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A multi agent modeling approach for an adaptive regulation in large scale complex systems

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***Abstract*— We deal with self-adaptive systems where each local entity has autonomy in the way of strong coactivity with others entities to make the emergence of a coherent general state of the complete system. The paper focus on the architecture of a self adaptive system based on massive multi agent systems. The system allows the monitoring and on-line restructuring thanks to ontology. It is dedicated to a complex system with continuous flux of information.**

***Keywords*—adaptive systems, massive MAS, multi-scale systems, morphological control, on-line systems.**

I. Introduction: The Concerned Domain

Nowadays networks and devices technologies are getting more and more advanced and their growing complexity allow people and machines to be connected in all the situations. Communications between people and/or machines are important . In many domains we observe an uninterrupted flux of information to complete the knowledge of the domain. It is the case when we deal with organization of autonomous robots [1, 2]. The robots have to take into account their environment and their tasks. Crisis management [3] is another example where the firemen and their colleagues need to coordinate their activities and decisions and to act in real time while receive a large amount of data. We are interested in studying the operation of such a large dynamic system in real time using simulation. The challenge is to define a model and simulate it to control the activities of the complete system. In this paper the modeling of such an organization using a multi agent system for applications such as those in transportation and logistics is discussed. The system we propose can be modified on-line at the knowledge level with automatic generation of agents but without development of any code. This paper is more accurate and complete than precedent versions.

II. The Self Adaptive System: The Objectives and the Knowledge

We have developed a system to manage dynamically the behavior of a team of autonomous robots without building any new model nor modifying any software, when a human supervisor wants to modify the knowledge and emotions of robots [4]. This work follows the Brooks approach presented in [5, 6]. using the adaptive architecture [7]. We are interested in distributed systems that manage very large flux of information for the control of numerous activities, assuring the coherence of each local activity with the global state of the system activities.

This requires solving the control problem of a large number of autonomous entities focusing on-line coordination of all the local activities.

We deal with self-adaptive systems where each local entity has autonomy in the way of strong coactivity with others entities to make the emergence of a coherent general state of the complete system [8]. This constraint of strong coherence between non-homogeneous entities leads to a fine control using the dynamic links between the actions of the local activities and the global situation, passing from actions of aggregation or recession of the local entities. Fig. 1 gives a global view of the entire proposed system.

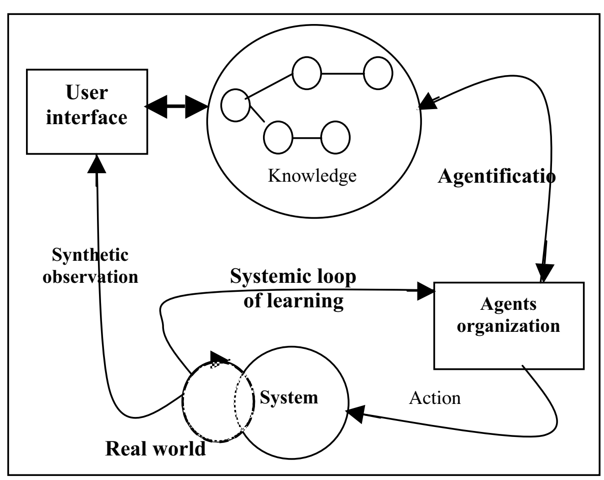

Figure 1. Global view of the complete system

In our approach, a self-adaptive system is a system composed of two different but strongly linked layers [9]. Fig. 2 shows the two layers linked to the real world. The semantics and the knowledge of information entering into the system are expressed and evaluated for its tendencies. The description of these layers is:

- Operational layer is for interpreting and managing inputs and the reactive effects and for logical and rational automatic actions.
- Distributed control layer is for representing the current action of the system in its environment, and for controlling the operational layer according to a set of predefined general characteristics.

The system is active with predefined general goals and tendencies with the means of its structure. The control layer represents a precise description of the current situation generated from the flux of information. The information is analyzed by the elements of the operational layer with the objective to react under its good tendencies. This control layer is constituted of many entities in permanent action of reorganization, adapting it internally to make the emergence of the pertinent local actions to make on the environment, in the light of a coherent global action.

