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MULTI-AGENT SYSTEMS AND TERRITORY:
Concepts, methods and applications

Cavezzali Aldo, Rabino Giovanni

Dept. of Architecture and Planning (DiAP) - Polytechnic of Milan – Piazza Leonardo da Vinci 32 - 20133 Milan Italy - aldocave@tiscali.it - giovanni.rabino@polimi.it

ABSTRACT

This paper analyses the multi-agents systems that are now considered the best tool to simulate and study real world.

We review the main characteristics of a multi-agents system, namely interactions and co-operations of agents, communications between them and finally the schedule of actions and jobs assignment to agents.

The multi-agents system approach is increasingly applied in social and economic sciences; so we study mainly the territorial applications. In these applications new characteristics arise from the consideration of territory: land and space where the agents live or territory as an agent in itself, that evolves in the time.

1. Introduction

In the last decades of the twentieth century there was an important increasing of the possibility of representation of real systems through computer instruments. This led to be able to study better their characteristics, to understand their basic components and, often, to simulate their evolution in time. There was also the emergency of the necessity of representation of those systems whose structure is not completely known, that means they are not mathematically expressible, or of those systems which have no solutions, even if they can be described through equations.

A typical case is that of social sciences, which saw the evolution from a concept of society based on the idea of homo oeconomicus, whose (rational) behaviour follows the rules of classical economy giving origin to a mathematically representable society, to that of a society in which complex phenomena emerge. The way this society works is not the direct result of the sum of the behaviours of its members (homo socialis), which themselves can't be foreseen in a deterministic way. The same necessity to represent phenomena with high complexity emerged in a more strictly economical field and, in the last few years, also in the territorial field (Axtell Robert ,2000)

The simulation with the use of agents can give an answer to such needs, as it offers the possibility to represent individuals, their behaviour and their interactions. So it's possible to analyse a phenomenon as the result of interactions of autonomous entities, the agents. Multi-agents simulation makes it possible to create artificial micro-worlds, that are models of real systems, whose parameters (of state or of functioning, quantitative or qualitative) we can control at any level. One of the most interesting aspects that is offered by multi-agents systems is the possibility to experiment the consequences of any theory and of any possible alternative, in a rapid and efficient way, on the models of society that are so obtained.

The advantages of the representation with agents compared to the classical mathematical one are many: first of all the representation always gives an output that can be understood also by people who don't know deeply the dynamics of the system we are studying. Then the system can be represented in a realistic way by modifying the characteristic parameters of the agents or by differentiating the agents themselves; for these operations the help of computer experts is not needed. In the end even if there is the necessity to modify the scale of the model not great variations of the code of the simulation program are needed. What said does not mean that is possible to program an agents-based simulation system without knowing deeply its dynamics; in other words multi-agents systems are not “black box” models, but they are remarkable the same because they look extremely “user-friendly” if compared to other simulation systems.

As a consequence of all this the great versatility and simplicity of use of agents-based models emerges, so that the U.S. Academy of Sciences promoted agents-based modelling as *the most promising paradigm for the next five years.*

2. What multi-agents systems are: basic characteristics and constitutive aspects

Multi-agents systems are physical or virtual systems which can carry out a program of work that is assigned to them and that, usually, determines their characteristics and their structure. Virtual systems, which we will deal with, usually represent the behaviour of real existing systems or that of systems whose possibility of realisation we want to study.

MAS are basically constituted by numerous entities, the agents, which are well separated from one another and act in (partial) autonomy. In fact we often refer to the concept of Distributed Artificial Intelligence.

A **multi-agents system** is constituted by the following **elements**:

- an environment (bi o tri-dimensional)
- a collection of agents, the active entities of the system
- a collection of objects, whose spatial coordinates are known, that interact with agents
- a number of laws, which regulate all the agents’ activities

An **agents** is a (physical or virtual) entity that:

- acts in an environment
- can communicate with other agents
- is lead by a set of “rules”, in the form of individual objectives or satisfaction/survival functions, that are to be optimised
- has its own resources to accomplish its objectives
- has a (limited) perception of the environment that surrounds it
- has some skills and can place them to other agents’ disposal
- can be able to reproduce itself
- its behaviour is such as to satisfy its needs and to accomplish its objectives, taking account of resources and skills that are present, of the environment and of communications with other agents

The most interesting aspect of a multi-agents system is the relation between the single agents and the organization which the agents is part of, because the agents is the main element of the organization and so it determines its characteristics, but at the same time it is conditioned in its acts by the structure it belongs to.

