Conception of large multi-agents systems using statistical analysis : application to the behavior of complex social systems

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Abstract

We deal with systems using massive multi-agent organizations and expressing complex problems like the representation of behavior of social organizations. We propose an analysis and an operating representation of multi-agent organization in a geometric way, using specific multi-agent organization in a morphologic agent space. We propose also an architecture expressing the behavior of the massive multi-agent organization. So we open the way to the implementation of self-adaptive systems. We present an application for prediction of the migrations in a very large city.

Introduction

We study complex social organizations modeled with very large organizations of agents. More precisely, we are interested with simulation systems involving a very large amount of software weak agents. For instance, a significant example is provided by a system expressing the behavior in space and time of social organizations in a large city. In usual case, such a system is build with a centralized intelligent control of its inner information stream. This approach of the problem is clearly a strong reduction. We propose a distributed model using a large amount of software agents expressing the significant dynamic parts of the real phenomena. All the parts of the system are expressed using variable groups of agents and all the parts are in a loop of co-evolving process.

The structure of the simulation system is built using ontology. Thus, by expressing all the knowledge of the domain, and all the concepts and their relationships, using statistics tools, we deduce the elements of action, functionality, movement that are expressed with several kind of agents. Each of these agents is simple, weak like, rational, and strongly bound up with some others [10]. Using a specific agentification method we describe in this paper, we obtain a massive multi-agent system expressing the dynamic evolution of the phenomena. And, meanwhile the system is running, some agents can be created again, increasing the complexity of the organization. We are in the case where the organization of agents is a like a very complex and dynamic system, where the basic elements are active and pro-active, as always agents are. And such an organization can be distributed on networks of computers (Axelrod 1997).

The behavior of the agent organization is made of actions, communication, transformation of agents, and also creation and death for some agents. Then, the main problems are the representation of the behavior of such a large dynamic organization, and also its control. We think it is possible to express the global state of the organization, but the external control in real time is positively impossible: we can only have an inner control, by the system itself on its organization. We propose a way for the representation of the behavior and of the inner-control of the agent organization. The architecture we propose is build upon the agent organization and is strongly reacting with its organization make clearly a self-adaptive one.

At last, such a system provides a way for the real time evaluation of all massive multi-agent systems. We propose a model based on specific multi-agent architecture, grasping the initial agent organization, supplying a geometrical representation of the current state of the agents of the organization. Then, such a system expressing its self current state can situate its organization in the evolution of groups of agents, can appreciate the state of the distributed organizations in the case of a distributed system and, like that, can modifies in real-time its behavior. Such a system is self-adaptive in its behavior, like the social behavior in large cities.

The paper is organized as follows: section one outlines our proposal, section two describes the proposed system architecture, sections three presents the knowledge acquisition, sections for and five detail the components of the system architecture, section six and seven expresses the notion of morphology of agent organization and finally section eight presents the conclusion.

Proposal

We have to study the complex social problem of the migrations in a large city and we are looking for a behavioral model simulating this problem in time. A statistical analysis founded on census provides a lot of significant characters and of groups of characters. Using these analyses, we have to study the dynamic evolution of the phenomenon. We use an agent approach founded on massive multi-agent system. The agent organization represents, by a specific agentification method, an accurate knowledge about the behavior of the phenomenon. We consider the behavior of this agent organization as a dynamic system in time (Rocha 1997). So, we have to express the specific space where this dynamic system is well defined. We have to find the dimensions of such a space. And we have to compute the conformation of the organization in such a space, which is in a geometrical way. We set up a geometrical hypothesis about the agent organization.

We use, for the description of the agent organization, the notion of geometrical form in a specific hyperspace. And we have to compute the geometrical forms in this geometrical space in a dynamic way again, using specific agents rather than vectors and points as in mathematics. We express the behavior of the agent organization with an other agent organization, the so-called *morphology organization*. Then, we analyze this second agent organization with a third, the so-called *analysis agent organization*. This last agent organization computes, in the terms of the first agent organization, which is at the knowledge level in the system, the meaning of the behavior of the first agent organization. We set up a systemic loop from the first agent organization to its representation in the terms of the third agent organization. And this third agent organization can have an influence on the first, can control the first, and can operate the self-control of the behavior of the system.

