Toward Data Science Computing Model: Interactive Granular Computing (IGrC)

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EXTENDED ABSTRACT[4]

Rough sets, introduced by Zdzisaw Pawlak [1], play a crucial role in the development of Granular Computing (GrC) [2–4]. The extension of GrC to Interactive Granular Computing (IGrC) (initiated by Skowron and co-workers [5–7][5]), requires generalization of the basic concepts of rough sets and GrC. For instance, it is needed to shift from *granules* to *complex granules* (including both physical and abstract parts), information (decision) systems to interactive information (decision) systems as well as methods of inducing hierarchical structures of information (decision) systems to methods of inducing hierarchical structures of interactive information (decision) systems. IGrC takes into account the granularity of information as used by humans in problem solving, as well as interactions with (and within) the real physical world. The computations in this IGrC model are realized on the interactive complex granules and that must be based on the consequences of the interactions occurring in the physical world. It is worthwhile to cite here the following opinion [8]:

> *It seems that we have no choice but to recognize the dependence of our mathematical knowledge (...) on physics, and that being so, it is time to abandon the classical view of computation as a purely logical notion independent of that of computation as a physical process.*

Consequently, the computational models in IGrC related to the complex phenomena cannot be constructed solely in an abstract mathematical space. They must also take into account continuous interactions with and within the real physical space. In particular, the computational models cannot ignore the laws of physics. It is worthwhile to cite here the opinion of Immanuel Kant (see [9], p. 4):

[5] see also publications about IGrC listed at https://dblp.uni-trier.de/pers/hd/s/Skowron:Andrzej

> [...] *cognition is the result of the interaction of two independent agents, the mind and the real object.*

With the interaction rules learned from the acquired data through computations an agent can approximate complex vague concepts related to the expectations of the agent. This agent itself can be regarded as a complex granule. The objective of IGrC is also in line with the proposition of Fredrick Brooks (a recipient of the Turing Award). According to him [10]:

> *Mathematics and the physical sciences made great strides for three centuries by constructing simplified models of complex phenomena, deriving, properties from the models, and verifying those properties experimentally. This worked because the complexities ignored in the models were not the essential properties of the phenomena. It does not work when the complexities are the essence.*

The IGrC models, in the form of complex networks of complex granules, have to be created adaptively and autonomously through a process of continuous interaction with real world. Due to the uncertainty in the perception of situations different local models, which are discovered, can be inconsistent with each other; but their relevant aggregation should lead to the discovery of a new knowledge about the perceived situation. It should be noted that models created in the abstract space must be also able to adapt to the changes perceived in the external physical reality. The main aim of the current research in IGrC is to develop the IGrC models over complex granules. More compound granules are represented by networks of interacting simpler granules changing with time. Any IGrC model must also be able to direct the attention of complex granules (e.g., agents) to focus on the significant fragments of the reality that are measured by the sensors and explored by the actuators used in performing the actions or plans. Results of interactions are collected in information systems (data tables), which constitute some fragments of the complex granules.

Following another Turing Award winner, Leslie Valiant, these tables are then aggregated to create new complex granules as computational building blocks for cognition[6].

There are many challenges related to IGrC. Some of them are related to reasoning, called *adaptive judgment* [11, 12], about properties of complex granules and interactive computations over them. One of the main aim of adaptive judgment performed by complex granules (e.g., agents) is to derive conclusions regarding selection of action(s) that should be currently initiated (or terminated). The actions are activated on the basis of the satisfiability of some complex vague concepts labelled by actions. It should be noted that these concepts are drifting with time. Adaptive learning of such concepts based on judgment is a great challenge[7]. The whole process towards inducing approximation of these vague concepts labelled by actions may be treated as a process of discovery of a *complex game*. In such a game, the concepts (along with their respective associated judgement mechanism) can be treated as the players. These players using their judgement mechanism can derive arguments *for* and *against* the satisfiability of the concepts

[6] see `https://people.seas.harvard.edu/~valiant/researchinterests.htm`

[7] Some progress in this direction was made using reinforcement learning but much more work should be done when we deal with complex real-life applications (see, e.g., [13].

on the basis of the information about the perceived situation. Furthemore, there are other judgment mechanisms, in the hands of a judge, that can be used to resolve conflicts among the collected arguments to select the winning player (concept). Then action labelling the winning concept is initiated.

It should be also noted that approximation of the complex vague concept should be based on a notion of adaptive judgment rather than only on the basis of partial inclusion of sets which is widely used in the rough set approach. The former approach is much more general than the latter one. The approach based on judgment is especially relevant when in data analysis it is required to have a deeper judgment about the perceived complex situation related to the classification of complex vague concepts. The approach based on partial containment of sets alone is not satisfactory for dealing with many real-life applications, where more advanced judgment should be made to identify the perceived situation, to classify it relative to the complex vague concepts or to reason about risk for supporting the decision making. In particular, it is needed to develop new logical tools for reasoning based on judgment toward approximation of complex vague concepts, *i.e.*, the rough set approach based on adaptive judgment performed over computations on complex granules. This, in particular, creates a room for extensions of rough sets to adaptive rough sets and rough sets over distributed networks of granules changing with time.

Another challenging research direction is related to self-organization in synthesis of complex granules and their networks.

Finally, it is worthwhile mentioning that IGrC is also in agreement with the recently raised discussions about the Turing test for intelligence. In addition to linguistic aspects and reasoning, it incorporates perception and actions, and it follows what Leslie Valiant's calls *ecorithms* [14, 15].

The proposed model of computation based on complex granules seems to be of fundamental importance for developing intelligent systems dealing with complex phenomena, in particular in such areas as Data Science, Internet of Things, Wisdom Web of Things, Cyber Physical Systems, Complex Adaptive Systems, Natural Computing, Software Engineering, applications based on Blockchain Technology, etc (see, *e.g.*, the first works using IGrC related to some of these domains [16, 7, 17]).

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