This duality between “micro” and “macro” system can be represented in the following way:

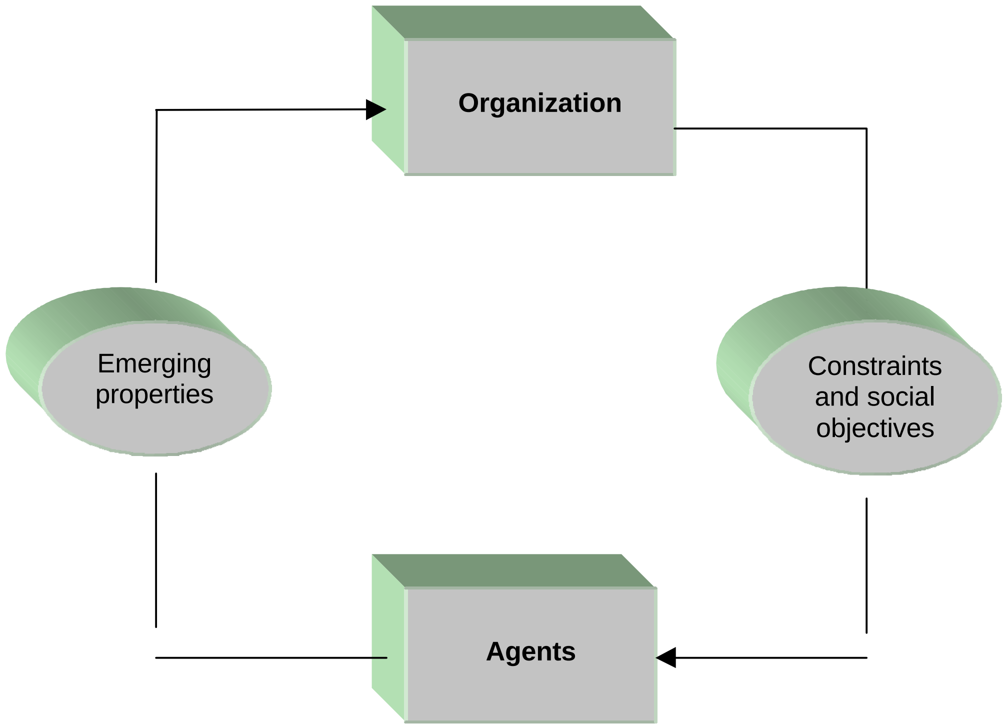

Figure 1: The agent - organization loop

There are two **main categories of agents**: **cognitive agents** and **reactive** agents. The former have a basic knowledge that comprehends the data and the information that are necessary to accomplish some tasks and to interact with other agents and with the environment. So they are intentional agents, who know their own objectives and plan their actions in the right way to accomplish them. Reactive agents instead are not able, individually, to follow a plan of action to reach an objective, but they can just react to external stimuli, following their programming laws. They can accomplish their tasks the same, but the intelligence is only at the group level and not at the single agents level. A classical example from the natural world is that of the ant-hill: every ant can be seen as a simple reactive agents (it’s not aware of its own objective, but it follows the instinct that leads it to accomplish the task it’s specialised for), but from this derives an organization that is the same very efficient at the group level. In the reality the agents' behaviour is usually lead both by the necessity to satisfy personal needs (deriving from the personal programming characteristics of the agents) and from stimuli coming from the environment.

Relationships among agents give origin to different forms of interaction: every time that the reciprocal actions of two or more agents lead them to a dynamic relation there is an interaction. This interaction influences the agents' future behaviour. Interactions are the basis for the development of social organisations among agents and at the same time they are the product of the organisation itself. We can say they represent the deep reason of the existence of MAS, because isolated agents, not interacting with any other, cannot be considered as a part of a system. Despite the many different possible interactions, we can define a *situation of interaction* as "a series of behaviours deriving from the assembling of agents who must act to reach their own objectives, taking account of the (more or less) limited resources and individual skills" (Ferber Jacques, 1999).

In the following table the main kinds of interaction are resumed. They have been determined taking account of compatibility of the agents' objectives, availability of resources and of the agents' skills.:

	CRITERIA		
	Objectives	**Resources**	**Skills**
Independence	Compatible	Sufficient	Sufficient
Simple collaboration	Compatible	Sufficient	Non sufficient
Obstruction	Compatible	Non sufficient	Sufficient
Coordinated collaboration	Compatible	Non sufficient	Non sufficient
Individual competition	Incompatible	Sufficient	Sufficient
Collective competition	Incompatible	Sufficient	Non sufficient
Individual conflict over resources	Incompatible	Non sufficient	Sufficient
Collective conflict over resources	Incompatible	Non sufficient	Non sufficient

Table 1: A framework for agents' interactions

We define as **situation of cooperation** the one when the insertion of a new agents improves the group result in a more than proportional way and/or the action of agents is useful to avoid or to solve potential or effective conflicts. So we define as *intentional cooperation* the kind of cooperation that the agents consciously search for, *reactive cooperation* the kind when at least one of the two former conditions is verified, even if without any explicit intention of the agents.

