Towards Virtual Experiment Laboratories: How Multi-Agent Simulations Can Cope with Multiple Scales of Analysis and Viewpoints

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Abstract. When studying complex phenomena, we face huge difficulties to conceive, understand, not to say handle the synthesis process which, from many interacting events, produces an emerging, recognizable, persistent and structurally stable, macroscopic event. Such a topical issue calls for specific tools, among which the development of multi-agent simulations has proved a promising approach. However, current multi-agent simulations provide no means of manipulating as a whole dynamically created groups of entities which emerge at different granularity levels. To our mind, giving full a sense to multi-agent simulations would consist though in making use of such potential groups, by granting them an existence of their own and specific behaviours, thus providing means of apprehending micro-macro links within simulations. We present here a conceptual reflection on such an organization, in the light of our own experience in the development of the RIVAGE project at Orstom, which aims at simulating runoff and infiltration processes. We believe that the development of our methods in the field of physical processes will provide new ideas and tools useful for many multi-agent architectures and modelling purposes, so as to give shape to the concept of virtual experiment laboratories.

Keywords: multi-agent simulations, multiple level of abstractions and scales, emergent phenomena, micro-macro link.

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1 Introduction

The context of our research is the application of multi-agent systems to the simulation of complex phenomena. Such an approach has aroused an increasing interest among the scientific community for the last few years. The simplicity of the multi-agent formalism is indeed appealing: building a computable representation of the studied reality by giving to each analysis entity of the studied domain an equivalent entity in the computer representation. The computer model...
results in a fairly good image of our own model of reality and as such is easier to apprehend than classic models. Moreover it enables the simulation of a wide range of systems which have so far fallen beyond the scope of classic models - e.g. ecosystem modelling, insects’ societies as in MANTA (Drogoul et al 1993).

However, the design process proves much more difficult when studying complex situations involving phenomena which proceed and interfere at different time and space scales, or situations in which the emergence of complex phenomena occurs. Current multi-agent simulations have so far provided but means of observing and \textit{a posteriori} interpreting such emergence situations, and have not taken enough interest in the handling of multiple viewpoints within a simulation: for instance, when we naturally adopt both a reductionist and a holistic point of view on a phenomenon - if we wish to model the crowd of a demonstration, the procession may be considered as a multitude of individuals with their own behaviours and as some sort of a snake winding up the streets at an average speed. Such a capacity to gather many points of view and to give an ambivalent nature, collective set of individuals and individual with its own existence, to the observed reality is part of the intellectual gymnastics of the scientist, and as such enters in the specification of effective tools for conducting simulation experiments. To our mind it would give shape to the concept of virtual experiment laboratories mentionned in (Ferber 1995 p40-45) or (Treuil et al 1997).

In the RIVAGE project at Orstom (Perrier and Cambier 1996, Solignac 1996, Servat 1997), we try to apprehend the circulation of water in all the forms that hydrologists think worth considering - individual water entities, or waterballs stagnating water zones, flowing water paths, etc. -, by giving them an agent representation. When considered at their own level, these forms do not obey the same behavioural laws and evolve according to different time and space scales. Their emergence during rainfall reveals a scale transfer: a pond results from the accumulation of interacting waterballs in the same area, its attributes - spatial extension, volume - come from the collective activity of these waterballs (in the same way as densities in statistical physics result from the collective activity of gas particles); the attributes of a ravine, which results from the concentration on a given water path of a waterball train in constant renewal, can be seen as the synthesis of the historical records of all waterballs momentarily involved in the ravine.

The hydrologist's object of study thus seems to let itself organize in different entities which belong to different levels, recursively including one another. However, it is much more complex than that: several levels must be simultaneously considered to account for the reality of the ravine phenomenon - both global and individual. Indeed, some hydrologists would even call a ravine, the resulting erosion of the ground after rainfall, which shows how complex it is to give an exact definition of the phenomenon, and at the least rejects as simplistic the representation of a ravine as a mere train of waterballs.

