Foreword to the Special Section on Granular Computing

IN this special section, we have five papers that are selected from a pool of 16 submissions. Due to editorial processes, two selections have gone to a regular issue and "physically," there are three papers here.

In order to give a wider view, the selection has been biased towards the diversity, both in its structures and domains of applications. As Granular Computing (GrC) is an emerging field that has grown exponentially since the term was proposed by us [11], a small selection might not give an appropriate big picture. So, in addition to the summary of each article, which is often provided by the authors, we (Lin) also provide an introduction from the global point of view.

What is Granular Computing(GrC)? So far, there are no formal definitions yet. The difficulty is in the concept of information granulation. Here is Zadeh's intuitive definition [9]:

- "information granulation involves partitioning a class of objects (points) into granules, with a granule being a clump of objects (points) which are drawn together by indistinguishability, similarity, or functionality."

Structure-wise, these five papers represent five *mathematical* interpretations of the intuitive words "drawn together by" X, where X is the name of the constraints. Recall that "the foundation of TFIG" (Theory of Fuzzy Information Granulation) and "its methodology are mathematical in nature" by Zadeh [10].

First Interpretation: This is a relation/logic-based view. Let U be a set. Let $O_1, O_2, \ldots O_n$ be n objects that are "drawn together by" X. Observe that the order of the objects may be important, so a granule is a tuple, not necessarily a set. The collection of such n-tuples forms a n-ary relation X. Let β be a collection of such n-ary relations, which can be either fuzzy or crisp. Note that both n and X could vary. The pair (U, β) is called a Relational Granular Model (Fifth GrC Model). In the crisp case, β is a relational structure (without functions) in the First Order Logic.

The first paper can be interpreted in several ways; we choose an advanced one: it is viewed as an illustration of the transformation theory of relational granular models. A change of granularity induces a transformation of n-ary relations, namely, simple relational granular models.

I. Extended DNF Expression and Variable Granularity in Information Tables by Mineichi Kudo and Tetsuya Murai

This paper addresses variable granularity on an n-ary relation (an information table.) The paper examines the induced structures and representations of quotient relations (transformed granular models) of a nested sequence of partitions.

Digital Object Identifier 10.1109/TFUZZ.2008.921400

In an information table (a relation) to be analyzed mainly for obtaining rules, an appropriate level of granularity may express the meaning of the rules better than any other level of granularity.

In this paper, a chain of different levels of granularity is presented as hierarchical quotient sets with the corresponding equivalence relations. Reduction is given a new definition in such a general framework.

Another important point is seen in the choice of granularity. Closed tuple sets and closed attribute sets are formally analyzed via Galois' connection as an important criterion to choose granularity. Such a duality is shown to help develop efficient search algorithms in data mining or knowledge discovery. An algorithm, polynomial in the number of attributes, is also shown to obtain such a family of closed tuple sets for a given tuple set.

This article is a basic study to reformulate several concepts. Therefore, it is not completely clear yet what to do with these concepts. However, the authors believe that the concepts should give several kinds of intuition for actual data processing. In particular, a granularity-chain framework and a family expression of conjunctive maximal closed subsets seem promising.

Second Interpretation: This is a special case of the First interpretation, namely, $n = 2$. However, historically, this was the earlest interpretation. In [4], it says that "drawn together" implies certain level of symmetry in the clumps. Namely, if P is drawn towards Q, then Q is also drawn towards P." To avoid that, we will use the phrase "drawn toward the object P," so that it is clear the reverse may or may not be true." Based on this paraphrase, the neighborhood system (pretopology) [1], [2], and [3] was used to define a localized version of granulation, called Local Granular Model (First GrC Model): With each point $p \in U$, there is associated a certain *class* of crisp/fuzzy clumps at p, where each clump is a collection of objects that are drawn toward p by X, where X varies through the *class*. This association is derived from the concept of topological spaces (topological neighborhood system).

If at each point p, X is a unique value (the class is a singleton), then the neighborhood system is called the Binary Neighborhood System (BNS), denoted by B. The unique subset at each point p is called a neighborhood at p, and is denoted by $B(p)$. The pair (U, B) is called a Binary Granular Model (Third GrC Model).

If X varies through the same finite class for every p, that is, the pair (U, β) with β being a collection of BNS, is called a Multi-Binary Granular Model (Fourth GrC Model). If all BNS are equivalence relations, Pawlak call it a knowledge base [6]. This paper considers a generalized knowledge base, namely, β is a collection of equivalence relations and their fuzzy generalizations.