Such a system must continuously construct representations of the whole events of the environment according to reasons that will be its own, according to its specific situation of action into this environment. The notion of representation, the internal distributed object continuously constructed, that represents a general plan of action declined into many sub-plans, is fundamental. So, the notion of adaptivity is considered in the strong way therefore. In the specification of the system, the determinants of this representation allowing reaction into an adaptive way are defined first, according to the capacity of action of the system and to its general tendencies. They precise the very general goals of the system, its fundamental characters for its choice of regulation. The system has to solve many sub-problems under the focus of a general goal specified by the current representation of the situation. Then, the system conceives a representation of the real situation from the operational layer under some fundamental tendencies, it elaborates some local plans, generates a global and an unified plan of action using synthesis and emergence, and acts on-line, continuously analyzing the effects of these actions.

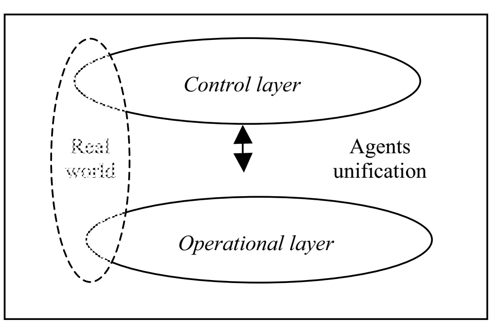

Figure 2. The two layers

For construction of such a system, decomposition into precise functional parts applying optimization functions are needed. This is because the active parts have roles that evolve during the plans generation and the global situation has no stable state. The fundamental property of such system is the continuous re-organization of its operational layer that allows generation of on-line plans according to the general representation. For these reasons, the multi-agent paradigm is used at all specification levels of the system's architecture.

III. Agentification Approach

The basis for construction of a system is the agentification of the knowledge and the global goals and tendencies that allow the activity of the system in its dynamic environment to be effective. The proposed system architecture is made of two distinct layers using agent's organizations. They consist of Aspectual agent's organization and Morphology and Analysis agent's organizations (Fig. 3). These organizations express the representation and intention of action or reaction of the system in the current environment while satisfying of the general goals and tendencies, which are actives at each moment. The analysis agent's organization achieved with these specific agents allows a kind of self-control of the system's behavior.

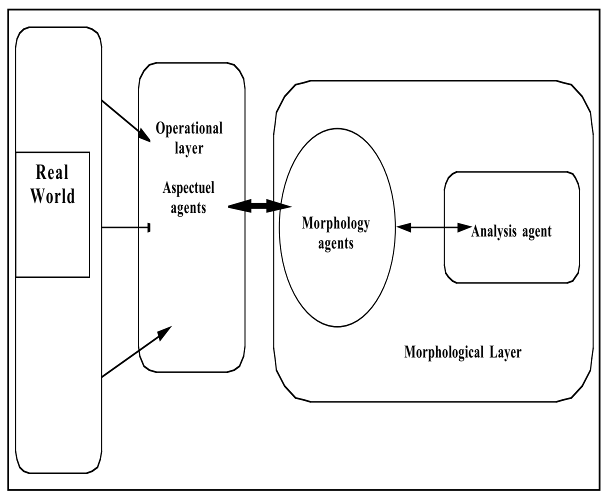

Figure 3. The three agent's organization

Each agent of the operational layer that operates at the system interface level takes the information from the outside and transmits its logical interpretation via its accountancies to inner agents. In this way, each captor of the physical part of the system is linked to many agents for realization of numerous interpretations.

We consider any agent like a software entity that:

a) is autonomous,

b) has some rational/logical knowledge and precise goals,

c) has social faculties and uses accountancies to link with others agents, *d) is reactive (really pro-active) and is able to redefine goals and take some personal initiatives.*

This autonomy leads one to consider the agent like a small set of processes, like an entity, that are able to execute a set of instructions in its context. The social faculties of an agent is the possibility of coactivity with others agents using its accountancies. The main activity of the agents is their aggregations into strong and coherent groups to develop common and to coordinate local plans. The use of agent type drags the existence of agent groups in order to achieve the negotiated common goals. The notion of pro-activity is fundamental and comes back to introduce in the agent the notion of intention and modification of its own goals, when it analyzes the effects of its actions.

IV. Aspectual Agents: the Operational Layer

The operational layer, in the system's architecture, is used for the reification of the information exchanged with the outside. Such information, which is a continuous flux that comes from non-homogenous sources, is called Informational Data. The operational layer is used for the construction of the current representation that allows actions. The agents of this layer are called Aspectual Agents. Where ontology reifies their semantic traits; their implicit relations are taken out of the Informational Data [10]. Because there are numerous sources of non homogenous information behavior of the elements of the environment are numerous and they use multiple causal relations, we have a very important number of aspectual agents.

