Rough-Granular Computing
Extended abstract

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Solving complex problems by multi-agent systems in distributed environments requires new approximate reasoning methods based on new computing paradigms. One such recently emerging computing paradigm is Granular Computing. Granular computations are performed on information granules representing vague and complex concepts delivered by agents engaged in tasks such as knowledge representation, communication with other agents, and reasoning. We present the rough-granular approach for modeling of computations in complex adaptive systems and multiagent systems. Information granules are all objects constructed in modeling of computations and in approximation of compound concepts as well as approximate reasoning about them. Among examples of information granules are information systems and decision systems, elementary information granules defined by indiscernibility neighborhoods, families of elementary granules (e.g., partitions and coverings), relational structures obtained by granulation of objects or classes of relational structures (representing structured objects and their classes), elementary and compound patterns (e.g., clusters of already defined patterns, hierarchical or behavioral patterns, protocols of cooperation), decision rules on different levels, interaction patterns, sets of decision rules, strategies searching for relevant features, rough inclusions, approximation spaces, fusion operations of information granules, negotiation and conflict resolution strategies, classifiers constructed for compound and vague concepts. We discuss rough set based foundations for information granule calculi and methods for inducing relevant information granule constructions from data and background knowledge. The proposed methodology of approximate reasoning has been applied for solving complex problems in areas such as identification of objects or behavioral patterns by autonomous systems, web mining, and sensor fusion.

Basic Concepts Relative to Judges

We discuss the basic components of agents (called here as judges) which are performing their tasks. In particular, they are interacting with the other agents in the environment, approximating vague concepts and have ability of reasoning about approximated concepts. The basic concepts relative to the judge J are the following:

- $\mathcal{N}$ is the set of information granules accessible by J (e.g., neighborhoods of objects, sets defined by the left hand sides of decision rules, sets defined by classifiers together with the classifiers, granules accessible by J through interaction with other judges, e.g., representing other sources of knowledge). Information granules are all constructive objects definable (accessible, generated) by the judge J which are used by J for representing knowledge, approximate reasoning, and interaction with other judges and/or the environment.

- There are some goals (targets) for the judge J to achieve, e.g., preserving some constraints with some priorities or achieving a state with a given property. $\mathcal{G}$ denotes the granule representing goals for J. In particular, constraints and targets are defined by means of information granules.

- ENV_J denotes the set of all judges interacting with J (directly or indirectly).

- $Inf : States(ENV_J) \longrightarrow \mathcal{N}$ is the information function about states of the environment from the set
$$States(ENV_J)$$
perceived by J. By $\mathcal{N}_{Inf}$ we denote the set $Inf(States(ENV_J))$.

- $\mathcal{S}$ the set of judgement strategies of J. Examples of judgement strategies are listed below.

- $\models^+_{deg}$, $\models^-_{deg}$ are binary relations in $\mathcal{N} \times \mathcal{N}$, called the rough inclusions of J with the following intended meaning: $u \models^+_{deg} u'$ if and only if the granule u is matching the granule u' to a degree at least deg; $u \models^-_{deg} u'$ if and only if the granule u is matching the granule u' to a degree at most deg. The strategy of matching is one of the basic strategy used by J is the judgements.

- $\mathcal{N}^+_u(deg) = \{u' : u \models^+_{deg} u'\}$ for $u \in \mathcal{N}$. Granule u votes “for” granules from $\mathcal{N}^+_u$ (relative to deg).

- $\mathcal{N}^-_u(deg) = \{u' : u \models^-_{deg} u'\}$ for $u \in \mathcal{N}$. Granule u votes “against” granules from $\mathcal{N}^-_u$ (relative to deg).

- $\mathcal{B}$ is the set of behavioral patterns of J (e.g., decisions, actions, plans). These are some specific information granules too.

- $Lab : \mathcal{N} \longrightarrow \mathcal{B}$ is the (partial) labelling function assigning the behavioral patterns to (some) information granules.

- S is one of the judgement strategy of J making it possible to select a particular behavioral pattern as a reaction on the perceived information about the environment. In particular, S uses in judgements granules from $Lab(\mathcal{N}^+_u(deg))$ and $Lab(\mathcal{N}^-_u(deg))$ for different deg, where $u = Inf(x)$ and x is the current state of the environment, and the labelling of these sets of granules by behavioral patterns.

