], property-oriented concepts [7], object-oriented concepts [55,56], AFS-concepts [43] and approximate concepts [15] have been presented to meet different requirements of cognitive knowledge discovery. These well defined concepts can be distinguished from one another according to the characteristics of their intensions whose forms may be conjunctive, disjunctive or mixed. Very recently, by combining the theory of three-way decisions with formal concept analysis, Qi et al. [31,32] proposed the notion of a three-way concept to support three-way decisions in formal contexts, in which the main strategy is to incorporate the idea of ternary classification into the design of extension or intension of a concept. However, the existing methods on the studies of three-way concepts are constructive, which means that the three-way concepts were generated by introducing certain concept-forming operators in advance. In other words, researchers may define different three-way concepts with different properties, which results in a problem that which properties are the intrinsic ones of characterizing three-way concepts. The answers on this problem are important because they can help to understand the most basic decision-making mechanism of three-way concepts. So, axiomatic methods are required to look beyond appearance for the essence of three-way concepts in making decisions. The main theme of our paper is to address this problem.

Concept learning is to adopt certain approaches to learn unknown concepts from a given clue such as concept algebra system [41], queries [1], cognitive system [66], cloud model [44], set approximation [16], iteration [35], etc. According to Yao's information processing triangle [57], concept learning can be investigated from three aspects: the abstract level, brain level and machine level. More specifically, concept learning in the abstract level is to be analyzed in philosophy, mathematics and logics. For example, the formalization of the notion of a concept often refers to the principles from philosophy [14], the establishment of general concept-forming operators needs axiomatic methods [23], and logics are beneficial to the design of coherent cognitive systems. Concept learning in the brain level is to be discussed in psychology and neuroscience. For instance, the principles for perception, attention and thinking in cognitive psychology must be appropriately taken into consideration in exploring axiomatic methods [14,16]. Moreover, bi-directional recall between neurons can help to define reasonable mappings between the extension and intension parts of a concept [2]. Concept learning in the machine level is to be studied in computer science and information science. More attention has been attracted on this aspect because many kinds of effective methods [1,14,35,49,50] were developed to learn concepts from a given clue. In fact, concept learning in the abstract, brain and machine levels are relatively independent and closely related to one another. That is to say, on one hand, each of them can be researched independently. On the other hand, results from any one of them are beneficial to the better understanding of the other two. In our opinion, only by considering these three aspects in a unified framework can we have a comprehensive understanding of concept learning. The current work has an interest in the study of three-way concept learning from the abstract and machine levels.

Granular computing [63] has emerged as a unified and coherent platform of constructing, describing, and processing information granules. Currently, all kinds of models have been designed for information granules [3,4,26–30,36,45,54]. Generally speaking, the collection of information granules induced by a (resemblance, proximity, functional, etc.) relation can form a single granularity of the universe of discourse. In many practical applications, however, multiple granularities (often termed as multi-granularity) are also needed for problem-solving. For example, in a classification problem with several experts, it is a common situation that different experts have different views on dividing samples into classes. Under such a circumstance, each expert may give an independent granularity of the samples according to his or her personal preference. Then the final classification result can be obtained by effectively combining the multiple granularities from these experts. In fact, the multi-granularity view has been widely used in rough set theory. For instance, considering that multiple granularities will be generated in multi-scale datasets [47], Wu and Leung [48] studied how to select optimal granularity for optimization of the granulated information. Optimal granularity selection was also investigated from the viewpoint of local approaches [40]. Liang et al. [20] adopted the multi-granularity view to accelerate the speed of finding an approximate reduct. Based on multi-granularity, Qian et al. [33,34] put forward two novel rough set models (i.e. pessimistic and optimistic multi-granulation rough sets) for information fusion, and they designed a classifier based on these two kinds of multi-granulation rough sets. Moreover, multi-granularity has further been integrated into neighborhood-based, tolerance, covering and fuzzy rough set models [11,21,22] for complex information fusion. Also, the classical and generalized rough set models based on multi-granularity have been compared and connected with other theories such as formal concept