12. Multi-agent systems and role games: collective learning processes for ecosystem management

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12.1 INTRODUCTION

For several years now, a field of research on simulating societies in interaction with their environment has been taking shape. Methods such as multi-agent systems (MAS) can be used to create virtual societies. The effects of interactions among different behaviors on resource dynamics and associated feedback are simulated. Modelers use such methods to create computer representations of dynamics observed in the field. The multi-agent methodology, which results from research on complexity, corresponds to the evolution of concepts described by Attonaty *et al.* (1990): after using operational research methods to identify the solution to a given problem, researchers turned to ways of representing a stakeholder's strategic and tactical decisions through expert systems or simulation methods. Then, multi-agent systems provided a new tool for the modeling of complexity and particularly the modeling of collective decisions. Our team[1] has been using MAS in several ways.

1. First, we developed abstract models, also called artificial societies that help to understand the generic properties of interacting processes. We mainly developed models on non-merchant exchanges and reputation (Rouchier and Bousquet, 1998; Rouchier *et al.*, 2001b; Thébaud and Locatelli, 2001), models on economic tools for the regulation of economic

exchanges (Antona *et al.*, 1998), and models on spatial dynamics (Bousquet and Gautier, 1998; Bonnefoy *et al.*, 2000).
2. We also developed applied models to understand the dynamics of natural and renewable resources and their management (Barreteau and Bousquet, 2000; Bousquet *et al.*, 2001; Rouchier *et al.*, 2001a).
3. We developed a modeling tool (CORMAS, *common-pool resources and multi-agent systems*) (Bousquet *et al.*, 1998).
4. We also worked on defining the possible uses for these MAS tools within the very wide framework of collective decision support. The objective of this chapter is to propose a method and present our first results.

The use of MAS models is a key issue. As with any kind of representation, these models can be used to increase scientific knowledge about the ecological and social processes at stake. The question of the organization of this learning process remains. There is an old debate between two paradigms (Checkland, 1981; Funtowicz and Ravetz, 1994; Röling, 1996). Schematically, on the one hand, researchers following a positivist paradigm try to discover the objective truth. This knowledge is used to develop and deliver new technologies or new management rules. On the other hand, the constructivist paradigm assumes that reality is socially constructed. As Röling (1996) said, 'Based on their intentions and experience, people construct reality creatively with their language, labor, and technology. Different groups do this in different ways, even if they live in the same environment. The same people change their reality during the course of time in order to adjust to changing circumstances.' Although the scientific knowledge on biophysical and social processes is to be used, this second paradigm is the epistemological context of our research. The collective creation of a common artificial world serves to create a shared representation and to simulate various scenarios with the stakeholders, among which are the scientists. We have been interested in using MAS models in the collective decision-making process for ecosystem management. Unlike the conventional decision-making process derived from Simon's model (Simon, 1947), which defines a decision as a rational calculation on the part of a more or less fully informed decision-maker, our studies see the decision-making process as a series of interactions between stakeholders with various objectives and with varying degrees of importance and influence. Within this framework, any decision, particularly if collective, is context-dependent and should be seen as a stage at a given time *t* in the continuous process of management of a complex issue. The emphasis has shifted from the static to the dynamic and from an individual to a collective level. Several approaches for collective ecosystem management exist.

Adaptive management (Holling, 1978; Walters and Hilborn, 1978) is an approach based on the recognition that ecosystem management requires flexible, diverse, and redundant regulation, monitoring that leads to corrective responses, and experimental probing of the continually changing reality. Although adaptive management is an approach conceived by ecologists, they recognize that adaptive capacity is dependent on knowledge – its generation and free interchange – and the ability to recognize points of intervention and to construct a bank of options for resource management. Thus, interactions with stakeholders for the generation and interchange of knowledge are required. This social process of generation and free interchange of knowledge may lead to new interactions and thus to the issue of devolution of power. Co-management (Berkes, 1997; Borrini-Feyerabend *et al.*, 2000) is defined as a partnership in which local communities, resource users, governmental agencies, non-governmental organizations, and other stakeholders share, as appropriate to each context, the authority and responsibility for the management of a specific territory or a set of resources. Patrimonial mediation is presented as one of the approaches contributing to understanding and practicing co-management (Borrini-Feyerabend *et al.*, 2000). 'Patrimonial' is defined by Ollagnon (1991) as 'all the material and non-material elements that work together to maintain and develop the identity and autonomy of their holder in time and space through adaptation in a changing environment'. A patrimonial representation of a territory, an area, or a set of resources links past, present, and future generations of managers, focuses on the owner's obligations more than on the owner's rights, and promotes a common vision of sustainability that reconciles the needs and opinions of various actors. Mediation is a negotiating method that brings in a third, neutral party in order to obtain agreement among the parties involved in the process; it is an approach in which each party's views on the issue or problem are translated for the others (Babin and Bertrand, 1998).

