When Agents Emerge from Agents : Introducing Multi-Scale Viewpoints in Multi-Agent Simulations

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Abstract. Current multi-agent simulations, which have many individual entities evolve and interact, often lead to the emergence of local groups of entities, but provide no means of manipulating them. To our mind, giving full a sense to multi-agent simulations would consist though in making use of such dynamically created potential groups, by granting them an existence of their own, and specific behaviours. Brought into operation, they would provide effective and new tools for modelling purposes : for instance, encapsulating physical laws which depend on scaling, thus giving means of apprehending micro-macro links in multi-agent simulations, or introducing the experimentater's viewpoints on the specific behaviours of such groups. We thus have to imagine how to give any set of agents means of becoming aware of their mutual interaction, and giving birth to new types of agents out of their collective activity. In other words we look for a computer equivalent to our own emergence recognition ability. We present here a conceptual reflexion on such matters in the light of our own experience in the development of the RIVAGE project at Orstom, which aims at simulating runoff and infiltration processes. Conversely, we believe that the development of our methods in such a novel and original field of research as the multi-agent simulation of pure physical processes will provide new ideas and tools useful for many multi-agent architectures and modelling purposes.

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. However, the design process proves much more difficult when studying complex situations involving both different time and space scales. Current multi-agent simulations have so far provided but means of observing and *a posteriori* interpreting emergent phenomena that occur in such situations, and have not taken enough interest in the handling of multiple viewpoints within a simulation : for instance, when we want to adopt both a reductionist and a holistic point of view on the same phenomenon.

To build effective tools of simulation, we have to find an explicit *tangible* computer equivalent to such an emergence recognition process. We are convinced that such an issue may be tackled by giving full a sense to the agent concept : allowing the dynamic creation of agents by agents themselves. Within the computer simulation, higher level entities are locally and dynamically created by a set 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.

These issues have echos in the community of multi-agent systems as a whole, namely in the field of distributed planning and reasoning (see Rao *et al* 1992 and their notion of social agents, a discussion on boundaries and identity of aggregated agents in Gasser 1992, or Wavish 1992). In this paper however, we have deliberately decided to quote mainly works from the simulation community.

We shall start our discussion with a short historical account of the development of the RIVAGE project at Orstom, which aims at simulating runoff and infiltration processes in a distributed way (see section 2). We show how we have come up to the idea of agents emerging from agents as a way to solve some important computational problems in the building of such a simulator. Then we go back to some fundamental questions as emergence, group creation in Social Sciences, scale transfer in Physics, which inevitably come into question when trying to cope with multiple scales and viewpoints in simulations (sections 3 and 4). From this dicussion we draw some guidelines for the design of such simulators (end of section 4). Eventually we present some preliminary results in the implementation of a discrete version of a RIVAGE simulator (section 5).

2 The RIVAGE Project

The RIVAGE project aims at modelling runoff, erosion and infiltration on heterogeneous soil surfaces. Such an issue has for a long time motivated lots of experimental studies (e.g. EMIRE program at Orstom Senegal, Planchon and Estèves 1995), because of the impact of runoff and erosion on tropical soils, but also in temperate countries (e.g. Cros-Cayot 1996). It has also motivated lots of modelling researches (e.g. Perrier 1992, Abbot *et al* 1986, Crave 1995).

At the beginning of the RIVAGE project is the meeting of two communities : computer scientists specialists of multi-agent simulations and hydrologists concerned by on field studies as well as models. For the last few years, we have experienced the benefits of multi-agent simulations in the field of complex system modelling, in a wide range of domains (e.g. Cambier *et al* 1992, Treuil and Mullon 1996). As a result we think of applying such a formalism to represent and simulate natural objects and physical processes, as described by researchers working on natural complex environments. More precisely, many factors have an impact on the hydrological surface behaviour of a soil - topography and nature -, of the vegetation and of different flowing networks, either natural (hydrological networks, ravines or streams, ponds or lakes, etc.) or human made (permeable ditch and impermeable road networks, anti-erosion layouts, etc.). Classical approach try to superpose all these different types of information - which are assumed constant - and make them fit in one unique lattice of given scale, so as to use a unique hydrological model based on different theoretical and integrating parameters. The diversity of the underlying scales and mechanisms is more or less erased, which nevertheless does not preclude from obtaining good prediction capacities - at least in so far as only global variables are concerned (e.g. input rain intensity vs. output flow relationship). However it is much more difficult to take into account the influence of different local factors, heterogeneous and dynamic, or to introduce specific behaviours which do not let themselves easily translate in terms of numerical parameters of equations distributed on the whole domain of study.