So, we propose a general software architecture, so called a Representation Sub-system, wrapping the behavior of a large primal agent organization, the so-called aspectual agents, computing and delivering the local and global aspects of the current and future state of all the agents' groups in the primal organization [cf. figure 1]. This software allows the expression and the realization of the self-control in a system founded on a large agent organization.

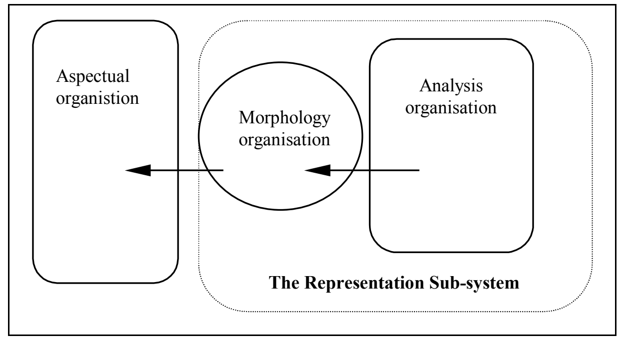

Figure 1. The system with its Representation sub-system

Knowledge acquisition and statistical analysis

The described architecture will be applied on the analysis of urban dynamics. A case study is carried out, about intra-urban residency changes along one generation in a large city in a developed country. We are interested in the residency mobility, its implications on the housing market and the urban modifications they improve. We have to deal with the modeling problem in a dynamic way of the transforming processes of the urban space taking into account the residential behavior of the households. The objective is to identify the preferential links which with certain types of households make correspond specific categories of residences and reciprocally. It is also to follow the evolutions of these links, taking into account increasingly complex recombining of the families and their residential courses.

For that, it is necessary to seize the interactions between households and housing. But these levels of definition of observation entities are too fine making the system of study too complex. One thus makes the choice work on agglomerates of households and residences. The objects of observation are contrasted social groups and types of habitat for which it is question to follow the evolutions and their interactions over one period of a generation and on the scale of the district. These objects are built on the basis of several descriptive criterion starting from typological multidimensional analysis: the social groups are defined by the socioeconomic characteristics of households, the types of habitat by building materials, the capacity of greeting and the access to the public services of the residences.

The question of permanence of these evolutionary objects is of primary importance and remains a true methodological problem. It is a question of being able to apprehend the manner: whose groups of individuals migrate collectively or are done and demolish themselves over several periods; whose types of housing change on a same space, whose objects evolve/move in time in order to be able to ensure their follow-up? It is then question to develop a simulator of urban migrations under the paradigm agent, which is well adapted to the dynamic of the problem.

We use data from different census. We can have several advantages of this data acquisition: the databases of the census provide general information on the households, the individuals composing the households and their housing, representative of the potential units of observation. This information is standard and easy to access; indeed, it allows covering the whole town.

To establish those groups of households and housing we use typological method (Lebart, Morineau and Piron 2000). We carry out a behavioral analysis from all the characteristics of the population. It allows marking out a fluctuating and continuous set of data concerning the population of the city, to seek specific structures and organizations and to define patterns of them. Groupings of households constitute fuzzy forms with dubious contours. That is enough to observe the tendencies, to formulate assumptions on residential mobility and to produce indicators. In a context of simulation, this offers several advantages: to consider the basic unit, to take account of a great number of variables, to consider the crossing of the types of residences and households, to obtain syntheses on the various behaviors of household, their habitat and their space distribution. It is possible thus to vary the granularity of the level of observation; the principles evoked previously allows adopting a global and synthetic solution initially and to refine with the sight of the results until reaching an " optimal " granularity (i.e. below which one obtains a too great complexity of behaviors).

The typological analysis is carried out on more than one million households of the city. Twelve characteristics of households are used: sex, age, birthplace, place of previous residence, frequentation of a school establishment, level of study, number years in the sum of money level of study, matrimonial statute, has worked the week previous the investigation, statute in the activity of the week previous the investigation, statute of occupation of housing, number people in the household. Twenty other variables (localization, the characteristics of housing and the equipment of the households) are used to illustrate and to enrich typology. It results in 9 typical classes defining 9 social groups

Those groups are different according to social characteristics (level of study of the head of household, activity, number of people in the household) which define three types of social classes:

- an upper class, very specific and strongly structured, with by a higher study level and executive status;
- a middle class with a secondary level, employee status and having 4-5 people in the household;
- a popular class with primary education level, an independent statute and having more than 5 people in the household.

Gender of the head of household contributes to differentiate these groups: there are two subgroups of the middle class according to this characteristic.