In our research, we try to develop an approach for the use of simulation models, in particular multi-agent systems, within the context of such patrimonial mediation experiments. This method uses role games to acquire knowledge, build a MAS model, validate the MAS model, and use it in the decision-making process. We named it 'companion modeling' because it is used as a tool in the mediation process – the social dimension of the companion – and it co-evolves with the social process, temporal and adaptive dimension. We started different applications to assess whether models and role games can be used successfully together to support collective decision making, and to explore different uses of these coupled tools. Six tests of the approach have been conducted and they illustrate the article. The goals of the different experiences are:

- To simulate the variability of irrigation schemes in Senegal. A model was created and a role game designed to present the model to the various stakeholders. The model and game were used in villages and at a training centre.
- To help with mediation in biodiversity management processes in Madagascar. A spatialized resource dynamics model was programmed for use as a dynamic support for negotiations between stakeholders.
- To predict the impact of silvo-pastoral development within the framework of forest fire prevention plans in a region in the French Mediterranean. A model of negotiations between foresters and livestock farmers was developed in relation to Mediterranean forest management. It was then simplified into a role game with a view to producing a typology of land management strategies and negotiating methods, and to providing a teaching aid to develop management capacities or explain the constraints relating to each user. This was subsequently used for training purposes.
- To simulate scenarios of adaptation to the spontaneous establishment of conifers in natural ecosystems with high patrimonial values in the South of France. A model of herders' individual practices and actions of conservationists was developed and it led to a role game. During the role game, the model served to simulate the dynamics of the resource.
- To test hypotheses about the differentiation of households at the end of the cooperative period in a region in northern Vietnam. A role game was proposed to collect information and feed a MAS model that is presented to stakeholders for validation and discussion.
- To facilitate discussions between populations and their local representatives in the case of the decentralized allocation of land in the Senegal River delta. During village workshops, role games were used to help stakeholders develop a common model, which was then computerized in the form of a MAS. The model was then used to simulate the scenarios imagined by the stakeholders, which triggered a group discussion of the possible evolution of the interactions between users and resources and of the steps that could be taken to adapt to these changes.

Our chapter begins by covering the principles on which this approach was based. We then go on to present the various tests that demonstrated that it is possible to use models in this way, and indeed that this method is effective in supervising a collective decision-making process. The different uses of role games and models in the mediation process for co-management of resources are then analysed. In some cases, the model simulates the dynamics of a resource and provides a dynamic basis for a negotiating game, while in others the scientists' model has been converted into a role game with a view to validating or more clearly explaining stakeholder strategies. In the remainder of the cases, role games are used for the collective construction of a MAS, which is implemented and then presented for discussion. Lastly, we draw some conclusions from this work and suggest certain prospects, particularly the issues of institutional arrangement and assessment of the process.

12.2 MODELS, GAMES, AND STAKEHOLDERS: A REVIEW

The development and use of MAS models and role games for collective decision making in natural resource management (NRM) is very new. In this review we start presenting contributions on interactive modeling which do not use these tools but give interesting conclusions or adopt different approaches. Firstly we present selected contributions in participatory modeling (with other tools than MAS and role games) to support problem solving. Then we present contributions on the use of models and experiments to explore theories on human behavior. We end with the few contributions on the joint use of models and role games for education and management of resources.