We are leading a methodological research without *a priori* precise time and space scale. We are willing to reproduce not only water flows at the outlet of a domain, but also to simulate the spatial distribution of water paths, level and extension variations of a pond or a ravine, as well as the creation of new water storage points, and eventually to handle the apparition of local interactions (such events as drawing water from a pond or building of walls to prevent erosion and runoff).

The idea of our modelling approach is to consider water as a set of multi-scale agents which evolve independently in the environment from which they locally extract the information they need. The first level of this configuration consists of a population of individual entities, waterball agents, which move according to their local environment. In (Perrier and Cambier 1996) this environmental information is given by several parallel discretisations of *a priori* independent levels of information (soil or vegetation maps, topographical map, map showing human layouts, etc.). Waterballs are the actual mediators between those different spatial information types, in so far as they introduce, when needed, a local superposition of information sources relative to the studied processes.

The computation of waterball motions at the surface depends on the topographical map. It is done in a deterministic way - the motion is assumed to be that of a mobile on an inclined plan with acceleration and friction forces (Solignac 1996). The basic idea is to make such a motion computation as independent as it may from the type of geometric representation used by the topographical map : the waterball motion is determined by the local normal vector which is internally computed by the topographical agent on request of a waterball. Thus we try to consider the action space of waterballs - which we perceive as continuous - as being independent from the structure of the information which determine this action - topographical and other information. The first implementations are promising as far as the openness of the model is concerned - addition of new actors, such as a new soil map for infiltration or an obstacle dynamically set up on a slope which waterballs perceive when drawing near and which locally alters waterpaths (Solignac 1996).

In the course of its motion on the surface a waterball may come down to a local minimum, which leads to the creation of a pond. From a general point of view, the accumulation of water in certain points (ponds and streams already existing and ravines created in the course of the simulation) leads to different hydrological behaviours (volume, height and spatial extension variation of a pond, flow rate and spatial extension variation of a ravine).. Therefore we try to define new types of hydrological agents (ponds, ravines, etc.) which interact with waterballs and to specify the conditions of their creations and evolutions. A pond is dynamically created when the speed of a waterball becomes null on a local minimum of the topography. But the determination of its variable spatial extension and outlet from topographical data leads to important geometrical problems (Solignac 1996). Such computations have been possible for specific topographical representations but with a consequent loss of independence between the pond agent and the spatial support of its states and actions. The idea we have come up to then consists in considering the pond as a collective set of waterballs. Each waterball agent is provided with a capacity of memory (historical record of the path followed), which enables the consistution of a representation of the drainage area on the sole basis of the information stored by waterballs. Thus pond and waterballs share the same representation of space linked to action and coexist at different levels of organisation.

3 Capturing Scale Transfer Processes in Simulations : Why?

3.1 Reality Is Perceived at Different Scales

When looking at a sand pile, the first thing we perceive because of the poor keenness of our vision is a whole. Of course we know that this whole is made up of lots of sand grains which we could see if we drew closer. Fortunately enough we do not constantly think of the sand pile as a collection of grains and we naturely perceive it as a whole, disregarding its “particularness”.

When looking at a traffic jam, we do not only see a collection of cars, but a self-organized object which actually grows in the opposite direction that the cars slowly follow. The same phenomenon occurs when taking part in a demonstration. We may talk with friends that are walking beside us as if the whole procession did not exist. But we may as well feel ourselves carried along by the crowd as if all the people taking part in the demonstration were a unique whole, moving individuals along the streets, constraining our own behaviours.

Moreover we commonly reify the group we feel we belong to. Gilbert gives an example of such a situation (Gilbert 1995b), for instance when people are influenced in their consumption decisions by their adoption of a lifestyle : “there are some people who quite consciously adopt lifestyles and others who discover that they have adopted a lifestyle. These people are quite likely to categorize themselves as the sort of people who follow this lifestyle, to band together as a group (e.g. punks, students, old age pensioners) and to contribute explicitely to the evolution of the lifestyle".