We thus have to find a tangible equivalent to the scale transfer which will not only be observable \textit{a posteriori} as in current multi-agent simulations, but explicit. We are convinced that such an issue may be tackleded by giving full a sense to
the agent concept: allowing the dynamic creation of agents by agents themselves. Within the computer simulation, entities are locally and dynamically created by a group of agents which share for some time a structurally stable interaction and give shape to this interaction in the form of an agent of higher granularity. This interaction agent, or group agent, encapsulates both the knowledge of a physical law, either learnt or predefined - flow rate evolution in a ravine, spatial extension variation in a pond - , which is specific to its level, and the capacity to control the evolution of the lower granularity agents. Our approach is in keep with the natural reflex in computer science which consists in making the system's organization an object of the system itself.

We shall start our discussion with an overview of some examples of applications in the field of multi-agent simulations, which will show the generality of such questions. In the light of these examples and particularly of the RIVAGE project, we then present a conceptual reflexion on how to introduce groups in a multi-agent simulation. The implementation of a discrete version of the simulator enabled us to start an investigation on such matters (Servat 1997). In this contribution, we try to shed light on the following points: regrouping rules, creation itself and control issue within the group agent and the group of agents.

2 The Need for Multi-Scale Viewpoints in Simulations

One should not consider the idea of an individual-based simulation as the apanage of the multi-agent approach. As a matter of fact, cellular automata have long before proposed such an approach. In the field of fluid mechanics, it has led to lattice gas models in which fluid particles circulate through the cells of the automata network and undergo shocks between themselves, their trajectories thus deflected. Such models provide an alternative approach to the resolution of Navier-Stokes equations in order to apprehend the behaviour of a fluid in a space with any given bounding conditions. Numerous researches are led in this field, which meet promising success (Fredkin 1990, Toffoli and Margolus 1990). In these approaches, it is yet impossible to manipulate the emergent phenomena, and the experimentater is restricted to a passive observation: he can but record that phenomena occur, such as liquid or gas clusters' creation. Everything is considered at the lowest level of granularity, which does not coincide with the analysis level considered by the experimentater. At this point arises the essential problem of the observer's role in simulations (Balian 1995) and of the relevant scale of analysis (Perrier1990). In multi-agent simulations of pure physical process, the passage from a microscopic description level to a macroscopic one becomes essential, due to the nature itself of the phenomena that we wish to model. The need for some intermediate level of agents which would handle the passage from a microscopic to a macroscopic level becomes crucial, as stressed in (Marcenac and Calderoni 1997) - a simulation of earth-quakes.

Such a lack is to be found in current multi-agent simulations as well. In MANTA (Drogoul et al 1993) for instance, simulations reveal the emergence of
a division of work among ants: the artificial ants achieve in turn different tasks, such as taking care of the nest or searching for food, as if they were obeying to some sort of a fixed schema of existence and taking part in different social groups. Such emergent groups are essential objects of study for ethologists, which have gathered masses of information about them. However, such groups do not exist in the simulation and no proper means of intervening on them to conduct experiments are provided. The ethologist would like though to be able to introduce such social groups: the ants’ nest would be considered, not only as a collectivity of individuals, but as an interaction between groups. Recursively, an agent could be created to incarnate the whole ants’ nest, with its own characteristics: hunting area, consumed resources, laying cycles, etc. These abstract categories, such as the ant agent, the social group or the ants’ nest agent are as many faces of one unique reality. According to the aims of the simulation, it will be, in turn, more convenient, as the ethologists do, to adopt such different points of view and to simultaneously manipulate them.

In a different domain, we may take a look at the TREMMA project, described in (Marcenac et al 1997), which aims at building a model of the learner in an Intelligent Tutorial System. In this project, the evolution of the learner’s knowledge is simulated by the aggregation of agents, representing some parts of the reasoning. This possibility of representing knowledge with multiple levels of granularity gives then an important gain to provide a relevant help to the learner.

