HISTORY AND DEVELOPMENT OF GRANULAR COMPUTING

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Contents

Summary

Information granules and information granularity, which altogether give rise to the general framework of Granular Computing, offer interesting opportunities to endow information processing with an important facet of human-centricity. This facet directly implies that the underlying processing supports non-numeric data inherently associated with an adjustable perception of humans and generates results being seamlessly comprehended by the users.

This study offers an introduction to the concepts of information granules, elaborates on the main formal frameworks of Granular Computing (GC) such as sets (interval mathematics), fuzzy sets, probability, rough sets, and shadowed sets and afterwards looks at ways in which information granules are formed. Here we discuss a principle of a justifiable granularity and selected clustering methods such as Fuzzy C-Means along with their knowledge-based variants. In the sequel, presented is an idea of information granularity being sought as an important design asset in system design to enhance rapport of resulting constructs with the real-world phenomena and systems.

1. Introduction

Human-centricity comes as an inherent feature of intelligent systems. It is anticipated that a two-way effective human-machine communication is imperative. Human perceive the world, reason, and communicate at some level of abstraction. Abstraction comes hand in hand with non-numeric constructs, which embrace collections of entities characterized by some notions of closeness, proximity, resemblance, or similarity. These collections are referred to as information granules. Processing of information granules is a fundamental way in which people process such entities. Granular Computing has emerged as a framework in which information granules are represented and manipulated by intelligent systems. The communication of such intelligent systems with the users becomes substantially facilitated because of the usage of information granules.

The primary objective of this study is to present a general overview of the fundamentals of Granular Computing – information granules, their formalizations, essentials of processing and ways of the development of information granules themselves (in which we exploit experimental data along with the available domain knowledge).

We start with an introduction to the concept of information granule by providing a suite of real-world examples in which information granules occupy an important role (Section 2). In Section 3, we elaborate on the main formalisms being used in the description of information granules including interval analysis (sets), fuzzy sets, rough sets and probabilistic constructs. Then higher level and higher order information granules are studied. In the sequel, a series of algorithms supporting a construction of information granules is introduced. A concept of the justifiable granularity is used to form information granules that are supported by experimental evidence as well as come with a sufficiently high specificity. Clustering has been sought as a generic vehicle to form information granules on a basis of experimental data. This concept is revisited vis-à-vis the essence of information granules being regarded as a vehicle to capture domain knowledge and in this way contributing to the realization of human-centric constructs. Some essential roles of information granules are discussed in the setting of signal processing (Section 5). Information granules and information granularity are regarded as an important design asset – this feature is studied in problems of system modeling in Section 6. Conclusions are covered in Section 7.

2. Information Granularity and Granular Computing

Information granules permeate almost all human endeavors (Bargiela and Pedrycz, 2002, 2003, 2008, 2009; Zadeh, 1997, 1999, 2005; Pedrycz and Bargiela, 2002). No matter what problem is taken into consideration, we usually set it up in a certain conceptual framework composed of some generic and conceptually meaningful entities-information granules, which we regard to be of relevance to the problem formulation and problem solving. This becomes a framework in which we formulate generic concepts by adopting a certain level of abstraction, carry out further processing, and communicate the results to the external environment. A few examples offer compelling evidence with this regard:

Image processing. In spite of the continuous progress in the area, a human being assumes a dominant and very much uncontested position when it comes to understanding and interpreting images. Surely, we do not focus our attention on individual pixels and process them as such but group them together into semantically meaningful constructs – familiar objects we deal with in everyday life. Such objects involve regions that consist of pixels or categories of pixels drawn together because of their proximity in the image, similar texture, color, etc. This remarkable and unchallenged ability of humans dwells on our effortless ability to construct information granules, manipulate them and arrive at sound conclusions.

Processing and interpretation of time series. From our perspective we can describe them in a semi-qualitative manner by pointing at specific regions of such signals. Medical specialists can effortlessly interpret various diagnostic signals including ECG or EEG recordings. They distinguish some segments of such signals and interpret their combinations. In stock market, one analyzes numerous time series by looking at amplitudes and trends. Experts can interpret temporal readings of sensors and assess the status of the monitored system. Again, in all these situations, the individual samples of the signals are not the focal point of the analysis and the ensuing signal interpretation. We always granulate all phenomena (no matter if they are originally discrete or analog in their nature).