This ability to change our way of perceiving the world, according to where we sit so to speak, accounts to a wide extent for our capacity for modelling reality. We are able to conceptualize part-whole relations according to our perception of correlations or constraints and at the same time disregard non fundamental peculiarities so as to build new abstractions : that is precisely the basic exercise in the intellectual gymnastics of the scientist, to simultaneously adopt different points of view on observed phenomena.

Indeed, as underlined by Stöckler (1991a), such a capacity becomes truly essential when apprehending complex systems : "Contrary to the ideal of complete description with as many details as possible, complex systems require a simplified characterization which nevertheless saves the essential features of the system. For practical reasons, details which are not important in a particular context should be neglected." And moreover, it is useful to introduce new concepts on the higher levels if the macro-level exhibits constant structures. Such higher level abstractions prove more useful for explanations than irrelevant atomistic details, even if they do not point at irreducible new entities or forces (Stöckler 1991a). Such abstractions help us to apprehend reality and build models which are by essence simplifications of the actual reality.

3.2 Simulations Should Integrate Different Scales

Having said that, we are inclined to expect simulators, which are models put in process, to inherit from such an ability. As a matter of fact, most simulators show poor capacities as far as handling multiple viewpoints and scales is concerned. They often deal with one unique level of analysis, whatever the modelling formalism : for instance, the level of the ants in MANTA, a multi-agent simulation of ant societies (Drogoul *et al* 1995), the level of gaz particles in lattice gaz methods - cellular automata dedicated to hydrodynamics - (e.g. Fredkin 1990, Toffoli and Margolus 1990), the level of fishes in SEALAB, an individual-based modelling of fish demographic behaviour (LePage and Cury 1996).

Some simulations do handle objects that belong to different granularity levels. In (Bousquet *et al* 1994) for instance, fishermen, ethnic groups and fishing ponds are represented. But in those cases, all the different entities - and thus levels - that are present in the simulation are static objects built at design time : groups neither dynamically appear from the lower level nor vanish in the course of the simulation.

To be fair, these simulators do not rest upon one unique level of analysis, rigourously speaking. They exhibit emergent phenomena : interactions among objects at the ground level give rise to different types of objects at a higher level. For instance in MANTA, social structures such as a division of labour emerge as a consequence of the behaviour and interactions of individuals. However such emergent phenomenon must be analysed after the simulation process in the light of the data produced. At the end of (Drogoul *et al* 1995), the authors admit that such post-analysis requires a huge amount of work before being able to conduct new experiments on its basis.

Instead, we believe that simulators *should* be able to handle processes at different time and space scales and integrate such emergent phenomena. Two main reasons account for this.

On the one hand, it is a question of cost-efficiency. Simulator designers express major concern about the ability of simulators to scale up when the number of simulated objects increase. For instance, Scheffer *et al* (1995) admit that a major problem with individual-based models is that the typically large number of individuals needed requires impractically large computation times. They suggest to add an extra feature to each model individual : the amount of individuals that it actually represents. In the course of the simulation, some global process regroups similar individuals into super-individuals, so as to reduce the computational burden. It is all the more important to try and cope with such a problem, as it is precisely when large number of individuals interact and lots of computation is required, that the most interesting phenomena occur : Darley (1994) considers for instance that "emergence is purely the result of a phase change in the amount of computation necessary for optimal prediction of certain phenomena".

On the other hand, there are more conceptual reasons that account for such a need. Recall the example of the consumption decision making. Not only can we as observers distinguish patterns of collective action but the agents themselves can also do so and therefore their actions can be influenced by their recognition of these patterns. In other words, a simulation of such a process would have to model (Gilbert 1995b) :

1. The emergence of patterns of consumption in the society as a result of social imitation of individual agents' consumption decisions,
2. The perception by agents that these patterns exist,
3. The categorization, or social construction, by agents of these patterns into some small number of lifestyles,
4. Eventually the influence of agents' adoption of these lifestyles on their consumption decision making, leading to the evolution of adapted or new consumption patterns.

In the case of the RIVAGE project, suppose we want to model the action of drawing water from a pond. We cannot possibly do so by describing each interaction between the agent that draws water and each waterball. We do need to introduce the pond agent, as a realistic counterpart.