This agents' organizations and its continuous relation with the outside of the system have numerous communications between themselves and entail the emergence of some specific shape expressing the current representation for the actions into the environment.

First, we have a large domain of ontologies and historic knowledge and we obtain several hierarchies of knowledge and meta-knowledge allowing to precise the situation of the domain to manage [11]. For the aspectual agentification, we extract from this knowledge about the domain and taking into account the objectives of the system, the pertinent characters for the analysis of the situation and for the action called semantic traits.

Second, from this knowledge, we use a specific agentification methodology for the transformation of the knowledge in the dynamic way of agents' organizations [7]. We extract from knowledge the pertinent characters. We call such characters the *semantic traits*. A semantic trait is a specific knowledge having a category, many specializations and many links to other knowledge. We associate with each semantic trait several agents called the *aspectual agents*. The latter express dynamically the pertinence, the activity and the relations of a semantic trait. We obtain in this way a massive multi-agent system of aspectual agents.

Each information entered in the system has the form of some numerical data: an Informational Data. We first apply a categorization about this information. In fact it is a categorization of the perception of the environment by the system itself with transformation of information into knowledge, such as the images and sounds the system can perceive. We use, for this *a priori* categorization all the well-known ontologies of the domain.

For each input, we obtain many semantic traits in the form of activity of aspectual agents that express the characters of this relative used knowledge. Each semantic trait is expressed with several aspectual agents for matching with the semantic trait. Please note that a semantic trait is matched with many aspectual agents such as the well-corresponding agents, the converse agents, the proximity agents and so on. They may be perceived like a cloud made of a dynamic group of aspectual agents around the reified semantic trait (Fig. 4).

The aspectual agents are in charge of reifying semantic traits that are extracted from the information passed by the inputs provided by the system captors. The semantic categories are not isolated from each other but are linked in each agent using a semantic proximity matrix. This matrix is expressed by the ontologies that the system can modify while it is in use [7, 12].

This aspectual organization will grasp the communicational data in order to extract its characteristics. The aspectual agents represent, by their actions and pro-action, the emergence of semantic traits relative to the current situation, taking into account with the proximity with the others previously expressed semantic traits. The memory of the system is in the state of the aspectual agents organization. Each agent expresses characteristics and partial signification about the situated information contained in the communicational data. Meanings of all the current communicational data are expressed with the formation and transformation of groups of aspectual agents [13].

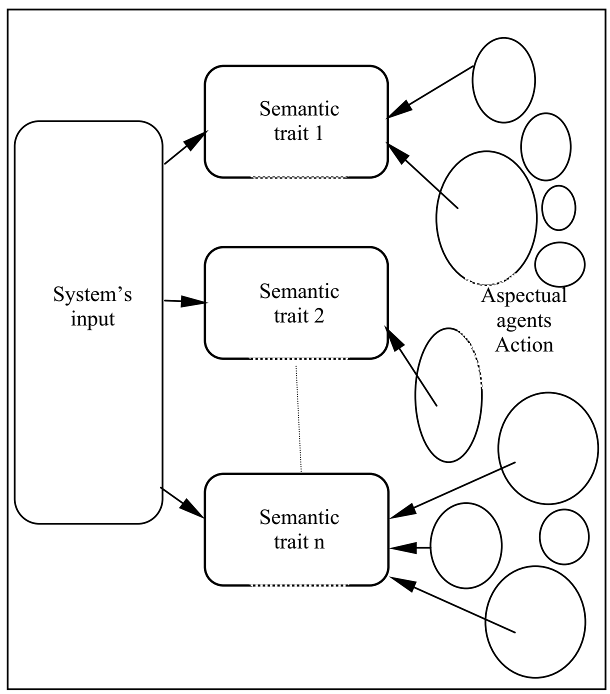

Figure 4. Semantic traits and aspectual agents

V. Morphology and Analysis Agents: The Control Layer

The objective of the second layer is to exhibit the proper shape expressed from the activities in the first layer and to operate in a fine and multi-scale control of the agents' activities which leads into mergence of the current representation.