Lastly, the age of the head of household has to be taken into account in the typology to represent a relatively traditional cycle of life: the young people are unmarried or live in free union and are tenants; the illiterates and reprocessed are old people.

The combination of these three principal characteristics defines 9 social groups. Details are given in table 1.

Upper class: These households are headed by a man, married, living in apartments of residential zones
Young man: These households are headed by a young man, living in free union, with secondary level, employee and tenant of a precarious habitat in a under equipped zone
Middle class, man: These households are headed by a married man, with secondary level, with an independent activity or boss statute, becoming owner of a house in an equipped zone
Popular class, man: These households are headed by a man, with primary level, with an independent activity statute, living in couple with a large family, owner of a house in an under or not equipped zone
Illiterate: These households are headed by a old woman, illiterate, without activity, owner of a another housing in an under or not equipped zone
Young woman: These households are headed by an old woman between 35 and 50 years, divorced or separated, employee, with secondary level, tenant of a precarious habitat in equipped zone or not equipped zone
Middle class, woman: These households are headed by a woman, rather old, widowed or separated, domestic, with primary level, owner of a house in equipped zone
Woman without activity: These households are headed by a woman rather old, widowed or separated, domestic, city nonnative, with primary level, owner of a house in equipped zone
Retired: These households are headed by an old man, retired, with primary level, married with a large family, owner of a house in equipped zone

Table 1: Groups of households

Housing can shelter several independent households. We retain the characteristics of building materials and the access to public services; the analysis gives five types of housing standing out a quality scale of habitat (precarious or no precarious) and public equipment (electricity, water and drain; electricity; no equipment):

- Apartment in equipped zone;
- House in equipped zone;
- Precarious lodgment in equipped zone;
- House in under or not equipped zone;
- Lodgment in not equipped zone.

But if working on the data of censuses produces profiles of traditional and generic individuals or households and fig a permanence of the groups, it is not true for the housing; in twenty years, the evolution of a town is important. So we may take into account permanence or instability of behavior of households and housing.

System general architecture

An important characteristic of knowledge in communicational situations is its inherently dynamic nature. We have to express the knowledge coming from statistical analysis into agent organization. We build a so-called Representation System, modeling the behavior of the phenomenon.

The architecture we propose for the Representation System, is made of three distinct layers [cf. Figure 2]:

1. The first layer reifies information and knowledge of the phenomenon: they are coming from the statistical analysis. We call this information the *Informational Data* (ID). An ID is a set of data, in the form of numerical data, from the real world that the Representation System will take into account and will treat. In the case of social behavior, these data are all the knowledge extracted from statistical analysis and forming a large set of linked semantic traits. The agents of this layer, called the ***aspectual agents***, reify the semantic traits pulled out of these data and the explicit and implicit relations between these semantic traits. All these agents provide from the ontologies. They will communicate among themselves and entail the emergence of some shape. In fact, we obtain a large dynamic set of elementary knowledge, each element having the ability of communicating with some others.
2. The second layer made of so-called the ***morphological agents***, will have to reify (or "thingify") and to exhibit the shape expressed from the previous layer. This agent organization creates something similar to a "system's concern".
3. The third layer will in turn rationally work on what has been highlighted by the morphological agents. It is an architecture concerning self-organization; compound of rational agents called the ***analysis agents.*** At this level, the agents express the signification of the global behavior of the first level agents in theirs terms, so at the knowledge level for the system.

These three levels, of aspectual, morphology and analysis agents, express for the system, the representation of its situation in the current environment. And this representation, with its analysis achieved with the third agent organization, allows the self-control of the behavior of the system. For this, the systemic loop has to run fastly.

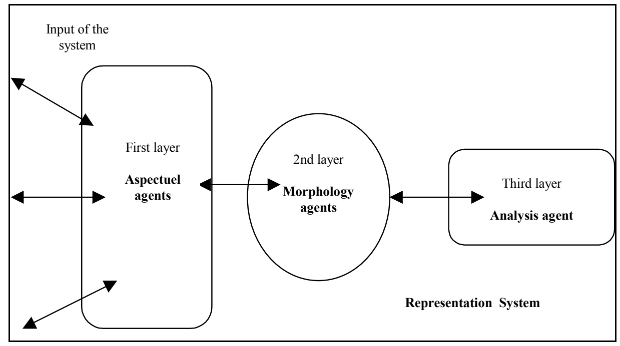

Figure 2. The three agent organizations

So, we have three organizations of agents wrapping the effective information entering in the system. The organizations appreciate the semantic and the knowledge of all the information from the outside of the system and express its situation, its situated position in the environment as an action space. We now describe these three organizations.

