HOW TO ASSEMBLE HETEROGENEOUS MAS TO BUILT COMPLEX SYSTEMS ?

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Abstract. Some complex systems premise a particular interpretation based on heterogeneous parts identified into the system. These parts represent data processing process and decision-making process that must to cooperate. This is for example the case for robotics control, submarine or flight control and geographic information systems. To model these systems, we utilize heterogeneous MAS to built those parts and assemble them into great system. This model is called MMASS (Multi MAS System) and requires a third part to communicate heterogeneous MAS. This part is also modeled with multiagent techniques, by a hybrid and recursive MAS. This paper presents the MMASS model and MORISMA (Recursive Model to Interact MAS) applied to a cartographic generalization system, with good results. These models were applied in others systems, and the perspectives is to generalize them for a reuse in generic cases.
Key Words : multiagents systems, recursive layer, hybrid architecture, integrated reasoning.

1   Introduction

The complexity of system is related to the amount of information that we find in it. This information can be presented as a knowledge set of heterogeneous nature and heterogeneous granularity. In complex systems domain, we can identify sites where information are processed and sites where decisions will be taken from such information. It works as both data processing system and decision-making system exist into same analyzed complex system. This is for example the case for the air traffic control systems, submarine or flight control, geographical information system, robotics control etc. We are interested for the Cartographic Generalization domain, and study the information stream that circulates between data processing system and decision-making system, in order to integrate the complex system reasoning from data to decision.

The studied cartographic generalization system was developed in A.G.E.N.T project (Automated Generalization New Technology) whose objective was the automatic generation of geographic maps in substitution to the exhausting work of specialists of area. In this application domain, the data are represented by geographic objects (as roads, building, etc.) that are congregated in a geographic database, according to the information supplied for the user. The main problem in this process is to choose the best way to represent an enough number of geographic objects in a lesser surface, using symbols that preserve the object identity.

In the case of complex systems, it is necessary to consider its features and the generated difficulties for them to design the modeling process. The complex system is a nonlinear system that presents a complexity at an organizational level and whose components are considered independents with relation to the system. It generates difficulties in its interpretation process as the integration of those components in the system, its dynamics in the machine, and the evaluation of individual results from where derive the system behavior as a whole. These affirmations aims us to believe that the classic Intelligent Artificial (IA) techniques are not very adaptable to the complex systems modeling, yielding space to the distributed approach of multiagent systems, that uses autonomous entities to describe communication, autonomy and cooperation mechanisms.

The model using multiagent techniques was already a study object of [9], [3] and [4] works. An analysis of such systems can be found in [5] where concepts as recursion, emergency, abstraction levels, hierarchical and recursive architecture are applied in accordance with the objective of each system. The model that we propose, congregates these concepts conjugated in an only dynamic and flexible structure that adapt conveniently oneself to reply to system evolution.

Our study is concentrated in a complex systems range where we can identify a part dedicated to the decision and an another part to treat data system. The complex system is interpreted as a hybrid system and is modeled in accordance with the multiagent systems techniques. The problem is how to resolve the interoperability between the heterogeneous parts of this system in order to become it most efficient possible. We propose to model each heterogeneous part

as a specific MAS, and to assure the interaction between these heterogeneous MAS by a third MAS charged to reduce the complexity of existent data stream between them. The intermediate MAS or interaction MAS is a dynamic system that evolves in accordance with the constraints imposed for the other multiagent systems, adapting oneself to facilitate the data processing.

2 A Hybrid MAS Model to Complex System Conception

The proposition is to model a specific class of complex systems through the identification of heterogeneous parts : data processing and decision-making [6]. Each part will be represented by a cognitive MAS and a reactive MAS, respectively, based in works realized in the domain [2] [8]. The use of both cognitive and reactive MAS imposes the construction of an intermediate module that will serve as interaction vehicle between these heterogeneous systems. This interaction occurs through a bi-directional control flow that goes from decision to data, and vice versa. During the execution, the cognitive society sends information to the reactive layer to guide the reactive agents, and at the same time, the evolution of reactive society modifies its environment that is perceived in a different way by the cognitive agents. The exchange of informations makes to evolve the system as a whole.