In the case of the RIVAGE project, waterball agents move on a studied surface, with respect to gravity. Due to run-off, these waterballs agglutinate and give birth to pond and ravine agents. In the simulator (see figures 1, 2 and 3), the space is represented by a tridimensional network, where each cell is an agent and may receive a unique waterball. Rain is simulated by periodically introducing waterballs. At every cycle, balls move from one cell to the first free cell, among the lowest ones in a cubic neighbourhood of 26 cells. If there are several possible cells, one is randomly chosen. A cell, situated at the edge of the surface, evacuates its ball and the ball is removed from the simulation. The cells may take three inner states: state 0 if free, state 1 if occupied, state 2 if occupied by a ball which is trapped and may no longer move, due to the overcrowding of its neighbourhood. Cells update a history of their states, on the basis of which they proceed to regroupings and give birth to ravine and pond agents. These new agents take control over the regrouping cells, and in particular, they handle waterball flows themselves, via their outlets from groups to groups, without having balls moved from cells to cells. These group agents are given self-observation capacities which enable them to decide their own partial dissolution, when, in the case of a pond, a free neighbouring cell is found, or in the case of a ravine, the stock of waterballs received in one cycle decreases.
Initial state. The user has set up a pond agent, shown in dark gray. The white cells represent the relief.

Fig. 2. The pond agent from Fig.1, obviously too extended, dissolves itself, freeing its cells, in light gray, and giving birth to the regrouping of cells in medium gray on the slope.

Fig. 3. Final state. The pond reappears in dark gray, with proper dimensions. The regrouping of cells in medium gray goes on, in one big ravine agent. A few free cells are also found, in light gray.
3 Regrouping Rules

The regrouping of agents rests upon the recognition at some time of an interaction or a correlation between agents, see Fig.4, which, due to its persistency and characteristics, reveals a phenomenon, and as such, may potentially give birth to an agent which would incarnate the phenomenon: a set of waterballs confined in a space area and immobilized by their mutual congestion, premise of a pond or a puddle; a set of waterballs, taking close paths and forming a train of waterballs, premise of a ravine. This mutual recognition calls for memory capacities - for instance of the path followed, or of a state (moving or immobile) - and environmental perception capacities - agents close to one another in a given neighbourhood -, (Treuil et al 1997). Once the interaction reckoned, the creation of group itself may occur.

The implementation of a discrete simulator linked to the RIVAGE project has been an opportunity for us to start an investigation on the rules that would proceed for the regrouping of a set of agents. So far our investigation has led us to consider:

1. Similarities between inner states of agents: in the discrete version of the RIVAGE simulator, each cell may take different states - 0 if free, 1 if occupied by a waterball, and 2 if the ball that occupies it is trapped and may no longer leave the cell. A cell in state 2 observes its neighbourhood and, noticing that it is surrounded with cells in the same state, considers forming a pond agent. In general, the state of an agent may be a vector of attributes with various values - temperature, pressure -, or a task - food searching, taking care of the nest, etc.

2. Connecting relations or partnerships: our cells from the previous example are the nodes of a tridimensional graph, and have thus connecting relations among themselves, defined in a given topology. This neighbourhood is not necessarily the set of cells they are directly connected to: for instance, we may imagine the modelling of a subway plan by a multi-agent system, in which agents representing stations reachable within a unique connexion would be considered in the same neighbourhood. Beyond that, we may also imagine partnership relations that link a producer agent with a consumer agent. In the case of agents that look for information on the web (Moukas 1996), we are often faced with such types of agents: a personal agent in charge of the user's requests, and a certain number of agents that actually look for information. Between such two types of agents exist relations of acquaintancies, more or less reinforced with respect to the success of their association - mutual confidence with respect to the user's satisfaction.

The communication between agents may be the support of the computing of similarities between neighbouring agents' states. Generally speaking, it is a computation of a distance, the definition of which depending of course on the objectives and the attributes to compare. Suppose that A and B are two agents and $E_a$, $E_b$ their respective state vectors, we compute $|E_a - E_b| < \theta$, where $\theta$ represents
a given vector of the minimum distance below which two agents are considered as close to each other.