This layer is made of an agent's organization called the Morphology Agent's organization. This agent organization creates something similar to a "system's concern". As it is hard to follow the activities of a very large number of active aspectual agents, we therefore study them as a whole using metrics for activities. A geometric way allows distinguishing shapes and forms in their actions and interactions. Morphology agents use those shapes and forms to give a view of activity of the aspectual agents used in Agent's Landscape [3]. The role of these morphology agents is the interpretation of the activity using the relations between agents that represent the semantic proximity of the reified categories. We study the structure of the agent's activities in a specific space according to their typical characteristics.

In order to explain the behavior of an aspectual agent's landscape, we can describe the activity of these agents in a nine space dimensions called the morphologic space where the axes are:

a) Organizational distance: This is the state of the agent compared with the state of the complete organization of the agents.

b) Velocity: This is the speed an aspectual agent has developed so far.

c) Facility: This is the ease with which an aspectual agent has developed so far.

d) Supremacy: This is a measure of the ratio enemy allied of each aspectual agent.

e) Complexification: This is a measure of the evolution of the components of the agent and their links for forming a simple or a complex.

f) Communicational stream: This is a measure of the frequency and intensity of the agent's communications.

g) Intensity of the internal activity: This is the expression of the exchanges between the inner components of the aspectual agent before any action by the external agent.

h) Persistence: This is a measure of the lifetime of the agent.

i) Dependency: This is to express whether the agent is free or depends on others.

The morphology agents generate forms in the morphologic space. Each point in that space is a morphological character of collective agent's activity, where the activity of a group reifies an aggregation. The groups, (there are many groups with problems of supremacy) can move, act, communicate, aggregate, and transform making the domain dynamic (Fig. 5). This point of view, in a dynamic way, generalizes the CPA (Component Principal Analysis) which is the classical statistical method used widely in data analysis and compression.

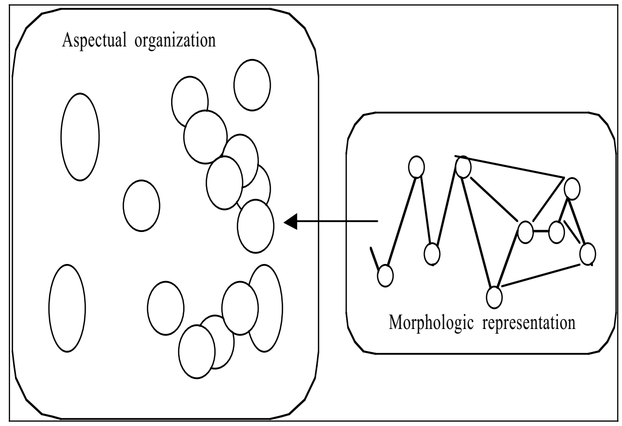

Figure 5. The emergence of aggregations from the aspectual agent's organization.

Some of the morphology agents, using specific metrics, can aggregate into structures that will lead into the general representation. They provide all the specific characters of aspectual agent's organization activities. These aggregations of morphology agents use some metrics of the morphology space. The morphology agents have some peculiar reading, which is part of the interpretation of the organization of the aspectual agent's landscape and aggregations (Fig. 6).

Using the characters of the morphologic space, we can determine the main semantic characters of the aggregation of the aspectual agents' operational layer. The analysis agents are used to act on the morphology agents. By matching the shapes in the morphologic space, an analysis agent tries to exhibit specific characters in a semantic space which corresponds to the interpretation of the knowledge in the environment and the time for building partial plans using classical optimizations functions. An analysis agent has to cooperate with other analysis agents to generate, cooperate, and solve the conflicts. This is a significant representation that corresponds to the global position of the system action in its environment.

In order to cooperate the agent societies have to communicate with each other. Direct communication can be employed when the number of agents involved in the interactions is not large. However, as the number of agents increase, the number of links between agents and the quantity of information exchanged between agents becomes complicated, creating serious problems such as coordination and control [10].

In previous work, we have studied the cooperative problem for solving processes. Some of the approaches have been provided in our previous work in [14]. We have presented in [15] a simple and flexible model that is capable of responding for the two extremities of multi-agent systems (self-interested agents and cooperative agents). The majority of existing works are focused on one of them. There we have also presented all aspects of the cooperating processes, ranging from recognition of the potential to cooperation for execution. In the future work, we plan to integrate the cooperation of the multi agents' cooperation for the implementation of the present work.