The aspectual agents

The basis of the construction of the system is the agentification of the knowledge and functionalities needed for the “putting into situation” of the system in its environment. We have a lot of knowledge about the problem w have to solve and coming from ontology, and the things or parameters coming from the system' environment.

First, we use one or many ontologies for the knowledge extraction, in a classical way. For that we can profit of the statistical analysis about the situation we have to express. So, we obtain several static hierarchies of knowledge and of meta-knowledge (Lenat and Guha 1990).

Secondly, from this knowledge, we use an agentification methodology for the transformation of the static knowledge in a dynamic way using software weak agents (Collinot and Drogoul 1996) (Cardon 2000). In fact, we extract from knowledge the pertinent characters we called *semantic traits*. We associate at each semantic trait several agents we called *aspectual agents*, expressing dynamically the pertinence 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 symbolic and numerical data (an Informational Data).

We first apply a categorization about this information, in fact a categorization with transformation of information into knowledge as, for example, with the images and statistics the system can use. We use, for this *a priori* categorization, all the well-known ontologies of the domain.

Then, we obtain, for each information, a lot of semantic traits expressing the characters of the relative knowledge. Each semantic trait is expressed with several aspectual agents matching for this semantic trait. We can notice than for a semantic trait we have a lot of aspectual agent matching it: the well-corresponding agents, the converse agents, the proxy agents and so on, expressing like a cloud made of a dynamic group of aspectual agents around the reified semantic trait [cf. Figure 3].

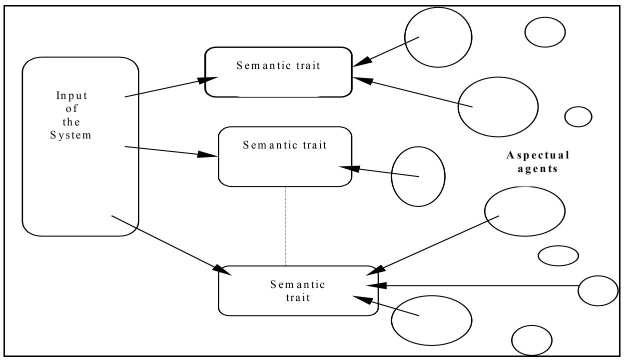

Figure 3. The aspectual organization upon the semantic traits

The aspectual agents are in charge of reifying semantic traits pulled out the information passed by all the input expressed with the system captors. The semantic categories are not isolated from each other but are linked, in each agent, with the use of semantic proximity matrix, expressed with the ontologies, and that the system can modify in use.

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, the knowledge of the system is into the state of the aspectual agent organization. Each agent expresses characteristics and partial signification about the situated information contained in the communicational data and the meaning of all the current communicational data are expressed with the formation and transformation of groups of aspectual agents (Cardon 2000).

Agentification method for aspectual agent organization

At the conception step of a massive multi-agent system, we need to define the basic categories of knowledge for aspectual agents, with regard to the functionality of the system. For example, for social behavior, we need to define the categories providing the movements of the households, such spatial and temporal categories. We lay down the hypothesis we can build the system from a generating agent organization. This generating organization is build with little specialization, with essential categories, systematically taking into account the opposing characters of various categories from the ontologies. Each agent reifies a semantic trait in a category. For each created agent, we create and associate opposite agents, dual agents, close by agents, etc.. Like this the system will be redundant, with a great freedom degree in its organization.

We shall develop the system in an incremental way rather a functional one (Müller 1998). We have to increase the agent organization with new agents from the previous, after some steps of working for the system.

