Artificial Intelligence Perspectives on Granular Computing

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1 Introduction

The theory of rough sets, proposed by Pawlak (1982, 1991, 1998; Pawlak and Skowron, 2007a, 2007b), offers systematic approaches for analyzing information tables in terms of indiscernibility, granulation and approximations. It has led to many useful and effective approaches for data analysis and machine learning.

The notions of indiscernability and definability can be defined by a decision logic language in an information table (Yao, 2007a). A set of objects is definable if we can find a formula defining the set, namely, the set consists exactly of these objects satisfying the formula. Two objects are indiscernible if we cannot differentiate them by any formula, namely, they satisfy exactly the same set of formulas. This formulation is consistent with Leibniz Law that identify is defined by means of indiscernibility (Krause and Coelho, 2005). It is also in the same line of thought as the theory of granularity suggested by Hobbs (1985) and the theory of abstraction studied by Giunchglia and Walsh (1992).

The indiscernibility of object is formally characterized by an equivalence relation, and equivalence classes are granules of the induced partition. Such a granulation of universe leads to approximations. Since not every subset of the universe can be expressed as a union of some equivalence classes, one needs to approximate it from below and above by a pair of sets that are unions of equivalence classes. One of the distinct features of rough set theory is that the iniscernibility is a relative notion defined with respect to a particular subset of attributes. When different subsets of attributes are used, one obtains different partitions. The relationships between these partitions are used to study the dependency of attribute sets.

The philosophy of rough set analysis is general enough to be applicable to many problem-solving tasks. It, in fact, has a major influence on an emerging field of study known as granular computing (Inuiguchi, Hirano and Tsumoto, 2003; Lin, Yao, and Zadeh, 2002; Pedrycz, Skowron and Kreinovich, 2008). The theory of rough sets (Pawlak, 1998) and the theory of granularity (Hobbs, 1985; Keet, 2008) offer artificial intelligence perspectives on granular computing (Yao, 2008a). Specifically, granular computing can be viewed as a study of human-inspired problem solving and information processing (Bargiela and Pedrycz, 2008; Yao, 2008b).

The next two sections, taken from a previous paper (Yao, 2008b), summarize the main points of a view of granular computing as human-inspired problem solving.

2 Human-inspired Granular Computing

Humans tend to organize and categorization is essential to mental life (Pinker, 1997). Results of such organizations are some types of structures. Humans tend to form multiple versions of the same world and to have several kinds of data presentations in the brain (Pinker, 1997). For a particular problem, we normally have several versions of descriptions and understanding (Minsky, 2007). Humans consider a problem at multiple levels of granularity. This allows us to focus on solving a problem at the most appropriate level of granularity by ignoring unimportant and irrelevant details (Hobbs, 1985). We can readily switch between levels of granularity at different stages of problem solving (Hobbs, 1985); we can also easily switch from one description to another. Granular computing research aims to formalize some or all of them.

Granular computing focus on a special class of approaches to problem solving; this classes is characterized by multiple levels of granularity. Regarding human intelligence, Minsky (2007) points out that humans have many "Ways to Think." We can easily switch among them and create new "Ways to Think" if no of them works. It is easy to convince us that humans have many approaches to problem solving. The use of multiple levels of granularity and abstraction is only one of them. It may be more realistic for the study of granular computing not to cover the whole spectrum of approaches to human problem solving. Therefore, we restrict study of granular computing to human-inspired and granularity-based way of problem solving.

The study of granular computing has two goals. One is to understand the nature, the underlying principles and mechanisms of human problem solving, and the other is to apply them in the design and implementation of human-inspired machines and systems. They in turn lead to two classes of research on granular computing, namely human-oriented studies and machine-oriented studies. These two types of studies are relatively independent and mutually support each other. The former focuses on human problem solving and the latter on machine problem solving.

The study of granular computing serves two purposes. First, an understanding of the underlying principles of human problem solving may help more people to consciously apply these principles. Once we articulate and master these principles, we become a better problem solver. We use the phrase "granular computing for humans" to denote this aspect. Second, an understanding human problem solving is a prerequisite of building machines having the similar power. The human brain is perhaps the only device that represents the highest level of intelligence for problem solving. Unlocking the mechanisms of human brain may provide the necessary hints on designing intelligent machines. Results from human-oriented studies may serve as a solid basis for machine-oriented studies. Once we have a full understanding of human problem solving, we can design machines and systems based on the same principles. We use the phrase "granular computing for machines" to denote the second aspect. In summary, granular computing is for both humans and machines.

3 A Grand Challenge for Granular Computing

Granular computing face the similar challenges as artificial intelligence.