Granulation of time. Time is another important and omnipresent variable that is subjected to granulation. We use seconds, minutes, days, months, and years. Depending upon a specific problem we have in mind and who the user is, the size of information granules (time intervals) could vary quite dramatically. To the high-level management time intervals of quarters of year or a few years could be meaningful temporal information granules on basis of which one develops any predictive model. For those in charge of everyday operation of a dispatching plant, minutes and hours could form a viable scale of time granulation. For the designer of high-speed integrated circuits and digital systems, the temporal information granules concern nanoseconds, microseconds, and perhaps microseconds.

It is also worth noting that information granules are examples of abstractions. As such they naturally give rise to hierarchical structures: the same problem or system can be perceived at different levels of specificity (detail) depending on the complexity of the problem, available computing resources, and particular needs to be addressed. A hierarchy of information granules is inherently visible in processing of information granules.

Even such commonly encountered and simple examples are presented above are convincing enough to lead us to ascertain that (a) information granules are the key components of knowledge representation and processing, (b) the level of granularity of information granules (their size, to be more descriptive) becomes crucial to the problem description and an overall strategy of problem solving, (c) hierarchy of information granules supports an important aspect of perception of phenomena and deliver a tangible way of dealing with complexity by focusing on the most essential facets of the problem, (d) there is no universal level of granularity of information; commonly the size of granules is problem-oriented and user dependent.

What has been said so far touched a qualitative aspect of the problem. The challenge is to develop a computing framework within which all these representation and processing endeavors could be formally realized. The common platform emerging within this context comes under the name of Granular Computing. In essence, it is an emerging paradigm of information processing. While we have already noticed a number of important conceptual and computational constructs built in the domain of system modeling, machine learning, image processing, pattern recognition, and data compression in which various abstractions (and ensuing information granules) came into existence, Granular Computing becomes innovative and intellectually proactive endeavor that manifests in several fundamental ways:

- It identifies the essential commonalities between the surprisingly diversified problems and technologies used there, which could be cast into a unified framework known as a granular world. This is a fully operational processing entity that interacts with the external world (that could be another granular or numeric world) by collecting necessary granular information and returning the outcomes of the granular computing
- With the emergence of the unified framework of granular processing, we get a better grasp as to the role of interaction between various formalisms and visualize a way in which they communicate.
- It brings together the existing plethora of formalisms of set theory (interval analysis) (Moore, 1966), fuzzy sets (Zadeh, 1965, 2005), rough sets (Pawlak, 1982, 1991; Pawlak and Skowron, 2007) under the same roof by clearly visualizing that in spite of their visibly distinct underpinnings (and ensuing processing), they exhibit some fundamental commonalities. In this sense, Granular Computing establishes a stimulating environment of synergy between the individual approaches.
- By building upon the commonalities of the existing formal approaches, Granular Computing helps build heterogeneous and multifaceted models of processing of information granules by clearly recognizing the orthogonal nature of some of the existing and well established frameworks (say, probability theory coming with its probability density functions and fuzzy sets with their membership functions)
- Granular Computing fully acknowledges a notion of variable granularity whose range could cover detailed numeric entities and very abstract and general information granules. It looks at the aspects of compatibility of such information granules and ensuing communication mechanisms of the granular worlds.
- Granular Computing gives rise to processing that is less time demanding than the one required when dealing with detailed numeric processing (Bargiela and Pedrycz, 2003, 2005 (a) (b))
- Interestingly, the inception of information granules is highly motivated. We do not form information granules without reason. Information granules arise as an evident realization of the fundamental paradigm of abstraction.

Granular Computing forms a unified conceptual and computing platform. Yet, it directly benefits from the already existing and well-established concepts of information granules formed in the setting of set theory, fuzzy sets, rough sets and others.

3. Formal Approaches to Information Granulation: An Overview and Generalizations

We start with a concise overview at the formal approaches being key contributors to the area of Granular Computing. The two prominent features of the area concern a remarkable diversity of formal frameworks and an increasing tendency of hybridization of various approaches as well as their conceptual augmentations.

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Biographical Sketch

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