The hybrid MAS model presents three levels composites by three homogeneous MAS. In the upper level, there is the cognitive MAS (SMAC), the lower level presents the reactive MAS (SMAR) and the intermediate MAS is conceived to bind two societies. The cognitive and reactive layers use different resolution methods (data-driven and goal-driven) and the intermediate layer is charged in fusing these two types of resolution. The final but is to get a hybrid multiagent system that integrates the cooperative layers - this system is called Multi-MAS System (MMASS).

The creation of intermediate layer is the reply to the interoperability question between two types of internal systems of MMASS. This layer uses a dynamic, multi-levels and recursive architecture represented in a third agent society. The recursive choice assures an efficient reduction of complexity, allowing to completing the transition between reactive and cognitive granularities by the adoption of abstraction levels. The justification of this layer exceeds the possibility of fusion of resolutions. The structure allows treat, in a dynamic way, the decomposition and recombination of information between heterogeneous layers. This intermediate layer presents a particular model called Interaction Recursive Model between MAS (MORISMA).

3 The Complex System Stability using MO-RISMA

We consider a MMASS, with its three heterogeneous MAS, as a representative model of complex system. The reactive society of MMASS in constant evolution, try to converge its agents to the final but of system. The reactive agents follow the resolution algorithms - defined by the designer - that determine its behaviors. The interaction between them occurs through the environment that also changes in the time. During the system life, diverse reorganizations of reactive layer are attempted in order to obtain stability for the agents.

At the recursive layer, recursive agents control the reactive agents. A recursive agent, observing the group that it generates, must interpret the properties that emerge of interaction of group. This emergence is seen as an evaluation of reactive group made by recursive agent according to the some observation parameters. These parameters, derived from reactive individual behaviors, are the evaluation criteria that allow translating the situation of group. Four evaluation criteria are considered with relation to the reactive group : satisfaction, task complexity, internal disturbance and external disturbance.

These evaluation criteria become parameters of recursive agents who coordinate a reactive group and must take a decision according to a specific situation. These parameters can then identify a modification in the group situation, as a noise in the organization, that must be treated by recursive agent through the activation of specific dynamic mechanisms to prevent the group instability. Or then, if the parameters not accuse any modification in the group criteria in compared with the last verification, the group maintains its state.

The unrolling of levels at recursive layer is due to active dynamic mechanisms. The question is to find the abstraction level more adaptable in organization to take a given decision. This question can aims either to a regrouping of reactive groups to increase the information gamma for the evaluation or to a partition of group to detail and to refine the evaluation. These two possibilities have, as but, to reduce the task complexity of recursive agent and for consequence, of the reactive group that it controls.

3.1 The Hybrid Recursive Agent Model

The agent model of intermediate system must be hybrid and recursive, therefore the agent must be able to interact with the agents of both higher and lower layers. The recursive agents are classified as elementary or composite. The elementary agents constitute the leaves of recursive architecture and possess a hierarchic link with the layer of reactive society. Each elementary agent controls a group of reactive agents placed in lower layer. The composite agents are agents who had suffered a decomposition and had created a new society of elementary recursive agents. The decomposition is set dynamically during the system execution at the moment where the agent becomes too complex for its task. The agent's complexity notion is defined by the system connector and is

one of evaluation criteria of recursive agent.

At the interaction level, the model must to admit a reactive interaction module (perception / action of the environment) used by agents connected to reactive layer. And also a cognitive interaction module (communication by messages between the agents) used by agents directly linked to the cognitive layer and also by the composites agents. For agent control, the model presents a self-analyzes module, which constantly evaluates its present situation (by measures according to its performance) and sets the specific and necessary mechanisms to keep its stability and to guarantee the system dynamics. These mechanisms determine the agent's capabilities to decompose, recombine and also to argue with the other agents of its society to treat a problem at its local level.