II. Evidence Resolution Using Concept Hierarchies by Frederick E. Petry and Ronald R. Yager

In this paper, Yager and Petry investigate the use of granulation for the resolution of seemingly contradictory evidences used in decision making. Specific to this approach is the use of the granulation provided by the categories of a concept hierarchy. For example, the conflict in the city of Joe's residence as manifested by the two pieces of the evidence "Joe lives in San Francisco" and "Joe lives in Los Angeles" can be resolved by going up the hierarchy to the state and claim that "Joe lives in California." However, as noted in this paper, this type of conflict resolution is constrained by the context in which the information is being used. Going too high up the concept hierarchy can make the information useless. Within this paper, the authors introduce ideas of complete and partial evidence resolution and formulate a concept of preponderance of evidence for decision making.

Third Interpretation: This paper fits into the Function Granular Model (Sixth GrC Model). A fuzzy set has been defined by membership functions, which are bounded real valued functions [8]. Conversely, we assume all bounded membership functions do define some fuzzy sets. Hence, fuzzy-set-based granular models are generalized to function-based granular models. One of the consequences of such generalizations is that the artificial neural network can be interpreted into this class [5].

III. Granular Neural Networks With Evolutionary Interval Learning by Yan-Qing Zhang, Bo Jin, and Yuchun Tang

The authors design a granular neural network based on granular sets, interval-valued granular reasoning methods and genetic algorithms. The new evolutionary interval learning algorithm can generate granular rules efficiently for different applications such as nonlinear function approximation (the granular neural network is trained to approximate a multidimensional nonlinear function effectively) and bioinformatics (the granular neural network is used for binary colon tumor classification).

Fourth Interpretation: The model of this paper is a binary granular model that has been explained in Second interpretation. Note that a BNS B defines a binary relation B_R and vice versa: The neighborhood $B(P)$ is equal to the set of all right-hand side elements, x, of the pair (p, x) ($\in$ B_R). Such a (right) neighborhood $B(P)$ can be called a right granule. Similarly, a (left) granule can also be defined. The notion of "community" in this paper is essentially defined by the cardinalities of left granule and right granule.

IV. A Novel Approach for Mining and Fuzzy Simulation of Subnetworks From Large Biomolecular Networks by Xiaohua Hu, Bahrad Sokhansanj, Daniel Wu, and Yuchun Tang

This paper appears in Vol. 15, No. 6, pp. 1219–1229, December 2007. Note that a binary relation is an algebraic notion. In computer science, it is often represented as a network, a graph, etc. Mathematically, this paper is a GrC model based on binary relation.

The method explained in this paper consists of three steps. First, the biomolecular network is derived using data mining approaches to extend the initial conceptual biomolecular network from the literature search, etc. Second, once the whole biomolecular network structure is complete, a novel scale-free network clustering approach is applied to obtain various subnetworks. Third, fuzzy-rule-based models are regenerated for the subnetworks and simulations are run to predict their behavior in the cellular context. The modeling results represent hypotheses that are tested against high-throughput data sets (microarrays and/or genetic screens) for both the natural system and perturbations. If computational results do not match experimental or previously published results, then new hypotheses are formed and used in the data mining and analyzing steps to refine the biomolecuar network for the next iteration.

This is repeated until a good match between model and data is obtained.

Fifth Interpretation: This paper belongs to the class of Algorithmic Granular Model (Seventh GrC Model) or more generally Granular Model of "How to Solve (Compute) it" [7].

V. Retraction and Generalized Extension of Computing With Words by Yongzhi Cao, Mingsheng Ying, and Guoqing Chen

This paper appears in Vol. 15, No. 6, pp. 1238–1250, December 2007. Fuzzy automata are "fuzzy subsets" of automata where transitions have grades. They can be regarded as automata labeled by a pair of numbers (grade) and symbols. The number are manipulated by fuzzy operations (e.g., min and max), which can be carried out by algorithms. So fuzzy automata are (classical) Turing machines.

Here is the authors' summary. Computing, in its traditional sense, is centered on manipulation of numbers and symbols, and is usually represented by a dynamic model such as all kinds of automata. Motivated by this and Zadeh's paradigm of computing with words, Ying proposed a kind of fuzzy automata, whose input alphabet consists of all fuzzy subsets of a set of symbols, as a formal model of computing with all words. This paper establishes a general formal model of computing with words, which is more robust and can be easily generalized to other computational systems such as pushdown automata and Turing machines. This work can be regarded as an attempt to developing a computational theory for Granular Computing.

Tsau Young (T. Y.) Lin, *Guest Editor*
Department of Computer Science
San Jose State University
San Jose, CA 95192 USA

Lotfi A. Zadeh, *Guest Editor*
Department of Electrical Engineering and Computer Science
University of California, Berkeley
Berkeley, CA 94720 USA

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