The agentification method is the following:

1. Definition of fundamental categories C_f of a reference ideal system. This set of categories is very complex and can't be implemented.
2. Definition of an initial family of categories F_i, strictly included in C_f. We choose to build the system from a reasonable reduction of C_f. We build the first agent organization O_A corresponding to F_i. At each semantic trait of a category of C_d, we build a set of agents reifying this trait, with its contrary, its opposite, its close semantic traits.
3. The O_A organization constitutes, in working, a dynamic system $S = O_A \times T$. Then we obtain an application *Effect* of F_i in S: *Effect* : $\{F_i\} \rightarrow S$, where S is the space of observation of the behavior of the system. This application links an abstract space composed of families of categories reifying semantic traits in numerous agents with a set of observable situations of the system in use and expressing the behavior of the system. We shall propose a way for this representation in next paragraph. So, we can remark, in the image of *Effect* application, some regularities and also some anomalies or disrupters. These observations lead the modification of the current agent organization, with the adding of new agents, the modification or canceling or old agents. We increase the system with new categories, with new agents. Each addition in the system with a new agent can modify O_A in whole, taking into account the transitivity of the agent's

acquaintances. The set of current reified categories F_c (at first F_c is F_i) is the result of these modifications: $F_c \leftarrow F_c$ modified at building. $O_A \leftarrow O_A$ with the modification de F_c

4. We can define in the behavior of the agent organization O_A inevitable sets and reduce the organizational complexity of the system, or, at contrary, set up constraints in agent groups. And we can introduce genetic in the agent development in the way of optimization of the behavior of some agent groups (Cardon, Galinho and Vacher 2000). $F_c \leftarrow F_c$ modified by self-transformation and genetic of agents in O_A.
5. The system start from an initial building with generating agent organization reifying categories F_i and develop itself with successive modifications – deletions of agents, reifying new categories or completing older, increasing the organizational degree of the system.
6. We compare the current agent organization O_A reifying the current categories F_i with the referential system C_f. If there is no important distinction and if the behavior of the system is correct, we consider the building finished, otherwise, we return in step 3. Such building is incremental and produces an adequate system rather an optimal one.

This agentification method is in fact adaptive for the builder and the system. The incremental modifications are made after the system has run, after it has modified itself its agent organization. This is a learning way to build this kind of system.

The morphological agents

With the very great number of active aspectual agents, it isn't possible to follow them individually. We therefore study them as a whole, distinguishing shapes and forms in the interactions between them. This is a geometrical hypothesis. We appreciate such a form in a geometrical way, using a specific organization of agents: the morphology organization [cf. Figure 4].

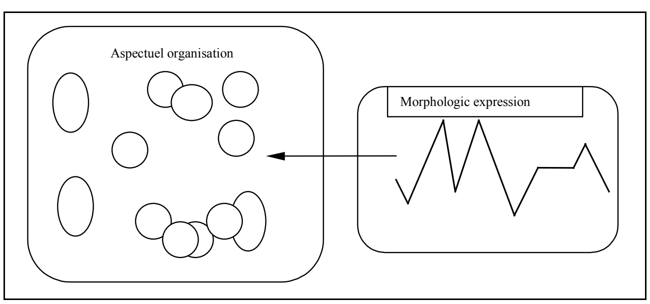

Figure 4. The morphologic space expressing the aspectual organization

We call this view of aspectual agents, considered as an active population, an ***Agent Landscape*** (Lesage 2000). An agent landscape is the whole set of active aspectual agents, considered as well understandable in the following way, it is:

1- the set of reification by agents of the semantic traits contained in the Informational Data and sent by all the information sources in the system,
2- the set of relations between agents, representing the semantic proximity of the reified categories,
3- the structure allowing sorting these agents according to typical characteristics and determining the general characteristics of the states and relations of the aspectual agents landscape.

We now explain the way we use to express the behavior of an agent landscape. An agent landscape will be represented by specific projections of the studied agent organization according to nein axes. Such a representation defines a new space of dynamic description of any agent organization. We call this space the ***morphologic space*** [C.f. Fig 5]. The nine axes of the morphologic space are the following:

1- organizational distance: the state of the agent compared with the state of the whole agent organization,
2- velocity: the speed, with which an aspectual agent has developed so far,
3- facility: the ease, with which an aspectual agent has developed so far,
4- supremacy: a measure of the ratio enemy allied of each aspectual agent,
5- complexification: a measurement of the evolution of the components of the agent and of their links toward a more complex structure or a simpler',
6- communicational stream: a measurement of the frequency and intensity of the agent's communications,
7- intensity of the internal activity: the expression of the exchanges between the inner components of aspectual agent before external agent action,
8- persistence: a measurement of the time of life of the agent, dependency: the fact the agent is or is not free or dependent.