Each elementary agent has self-evaluation functions (see also [7]). It can evaluates its complexity degree ($F_{complexity}$), which evaluate if it has to decompose itself, according to principles adopted by the designer of system. It can measure its satisfaction level compared to its objective ($F_{satisfaction}$). It measures the disturbance degree due to other agents on its work, that avoid him to converge to a satisfactory result ($F_{disturbance}$). It can also evaluate its internal disturbance level through the reflection on its own behavior, which can in some situations, block its evolution ($F_{reflection}$). The values of these functions can vary from 0 to 1. However, each designer can modify these values for better evaluating of system behavior.

The elementary agent is provided with a stability function that calculates the internal state of agent (EA). The composed agent presents a stability function (ES) that is represented by observation function of internal states of all the agents of its society. The calculation of both stability functions EA and ES is shown below :

$$EA = f(F_{complexity}, F_{satisfaction}, F_{disturbance}, F_{reflection})$$
$$ES = f(EA_1, EA_2, EA_3, ..., EA_j, ... EA_n) = Min_{1 < i < n}(EA_i)$$

3.2   The Evolution of Dynamic System

The level number of recursive architecture is not fixed. This variation come from the agent's property to decompose and to recombine during the simulation, creating or eliminating dynamically groups of agents. This characteristic gives to the model its dynamic as the layer evolves.

The instability of one or more parameters can aims to a agent's state change. The self-evaluation functions evaluate these parameters and set the appropriate mechanisms. The decomposition mechanism is charged to create

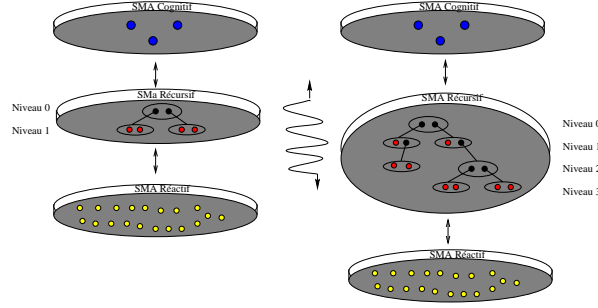| Function	Threshold	Appropriate Mechanism
Complexity	1	Decomposition
Satisfaction	1	
Disturbance	1	Negotiation
Reflection	1	Recombination

FIG. 1 – The Dynamics of model during the simulation

dynamically a agents society at a lower level formed by elements of initial group, for reduce its complexity. The situation starts when $F_{complexity} = 1$, but EA $= 0$:

$$F_{decomposition} : A_{elem} \rightarrow A_{elem} , A_{comp}$$

The elementary agent becomes a composite agent, who represents an image (local representative) of the created society, which stability function is equal 0 (ES=0). Every elementary agent, that has been created, possesses self-evaluation functions and its internal state equal to 0.

The recombination mechanism is defined at the composite agent level, which constantly have to supervise the state of its agents group at a lower level. The recombination occurs in two cases : 1/ if the created society by the elementary agent converged, 2/ if the negotiation between agents fail or 3/if exist an agent in this society that became unstable due to an internal disturbance ($F_{reflection} = 1$).

$$F_{recombination} : A_{elem} , A_{comp} \rightarrow A_{elem}$$

Mechanism of Negotiation. In the case where an elementary agent suffers external disturbances on its evolution ($F_{disturbance} = 1$), it has to initiate a discussion with other agents of its society to reaches its objective. If the negotiation has successful, the agent disturbance diminishes or even disappears, and the simulation continues. But, if it does not obtain a convenient arrangement between the agents, the negotiation fails and the elementary agent becomes unstable.

If it is unstable, the agent indirectly sets its society recombination transforming the composite agent into an elementary agent. The elementary agent inherits the external disturbance of its extinct ex-society and initiates a new negotiation. Once the mechanism activated, instability can move up to the cognitive agents of the first layer that have to verify the parameters that initiated this instability. The cognitive agents have therefore to plan again the global goals as well as the domain constraints.

4 Automatic Maps Generation System

The map generalization system was part of AGENT project - European program of research [1] - that had for objective to develop a software of map automatic generation based on multiagent techniques. To try to minimize the time expense manually with the map design and to keep the work quality, both models MMASS and MORISMA had been applied to the complex system of maps generalization, generating a dynamic system coherent with the expectations of professionals of domain.