12.2.1 Participatory Modeling to Support Problem Solving

The relationships between simulation models and collective decision making in natural resource management occupy a large part of the literature on adaptive management (Holling, 1978; Walters and Hilborn, 1978). Scientists from different disciplines and some decision makers develop a model and explore various scenarios. However, the model is often a biophysical one and very few papers mention the participation of stakeholders from different organizational levels in one of the modeling steps (from conceptualization to scenario simulation). We present here the ecosystem simulation models developed by Costanza and Ruth (1998), two references on integrated assessment models, and some Australian experiments (see Abel *et al.*; Chapter 13).

- Costanza and Ruth (1998) advocate the use of a three-step modeling process, with all steps involving the stakeholders. They use graphical STELLA programming, which allows the simple design of non-linear dynamic systems. The first step is to develop high-generality, low-resolution scoping and a consensus-building model involving broad representation of stakeholder groups affected by the problem. The second-stage research models are more detailed and realistic attempts to replicate the dynamics of the system. It is still critical to maintain stakeholder involvement and interactions at this stage of model progress. The third stage of management models focuses on producing scenarios and management options based on the earlier scoping and research models. They tested this methodology for Louisiana coastal wetlands, South African Fynbos ecosystems, and the Patuxent River watershed. The main lesson drawn from these experiments was that participation of various stakeholders has to be maintained through the various steps of the modeling activities. The second lesson was that these are long processes lasting for several years.

- Abel (1999, Chapter 13) presents the main principles of his approach on rangelands as complex adaptive systems. To understand these systems, one needs to elicit the mental models of the stakeholders. A mutual exploration of these mental models in a collective learning process is necessary for better management. In the project, stakeholders (aboriginal peoples, pastoralists, conservationists, and the minerals and tourism industries) developed scenarios of sustainable patterns of land use and policy makers designed the institutional changes needed to support changes in those scenarios. Researchers organized the stakeholder and policy processes and estimated the sustainability of land-use scenarios using conventional models. In this approach, stakeholders guide the questions and at the same time gain an understanding of processes, such as climatic changes or regional economic growth, with which they may not be familiar. Their scenarios were developed using a process and software developed by Cockes and Ive (1996): a spatial information-based mediation support process for resolving resource-use disputes, SIRO-MED. It is supported by the software WinLUPIS (Land Use Planning and Information System). It uses rules proposed by stakeholders to allocate land uses to mapping units. Stakeholders enter negotiations in which their land uses compete for land with the land uses of other stakeholders. The mutual adjustment of land allocations generally leads to an efficient and politically acceptable mix of land uses. WinLUPIS offers a range of tools to aid this process. WinLUPIS is not a simulation model, but it is an interesting experiment reflecting a shift in the use of decision support systems. The authors state that there is public demand for the procedural legitimacy the process offers. The policy process was also participatory: practitioners worked with researchers to build influence diagrams as a basis for understanding and then proposing changes in laws, policies, and organizations.
- Van Asselt *et al.* (2001) have identified two examples of participatory modeling in the field of integrated assessment. The RAINS (Regional Air Pollution Information and Simulation) model started as an IIASA project

(IIASA, 1999) and was subsequently used as the worldwide standard model, with scientific experts and policy makers participating in the model design. QUEST (Quite Useful Ecosystem Scenario Tool) is a computer game (Rothman *et al.*, 2001). The approach focuses on learning through scenario construction rather than through scenario results. Both of these models were not participatory models when their design started.

Little has been done in participatory modeling but lessons can be learned from participatory geographic information systems (GIS) research in NRM. This is a more advanced field of research. Today, manuals are available for extension agents in rural areas (CBFMO, 1998). Participatory GIS have demonstrated the ability of many illiterate people to use high-tech tools. The following authors have survey papers:

- Fox (1998) presents the principle of community mapping. Several responses followed his article. The use of spatial technology for community mapping and counter mapping is very useful but has some weaknesses. Constructive criticisms have to be borne in mind when using simulation models. Among others, the design of maps destroys the fluid and flexible nature of boundaries, increases the potential for surveillance and violation of privacy and ownership of information.
- Abbott *et al.* (1998) review participatory GIS. The same kind of constructive criticisms are made. GIS, like many technological innovations, both marginalizes and empowers people and communities simultaneously. Issues of confidentiality and privacy might be exacerbated: there are risks that local knowledge will become recorded and centralized.

