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Preface

# Rough sets and fuzzy sets in natural computing

Natural Computing (NC) is a discipline that builds a bridge between computer science and natural sciences. It deals mainly with the methodologies and models that take inspiration from nature (or are based on natural phenomena) for problem-solving, using computers (or computational techniques) to synthesize natural phenomena, or employ natural materials (e.g., molecules) for computation. The constituent technologies for performing these tasks include cellular automata, artificial neural networks (ANN), evolutionary algorithms, swarm intelligence, artificial immune systems, fractal geometry, artificial life, DNA computing, granular computing and perception-based computing. For example, artificial neural networks attempt to emulate the information representation and processing scheme and the discriminatory ability of biological neurons in the human brain together with characteristics such as adaptivity, robustness, ruggedness, speed and optimality. Similarly, evolutionary algorithms create a biologically inspired tool based on powerful metaphors from the natural world. They mimic some of the processes observed in natural evolution such as crossover, selection and mutation, leading to a stepwise optimization of organisms.

On the other hand, perception-based computing provides the capability to compute and reason with perception-based information as humans do to perform a wide variety of physical and mental tasks without any measurement and computation. Reflecting the finite ability of the sensory organs and (finally the brain) to resolve details, perceptions are inherently fuzzy–granular (f–granular) [21]. That is, boundaries of perceived classes are unsharp and the values of the attributes they can take are granulated (a clump of indistinguishable points or objects) [20,5]. Granulation is also a computing paradigm such as, among others, self-reproduction, self-organization, functioning of the brain, Darwinian evolution, group behavior, cell membranes, and morphogenesis, that are abstracted from natural phenomena. A good survey on natural computing explaining its different facets is provided in [4]. Granulation is inherent in human thinking and reasoning processes. Granular computing (GrC) provides an information processing framework where computation and operations are performed on information granules, and is based on the realization that precision is sometimes expensive and not much meaningful in modeling and controlling complex systems. When a problem involves incomplete, uncertain, and vague information, it may be difficult to differentiate distinct elements, and so one may find it convenient to consider granules for its handling. The structure of granulation can often be defined using methods based on rough sets, fuzzy sets or their combination. In this consortium, rough sets and fuzzy sets work synergistically, often with other soft computing approaches, and use the principle of granular computing. The developed systems exploit the tolerance for imprecision, uncertainty, approximate reasoning and partial truth under soft computing framework and is capable of achieving tractability, robustness, and close resemblance with human-like (natural) decision-making for pattern recognition in ambiguous situations [19].

Qualitative reasoning and modeling in NC requires to develop methods supporting approximate reasoning under uncertainty about non-crisp, often vague concepts. One of the very general schemes of tasks for such qualitative reasoning can be described as follows. From some basic objects (called patterns, granules or molecules) it is required to construct (induce) complex objects satisfying a given specification (often expressed in natural language specification) to a satisfactory degree. For example, in learning concepts from examples we deal with tasks where partial information about the specification is given by examples and counter examples concerning the classified objects. As instances of such complex objects one can consider classifiers studied in machine learning or data mining, new medicine against some viruses or behavioral patterns of cell interaction induced from interaction of biochemical processes realized in cells.

Over the years, we have learned how to solve some of such tasks, however many of them still pose great challenges. One of the reasons for this is that the discovery process of complex objects relevant for the given specification requires multilevel reasoning with the necessity of discovering on each level the relevant structural objects and their properties. The search space for such structural objects and properties is huge and this, in particular, requires fully automatic methods that are not feasible using the existing computing technologies. However, this process can be supported by domain knowledge which can be used for generating hints in the searching process (see, e.g., [1]). This view is consistent with [2] (see page 3 of Foreword):

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> *[...] Tomorrow, I believe, every biologist will use computers to define their research strategy and specific aims, manage their experiments, collect their results, interpret their data, incorporate the findings of others, disseminate their observations, and extend their experimental observations – through exploratory discovery and modeling – in directions completely unanticipated.*

Rough sets, discovered by Zdzisław Pawlak [9–13], and fuzzy sets, due to Lotfi A. Zadeh [16–22], separately and in combination have shown quite a strong potential for supporting the searching process for the relevant complex objects (granules) discussed above (see, e.g., [6,8,13,1,5,7]). Fuzzy set theory addresses gradualness of knowledge, expressed by the fuzzy membership, whereas rough set theory addresses granularity of knowledge, expressed by the indiscernibility relation. A nice illustration of this difference has been given by Dider Dubois and Henri Prade [3] in the following example: in image processing, fuzzy set theory refers to gradualness of gray level, whereas rough set theory is about the size of pixels.

In the issue we are presented recent research concerning application of rough sets, fuzzy sets and their combination also with other soft computing approaches to NC. Some of the papers consider particular methodologies and methods while the others concentrate on some general issues of computations in NC such as perception based computing (PBC). Altogether this issue presents recent results which can be classified into two main research directions of NC [4]:

> *[...] research that investigates models and computational techniques inspired by nature and, dually, attempts to understand the world around us in terms of information processing.*

This issue contains 10 selected papers which have been fully refereed in accordance with the high standards of Theoretical Computer Science.

The paper "Approximation of sets based on partial covering", by Zoltán Csajbók, proposes a possible generalization of approximations of sets relying on the partial covering of the universe of discourse. From a mathematical perspective, the author gives necessary and sufficient conditions for the cases when the new operators form a Galois connection. His paper also shows an interpretation for the new operations. The interpretation is based on the so-called MÉTA program, which is a mapping method of the natural vegetation heritage of Hungary.