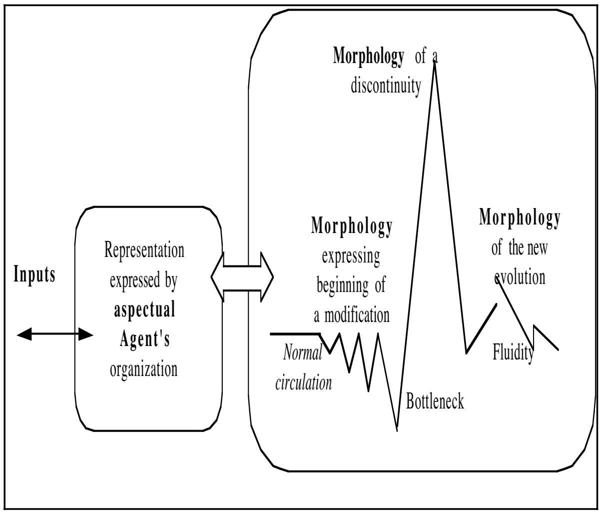

Figure 6. The morphology of aspectual organization in the case of a management system of traffic

The analysis of agent's organization reacts directly with the aspectual agents. This assures a global systemic loop, modifies the action of the aspectual agents organization, and the forms the aspectual agents' aggregations. This systemic loop is the inner control of the system, which makes the system adaptive. The three strongly linked agents' organizations set up a self-adaptive Representation System for its behavior.

Finally, we have a current representation for expressing the state of the system reaction. We have always a representation and the current one is a modification of the previous one. The systemic loop changes the expressing of continuity or bifurcations. This Representation assumes a conceptual representation of the current situation of the system at the knowledge level. We must also find a representation for the present and future situations according to some logical rules. Such representations should also include some inner intentionality to express the tendencies of the system.

The current and the predictive analyses of the morphology agents are, in fact, analyses of the dialogic situation between the system and its current environment. This interpretation is based on the analysis of the geometrical aspects of the morphology of aspectual agents' landscape using projection into the semantic. This is the morphologic hypothesis that was set up and used.

An analysis agent is a rational cognitive agent that acts as a local and focused knowledge base, the expression for knowledge general rules and behaviors. This agent tries to match the shapes in the morphologic space to generate specific characters in a space corresponding to the knowledge of action from the environment by building partial plans. This is an agent that cooperates with other analysis agents to generate a significant scene , by co-operation and solving conflicts. The conflicts correspond to the situated position of the system in its environment.

The analysis agents, by emergence, exhibit the semantic characters of the current situation of the system in its current environment. This is because the aggregations are linked with aspectual agents that can be recovered by the semantic traits. Once the predictive analysis completed, we have the current analysis and a set of possible future landscapes. However, the predicted futures are not pertinent. Thus the previously predicted aggregations with current aggregations need to be matched in order to validate the prediction. The system operates in a self-learning loop. It refines its predictions by having more reliable knowledge of the evolving events of the agent aggregations.

VI. RESULTS AND CONCLUSION

The present work shows how to build a self-adaptive system based on a massive multi agent system idea for complex systems. This system has been currently implemented in a prototype that we plan to improve its capacities based on the current work. The cooperation between agents and the issues on the distribution of the system are main research activities in the future.

As an application of such a system, we experimented with the first developed prototype. This involved the analysis of the discourses of the decision-making in management of crisis situations. The task was building an understanding of a dynamic and conflicting situation that was perceived by a Representation System through exchanged messages. These messages can be potentially incoherent or conflicting. To achieve this difficult goal, we proposed an original architecture for the Representation System based on the morphology of the behavior of a very large distributed aspectual agents' organization. They were evaluated by an analysis using a morphologic organization.

We transposed and applied this model for the construction of the system and representation of the world for a team of autonomous adaptive robots. The robots can express their intentions on their situated position in its current environment and act using their intentions.

Currently, we are considering the application of this approach in transportation and logistics systems that seems will be well suited for the hypothesis of the present work. We study nowadays a global system of management of traffic in city, to provide in real-time the state of traffic to the drivers, with the best way and the time out for precise destinations. The system must also allow the automatic management of signalization lights to regulate in real-time the stream of vehicles in the city. On this subject, we develop a more definite application for the management of teams of collective taxis, allowing to link by a real-time system of information, the users and the drivers. Another work under progress concerns maritime logistics particularly in the management and tracability of containers.

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