MAS are based on organisation of a group of agents in a way as to be able to accomplish tasks and to simulate processes: the agents are programmed to develop the forms of interactions we wrote about and, if possible, to co-operate, but their behaviour is not strictly pre-determined. So organisation is a dynamic concept; on its basis lies the organisational structure, that defines the organisation of the system on an abstract level and that takes shape in the concrete organisation, that is to say the shape taken by the organisation itself. So every organisational structure corresponds to many different concrete organisations, depending on environmental conditions, number and type of agents, tasks to be accomplished, etc.

3. Multi-agents systems: for which problems?

MAS are always constituted by different unities in relation with one another; however this is the general definition of a system. The element that characterizes them is instead the kind of relationship among the parts constituting the system: they are always non-linear relations. These relations describe a link among the unities that is characterized by the lack of constant relations within the elements, of well defined functions and of links that are constant in time. These characteristics lead to the definition of the concept of complexity: it's the definition of something that is itself undefined and difficult to express. On this concept philosofical and scientific communities have not been investigating for long and they are far from getting to a conclusion. For "complexity" we mean the enormous amount of non-evident and non-expressed relations that cannot be written in phisical or mathematical terms and that link together the internal entities in systems, and systems to other systems. This may even lead to the conclusion that any attempt to put borders to anything that is object of our study cannot but introduce simplifications that pull us away from the real comprehension of phenomena. This does not mean that the "complex thought" can give solutions that are radically different from those we already have in many subjects, but only that this way of thinking should destroy the exhaustive claim that is often implicitly present in the approach to problems.

According to Edgar Morin (Introduction to the complex thought, 1990) there are three principles that can help us to understand complexity.

The first one is the dialogic principle, that means to keep the duality between complementary and antagonistic terms inside the unity. Living organisation, for instance, is based on this principle: there are in it some elements of continuity and some of renewal that are strictly interdependent and necessary to one another. In cellular organisation there is, in fact, the continuous renewal of the proteins that give form and expression to the DNA structure, the same substance they are based on and whose structure remains almost unchanged in time. Every one of the two elements couldn't exist without the other. In the same way animal reproduction mechanisms take shape in the individuals that are generated that, at the same time, are the means of their transmission. So dialogic principle makes us see the duality as a part of unity, or even as its essential component.

The second principle, called organisation recurrence, specifies that between a system and its parts there is often a relationship of reciprocal and circular influence: the part conditions the whole, that in its turn determines the characteristics of the part This is the case of an individual in its society: society is the result of interaction among individuals, but in its turn it conditions them, giving them culture, conventions, language, etc. We are at the same time the products and the producers of our society. So there is a deep break with the traditional idea of cause and effect, of structure and superstructure.

The third principle, called **ologrammatic principle**, says that, as the part is inside the whole, the whole itself is contained in every part of its. Going back to the biology, the analogy with genetic patrimony of the cell is evident. In fact these genes give the information to build the whole individual, independently from the specific tasks of the cell. This idea is an overcoming both of the reductionist theories, that see only the parts, and of olistic theories, that see only the whole. The consequence of such idea is that the knowledge of the whole is possible only through that of its parts, and viceversa.

The three principles we've seen are deeply linked together and they put the basis for an idea of the world that is completely non-structured. In this world there is neither prevalence of the organisation on its parts or that of the parts on their organisation, so "the whole is in the part that is in the whole" (Morin). This is also the main principle that emerges from the analysis of MAS. So MAS are (probably often without their programmers or users are aware of this) expression of the overcoming of the simplification paradigm that has been widely dominating our culture so far.

In particular the **dialogic principle** finds an application to the MAS world by solving the appearing contradiction between the presence of an intelligence regulating the whole system and the lack of any structure created for the supervision of the system itself. This is the consequence of the identification of the place of the system intelligence with the emerging structure, so with something not existing *a priori* nor defined by the builder of the system. It's instead the result of the interactions among the agents themselves.

The **principle of organisation recurrence** can be applied to the relation between individual and organisation: the effect (the organisation) is one of the causes of itself, because it determines the agents' characteristics from which the organisation takes its shape and modifies itself in time.

The **ologrammatic principle** is evident in the relationship between local (or "micro") reality, and global, (or "macro") reality, saying that there is not a deep separation between the two levels of analysis. In the constitution of an agents instead is already included its role in the environment and towards other agents: the "micro – world" of the single agents is deeply connected to the "macro – world" of the system which the agents belongs to. Of course this is true also for the relation between local and global world, where the spatial dimension prevails, but the inseparability of the two worlds remains. So a system of agents is much more than a sum of agents and an agents is much more than a part of its system, and this leads to Morin's definition, according to which ologrammatic principle expresses the fact that "the whole is included in the part, the part in the whole".