- Q is the quality strategy of J for estimation of the closeness (similarity) between granules from $\mathcal{N}_{Inf}$. The closeness estimation is based on arguments "for" and "against" satisfiability of the compound "closeness" concept represented by Q. In this judgement J uses relevant granules from available granules representing accessible for J knowledge, often distributed among other judges, as well as the relationships between granules represented by matching degrees.

- *Adap* is the adaptation strategy transforming a tuple

$$(\mathcal{N}, \mathcal{G}, Inf, \mathcal{B}, Lab, \models_{deg}, \mathcal{S})$$

  into a new tuple. Observe, that judgements performed by J during adaptation can, in particular, lead to construction of some new granules (e.g., through cooperation with other judges), changing some strategies such as the matching strategy, the labeling strategy, the selection strategy for relevant behavioral patterns, an the strategy for estimation of closeness of granules.

- *Adap* can also be changed, e.g., by tuning some of its parameters.

Each judge is realizing some goals using behavioral patterns. The basic cycle of each judge is the following:

Basic Cycle of the Judge J

1. $(\mathcal{N}, Inf, \mathcal{B}, Lab, \models_{deg}, S, Q) := (\mathcal{N}_0, Inf_0, \mathcal{B}_0, Lab_0, \models_{deg,0}, S_0, Q_0)$; % initialization step.
2. $u := Inf(x)$; % is the granule representing perception by J of the current environment state x.
3. Applying S to $Lab|\mathcal{N}_u^+(deg)$ and $Lab|\mathcal{N}_u^-(deg)$ (using different selected deg) to obtain a relevant behavior $b \in \mathcal{B}$; % S efficiently selects the relevant granules from $\mathcal{N}_u^+(deg)$, $\mathcal{N}_u^-(deg)$ and performs judgements for selecting (constructing) the relevant behavior b toward achieving the current goal (target). During selection of b the judge J is also predicting the information $Inf_{pred}(b, x)$ returned from ENV_J as a reaction on the behavior b applied to the current state x of ENV_J. This is realized by a special judgement strategy of J.
4. Perceiving $Inf_{real}(b, x)$; %The judge J is perceiving the real reaction of the ENV_J in state x on the behavior b through the information $Inf_{real}(b, x)$ about the state obtained as the result of interaction of ENV_J in the state x and the behaviour b.
5. Estimation of the closeness

$$Q(Inf_{pred}(b, x), Inf_{real}(b, x))$$

   of $Inf_{pred}(b, x), Inf_{real}(b, x)$; % The judge J is using the quality procedure Q for estimation of the closeness (similarity) of $Inf_{pred}(b, x)$, and $Inf_{real}(b, x)$.

6. If the closeness is satisfactory then J continues from Step 2; otherwise J proceeds to the next step; % J uses a special judgement strategy in testing if the closeness is satisfactory.
7. $(\mathcal{N}, \mathcal{G}, Inf, \mathcal{B}, Lab, \models_{deg}, S, Q) := Adapt(\mathcal{N}, \mathcal{G}, Inf, \mathcal{B}, Lab, \models_{deg}, S, Q)$; go to Step 2;

All constructive objects involved in computations realized using the above schemes for judges are called information granules. Let us observe that the judges can have a hierarchical structure, i.e., one judge can represent a coalition of judges representing them in interaction with other agents existing in the environment. Such judges play an important role in approximate reasoning about population of agents.

One of the central problems of science today is to develop methods for compound vague concept approximation and approximate reasoning about them. Such concepts are also relevant for approximate reasoning about global behavior of judge's system. Without them we the approximate reasoning about global behavior of judge's system is becoming infeasible analogously to emergent patters in complex adaptive systems. Today, we do not have satisfactory mechanisms for discovery of relevant patterns for compound concepts approximation directly from data. However, we have developed methods for compound concept approximation using data and domain knowledge acquired from experts and performed successful experiments such as relevant ontology of concepts. Domain knowledge is making possible to discover relevant patterns for compound concept approximation. One of the greatest challenge is to develop evolutionary strategies searching without domain knowledge for such patterns. Hence, in particular, strategies for coalition formation and cooperation are of the critical importance in studying the behavior of judges. In this process of compound concept approximation and approximate reasoning about compound concepts the role of rough-granular approach is crucial. Also the role of rough-granular approach in discovery of relevant concepts for approximate reasoning about dynamics of judge's system will be more and more important. This is because rough-granular approach is offering a new modeling methodology and methodology for approximate reasoning about complex adaptive systems.