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Title Paper: Natural computing: A problem solving paradigm with granular information processing

Sankar K. Pal[a,1], Saroj K. Meher[b,*,2]

[a] Center for Soft Computing Research, Indian Statistical Institute, Kolkata 700108, India
[b] Systems Science and Informatics Unit, Indian Statistical Institute, Bangalore Center, Bangalore 560059, India

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ABSTRACT

Natural computing, inspired by biological course of action, is an interdisciplinary field that formalizes processes observed in living organisms to design computational methods for solving complex problems, or designing artificial systems with more natural behaviour. Based on the tasks abstracted from natural phenomena, such as brain modelling, self-organization, self-repetition, self evaluation, Darwinian survival, granulation and perception, nature serves as a source of inspiration for the development of computational tools or systems that are used for solving complex problems. Nature inspired main computing paradigms used for such development include artificial neural networks, fuzzy logic, rough sets, evolutionary algorithms, fractal geometry, DNA computing, artificial life and granular or perception-based computing. Information granulation in granular computing is an inherent characteristic of human thinking and reasoning process performed in everyday life. The present article provides an overview of the significance of natural computing with respect to the granulation-based information processing models, such as neural networks, fuzzy sets and rough sets, and their hybridization. We emphasize on the biological motivation, design principles, application areas, open research problems and challenging issues of these models.

1. Introduction

Natural computing refers to going on in nature and to perform computation with its inspiration. With this visualization and understanding, the essence of computation is enhanced and opened a way to look insights of both natural sciences and computer science. It is understood that nature inspired models are not the alternative methods; rather, they have been proven substantially as a much more efficient paradigm to deal with various complex tasks. Several studies can be referred, where the hurdles faced by the classical computing have been crossed successfully by the nature inspired models. For example, there exist various ways to build complex multi parameter statistical models for general use in classification or prediction. However, nature has extensive experience in a particular area of this design space resulting in a model, namely, neural networks [1]. This inspiration has guided much of the machine learning and pattern recognition community towards its exploitation and exploration that has proved extremely successful. Similar can be said in the use of immune system [2] metaphors to underpin the design of techniques that detect anomalous patterns in systems, or of evolutionary methods for design. Moreover, it seems clear that natural inspiration has in some cases led to the exploration of algorithms that would not necessarily have been adopted, but proven significantly more successful than alternative techniques. Particle swarm optimization [3], for example, has been found enormously successful on a range of optimization problems, despite its natural inspiration having little to do with solving an optimization problem. Evolutionary algorithms [4] use the concepts of mutation, recombination and natural selection from biology; molecular computing [5,6] is based on paradigms from molecular biology; and quantum computing [7] is based on quantum physics that exploits quantum parallelism.

There are also important methodological differences between various subareas of natural computing. For example, evolutionary algorithms and algorithms based on neural networks are presently implemented on conventional computers. On the other hand, molecular computing aims at alternatives for silicon hardware by implementing algorithms in biological hardware (bio-ware), e.g., using DNA molecules and enzymes. In addition, quantum computing aims at non-traditional hardware that would allow quantum effects to take place. Computer science undergoes now an important transformation by trying to combine the computing carried on in computer science with the computing observed in nature all around us. Natural computing is a very important catalyst of this transformation, and holds a lot of promise for the future research.

* Corresponding author. Tel.: +91 80 28483002x534; fax: +91 80 28484265.
E-mail address: saroj.meher@gmail.com (S.K. Meher).
[1] Fellow, IEEE.
[2] Senior Member, IEEE.

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The term natural computing though referred initially to describe only those systems that employ natural means, such as DNA or RNA strands, to perform computation, now its scope has broadened to cover the following three major areas:

- Computing techniques that take inspiration from nature for the development of novel problem-solving methods.
- Study of natural phenomena by means of computation.
- Computing with natural means.

Good surveys on natural computing explaining its different facets are provided in [8–13]. Natural computational models are most relevant in applications that resemble natural systems, e.g., real time control systems, autonomous robots and intelligent systems in general Natural computational systems have the characteristic features like – adaptability (to new environment, data), robustness/ruggedness (with respect to noise, faults, damage, parameter change, component failure), speed (real time response), abstraction and generalization (human-like learning for improving performance), and optimality (with respect to error rate). Any design engineer desires to have these features in his/her systems.