4. Current applications

MAS make it possible a great step forward in all social and economic simulations. Here in fact the classical approach, based on rational decisions theory, or on the so-called *game theory*, has failed to explain the actual behaviours of actors. This because multi-agents approach goes beyond the mechanical and descriptive vision permitted by the game theory. So we can programme entities whose motivations to act are very heterogeneous and not only deriving from an idea of "gain". For instance in the relations between different countries or in trade markets it happens that particular choices are made. They are choices that don't benefit the people that make them, or even cause a drawback for them, but they cause even greater drawbacks for the opponents or the competitors. So such choices increase the supremacy of the actors that make them.

According to Castelfranchi (2002) the reason of the crisis of rational decisions theory is not the fact that behaviours coming from motivations which have nothing to do with it (moral, identity, pro-social, emotional motivations) cannot be related to it. In fact a lot of behaviours that are considered as violation of rationality by psychologists and economists are not indeed, if we extend the concept of human rationality. In fact "the model of decisional rationality if correctly understood (and used) is neutral in front of subjective motivations and it couldn't shouldn't prescribe about them. So it is compatible with any possible motivation". The crisis of the reductive and simplistic model of rational decisions theory should be overcome, according to this author, by changing the decisional mechanisms and those of behaviour control, that means the whole architecture of the actor (agents). This because there are different levels and decision strategies and not all our behaviours are the consequence of "decisions". This does not simply mean to introduce the emotional sphere in the process of decisions, but also to consider the role of habit, of procedural knowledge, of rights, of constraints, of prohibitions, of sanctions (not only in terms of amount and probability, but also of consequences at social and psychological level). The author agrees in seeing a valid help to this new cognitive representation of "homo socialis" in artificial agents and simulation.

One of the best advantages of multi-agents representation is the fact that agents potentially learn everything, if they have enough memory capacity. The most interesting researches are about social and economical simulations and they show the evolution of systems as complex as the real ones. This starts from few data and leads the same to the constitution of complex organisational structures . In organisation and maintaining of such structures so as in the human ones, the role of **learning** and **transmission of knowledge** is fundamental.

The disciplines that take advantage from the numerous possibilities offered by multi-agents simulations are very heterogeneous, but they have in common the fact to study high complexity systems; such disciplines are the basis for a wider category that takes origin from their own meeting: cognitive sciences. **Cognitive sciences** deal with (natural or artificial) systems functioning, and in particular with the way a system collects and selects the information coming from the environment. Then it re-elaborates the information, it stores or cancels them, it communicates them to other systems and uses them to act and to accomplish its tasks. "Besides psychology, linguistic, neuro-sciences (that is the study of neuro-physiological basis of cognitive processes) and computational intelligence (that is intelligence reproduced in artificial systems), we go to explore territories at the border with philosophy, anthropology, genetics, ethology (animal behaviour study), economy (game theory), art, and more in general, the creation of anything is made by men. In this enlarged perspective, cognitive sciences become the field of study of anything has something to do with men's creative capacity and with all that they produce. What defines cognitive sciences is in fact an integrated approach" (Legrenzi Paolo, 2002*)*.

So cognitive sciences are the interface of all those disciplines that study the processes characterising the human mind and originating from it. A fundamental to the realisation of this meeting has come from computer as a calculating and simulation instrument. So MAS are certainly an efficient mean to investigate the problems dealing with cognitive sciences.

A good deal of the current applications of Mas are in the field of social sciences, as there are a lot of advantages that can be given by this simulation instrument.

Anyway social application in the way they are meant today, that is with a "bottom – up" approach, where interesting properties emerge during the simulation, are quite recent. In fact in 1990 they were still seen as "conditional" possibilities: "(. . .) the goal would be to establish some constraints, to specify the institutional environment or the agents' decision rules and then to run the simulation to see what happens. The idea is not to create a mathematical model with conclusions directly deriving from preliminary statements. The goal is instead to run the simulation like a mental experiment, where the interesting part is not the final result, but the way the process works. And we, the programmers, don't know how the process is going to work until the mental experiment is over The order should emerge not from the programmer's design, but from the spontaneous interaction from the constituting parts." (Lavoie et al., 1990)

In particular we can distinguish different social, economical and psychological categories of problems, that have been recently analysed by the multi-agents simulation or that could be. They can be resumed with their logical relations as follows:

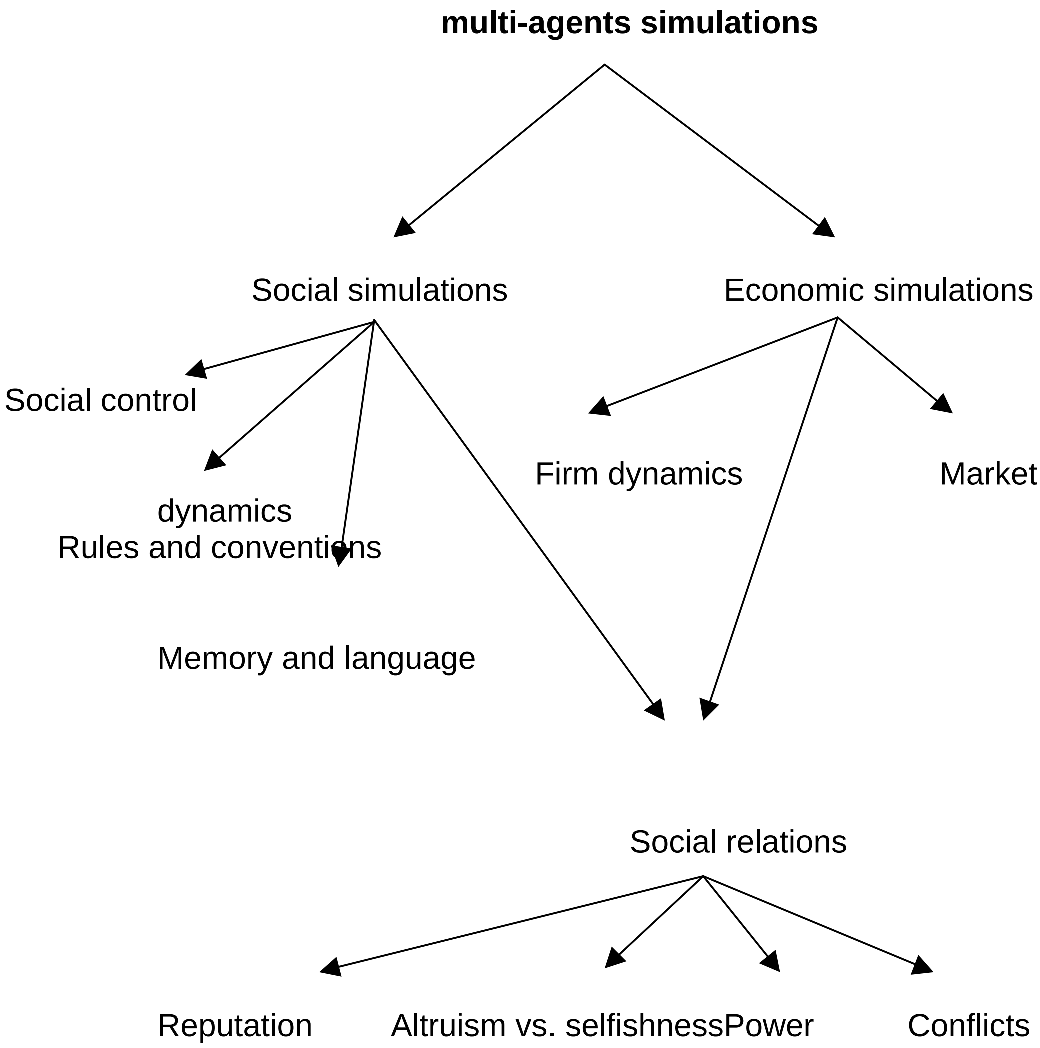

Figure 2: A taxonomy of Mas applications

Social control phenomena: in human societies there are many situations when some individuals monitor and control others' behaviours, with different intentions of course. There are in fact simple statistical investigations, that are useful for service supplying, tax collecting, social policies typical of the most evolved democracies; but there is also the control of any kind of expression or association, typical of totalitarian. Cognitive agents that are programmed with utility functions depending from other agents' actions are good candidates to represent a society where some people control some others. If the goal of some agents is to increase their own wellness, they try to condition other agents' behaviour in order to do so. (Conte Rosaria, Hegselmann Rainer, Terna Pietro, 1997).

In particular we mention here the research of Rosaria Conte and Frank Dignum (2001*): From social monitoring to normative influence*, where agents are driven also by a social efficiency function. The research aims at the analysis of social control and social influence phenomena that are based on the emerging of norms. The focus is on social control that is made by agents towards other agents and is based on norms, on the situations when the agents control their likes and on the way this influences the birth of common norms.

Emerging of norms and conventions: the same work deals also with normative phenomena in society, above all in the cases when norms are not planned by a superior entity having the complete knowledge of the processes regulating society and interpersonal relations. As we saw before, in this case a system rationality emerges, and this rationality regulates its behaviour in order to increase its own utility, or at least that of some members of its.