We say that both reasons essentially call for the same type of recognition process, which we naturely and constantly do in reality : to recognize the relevant level of analysis for describing interactions. Simulators should be able to provide means of doing the same. Indeed we have to find a tangible computer equivalent to our ability to perceive scale transfers : when individuals might be rightly consider as a group, that is as an individual of higher level, and conversely when the group as a whole no longer exists or is not sufficient to account for the underlying reality.

4 Capturing Scale Transfer Processes in Simulations : How?

4.1 From Individuals to Individual

So as to be able to build such simulators that would handle multiple viewpoints and scales and dynamical change of scale, a good starting point is to analyse our own ability to perceive an individual entity out of a collection of individuals. Put it differently, how do we recognize that "something macro" is going on?

Emergence Obviously this is related to the issue of emergence. We shall take a look at some definitions of this concept.

Stöckler (1991b) stresses that the notion of emergence has a pragmatic aspect : his main idea is that emergent properties occur if the tools of explanation, which are sufficient for the parts of a whole, are not adequate for a real understanding of the composed system. "I have proposed calling those properties of complex systems emergent which cannot be explained by those parts of the fundamental theory which are sufficient to understand the behaviour of the isolated components".

We may find another close definition of emergence in (Darley 1994), who considers an emergent phenomenon as "a large scale, group behaviour of a system, which does not seem to have any clear explanation in terms of the system's constituent parts". For him, emergence results from our inability to predict the outcome of accumulating interactions among objects. In those cases, the optimal means of prediction is simulation. Cariani (1992) would call it emergence-relative-to-a-model, which involves a change in the relationship between the observer and the physical system under observation - when the behavior of the system deviates from the observer's model of it.

Gilbert (1995a) speaks for considering that there are multiple levels of emergence, forming a complex hierarchy. "It may be the case that individual identity is best regarded as an emergent phenomenon, where the micro-level agents are sub-cognitive, such as neurons". Here as well the level of emergence depends on the relevant level of analysis according to an observer of the phenomenon.

The concept of emergence seems rather ambiguous indeed (see M.R. Jean 1997 for a more thorough discussion). We would like to retain two main aspects. First, the emergence phenomenon lies to a certain extent in a shift in our vision of things. Secondly, emergent phenomena reveal a shift in the behaviour of the whole.

Collective Individuals in Human Sciences In Human Sciences, the question of the observer's viewpoint and of the right level of analysis has continuously aroused conflicts among scientists. We will not try to summarize the debate which has divided the defenders of methodological reductionism and those of structuralism (see for instance Gilbert 1995a, Treuil 1995 or Caillé 1992 for an account of this debate). Rather we will echo some hints expressed by some authors in favour of an in-between way.

In (Smith 1998), the author says that : "Ever since social sciences first began to analyze groups of people as if they comprised a single entity or structural componenent a constant objection has been raised : social structural entities do not really exist save as heurisitcs". As a matter of fact, even if human consciousness so to speak is needed to observe such structures, they can be empirically shown to exist. For instance in Axelrod's experiments on the emergence of political actors (1995), the new organization resulting from alliance formations between states is shown to possess all the required conditions to be assumed as a state in its own right : effective control over subordinates - little rebellion and no independent foreign policy -, collective action - paternalism and joint foreign policy -, and recognition by others as an actor. This last feature is crucial. For some social simulation specialists (Gilbert 1995a), "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 society."

From this, we shall keep in mind that the knowledge of the existence of a group is part of the group itself. In other words, what seems to found a group is the acknowledgment from individuals that they belong to it.

Individual-Based Methods Historically individual-based methods have been used by biologists and ecologists, whereas agent-based simulations come mainly from computer scientists. In essence they are similar. When spatially distributed, these methods easily account for spatial heterogeneity of phenomena. Moreover they are easy to apprehend by the profane : individuals are taken as the natural units, which is both more realistic and intuitively straightforward. Besides, they are sometimes more cost-effective than other methods, especially when complex systems and demographical processes are concerned.

However it is not always easy to decide whether or not the phenomena require that we trace the actual evolution of each individual in the course of events, instead of simply describing them in statistical terms - in other words, when the continuity of identity becomes as essential as that of existence.