Granulation is a process, among others such as self-reproduction, self-organization, functioning of the brain, Darwinian evolution, group behaviour, cell membranes, and morphogenesis, that are abstracted from natural phenomena. Granulation is inherent in human thinking and reasoning processes. Granular computing (GrC) [14,15] provides a nature inspired information processing framework, where computation and operations are performed on information granules, and it is based on the realization that precision is sometimes expensive and not very 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 one may find it convenient to consider granules for its handling. Accordingly, granular computing became an effective framework in the design and implementation of efficient and intelligent information processing systems for various real life decision-making applications. The said framework can be modeled with principles of neural networks, fuzzy sets and rough sets, both in isolation and integration, among other theories.

In the present paper, we describe a brief overview of the granular information processing aspect of natural computing, and the significance of fuzzy sets, rough sets and neural networks, and their different hybridizations. Biological motivations, design principles and application areas of these individual models are stated along with some open research problems. Some characteristic features of granulation are explained through examples from existing literature. Finally, some challenging issues of the hybrid granular systems are mentioned.

2. Components of granular computing

Granular computing is a problem solving paradigm with the basic element called granules. The construction of granules is a crucial process, as granules with different sizes and shapes are responsible for the success of granular computing based models. Further, the inter and intra relationships among granules play important roles. In the following section, we summarize these concepts and components briefly.

2.1. Granules

The significance of a granule in granular computing is very similar to any subset, class, object, or cluster of a universe. The granules are composed of elements that are drawn together by indisccernibility, similarity, and functionality. Each of the granules according to its shape and size, and with a certain level of granularity may reflect a specific aspect of the problem or form a portion of the system domain. Granules with different granular levels represent the system differently. For example, an image can be described with three granules at the first level of granularity where each of the granules characterizes the regions of image with three basic colors, such as red, green and blue. At this level the information of the image may be categorized in a broader way, like greenery or bluish regions. If we go further into more details with respect to colors then each of the these three granules (color regions) can be described with their subsequent divisions. As an example, each of such divisions can characterize objects (granules) in a particular color such as tree, grass, bushes, where combination of these object regions forms the greenery region.

2.2. Granulation

Granulation is the process of construction, representation, and interpretation of granules. It is the process of forming larger objects into smaller and smaller into larger based on the problem in hand. Zadeh [14] described this idea as, “granulation involves a decomposition of whole into parts. Conversely, organization involves an integration of parts into whole.” This concept leads to the fact that granular computing involves in two basic operations, such as granulation and organization. Granulation starts from the problem space as a whole, partitions the problem into sub-spaces, and constructs the desired granules; while organization puts individual elements/granules together to form blocks and to build granules at expected levels. The criteria for the granulation process determine the action for granulating big granules into smaller or small into bigger. Further, the concept of partition and covering comes in the granulation process. A partition consists of disjoint subsets of the universe, and a covering consists of possibly overlap subsets. Partitions are a special type of coverings. Operations on partitions and coverings have been investigated in literature [16,17].

2.3. Granular relationships

Granular relationship among granules is a key factor in the process of granulation, as one needs to understand it very precisely for better solution. Granular relationship can be broadly categorized into two groups [18], such as inter-relation and intra-relation. The former is the basis of grouping small objects together to construct a larger granule based on similarity, indistinguishability and functionality; while the latter concerns the granulation of a large granule into smaller units and the interactions between components of a granule as well. A granule is a refinement of another granule if it is contained in the latter. Similarly, the latter is called coarsening of the former. These relationships function like set-containment in the set based domains.

2.4. Computation with granules

Computation with granules is the final step in granular computing process. Computing and reasoning in various ways with different granules based on their relationship and significance is the basis for the computation method. These operations, as described above, are broadly categorized as either computations within granules or computations between granules. Computations within granules include finding characterization of granules, e.g. membership functions of fuzzy granules; inducing rules from granules, e.g. classification rules that characterize the classes of objects; forming concepts that granules entail. On the other hand, computations