At the same two problems aims the study of Rosaria Conte and Mario Paolucci titled *Tributes or norms? Rationality depending on contest in social control.* This work compares different strategies for control and prevention of aggressions in a society where agents have to fight for scarce resources. The comparison is between the effects of an anti-social strategy, based on *ultimatum*, and those of a normative and merely utilitarian strategy. I The results of the simulation show that none of the three strategies in unconditionally good, while the efficacy of all them depends on contest.

Marie-Edith Bissey and Guido Ortona's research (2001) *Simulation on destruction of co-operative conventions* deals instead more strictly with the problem of what can be defined as **convention**. The study aims at the consequences of the invasion of non-co-operative agents in a community adopting co-operative conventions.

As a problem of convention can be seen also that of the birth of a **corporative culture**, that is the subject of Arianna Dal Forno and Ugo Merlone's research (2002) titled *A multi-agents simulation platform to model bounded or complete rationality agents in organisations*. The research deals with a multi-agents simulation to study the equilibrium rising in an organisation and to analyse the emerging of a *corporative culture.* This means the common behaviour based on assumptions and convictions that are shared among all the group members, and that are such as to keep their equilibrium position. No specific task for agents and the study is more focused on the choice process than on its result. The concept of effort of the agents is fundamental and is meant as the “engagement” level characterising a certain agents at a certain time; from this an output (gain) will come and it will be useful for the organisation, but its nature is not specified.

Memory and language: within the different studies about memory, language and its organisation, one of the most interesting is *The role of oblivion, of memory dimension and of spatial separation in dynamic language games*, by Juan de Lara and Manuel Alfonseca (2002). The simulation studies a multi-agents society where agents have to establish a common vocabulary, starting from a random one, in order to be able to co-operate. The vocabulary is limited to the nouns that are to be given to the possible shifts of the agents. The goal of the study is to verify in which way the speed of settling of a common vocabulary depends on that of word forgetting of the agents, on their memory dimension, on their number and on the presence of obstacles to their free movement.

Firm dynamics: multi-agents approach has been used for economical problems only in latest time and many applications were in the direction of firms’ organisation problems. Agents’ simulation methodology in fact was extended to firm applications, in particular to study supply chains, using *Swarm* development platform (Lin et al., 2000; Schlueter-Langdon, 2000). The build of simulation models, that are based on autonomous interactive agents, leads to the implementing of virtual structures representing parts of production structures in a firm or the whole of them. Programmers try to reproduce structures representing the functioning and internal interaction rules. The agents should not only act, but also decide the way of their own acting. The so obtained virtual firm can be the object of investigation and experimentation, exactly as if it was a laboratory structure. We point out here the valid works by Pietro Terna (2001-2002).

Market dynamics: an other sector than can be investigated with MAS is the operators system acting in a virtual market like a telematic stock exchange: every operator is characterised by its “rationality level”, by its motivations and pulsions, by a capacity to react. He can modify his behaviour with learning and he can be represented by an agents. In this case too we referred to Pietro Terna’s researches, made with the help of *Swarm* protocol.

Then there are a lot of emerging aspects in multi-agents simulations, about **social relationships** in general: agents’ reputation problems, conflict solving, selfish or altruistic behaviours, conquer and management of the power and leadership. Among the studies about **reputation**, that is the “opinion that other people have about an individual", exactly like in human societies, we signalize Juliette Rouchier, Martin O'Connor e François Bousquet's research (2001) about *The creation of a reputation in an artificial society based on a gift system.* This research analyses a aociety where goods circulation takes place out of market, through gift exchanges within the group of agents. The act of giving not only creates a relationship between the giver and the receiver agents, but also is observed and analysed by other agents. In this way the other agents of the group create a common image (reputation) of both. The task of the study is to understand the way reputaion is created and modified in time.

An other field of research is the emerging of **altruistic or selfish social behaviours**; on this aspect the debate is alive also in a strictly sociological field (this shows the strict interedependence between social and cognitive problems and multi-agents simulations). In particular the research tries to explain the emerging of altruism in those situations where it doesn't look to be convenient to the altruistic agents themselves. So we go back to the motivational problem underlined by *Castelfranchi*. A specific research on this subject (that anyway is transversal and common to other simulations) is Roberto Pedone and Domenico Parisi's *In which kind of social groups "altruistic" behaviours can evolve?* According to the Authors altruistic behaviours are an enigma under an evolutionary point of view. The selection among "relative" agents and reciprocal altruism (that is altruism that aims at rising analogous behaviours in other agents) can explain altruism only in particular situations. Some simulations were made and they showed how altruistic behaviours can emerge in social groups of genetically similar agents, but not in random groups. The Authors suggest that if behaviour homogeneity in a group can be guaranteed by some cultural mechanism, so altruistic behaviours can emerge and keep in time.