One interesting experiment, among others, is the work of Gonzalez (2000) on watershed management among the Ifugao (Philippines). The author presents GIS as tools for interactive learning, to facilitate what Giddens (1987) calls 'double hermeneutics' in science, that is, learning from one another. Furthermore, these experiments with participatory GIS are interesting because one can find experiences for scaling up the results obtained at the community level.

12.2.2 Models and Experience to Explore Theory

Modeling interactions between players is the objective of game theory. Game, here, has not the same meaning as role game. Game theory is an approach used mainly in economics: an interaction situation between two or several players is represented as a strategic game. Payoffs are associated with the different potential choices of the players. Thus it is possible to compute the expected results of the interaction according to the strategies of the players. Many models have been developed, particularly in the field of resource sharing. Reference papers in the field of common pool resources (CPR) management such as (Hardin, 1968; Ostrom, 1990; Stevenson, 1991; Ostrom *et al.*, 1994) are based on a game theory approach. We do not cover that literature because the stakeholders' strategies are modeled but they are not involved in the process. Some experiences in the field of experimental economics are more relevant for our review. Economists involved in institutional and policy research link game theory, institutional analysis, and laboratory experiments (Ostrom *et al.*, 1994). In this field, players are usually students but recent experiments have involved concerned actors such as farmers in Colombia (Cardenas and Ostrom, 2001). Players are usually interested in game results with a salary depending on their results in the game. The objective is to observe whether human beings behave as various economic theories predict. There are several experiments (Mason and Philipps, 1997; Sell and Son, 1997; Gintis, 2000b) and discussions on experimental economics and NRM. One important conclusion of these experiences is that game theory is relevant to model situations in which no communication between the players occurs. From their experiments with stakeholders, Cardenas and Ostrom (2001) conclude that a better understanding of the composition of groups is needed if we are to understand and forecast the efficiency of cooperation. Other works based on the comparison of experiments with managers or students have also pointed out that the expertise of the players in the field of the game improves their strategic behavior (Cooper *et al.*, 1999).

Agent-based modeling has been linked with experimental economics (see Jager and Janssen, Chapter 6)). Duffy (2001) uses an artificial agent-based computational approach to understand and design laboratory environments. Similarly, Deadman *et al.* (2000) describe the development of a series of intelligent agent simulations based on data from previously documented common pool resource experiments. These simulations are employed to examine the effects of different institutional configurations and individual behavioral characteristics. These results are compared with those experienced with human players. For instance, in non-communication simulations as well as in experiments, high performance leads to overinvestment in the CPR and the resultant drop in performance causes a reduction in group-wide investment in the CPR. As in the lab experiments, communication in these simulations does frequently result in the discovery of the optimal level of investment.

These experiments show a linkage between the human players involved in experiments of social interactions and agent-based models. The MAS models may be useful devices for both understanding and designing human-subject experiments. But the objective of the experiments is to test very theoretical rules given by economic theory and not to simulate a real-life situation. Consequently, the players do not participate in the design of either the model or the experiments. The objective of experimental economics, coupled with MAS or not, is to assess theoretical models when decision centers are more than one and psychological patterns are activated. We use role games both to elicit knowledge and to simulate it in a less controlled way. These two steps, collectively achieved, aim at setting up an agreed-upon representation of reality rather than assessing a theoretical pre-given one.

12.2.3 Models and Role Games for Education and Management

Our approach stems to a quite large extent from work with role games and policy exercises and negotiation (Mermet, 1993). This work has shown the suitability of such kinds of tools to support negotiated processes such as local development choices (Piveteau, 1995) as well as for educational purposes (Burton, 1994). This work has also pointed out some difficulties encountered in their use: slow and heavy design, difficult comparison of results, and difficult control of parameters as well.

Therefore, these authors plea for coupling with some modeling tools aimed at alleviating these difficulties. The several potential parallels between role games and MAS listed in Table 12.1 led us to try such joint use with MAS and role games.