Eventually, these criteria may have to be completed with some preconditions for creating groups, such as the number of agents involved in the regrouping, or owning an outlet for the creation of a ravine, so as to handle water transfers. Such preconditions are directly linked to the definition of groups. It seems for instance natural to consider that ponds are large clusters of waterballs.

Such a regrouping process may be considered as some sort of a dynamic local pattern recognition of emergent forms, or, as underlined by Treuil et al 1997, as a computation of correlations between agents, both spatially and functionally - a method used in the renormalization group in Physics. When brought to operation in the domain of social simulations, such recognition of emergence by the agents themselves could give the system the right level of complexity required to simulate human societies: "DAI simulations may have oversimplified important characteristics of specifically human societies, because the actors (agents) in these societies are capable of reasoning, and do so routinely, about the emergent properties of their own societies" (Gilbert 1995).

Fig. 4. Regrouping of individual agents

4 Adhesion to a Group

The bases of the regrouping of agents thus defined, we now have to think of the mechanisms which rule the creation of groups itself. Our cells have a capacity to agglutinate in clusters of cells which share some properties: as a matter of fact, it is a prestructuring of their environment. However, how do these prestructures become effective ones, or, in other words, how does the cluster give birth to the group?

First of all, we are faced with the problem of whether to predefine or not group types. We may actually imagine that agents could create one unique type of groups, completely general. However, the context of our applications and our objectives have led us not to do so and, on the contrary, to predefine some group types. Two main reasons account for our choice:

1. The predefinition of the group types that represent well-known objects of study for hydrologists, is a way to give them the opportunity to easily project
in the simulation their knowledge: attributes and behaviours of the group types. As a result they are provided with the extra opportunity to set up, at the beginning of a simulation, any pre-existing group, hypothetic though it may, so as to conduct experiments: a well-observed ravine for instance, or an hypothetic pond, obviously spatially too extended, as shown in Fig.1. The simulation will then confirm or invalidate the existence of such groups. We may not simply introduce a group of waterballs in those cases, because the behaviour of the ravine for instance may be known at a global level - flow rate -, and we do not know how to build a set of waterballs that would account for it. We may only know, according to the volume, how many waterballs will do, not their individual positions and speeds.

2. Besides, even when we do not have information (or do not want to presuppose information) on the emergent groups, we do have yet a piece of information on the nature of the groups: waterballs create water agent group. As well as in Axelrod's experiments on dynamic alliance network between states (Axelrod 1995), considered from an internal point of view, alliance networks suffice to give shape to and represent emergent states (such as the United-States from the thirteen colonies), but from an external viewpoint, we need to have a new actor (agent) which is undoubtedly a state on its own (for example when a European state interacts with the United-States). We need to have a pond to enable water drawing from ponds by human action in a simulation.

Still we may want to obtain emergent group specification - that means without any predefinition of group types. It seems interesting, as we might be able to discover new group types that we do not know of and which give us means of describing some situations in a new way. However, we have not worked so far on such a pure emergence approach: undoubtedly this will mean accept rather difficult a challenge in the field of learning, which for now falls beyond the scope of our research.

At present, individual agents gather and create groups whose types are among those defined by the user, in other words, they adhere to a particular type of groups. Such an adhesion to a group may be considered as an election process among agents. They have gathered in some sort of constituencies and must give their opinion in favour of one group or the other. The predefined groups are the election's candidates as long as their preconditions are satisfied by the set of individual agents. Each one of them chooses one candidate, with respect to the nature of its interaction with the other agents. In the discrete version of the simulator, we have defined for each group, one typical individual agent that would adhere to it. Thus every agent compares itself to the typical pond agent or ravine agent and chooses the one which is closer to itself. The election proceeds in a first-past-the-post system, but we may imagine, keeping on with the same metaphor, different systems of voting so as to solve potential conflicts between several possible groups.