Organizational distance
Velocity
Facility
Supremacy
Complexification
Communicational stream
Intensity of inner activity
Persistence
Dependency

Figure 5. The nine dimensions of the space of morphology

We express the points in the morphologic space (points in a space of nine dimensions) as specific agents acting with this nine characters. The morphologic space is dynamic and each point expresses a group of aspectual agents in action. We focus on the aggregation in the morphologic space, on the geometrical characters in this space. And these aggregations are dynamic, haven't pre-defined basins as attractors. The basins will be defined in use, as emergence of specific agents: the ***morphological agents***. So, we have to express the very dynamic representation of the aspectual agent landscape with a new agent organization strongly linked the aspectual organization. These agents will be the morphological agents.

The morphological agents are the expression of the aggregation of aspectual agents in the landscape, made with the behavior of these aspectual agents according to those nine criteria. The set of morphological agent's form a kind of dynamic space of nine characters, where each point in this space is in fact a morphological agent in action, moving, acting, communicating, aggregating and transforming itself. We can cast these forms or set of points according to the categories used in agentification and coming from ontology. We the can follow the evolution of the simulation from several aspects, with several point of view. We can interpret the evolution of the system in a semantic way.

This point of view generalizes in a dynamic way the component principal analysis used in statistics.

The representation of a massive set of agent is the fundamental result allowing the development of the general Representation System.

The analyze of the morphology: the analysis agents

The morphological agents, in turn, aggregate themselves into cognitive structures: the so-called chreods (Jorion 1989) (Cardon 2000). These chreods are group of morphological agents according to the metric of the morphology space, and they express the specific characters of aspectual agents. For this, they are seeds of meaning or concepts about the meaning of the handled knowledge, made from the emerging structures of the aspectual agent landscape. Chreods are the result of the binding of morphological agents according to the sharing of common topics that are instance of the ontology's semantic categories. Chreods are only potentialities and can be seen as many fragments of various seeds of possible future environment world's states. Along with the morphological agents themselves, they are some peculiar reading, part of interpretation of the organization of the aspectual agent landscape, and we have a lot of chreods.

Since we make the assumption that this reading of the Representation System is a conceptual representation of the current situation at the knowledge level in the system. We must find a way to conceive current and future world of representation of the current situation, according to some rational rules but with some inner intentionality. For that we predict the evolution of the aspectual agent landscape using organizations of ***analysis agents***.

The current analysis and the predictive analysis of the set of morphological agent are, in fact, analyses of the dialogic situation between the system using dynamic knowledge and its current environment or parameters. This interpretation is grounded on the analysis of the geometrical aspects of the morphology of aspectual agent landscape. This is the morphologic hypothesis we set up and use. For make this analysis, we use another specific organization of agents, the analysis agents one, using distributed rational rules with abilities of resolution of conflicts between them.

An analysis agent is a rational agent acting as a very local and focused knowledge base. We use organizational knowledge indeed. The set of analysis agents, matching the shapes in the morphologic space, try to generate partially characters, in a space corresponding to the real situation modeled and in the time building partially plans. An analysis agent is an agent and it have to co-operate with other analysis agents to generate, by co-operation an resolution of conflicts, a significant scene corresponding the situated position of the system in its run-time.

The analysis agents exhibit, by emergence, the semantic characters of the current situation of the system because the chreods are linked with aspectual agents, and we can recover the semantic traits. Once the predictive analysis has done its work, we are left with a current analysis and a set of possible future landscapes. But all those predicted futures are not pertinent, so we match the previously predicted chreods with current chreods in order to validate the prediction. The system operates in a self-learning loop. It should refine its predictions and the system will have more and more reliable knowledge concerning the forecoming event of the agent aggregations.

The analysis agent organization reacts with the aspectual agent, modifying the action of the aspectual agent organization. This systemic loop is the inner control of the system on itself. So we have an adaptive system; these three strongly linked agent organizations set up a self-adaptive Representation System for the behavior of the system. Like the real situation in a social behavior of a large city.

Conclusion

The task at hand was trying to build an understanding of a dynamic of the complex urban migrations in large city. To reach this difficult goal, we have proposed an original architecture in a Representation System based on the morphology of the behavior of a very large and distributed aspectual agent organization, evaluated with an analysis organization upon a morphologic agent organization.

In the urban application, the identification of model of preferential attribution of the residences to the households and the inhabitants to their habitat is in the heart of "problems of society". Therefore of such applications thus take all their direction as soon as one is confronted with the problems of degradation of cities of residences and the fear generated by the formation of the "ghettos". This application is in progress in a Ph.D. thesis.

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