The paper "Fuzzy Rough Granular Neural Networks, Fuzzy Granules and Classification", by Avatharam Ganivada, Soumitra Dutta, and Sankar K. Pal, describes a granular neural network in the NC paradigm, where the structure of granulation is defined on fuzzy rough sets. In this consortium, artificial neural networks, fuzzy logic and rough sets work synergistically, and use the principle of granular computing. The system exploits the tolerance for imprecision, uncertainty, approximate reasoning and partial truth under a soft computing framework and is capable of achieving tractability, robustness, and close resemblance to human-like (natural) decision-making for pattern recognition in ambiguous situations [19].

The paper "Evolutionary Fuzzy Clustering of Relational Data", by Danilo Horta, Ivan C. de Andrade, and Ricardo J.G.B. Campello, presents an evolutionary algorithm for fuzzy clustering capable of automatically estimating the number of clusters in data sets described only by pairwise proximities between data objects (relational data). The algorithm was statistically evaluated through a number of experiments and then compared with two traditional pseudo-exhaustive approaches that are also capable of estimating the number of clusters in relational data. The results suggest that the proposed algorithm is a promising alternative to the traditional approaches both in terms of accuracy and running time.

The paper "Fuzzy-Rough Nearest Neighbour Classification and Prediction", by Richard Jensen and Chris Cornelis, adapts the well-known nearest neighbor classification approach to take into account the lower and upper approximations of fuzzy rough set theory. Apart from the classical definitions for these approximations, the authors also invoke those of the Vaguely Quantified Rough Set model that makes the classifier more robust in the presence of noisy data.

The paper "Conservative and Aggressive Rough SVR Modeling", by Pawan Lingras and Cory J. Butz, describes a duality based on conservative and aggressive modeling of rough patterns using modifications of support vector regression. Conservative prediction of a rough pattern is contained within the tube of actual values, which in turn is enveloped by the aggressively predicted rough pattern. The paper describes how these prediction strategies correspond to trading strategies when they are used to model a financial market index.

There is a growing interest toward a deeper understanding, on the basis of pure mathematical approaches (including a categorical approach), of some application-driven issues related to, e.g., fuzzy set theory, rough set theory, or soft computing. Computational category theory links category theory and functional programming. The paper "Categorical properties of M-indiscernibility spaces", by Juan Lu, Sheng-Gang Li, Xiao-Fei Yang, and Wen-Qing Fu, is a continuation of discussion of categorical aspects of Pawlak's rough set theory. The aim of the presented research is to create categorical tools for better understanding the different issues in rough computing.

The paper "Fuzzy Quartile Encoding as a Preprocessing Method for Biomedical Pattern Classification", by Nick J. Pizzi, discusses a preprocessing method for pattern classification that replaces a feature value with the respective degrees of belongingness to a collection of fuzzy sets overlapping at the respective dispersion-adjusted quartile boundaries of the feature. This preprocessing method, empirically evaluated using five biomedical data sets, is shown to improve the discriminatory power of the underlying classifiers.

The article "Nature-Inspired Framework for Measuring Visual Image Resemblance: A Near Rough Set Approach" by Sheela Ramanna, Amir H. Meghdadi, and James F. Peters, on an utilizes a near rough set approach to capture the degree of nearness for complex visual objects. This is made possible by a number of perception-based extensions of the standard fuzzy metric that incorporate well-known pseudometrics in measuring the nearness of digital images. The hallmark of this

nature-inspired approach to measuring perceptual nearness is the organization of image pixels as a collection of visual information granules.

In the paper "Information Systems in Modeling Interactive Computations on Granules", by Andrzej Skowron and Piotr Wasilewski, applications of information systems in modeling interactive granular computations (IGC) are discussed. IGC are used in this project as foundations for perception-based computing (see, e.g., [15]). IGC are progressing by interactions between granules (structural objects of quite often high order type) discovered from data and domain knowledge. In particular, interactive information systems (IIS) are dynamic granules used for representing the results of the agent interaction with the environments. IIS can be also applied in modeling more advanced forms of interactions such as hierarchical interactions in layered granular networks or, more generally, in hierarchical modeling. The proposed approach is based on rough sets but it can be combined with other soft computing paradigms such as fuzzy sets or evolutionary computing, and also with machine learning and data mining techniques. The notion of the highly interactive granular system is clarified as the system in which intrastep interactions with the external as well as with the internal environments take place. Two kinds of interactive attributes are distinguished: perception attributes, including sensory ones and action attributes. This paper concludes with a presentation of the ACT-R system as an example of a highly interactive complex granule used in multi-agent simulations for steering the behaviors of particular agents, e.g., within cooperating coalitions.

The paper "Feedforward Neural Networks for Compound Signals", by Dominik Ślęzak and Marcin Szczuka, revisits one of the oldest and most established paradigms in the nature-inspired computing, the feedforward artificial neural network. The authors discuss the existing and possible new ways of using neural network approach and tools to process types of signals that are more compound and possibly structured, such as complex numbers, intervals, rough approximations, and vectors. They put forward their own idea for constructing and training the extended feedforward network capable of processing vectors instead of just real numbers. They discuss the possible application of proposed model in decision support and in modeling of complex phenomena.

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