In order to incarnate such a deliberating assembly, it may be convenient to gather the involved agents in some pre-groups, in charge of the vote-and the
counting. Such pre-groups may moreover be a communication support between agents during the group's lifetime. Thus, we may imagine that the dissolution of groups be voted for or against by the set of agents that belong to the pre-group. Such pre-group notion is to be compared to that of abstract groups which do not have at the beginning any behaviour.

5 Control Issue Within the Group Agent

We have to define the interaction rules, on the one hand between group agents that have been created and agents not yet involved in a group (macro-micro link), and, on the other hand among the agents that belong to the group and the group agent itself (micro-macro link). We must imagine a bubbling of free waterballs, ponds being created, and already existing ravines. How do we manage this set of agents from different granularity level, and how do we define the life cycle of the groups?

At issue is the control shared by individual agents and group agent and the destiny of the individual agents once regrouped. We may consider two visions:

1. The individual agents regroup but keep on existing as individuals. Thus they periodically participate in elections which decide of the group's destiny and the possible creation of new ones. For example, a pond exists but, periodically, the balls that belong to it, and other ones, still free, regroup and decide to create another pond, thus leading to the dissolution of the previous one, or to enlarge the existing pond, thus altering the pond's attributes. In this approach, the group agents do not have a complete autonomy, they are submitted to the decisions of the individual agents. Their behaviour is reduced to the computing of a certain number of macroscopic parameters - volume, spatial extension - , and to warning the user: hello, a pond has been created. The agents are but simple albeit exclusive observers of a given phenomenon.

2. The groups once created take control over individual agents and the group agent is given means of self-observation, through a polling mechanism among the agents that belong to itself. Thus a pond periodically observes its surroundings. Once aware that some of the balls may be evacuated, so it does and dissolves itself to a certain extent - or even completely, if there is no ball left, as shown in Fig.2. The balls thus freed may agglutinate with other ones as usual, see Fig.3. In this approach, the group agents are themselves responsible for their lifes and deaths, in complete autonomy with the exterior. The agents are no longer just observers, they are as well actors of the phenomena they incarnate and control the agents of inferior granularity belonging to them.

For the reasons that we have evoked above - that a phenomenon may (must) be seen as an individual entity with own existence and as a collective set of individual entities, for instance when the pond dissolves itself -, this latter approach seems much more appropriate to our mind. It seems actually more elegant that
of optimization of computing and resources, and in terms of reality modelling, to the creation of groups. We are far from a model such as cellular automata in which the exchanges are always handled at the lowest granularity level.

Therefore, the agents belong to different granularity levels: individual, group level, etc. The exchanges between agents of the same level obey to the level’s own rules: remember the transfer of balls above. The passage from one level to the other occurs while regrouping agents of the same level. The groups are provided with self-management capacities, in particular they can decide their partial or total dissolution with regard to their history, thus freeing the lower level agents that belonged to them. The individual agents that belong to groups have their behaviour altered; in the same way as a soldier marching in a troop must constantly adjust his walk with respect to the others. Thus a cell which belongs to a ravine keeps on receiving waterballs from its neighbouring cells, it no longer has a binary state (occupied or free). These balls increase the stock of the group ravine which from now on independently handles the flows from groups to groups. Balls are no longer transported from cells to cells within the ravine, but guided through the ravine’s path, according to its flow-rate. The individual agents in a group become some sort of information relay unit, which the group agent periodically polls to manage itself autonomously.

6 Coexistence with Recursive Regroupings

It is natural to plan right from the start to give the user the opportunity to handle multiple level regroupings, see Fig.5. It actually enables to define the pertinent scale of analysis of phenomena and to simultaneously use several levels of analysis. The same mechanisms for the regrouping may be applied to all levels, providing that the criteria may somewhat be adapted. We may thus not speak of similarities or distances between agents of different kinds, such as ravines and ponds. We have to use new metaphors. We have already spoken about the notion of partnership, instead of the notion of neighbourhood. We should go further in this direction and define new types of rules: functional regroupings, social regroupings, etc. A ravine for instance may know the groups it interacts with thanks to their outlets. On the bases of water transfers and flows, ravines may come to regroup within one large network which could handle the water flows on its own.