Table 12.1: Correspondence table between role games and MAS

Role-playing games	Multi-agent systems
players	agents
roles	rules
game set	interface
game session	simulation
turn	time step

There are a few experiences with the coupled use of models and role games for ecosystem management. Meadows and Meadows (1993) developed a famous role game called *Fish Banks*, which is used for educational purposes. Human players play the role of fish companies that share a common resource (two fishbanks). A simulation model simulates the dynamics of the resource that the human players harvest. The objective of the *Fish Banks* game is to illustrate and teach the tragedy of the commons principle: free access to resources leads to biological depletion and consequently to economic overexploitation. This game is played by students or resource managers. Another game associated with models is Burton's game (Burton, 1994). It aims at simulating the management of an irrigated system. These role games and simulation models have been used for educational purposes. These two models use the systems dynamics approach. Knowledge is represented as stocks and flows. Chapman (1987) compares gaming simulations (role games for us) and systems analysis. He states that systems analysis can cover only a very small part of the complexity that games can handle: 'Analytical statements are limited to a few components and the unwarranted assumption of a trend towards some equilibrium point ... Systems are reflexive, acting on component decision makers, who through their own actions and perceptions act on the system. These perceptions are by definition partial and imperfect. The only simulations which can include self-transformation and reflexive thought are ... gaming simulations.' We think that, in 1987, Chapman was unaware of new modeling methodologies such as MAS, which can capture the cited dimensions. The assumption is that MAS and role games share a common representation of complexity and can thus enrich each other.

Recently, following the experiments presented in this chapter, experiments started in Switzerland within the context of the Firma (Freshwater Integrated Resource Management with Agents) project (Hare *et al.*, 2002). The objective is to mediate coordination among stakeholders sharing water resources.

12.3 COMPANION MODELLING: THE USE OF MAS AND ROLE GAMES

In 1996, we proposed to use MAS and role games (e.g. Bousquet *et al.*, 1999) for better understanding and modeling of the decision-making process and for better management of natural and renewable resources. We presented the principles and the steps of a methodology which has been used and developed by the authors of this chapter.

One of the classic uses of simulation is for prediction, but this is not the option we have chosen. The very long term cannot be predicted in the economic and social field, though it is partially decidable. This is the hypothesis underlying the patrimonial approach (Montgolfier and Natali, 1987; Ollagnon, 1989). As Weber and Bailly (1993) said, 'Because the very long term is beyond the scope of prediction, if we wish to take it into account in the analysis of environmental problems, we must give ourselves very long-term reference points or objectives to guide the possible or impossible pathways of development. The long-term approach must inevitably be based on a scenario.' Because the rules result from interactions among stakeholders, they are legitimized in the eyes of all stakeholders and they incorporate particular perceptions. It is on the basis of a shared conception of how the present situation should evolve that stakeholders are able to 'decide' on very long-term objectives. On that basis, the scenarios that enable the objectives to be reached can be discussed. The entire mediation approach presupposes the establishment of an initial situation, in which the stakeholders are clearly informed of the issues that divide them and of their common dependence upon a solution to the problem at the origin of the mediation process. The challenge of the initialization phase is to enable stakeholders to express their perceptions of the present situation and of its evolution. When a 'map of perceptions', all equally legitimate and equally subjective, has been established and discussed, the stakeholders are asked to discuss the acceptability of prolonging existing tendencies.

How can simulations be involved in this process, that is, how can they help stakeholders to govern? The various stages of the patrimonial approach were given by Weber (1998) and presented by Borrini-Feyerabend *et al.* (2000). Below we present the different stages when a simulation model is used:

- Construction of an artificial world. The first stage, involving one or more researchers, is to gather information on the system under study. We suggest that fieldwork and modeling be performed in unison. The task is to identify the different stakeholders and perceptions and to use multi-agent systems for modeling. In a highly complex world, MAS provide a means to identify the most acceptable form of simplification by focusing questions on problems of representation the agents have on their biophysical and social environment, communication and exchanges among the agents, and control of the interactions. Simulation raises questions in the field that provide new data for the model.
- The second stage is a feedback stage that could also be referred to as validation of the knowledge represented in the model. The aim is to present the model proposed for the decision-making process to the stakeholders. It involves a thorough analysis of the representations and interaction processes among agents. Indeed, it is difficult to explain what has been 'put into the machine'. On the other hand, it is possible to put a stakeholder in the situation of the agent who is in the machine, with the hypotheses of representation, communication, and control that constitute the model. To perform this operation, we propose to use the role game methodology tested by the authors mentioned above. The artificial world is evaluated by plunging the stakeholders into it, that is, by creating a

world similar to the model. These stakeholders may be actively involved in the management system as users of the resource (farmers), regulators of this management system (managers or administrators), or observers of the system (researchers). Does the artificial world inhabited by these stakeholders resemble the real world? The aim is to validate a simulator in the same way as, for example, a flight simulator. A good flight simulator incorporates the same components of the decision-making process as in reality, rather than simply reproducing an actual flight. This stage may be included in the initialization phase of the patrimonial approach as it provides a means to establish a map of the various types of stakeholder and the different perceptions and interactions and to convert them into shared knowledge.