The National Academy of Engineering (2008) lists "reverse-engineer the brain" as one of the 14 grand challenges for engineering for the 21st century. An excerpt from its document is given below:

> *While some of thinking machines have mastered specific narrow skills -playing chess, for instance - general-purpose artificial intelligence (AI) has remained elusive.*
>
> *Part of the problem, some experts now believe, is that artificial brains have been designed without much attention to real ones. Pioneers of artificial intelligence approached thinking the way that aeronautical engineers approached flying without much learning from birds. It has turned out, though, that the secrets about how living brains work may offer the best guide to engineering the artificial variety. Discovering those secrets by reverse-engineering the brain promises enormous opportunities for reproducing intelligence the way assembly lines spit out cars or computers.*
>
> *Figuring out how the brain works will offer rewards beyond building smarter computers. Advances gained from studying the brain may in return pay dividends for the brain itself. Understanding its methods will enable engineers to simulate its activities, leading to deeper insights about how and why the brain works and fails.*

We may pose a similar challenge to granular computing. That is, a grand challenge for granular computing is to reverse-engineer the mechanisms of human problem solving. It is of significant value to both human and machine problem solving.

4 The Triarchic Theory of Granular Computing

The triarchic theory consists of three perspectives of granular computing: the philosophy of structured thinking, the methodology of structured problem solv-

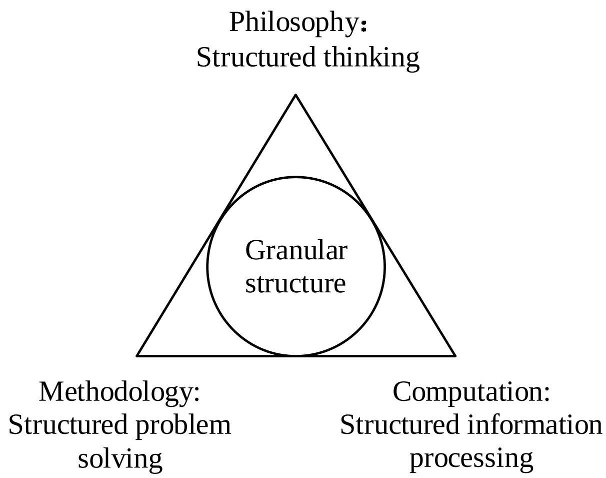

Figure 1: The granular computing triangle

ing, and the computation of structured information processing. A central notion is granular structures characterized by multilevel and multiview. While a multilevel hierarchy represents a particular view, a collection of many hierarchies represents a multiview description. The theory is developed in series of papers (Yao, 2000, 2004a, 2004b , 2005, 2006, 2007b).

As shown by the granular computing triangle in Figure 1, the main ingredients of the triarchic theory are granular structures and three perspectives. They are summarized as follows:

- **Granular Structures: Multilevel and Multiview**. Granular structures consists of inter-connected and inter-acting granules, families of granules interpreted as levels of differing granularity, and partially ordered multiple levels known as hierarchical structures. They are the results of a structured understanding, interpretation, representation, and description of a real-world problem or system. A hierarchy represents a problem from one particular angle or point-of-view with multiple levels of granularity. It is inevitable that a particular view given by one hierarchy is of limited power. A complete understanding of the problem requires the use and comparison of multiple hierarchies, and hence a multiview approach. Granular structures should reflect multiview and multilevel in each view.

- **Philosophy: Structured Thinking**. As a way of structured thinking, granular computing draws results from two complementary philosophical views about the complexity of real-world problems, i.e., the traditional reductionist thinking and the more recent systems thinking. It combines analytical thinking for decomposing a whole into parts and synthetic thinking for integrating parts into a whole. Granular computing stresses the importance of the conscious effects in thinking with hierarchical structures that model a complex system or problem in terms of the whole and parts.

- **Methodology: Structured Problem Solving**. As a general method of structured problem solving, granular computing promotes systematic approaches, effective principles, and practical heuristics and strategies that have been used effectively by humans for solving real-world problems. A central issue is the exploration of granular structures. This involves three basic tasks: constructing granular structures, working within a particular level of the structure, and switching between levels. The methodology of granular computing is inspired by human problem solving.

- **Computation: Structured Information Processing**. As a paradigm of structured information processing, granular computing focuses on implementing knowledge-intensive systems based on granular structures. Two related basic issues are representations and processes. Representation covers the formal and precise description of granules and granular structures. Processes may be broadly divided into the two classes: granulation and computation with granules. Granulation processes involve the construction of the building blocks and structures, namely, granules, levels, and hierarchies. Computation processes explore the granular structures. This involves two-way communications up and down in a hierarchy, as well as switching between levels.

5 Concluding Remarks

Granular computing is inspired by humans and aims at serving both humans and machines. A grand challenge for granular computing is to revere-engineer human problem solving. Once we understand the underlying principles, we can empower everyone to be a better problem solver on one hand, and implement machine problem solving on the other.

The results from rough set theory establish a good starting point for granular computing. Studies of artificial intelligence perspectives on granular computing may bring new insights and results, which in turn may enrich the rough set theory.

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