However further work is needed as far as the interactions between different granularity entities and between different types of groups are concerned. A possible way of research may consist in formalizing these interactions in the forms of rule systems. Can a pond merge directly with a ravine or dissolve itself ball after ball in the ravine? Is a waterball meeting a pond always absorbed by the pond?
All these questions have not been answered yet, and perhaps a reason for this is that we have led our investigations in a discrete domain on a tridimensional network of cells, for which it is easy to test whether or not a cell is free, but which also hides the problems of interaction between entities and group borders.

![Diagram showing levels of analysis during recursive regroupings](image)

**Fig. 5. Coexistence of several level of analysis during recursive regroupings**

### 7 Conclusion

We have presented the state of our reflexion on how to introduce and make to coexist groups of agents with different granularities. Our vision rests upon notions that are at the heart of the multi-agent formalism - groups, inclusion of groups, etc - which enable us to build within simulations an image of reality which is more faithful to the hydrologist's.

However, in the light of our experimentations, our objective, simple as it may seem at first sight, turns out to be much more difficult when brought into operation and formalized in terms of agents, and leads us to wonder about the very definition of the phenomena we want to simulate. Even though they may
be well-known and for long studied by the expert of the domain, we have experienced the necessity to build an operational typology of the analysis entities used in hydrology - or whatever the domain of application -, dedicated to their simulating within the multi-agent formalism. For instance, it has been so far rather difficult to give a proper definition, that is, an operational one, of what a ravine is, even if, basically, we may see it as a highly frequented water path which emerges due to run-off and that is responsible for some phenomena among which erosion, material transport, stream creation, etc. We need to work on the knowledge transfer of the domain, which is not quite surprising, as it is, if any, essential a process in the object oriented programming, from which the multi-agent approach inherits.

Besides, the use and implementation of a group recognition process among agents leads us to wonder about the very essence of the group. It is a set of entities showing some kind of unity with respect to objective parameters, correlations, but it is also a coherent, synchronized retroaction form the other group elements on the individuals themselves: in the same way as in a crowd or an orchestra. Specific architectures are needed, which go beyond the sole object modelling issues. In an object oriented system, the entities, their interactions and their organization are actually set up at design time, by the programmer. In multi-agent systems however, the organization, and even the interactions, are themselves objects within the system, and generally turn out to have higher a complexity level than the other objects of the system. In the case of such a simulator as in the RIVAGE project, the biggest part of the difficulty lies in such questions as the control within the group agent, the information distribution among agents, the organization of the recursive levels - in hierarchies or other models for instance -, the perception of time - relative to each entity, such as in Swarm (Swarm Team 1994). We have presented some of our views on these matters, but our work is still in progress and will undoubtedly bring new aspects into light that will give more precise a shape to our system.

Our goal is still a long way off, but already promising though, is a kind of new light shed on the agent concept itself. Such notions as groups, regroupings and recursive inclusions of groups, are at the heart of the multi-agent approach. They shape our vision of things and are thus to be found in the design of multi-agent systems that we conceive as models of this vision. However, the agent seems to have been so far reluctant to grow away from its elder, the object, its behaviour often reduced to a set of methods with a zest of asynchronism. With the underlying objective of integrating it among other agents which proceed in different time and space scales, the agent will have to provide the other with means of their creating itself. The ants' nest will not only be defined as an entity with its own attributes and behaviour - as in a classical approach - but indeed, as an entity which creation is let to the sole decision of the ant agents, these agents owning means of giving a material existence to the phenomena resulting from their collective activity, and furthermore, of coexisting with it. Its autonomy thus increased, the agent moves further away from the object, and the agent concept becomes even more meaningful.
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