4.1 Applying MMASS model to the System

The macro agent of SMAC The cognitive agents or *macro* agents of SMAC are charged to coordinate the homogeneity of results, activate and command the agents. Each agent in the group has a specific task in society. In this way, it exists a cognitive agent that interacts with the user to get the specifications for the geographic maps design. These specifications, following the different objectives, are related with the map topology, the map thematic or with certain parameters. The agents interact between them to converge to a global satisfactory result from each individual result.

The meso agent of recursive MAS The recursive agents or *meso* agents represent the temporary organizations of *micro* agents. These organizations are created from division process of geographic space. During the execution, changes in recursive structure can occur due to an unchainment of decomposition or recombination mechanisms.

The decomposition, in this case, is directly contingent to the urban density of organization when it exceed the threshold of complexity function. In recombination case, the mechanism is activated when, for example, a *district* group generalize itself ($\forall EA_i = 1 \rightarrow ES = 1$), the *city* recursive agent, who controls them, becomes satisfied and recompose. An another recombination possibility occurs when a *district* agent obtain a unsuccessful generalization for its group and the attempt to negotiate with its neighboring *district* agents fails. The agent becomes unstable ($\exists EA_i = -1 \rightarrow ES = -1$) producing the recombination activated by the *city* agent who controls it. Due to the dynamics of this recursive layer, the number of partition levels is not known *a priori*.

The micro agent of SMAR The *micro* agent or reactive agent belong to the SMAR and represent the most elementary entities of system : the geographic objects of real world (a building, a piece of road, a river). The generalization algorithms are attributed to the agents in accordance with its type - building *micro* agent or road *micro* agent. The *micro* agents use algorithms to interact with the environment, but by using the interactions with the organizations they determine the plans to realize and the constraints to respect. The objective of constraints is to reduce the number of possibilities which an agent can generalize a geographic feature. The *micro* agents must satisfy its constraints acting on its metric.

4.2 How the system works

The process starts translating the map specifications in a constraints set (as map dimension, the form, the accuracy, the maintenance of topology, etc) and the objectives for the agents. After that, it is necessary to make an analysis and an evaluation of these objectives and the current situation of an agent to generate decisions. In the following stage, it is necessary to evaluate the satisfaction degree of all agents through the measures of constraints. As a complex environment, the measures are taken at an agent level and at an organization level (recursive agents).

The recursive MAS is created with elementary agents representing the possible phenomena to be joined in the system, as for example the referring phenomena to the roads or to the building. Every phenomenon controls a part of map. Every recursive agent starts with $EA = 0$. They receive a message from cognitive agent with the order to start the generalization according to parameters supplied for this generation. The decision cycle of recursive agent follows the following order :

$$< Mag_i,\ mAg_0,\ \text{ORDER},\ \text{Generalize-Districts},\ Param_i...>$$

1. *Integrate news values of parameters*
2. *Evaluation of $F_{complexity}$*
3. *An important density aims to the map partition, it means, to decompose dynamically the agent mAg_0 to reduce the complexity process. It sets the decomposition mechanism and the partition process is initiated under a road linear objects group.*
4. *Creation of $mAg_{1.i}$ corresponding to each partition*
5. *Assignment of reactive agents to $mAg_{1.i}$ charged for theirs partitions*
6. *Sending of generalization message to the $mAg_{1.k}$.*

The recursion process is initialized and continues until it forms an initial partition that assures a reasonable complexity with relation to the parameters given by the cognitive layer. The recursive elementary agent command its group of *micro* agents to generalize by sending a sign in its environment or through the modification of theirs parameters.

4.3 Generalization Problems

In this application domain, the problem is concentrated on the geographic object control issue from database, in accordance with the specifications supplied by the user. The generalization consists to apply generalization algorithms to all the geographic objects of map, include to the neighborhood ones. With relation to the road problem, the high density of roads and the proximity between them aggravate the legibility problem. Therefore, as the local knowledge is not
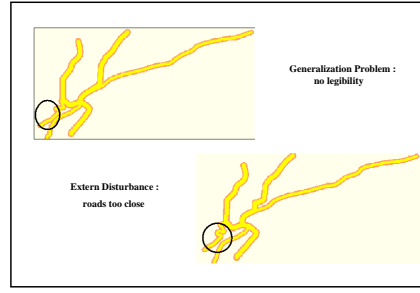
FIG. 2 – Problems of road generalization : high density and low legibility

enough for the generalization, it is necessary to make use of different types of representations in different levels.