For instance in Lotka-Voltera like dynamics, there are two individual states : either prey or predator. The macroscopical state is given by the numbers of preys and predators. The microscopic state is given by the state - prey or predator - of every individual. Thus, to each macroscopic state corresponds many microscopic states. If any permutation of individuals results in changes in the macroscopic state *destiny*, it is necessary to take individual behaviours into account (DeAngelis and Rose 1992). Otherwise the interactions among individuals are likely to be numerically integrable and should not be considered at the individual level.

So a topical question we are faced with in the course of an individual-based simulation is *when* we can soundly assume individuals as interchangeable with respect to the global destiny of the population. Indeed this question determines the validity of the adopted scale of analysis.

Scale Transfer in Physics The problems at issue have a special echo in Physics : the scale transfer.

Perrier (1990) gives a thorough account on that matter, in the field of hydrodynamics. Classically in Hydrology each model accounts for a unique specific level of study. For instance, hydrodynamic modellers are interested by porous media at a micro-level, whereas agronomists study the evolution of water stocks on a parcel and hydrologists develop their own models at the level of a watershed. In a sense this does seem to be rather normal and satisfactory an approach. As a matter of fact phenomena which have very different characteristic lengths generally have little influence on one another (Wilson 1989). We may separately study them. Water waves for example pulse through the medium but at every stage of their travel they are made up of different collections of water molecules. Fortunately enough we may accurately describe waves as perturbations in a continuous medium, disregarding the molecular structure of water.

However there are occasions when the need to take into account scale transfers becomes urging.

Sometimes, we are compelled to go deeper in complexity and consider things at a micro-level. For instance, the law of Darcy which accounts in a simple way for the flows in a macroscopically homogeneous porous medium with specific boundary conditions, fails to be extended to heterogeneous media. Unfortunately, at this level, local heterogeneities, geometrical and structural organizations of the soil might no longer be neglected. Working at the micro-level arises the question of how to extract global macro properties - that interested us in the first place -, from local micro processes. In other words how do we *computationnaly* proceed to a scale transfer?

For that purpose lots of methods have been used : mainly integrating differential equations in a continuous medium or using numerical simulations which rest upon a discretization of the porous space and even sometimes of the flows themselves (e.g. lattice gaz methods). The scale transfer essentially consists in some averaging. For instance in lattice gaz methods, in order to lighten the computational burden of huge sized networks, renormalisation group techniques have been introduced (Lesne 1995) : a macro-lattice stands for a particular area of the initial network, and is given macroscopic speed computed as the average of micro-speeds (coarse-grain averaging). Thus a smaller network is computed instead of the huge initial one. In this sense it is rather close a method such as that put forward by individual-based simulation designers, as seen above.

Yet we know even more critical situations, phase transitions for instance, for which we have to take into account a wide range of scales at the same time. For instance the phenomena associated with sandpiles manifest themselves only when all the sand grains are said to communicate globally with one another, that is when correlations occur at all length ranges.

So eventually the most important question that comes up with scale transfers in Physics is to detect phase transitions, so as to dynamically adapt our scale of analysis.

4.2 Hints for the Building of Simulators

We shall try and sum up the elements that result from our brief overview of the previous section.

Multi-agent simulations rest upon interacting entities. With respect to the intensity of their mutual interactions, such entities may show "various ways of being together". When interactions are rather loose, we are likely to perceive the entities as disorganized. On the contrary, when the interactions are more intense, the entities show various organizational structures. A structure emerges from another on phase transitions.

Such changes in the organization of the entities result in shifts in the vision of an external observer.

What actually happens during these phase transitions? Let us follow each individual entity which moves in some description space. When interactions are loose, individuals move about in the description space, in rather a free way so to speak, and thus may potentially visit the whole description space. Then under some circumstances, individuals adopt similar or coordinated trajectories, thus creating or entering a specific mode of existence, an ordered kind of mode (Prigogine and Stengers 1992).

Our hypothesis is that entities can locally and in a collective way *recognize* what their current mode of organization is, or at least that they are organized in some way. Such recognition can proceed locally (and not at a global level as in Marcenac *et al* 1997) because entities can detect a decrease in their own degree of freedom - their trajectories are somewhat constrained by others - and notice a correlative decrease in the others' degrees of freedom. Such process happens in a collective fashion as it is through communicating with one another that entities may be mutually aware of their correlations. As a result, a new entity is created by the decision of all correlated entities and incarnate their group.