- The third phase is the simulation phase. Simulation shows how the dynamics of the system arise out of interactions among stakeholders with different weights and representations. We can divide this phase into two subphases. Initially, the simulation can be performed in the form of role play, which enables stakeholders to validate the fact that it is indeed in the interactions among different representations that the motor driving the dynamics of the system is to be found. This first subphase also brings to light the different scenarios that are worth testing. Then, once this phase has been completed, the multi-agent model can be used to make simulations based on different scenarios. Simulations, both 'in ludo' and 'in silico', are also involved in another phase of the patrimonial approach in which, after long-term objectives have been defined, the various scenarios liable to lead to these objectives are tested and their results discussed.

12.4. SHADOC[2]

The first operation was conducted under Olivier Barreteau's PhD thesis on the viability of irrigation schemes in Senegal. The issue was the low outputs of the irrigated schemes in North Senegal. The initial objective was to explore whether the viability of these systems was in relation to the coordination modes among farmers within them. For that we had to design a virtual irrigated system in which to conduct experiments based on scenarios dealing with collective rules, individual behavioral patterns, and environmental parameters. This work could not be done in real systems for ethical and practical reasons. The focus on coordination methods and the viability of irrigated systems led us to use a multi-agent system in building the model. The desire to concentrate on the processes involved in the coordination methods rather than on the specific case of each type of irrigation scheme led us to build a virtual irrigated system typical of the central Senegal River valley, but which did not represent any particular scheme. It was not until later that we converted the model into a role game and presented it to stakeholders.

12.4.1 The Model

The model developed is an experimental aid for use in studies of real systems, which overcomes the constraints of size, duration, parameter checking, and potential negative effects on those parameters. In particular, it can be used to simulate the evolution of the system represented according to different hypotheses concerning initial collective and individual rules (Barreteau and Bousquet, 2000). The MAS produced, SHADOC (Figure 12.1), is based on a representation of an archetypal irrigated system in the central Senegal River valley. Computer agents represent mainly elements of the scheme (plots, watercourses, main canal, and pumping station) in relation to a society (farmers, credit access, and water allocation groups). Social agents have rules and partial representation in the system, notably representation of friendship links. The processes represented deal with the circulation of water and credit and with interactions about their allocation and access to them. After sensitivity tests, the model obtained was deemed appropriate for research purposes and capable of discriminating among scenarios according to their viability, which in this case was defined as the life span of the irrigated system without external intervention.

However, it is not necessarily easy for stakeholders outside the model creation process to grasp its logic. Even if they are familiar with information technology or with the area represented, the model is still somewhat of a 'black box'. We therefore had to find a way of opening the box in order to show farmers the work that had been done. Three purposes lay beyond that need of opening the black box: telling interviewed people what had been done with the collected information, partially validating the model, and testing its potential as a negotiation support tool (Barreteau *et al.*, 2001).

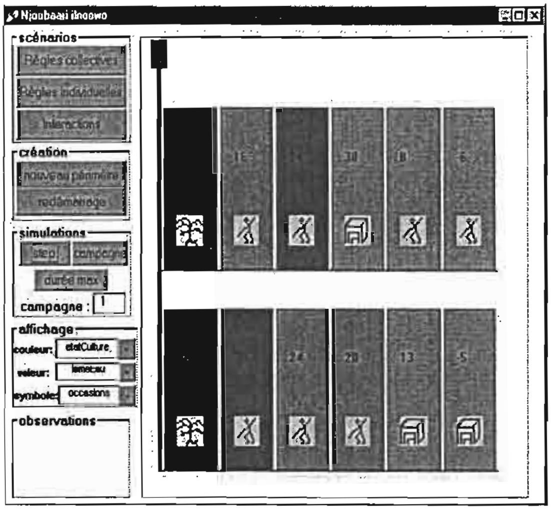

Figure 12.1: Interface of the model. The main window holds a view of the archetypal irrigated system with 12 plots, each belonging to one farmer, distributed among two watercourses. Colors (here levels of grey) represent cultivating stage, numbers indicate water level, and symbols are linked to random events occurring at each time step, of obligations to stay outside the plot. On the left, different buttons are available to entail user-specifying scenarios 'live'.