5. Land Use and territorial applications

As we saw before, phenomena that can be brought back to the wide world of complex interactions characterise a great part of real systems. Geographical and territorial systems are not different, as interactions among territory portions, among operators and among them and the territory itself have many elements of complexity. In the last twenty years geographers and urbanists have put into evidence an studied the great number of discontinuities (non-linearity, auto-organisation, etc.) that there are in this kind of systems. They have understood some of the non-intuitive behaviours and of the unforeseen new elements that there are in many territorial realities.

Territorial problems can be divided into to main categories:

1. Problems where territory is simply the “scenery” on which other subjects move and interact
2. Problems where territory is evidently modified by the actions of other subjects and it reacts with its own dynamics.

The concept of **space** is at the basis of territorial multi-agents applications. Sometime space is not expressed as an Euclidean distance between different points in a plane, if not in an “embryonal” phase of models. Local or regional scale representation of phenomena, that is much prevailing, involves an “elastic” space, where the determining distance for agents’ interaction is not the real, geometrical one, but the distance perceived by the agents themselves, that can vary in time and with the environmental conditions. So it’s a *space of relations* more than a strictly geographical space; of course this is the case of those applications in which space is not a direct active element of the system.

In many cases in fact space is an active entity, because MAS in territorial problems have usually their application in the study of the behaviour of territory as a consequence of many factors. These factors are the modifications brought by decision-makers on the basis of current urbanistic plans, of their variations, of program agreements and of all the urbanistic instruments that can be used. So it’s natural to give the different portions of territory the characteristics that are peculiar of real territory, above all the reaction capacity after interventions. So the matter is to attribute the role of agents to specific “functional portions”, if not to entire geographical areas (Occelli Sylvie, 2002).

To make a portion of territory an agents means to give the new entity some characteristics, as the use destination of urbanistic plans, the capacity of reaction to the use of nearby portions and that to the use of the portion itself, the sensibility to the use and the possible consequent decay, the “carrying capacity” specific for an use, the capacity to attract users and that to influence the development of nearby areas. So they are agents that, even if they can’t move, are endowed with real behaviour rule sets. Like for the most refined reactive agents systems in biological and social simulations, also from these territorial agents systems can emerge complex interactions and phenomena. In the following part we will examine two recent territorial simulation instruments: SimAC and SimPop.

One of the most interesting multi-agents applications that have been developed in the last few years is **SimAC** (Simulating Accessibility) project, by Sylvie Occelli and Matteo Bellomo (2000). It's the simulation of an urban space and of its habitual users (inhabitants and workers) to define the concept of **accessibility** of different urban functions.

The origin of the problem of accessibility studied here is in two notions: that of *activity space* and that of *urban performance management*. The first concept deals with the space where an individuals lives his everyday life, taking part in urban activities. Urban performance management is instead a concept linked to the town administration. It refers to the capacity to assure its functioning in order to improve its inhabitants' life conditions; it's not a mere service endowment, but the management of the interactions among the citizens' activity spaces.

The definition of accessibility is so divided in two levels: an individual level, that deals with individual action space, and a system level, that deals with spatial and functional organisation of activities. Action space is heavily influenced by individual resources and town service endowment, because budget constraints are determining for individual choices. The consequence is a great variety of action spaces among different people; moreover every individual action space changes in time, according to the different life periods (study, work, etc.) and the different environmental, social and technological conditions.

This research aims to the study of the problems deriving from the former "substantial point of view", that considers accessibility as a resource. So two main aspects have been pointed out:

The first one deals with the concept of *performance* of the action state, that is the function expressing the accessibility, that so must be maximized. This involves that the individual is aware of its action space, has a mental representation of it, he can modify it with learning and can act in consequence of it.

The second aspect is the existence of a notion of accessibility at a level that is superior than the individual one. This derives from the fact that action spaces are different and emerges from their interaction; this means that there are accessibility representations that are known at a common level. From these last elements the system accessibility concept can emerge.

Some agents, the **inhabitants**, represent people living in the urban system: they act, move, have precise intentions and know their environment (partially as "a priori" information and partially as the result of a learning process). So the inhabitants can catch information and vary their behaviour as a consequence of them and, above all, they can evaluate their action space performance.

An other kind of agents are **localities**: they are agents representing some urban space functions, used by the inhabitants (roads, parking, supermarkets, etc.). They cannot move but they can react to the use is made of them, by expressing characteristics like availability or congestion, opening times, etc. They not only put into evidence a performance, but also they compare it to that of other agents.

A last type of agents are **whispers**, that don't represent any real urban entity, but are vehicles of information, both for inhabitants and for localities. They express a series of signals of different kinds, as news, rules, advice or other signals; they are useful for the development of urban policies and for service supply. They have no physical location and they update continuously their information content.

From the description of agents representing localities is evident that the **urban space** implemented in the model is not a mere scenery where agents move, but it plays an active role.