So the agents must be provided with means of recognizing the emergence of structures in their environment. Some sort of a dynamical emergence recognition process must be built. The agents must be aware of the fact that their correlations between one another have lasted long enough, and consequently, that it is both more cost-effective and more accurate from a conceptual point of view, to consider them as a whole. This emergent whole would be represented as an agent in the simulation.

The next question is whether we should predefine such groups or not. In the case of RIVAGE, should waterballs agglutinate in completely general water groups or specifically in ponds and ravines? Both approaches have advantages and drawbacks.

A possible approach could be to look for some signature in the description space, or phase space, of the different predefined types of organization : for instance waterballs regrouping in a pond are immobile, their trajectories are a set of close points, on the contrary waterballs regrouping in a ravine have very close linear kind of trajectories.

However we may as well favour an all-emergence kind of approach, without any predefinition of groups. Indeed this may be necessary when we do not have clues about the groups that may appear and would help us create new ways of seeing the world.

But once the group created, the interaction rules between group and entities - control issue -, group and other groups, and group and observers of the simulation - how groups are seen by observers -, have to be specified. We may not do without a predefinition of the latter. Indeed, if we could, that would mean that such notions as volume, temperature, etc., could emerge as concepts in a simulation. This is by far too unrealistic, which seems to call for a predefinition of groups.

So it seems we have to deal with two different steps intimately connected with one another. Schematically, on the vertical axis an emergent process creates higher level entities out of lower ones, and some guided process rules the interactions between entities on the horizontal axis. The next section gives preliminary hints for implementational matters in the light of our own experience in the development of such a computer organization.

5 Emergence and Coexistence of Groups for Distributing Action Control : RIVAGE application. Preliminary Results

The implementation of a discrete version of the simulator in the RIVAGE project has allowed us to start an investigation on the means of introducing and making to coexist agents which emerge from the collective activity of other agents, within one simulation (Servat 1997).

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, gets rid of 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 an historical account of their states, on the basis of which they proceed to regroupings and give birth to ravine and pond agents. Their history account for several cycles and actually determine their belonging to one of the following categories :

1. A cell belongs to the category of *potential ravines*, when its history shows only states 1.
2. A cell belongs to the category of *potential ponds*, when its history shows only states 2.
3. Otherwise a cell belongs to the category of *potential hillsides*, that is when it is sometimes not occupied by a waterball.

Such a categorization tries to take into account the fact that some cells are more frequented than others.

Among the first two categories neighbouring cells may form clusters. When these clusters comprise a sufficient number of cells and obey to some preconditions, groups are created. A pond agent is created when a sufficient number of neighbouring cells are in the same cluster of potential ponds. A ravine agent is created when a sufficient number of neighbouring cells belonging to the potential ravines are in the same cluster, and when at least one of them is on the border of the surface or close to another already existing group : such a cell represents the outlet of the ravine.

These new agents take control over the regrouping cells, which are restrained to play a role of interface with the medium : they keep on receiving balls coming from other cells outside the group, but no longer handle waterball exchanges from cell to cell within the group.

The group agents handle waterball *flows* themselves, *via* their outlets, from groups to groups without having balls moved from cells to cells. Each group is given a maximum capacity of waterballs or stock (so far it is simply the number of cells in the group). Cells within the group accept waterballs to the extent of the group capacity, beyond this limit they act as impermeable membrane.

Periodically, groups try to get rid of their stock of waterballs, *via* their outlets. If the agent does not have an outlet towards the exterior of the surface, it asks other group agents which are linked to itself to take some or all of its stock.

The 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. The dissolution process so far amounts in the case of a ravine to free a number of randomly chosen cells proportional to the decrease of the flow received from outside, and in the case of a pond to free all cells. When the number of cells in a group falls below some critical threshold the group no longer exists.

Eventually we have to consider the interactions between different groups and between groups and individuals. This point is still under reflexion. The recursive regrouping of entities which share the same granularity - for instance the creation of a ravine network - can obey the same principles regardless of the level. Yet further work is needed as far as the interactions between entities of different granularities and between different group types are concerned. A possible way of research may consist in trying to formalise these interactions in the form of rules. May a pond merge directly with a ravine or does it have to dissolve itself ball after ball in the ravine? Is a waterball coming accross a pond always absorbed by the pond? All these questions have not been answered so far, and perhaps a reason for this is that we have made our investigations in a discrete representation of space, 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.