12.4.2 The Role Game

The game is played with 10 to 15 players and comprises three categories of trilingual cards (French, Pular, Wolof) describing possible behaviors for each player: the aim of planting for the first category (Figure 12.2), social status for the second, and the farmer's propensity to repay loans for the third.

Each player draws a card at random from each category, which describes his or her behavior during the game. The players are in a place representing the village. In another place representing the irrigation scheme, a structure corresponding to the number of players is drawn on a board, with the name of the player to whom the plot is attributed, while the amount of water and the choices made at the time of planting are taken into account when calculating yields (Figure 12.3). The game is played over a half-day in three stages: presentation of the game and the roles, the game itself, and discussion of the game. Each season is subdivided, in both the game and the model, into three phases that occur in strict succession: obtaining credit, irrigation operations, at the end of which potential yields are calculated, and evaluation, after which players may change cards if they wish. This role game was initially tested in the villages on which the thesis was based and, a year later, was presented to farmer associations and technical staff at a workshop organized in Senegal. The workshop lasted three days. On day one, the players discovered the role game, enabling them to complete one or two seasons. Day two was given over to a long game over five or six seasons to observe the long-term effects of the decisions made. The last day was spent on computer simulations.

Figure 12.2: The role game: the set of cards from which each player draws one at random. The left one gives the role of a farmer interested in production for self-sufficiency and income, the center one is for a self-sufficiency strategy, and the right one for a land tenure strategy.

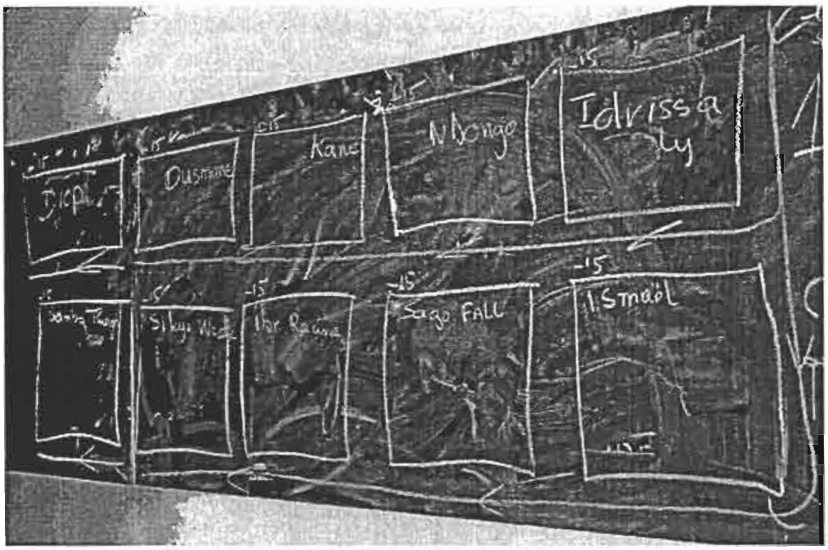

Figure 12.3: Blackboard featuring the irrigated scheme with plots, names of players, and water level during a game session in the Senegal River valley, here at the very beginning of a simulated cropping season. The participants are in discussion (exchanging services and information) while the supervisors update the resource dynamics (amount of water in plots).

12.4.3 Some Conclusions

The representations used in these two tools are both relatively abstract in terms of their relation to reality. However, this abstraction did not pose any particular problems when presenting the results of our work, either to field stakeholders or to researchers.[3] The game was well received in the survey villages, clearly showing the relevance of the two tools in representing irrigated systems. During game sessions, the players associated the roles with real farmers and, in some villages, our transportable game board had to be erased before we left to prevent other villages from seeing the 'mistakes' that had been made. This therefore enables us to go some way toward validating the MAS and the representations they include through play.