These representations, called *phenomenon*, are geographic entities formed by geographic objects groups. The *phenomenon* concept was introduced in analysis phase of design and, it was modeled and implemented according to model MORISMA. The figure 2 presents a part of map with diverse roads. In the first image, the local generalization attempt fails : the generalization gives two roads too agglutinated. The local knowledge of *micro* agents is not enough. It is necessary to have a vision in an upper level to generate all requisite information to get a good generalization. Recursive agents will supply different levels of abstractions through the dynamic reorganizations applied on the reactive agents. It is the recursive agent interaction that will try to converge the generalization problem.

The same occurs if *micro* agents tries the local generalization in the boundaries of partition : they can fail. It occurs due to a bad decomposition or to an effect exerted by partition limits on the *micro* agents. That implies in making-decision process of others *micro* agents placed in another partition. Consider the case of two buildings that are located in opposing sides of a river that will be generalized (see figure 3). Assuming that *micro* agent 2.1 for the local reasons, wants to move the river for the left side. This action cannot be carried out without implying in modifications on *micro* agent 1.1 and therefore, on all *micro* agents of partition 1.

The recombination mechanism allows two options : either congregate two partitions by the fusion of two *meso* agents, or to set negotiation mechanism between two *meso* agents implied and modify the parameters of *micro* agents to get a satisfactory bordering generalization.

The mA_{g1} detects its society instability due to the $F_{disturbance}$ function. It then builds the society image to be able to make use of the necessary informations
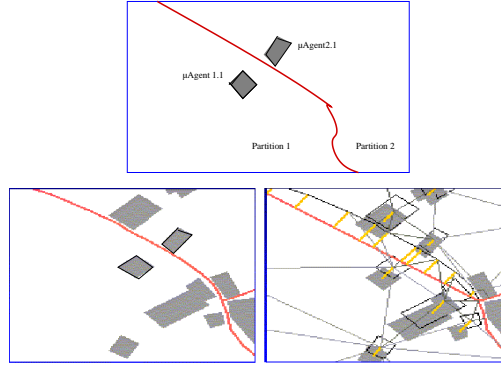
FIG. 3 – Problem of road generalization

and starts a interaction process with mA_{g2}. This negotiation allows to decide the application of new operators of generalization for the *micro* agents or to eliminate some of them. In the failure case, mA_{g1} become unstable (EA=-1), which provokes the *meso* agents reorganization at upper level. In the successful case, the agent is not *disturbed* anymore (card($F_{disturbance} < 1$)) and retakes its execution state (EA = 0).

The two agents suffer a external disturbance (one hinders the other to carry through a good generalization) what it sets negotiation mechanism. As result, either the negotiation is successful and the parameters of *micro* agents are modified, what it allows to find a satisfactory generalization. Or then, the negotiation fails and the recombination mechanism is set in motion. The society of elementary agent recompose and the composite agent became a elementary agent who will try a negotiation again.

4.4   Conclusion

This methodology contributed for agents development. The *micro* agents executes different algorithms and can either to keep the result if that suits them, or to abandon it and try a new algorithm. The *meso* agents coordinates the generalization, avoid eventual conflicts and keeps the global consistency of system.

The advances generated by the application of both MMASS and MORISMA models to AGENT generalization system, even applied partially, brought contributions at a cartographic level and at a analysis system level :

- contribution for a better definition and application of the *Voyelle* method for systems design ;
- first great MAS application in the GIS domain ;
- profit, at a quantitative level, referring to the map generation ;

– the method demonstrates that a coherent strategy has a better adaptation to resolve complex problems than a strategy based on atomic commands (as used in the concurrent systems).

The joint application of this two methods was already tested in another system (Fire Control Simulation), now integrally. The objective is to allow an another Modeling Approach for complex systems, respecting the existent heterogeneity, its inherent dynamics and the autonomy of its different components.

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