We are currently working on an adaptation of the processes implemented in the discrete version of the simulator to a continuous one. In this continuous version, waterballs no longer move from cell to cell in a discrete lattice, but move in a tridimensional continuous space, which is much more in keep with our own vision of the physical reality. Such an adaptation needs that we be able to handle interactions among agents - to spot them as well as to put agents in interaction. The absence of a fixed frame of reference - no discrete lattice - leads us to think about setting up, besides a distributed control of action, a distributed control of space which puts action entities in relation. We have started to implement such a control of space in the form of a dynamic structure of mediator agents.

6 Conclusion

Our discussion about such concepts as scale transfer, emergence, individual-group relation in social sciences gives us a much more precise vision of the type of system we need for the applicative goals of the RIVAGE project. This vision rests upon such notions as groups, inclusion of groups, which are at the heart of the multi-agent formalism and enable us to model the reality in much more faithful a way to the hydrologist's.

Moreover it seems to us that the question of handling multiple viewpoints and scales in simulations is shared by a wide community of researchers from different domains (ecology, social sciences, ethology, physics, etc.). We hope that some of the reflexions we have presented here will contribute to start a fruitful debate on those topics.

From an implementational viewpoint, lots of further work is needed. We have mainly dealt with the dynamic creation of groups but have not quite formalized what it actually means for an agent to belong to a group - inhibition of some individual behaviour, inheritance of other behaviour, internal variables restrained to a certain range, etc. Undoubtedly this research will bring new aspects of the agent programming paradigm into light. If we give agents means of creating new agents out of their collective activity, we will have to implement new architectures which provide means of dynamically creating their own organizations.

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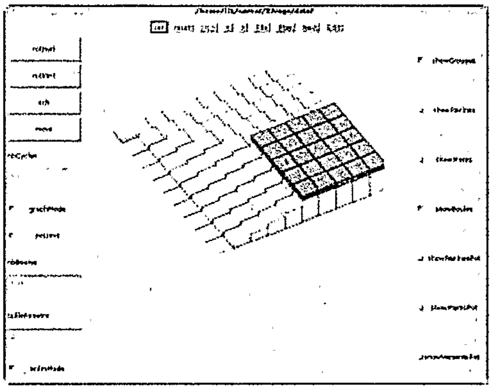

Fig. 1. Initial state. The user has set up a pond agent, shown in dark gray. The white cells represent the relief

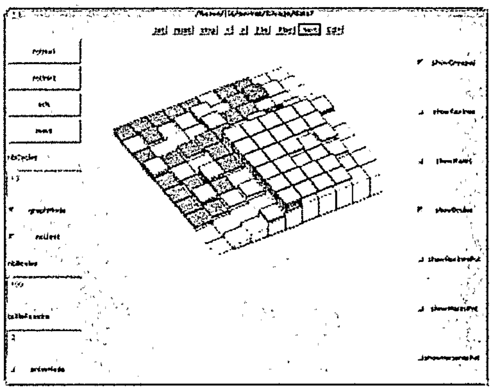

Fig. 2. The pond agent from Fig.1, obviously too extended, dissolves itself, freeing its cells, in light gray, and giving birth to the regrouping of cells in medium gray on the slope

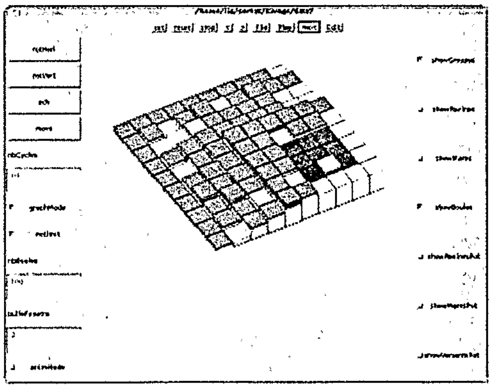

Fig. 3. Final state. The pond reappears in dark gray, with proper dimensions. The regrouping of cells in medium gray goes on, in one big ravine agent. A few free cells are also found, in light gray

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