The **initialisation** of the model is based on some main steps:

- Home and work localities are assigned to the inhabitants
- Localities are assigned to some nodes and they are given their carrying capacity (sustainable visitors number)
- Temporal values (representing journey times) are given to the links between cells.

The **simulation** starts with inhabitants calculating the most rapid way to go to work and to come back home. Then every inhabitant follows the chosen path, that is divided into arcs, and he perceives the effective time spent to pass cross arc. The next day, on the basis of the so collected information, the inhabitant calculates again the best way and he follows it. Localities instead register arrival times of visitors and their distance from their work places; if necessary, localities, register also their own saturation. Whispers calculate a series of accessibility indicators referred to every locality. Their activity is fundamental for knowledge transmission and it allows the updating of the inhabitants' journey times, so they can chose more and more rapid paths.

In the experiments that were made some common characteristic were evident:

- Perceived and real journey time decrease along the 50 days of simulation; this shows that spatial knowledge is created in time. So accessibility increases in time.
- The increasing of accessibility tends to level as much as time date approaches; this indicates the approaching of a stationary state, when no further journey time reduction is possible.
- The differences between house – work journeys and work – house are bigger for perceived times than for observed times.
- Perceived times are always longer than real ones and they are much more variable

An other evident result is the decrease of the number of nodes crossed by the inhabitants: it's a further demonstration that these agents update their path.

As a conclusion, we can say that the simulation shows that the simple path minimising strategy is enough to observe a decrease of journey times, that involves an increase of accessibility. This does not exclude, of course, that individual behaviour may be motivated by different principles, according to economic or social situation and to the agents' activities.

An other interesting simulation tool is **SimPop**, created in 1996 by Stéphane Bura (LAFORIA), France Guérin-Pace (INED), Hélène Mathian, Denise Pumain and Lena Sanders. It's a program to study **city nets** and in particular the dynamics that lead to a structure where a hierarchical town system emerges, starting from scattered villages. Urban functions are different with levels and specialisation and starting parameters can be changed in order to study different population dynamics.

Agents represent the ideal portions of territory; every one of them can give hospitality to a settlement. Different development of such settlements and functional differences emerging in time are simulated. Every "cell", whose shape is generally squared or hexagonal, has its own specific geographical characteristics: a natural environment (plain, mountain, see, etc.), some segments of communication nets like roads or rivers, some natural resources that can be exploited by the human population settling down there. Some cells have also a resident population associated.

The **simulation** starts with the definition of a study territory, represented by a grid. Here there are places that permit population settling and places where this is not possible, that will remain uninhabited along the whole experiment. Then some places are defined as inhabited since the beginning and a starting population is attributed to them. Other parameters are initialised, i.e.:

- Amount of resources (for agriculture and industrial production)
- Population growth rate
- Productivity level
- Consume level
- Apparition thresholds for new functions
- Spatial concurrence rules
- Product and information exchange rules

The simulation goes on with an iteration sequence, every one corresponding to an arbitrary and quite long (for instance a decade) period. A labour division process is simulated, and this causes the specialisation of different villages and the origin of their hierarchy. Moreover the specific function of every centre are shared among the resident population and whenever a new function is acquired, part of the population is taken away from other activities and dedicated to it. Of course in the meantime a population dynamic is present.

The condition for the development of an urban centre (and so for the acquiring of new functions) is the presence of a *surplus* of economical resources, compared to the inhabitants' needs and deriving from goods production. Every settlement first of all tries to satisfy its own needs with its internal production, but if not possible it settles some exchanges with nearby centres. From this necessity the specialisation process derives. This process involves also concurrence phenomena between different centres, that determine hierarchy as a consequence of this and of population growth. So every centre can acquire or loose functions, depending on its rank and with criteria that are typical of every kind of function.

The results of the simulation can be represented with curves and population evolution graphics, and with graphics representing resources, number and size of towns, their urban function, etc.

6. Conclusion

The work tried to put into evidence the potentiality of a simulation tool that is still relatively unknown out of academy and research ambit, but that can be used in many fields. In particular we think that in the territorial field multi-agents simulation can be a valid help for the decision-maker, as it gives a representation of the problem and of the effects of alternatives that is easy to read and to understand.

We wanted to offer a vision of current models that was rapid but as much complete as possible, in order to suggest how they can be used for territorial studies. Of course this vision is limited by the rapid evolution of the subject and people who want to make use of this tool must update their knowledge continuously. In any case it's evident that even the simple models we saw, that deal with specific and well-defined systems, can be the cue to elaborate other simulation tools. These tools should permit to afford the many territorial, economic and social problems that the planner and the decision-maker have to solve almost every day. However the possibility of a complete and numerical analysis of the results is fundamental to make this tool become a valid decision support.

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