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Concept learning via granular computing: A cognitive viewpoint

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A B S T R A C T

Concepts are the most fundamental units of cognition in philosophy and how to learn concepts from various aspects in the real world is the main concern within the domain of conceptual knowledge presentation and processing. In order to improve efficiency and flexibility of concept learning, in this paper we discuss concept learning via granular computing from the point of view of cognitive computing. More precisely, cognitive mechanism of forming concepts is analyzed based on the principles from philosophy and cognitive psychology, including how to model concept-forming cognitive operators, define cognitive concepts and establish cognitive concept structure. Granular computing is then combined with the cognitive concept structure to improve efficiency of concept learning. Furthermore, we put forward a cognitive computing system which is the initial environment to learn composite concepts and can integrate past experiences into itself for enhancing flexibility of concept learning. Also, we investigate cognitive processes whose aims are to deal with the problem of learning one exact or two approximate cognitive concepts from a given object set, attribute set or pair of object and attribute sets.

1. Introduction

Cognitive computing is the development of computer systems modeled on the human brain [38]. It embodies major natural intelligence behaviors of the brain including perception, attention, thinking, etc. As an emerging paradigm of intelligent computing methodologies, cognitive computing has the characteristic of integrating past experiences into itself [22]. Nowadays, this theory has become an interdisciplinary research and application field and absorbed methods from psychology, information theory, mathematics and so on [37,39].

Concepts are the most fundamental units of cognition in philosophy and they carry certain meanings in almost all cognitive processes such as inference, learning and reasoning [37,50]. In this sense, a concept is in fact a cognitive unit to identify and/or model a real-world concrete entity and a perceived-world abstract subject. As is well known, how to efficiently learn concepts from various aspects in the real world is the main concern within the domain of conceptual knowledge presentation and processing. Up to now, for meeting the requirements of data analysis and knowledge manipulation, all kinds of concepts which carry certain meanings have been proposed such as *abstract concepts* [37], *Wille's concepts* [42], *object-oriented concepts* [48,49] and *property-oriented concepts* [9].

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In philosophy, a concept can generally be identified by its extension part (often called *extent*) and intension part (often called *intent*) which can be determined with each other [9,37,42,48,49]. The extent of a concept is the set of all objects or instances that the concept denotes, and the intent of a concept is the set of attributes or properties that a concept connotes [37,42]. In order to reflect the relationship of specialization and generalization among concepts, a structure of concepts can further be built by defining a partial order on the concepts under consideration. By this means, the obtained concept structure often forms a *complete lattice* no matter what kinds of meanings we give to the concepts, and hence some scholars from the community of *formal concept analysis* [42] called it certain *concept lattice* instead. For example, different concept structures have been proposed by specifying certain meanings of the concepts in the real world such as Wille's concept lattice [42], object-oriented concept lattice [48,49], property-oriented concept lattice [9], *AFS-concept lattice* [40], *power concept lattice* [11] and others [6,15,16,20,21]. Note that these certain concept structures or lattices establish rigorous mathematical models and provide formal semantics for data analysis in practice. In other words, meanings of real-world concrete entities can be represented and semantics of abstract subjects can be embodied by these certain concept structures. All in all, learning concepts (sometimes including their corresponding structure) has been investigated from various aspects. However, the current paper focuses on this issue from a novel aspect (i.e., a cognitive viewpoint).

Note that, generally speaking, learning a certain concept structure from a given dataset is computationally expensive when its size is large. The reason is that the number of concepts in the structure will increase exponentially in the worst case. Considering that *granular computing* gives rise to processing that is less time demanding than the one required when dealing with detailed numeric processing [2–4]. *Information granule*, the basic notion in the theory of granular computing which can broadly be viewed as a collection of information granules and the area of intelligent computing revolving around them [26], was introduced into Wille's concept lattice as an attempt to decrease computation time [43]. In a general sense, by information granule, one regards a collection of elements drawn together by their closeness (resemblance, proximity, functionality, etc.) articulated in terms of some useful spatial, temporal, or functional relationships [52,53]. In fact, information granules are intuitively appealing constructs, which play a pivotal role in human cognitive and decision-making activities [24]. It is also worth stressing that information granules permeate almost all human endeavors [2–5,24,25,27,53,54]. For example, information granules have been studied in *rough set theory* [17,23,29,30,35,44,46,47] extensively which is considered as one of the approaches of granular computing, and applied in *formal concept analysis* [10], *evidence analysis* [33], etc. Recently, studies on combination of granular computing with formal concept analysis have been made by several researchers [7,12,19,31,41,43,45,56]. And what is particularly worth mentioning is that information granules in formal concept analysis mean granular concepts [43] which are the basic concepts used to deduce others. As a matter of fact, in order to improve efficiency sharply, learning concept structure indeed needs the idea of granular computing no matter how we specify the certain meanings of the concepts in the real world, no exception to cognitive concepts to be discussed in the current paper.

Note that the aforementioned concepts were learned using constructive methods, which means that the concepts were formed by defining certain *concept-forming operators* [9,11,16,40,42,48,49]. In the meanwhile, axiomatic methods are also needed in terms of learning methodologies in which concepts are learned by establishing *axiomatic systems* (i.e., sets of axioms). To the best of our knowledge, axiomatic systems of concept learning were often called *concept systems* instead. In recent years, there have been several concept systems proposed for certain concept learning such as *cognitive system* [45], *concept granular computing system* [31], *generalized concept system* [19] and *generalized dual concept system* [18]. At the same time, it should be pointed out that these concept systems can also be used to learn the certain concepts which were obtained by using the constructive methods in [9,11,16,40,42,48,49]. Compared with constructive methods, axiomatic methods try to look beyond appearance for the essence of concept learning. However, the existing concept systems cannot integrate past experiences into itself. In other words, they are not able to deal with e.g., dynamic data and thereby are lack of flexibility for data analysis in practice. Besides, no explanation was provided to the background of the axioms of the existing concept systems, which means that they are too abstract to be understood. But, as far as we know, it is possible to solve these problems to some extent by means of concept learning based on cognitive computing because this kind of computing approach has the characteristic of integrating past experiences into itself and the background of simulating intelligence behaviors of the brain including perception, attention and learning.

To sum up, concept learning deserves to be studied based on granular computing from the perspective of cognitive computing, which may be beneficial to understanding and describing human cognitive processes in a conceptual knowledge way. Our current study mainly focuses on this issue. More precisely, the problems to be discussed are analysis of cognitive mechanism of forming concepts, integration of granular computing into cognitive concept structure, establishment of cognitive computing system, and implementation of cognitive processes. Note that the proposed cognitive computing system not only can integrate past experiences into itself by recursive thinking, but also is easy to be understood because cognitive mechanism of forming concepts is analyzed in advance based on the principles from philosophy and cognitive psychology.

The rest of this paper is organized as follows. In Section 2, cognitive mechanism of forming concepts is analyzed based on the principles from philosophy and cognitive psychology, including how to define concept-forming cognitive operators, construct cognitive concepts and induce their hierarchical structure. In Section 3, granular computing is integrated into the induced cognitive concept structure. In Section 4, we put forward a cognitive computing system in which the notions of a cognitive computing state, an object-oriented cognitive computing state and an attribute-oriented cognitive computing state are proposed. In Section 5, we investigate the cognitive processes whose aims are to deal with the problem of learning one exact or two approximate cognitive concepts from a given object set, attribute set or pair of object and attribute sets. In Section 6, we discuss the main differences and relations between the proposed concept learning approach and the existing