The tools were also warmly welcomed in the game sessions conducted in the field: several players asked if they could keep the game for use in their own village. What now needs to be done is to distribute it and monitor how it is used, which sends us back to the question 'How can stakeholders be brought to the negotiating table?'. Even if the process has not yet fully reached this stage, the discussions prompted by the game show that the launch of a discussion process can lead to real negotiations, including a comparison of different points of view.

12.5 STRATAGENES

In Madagascar, plant genetic resource management is sometimes transferred to a local level under contracts between the state and local communities. This transfer calls for coordination among the various stakeholders concerned before negotiation of a contract. Local management of plant genetic resources involves biologically, economically, and legally complex processes.

The development of a game called 'Stratagenes' made it possible to integrate knowledge of use in managing certain species and to make it available, albeit in different forms, to the stakeholders concerned about their management (local representatives, farmers, foresters, NGOs, collectors-exporters, scientists, etc.). The completion of a fictitious negotiation, supervised by a mediator, enables the players to see the short- and long-term issues at stake in their individual and collective decisions. The players are challenged to negotiate, within a limited time, a transfer of responsibility enabling viable management of plant genetic resources and a fair share-out of the resulting benefits.

12.5.1 The Role Game

The role game was created interactively and iteratively. Several game sessions were conducted with experts in each role (sociologists, biologists, foresters, economists, etc.) to identify the elements that would be necessary and useful to model. The game was then tested with non-specialists to check whether it was fun to play. After each session, it was adjusted and improved.

12.5.2 The Role of Multi-Agent Modeling

Role games use multi-agent modeling to create the biological, economic, spatial, and temporal dynamics of the decisions made by the players. At each stage, the decisions made by the players have an effect on the resources modeled and have economic repercussions for each stakeholder. Modeling can be used to test management schemes on a decade scale to assess the long-term effect of contract conditions.

12.5.3 Some Conclusions

This tool can now be used to identify useful knowledge and ensure that it is integrated into a formal model. The plan is to use it to help train those involved in the transfer of management and local negotiators before negotiations proper begin. To this end, it is currently being adapted semiotically and linguistically in conjunction with our Madagascan counterparts, and there are plans for tests with local stakeholders.

The development of such a tool is an attempt to integrate knowledge, innovations, and practices into a decision-making process in which every stakeholder is involved and benefits from the representations of his or her partners or adversaries. The first game session with those in charge of plant genetic resource management nationally in Madagascar demonstrated the merits of such role games in fitting administrative decisions into a decision-making process involving other stakeholders. It also brought researchers from different disciplines face to face with use made of their expertise and it was their responsibility to identify and prevent persistent misapprehensions.

12.6 SYLVOPAST

The Sylvopast model was developed to represent the spatial dynamics involved in silvopastoral development and to describe possible strategies for striking a compromise between livestock farmers and foresters. The issue is the silvopastoral development within the framework or prevention plans in French Mediterranean region. Four fundamental questions were tackled:

- How can the evolution of a silvopastoral system governed by contrasting pastoral and silvicultural management rules be simulated?
- How can a representation be produced that is shared by all the stakeholders in the dynamics of the forest area being developed?
- How can the acceptable forms of cooperation be evaluated in the medium and long term?
- What type of spatial structure would best satisfy the objectives of each stakeholder?

12.6.1 The Model

The basic principle behind the design of MAS is that any forest area can be defined by combinations of plant structures (tree/shrub/herb), whose attractiveness differs depending on the type of user, and which are subject to a specific dynamic linked to management methods. At the same time, the management methods used in the different spatial units are the result of a compromise between the different agents concerned, based on a hierarchy and weighting of the objectives attributed to those units.

In the Sylvopast model, eight vegetation structures were chosen, based on the possible combinations of trees, shrubs, and herbs, whereas two types of agents whose objectives sometimes diverge but who are subject to the same main risk (fire) intervene in the area: foresters and their laborers, and herdsmen and their herds.

The virtual forest is a closed space of 2,500 cells subject to a westerly wind, and with some probability of fire and climatic hazards. Each cell is randomly defined by its plant formations and the age of the dominant trees it contains. It also bears traces of the human interventions it has experienced (date of last grazing, clearing, sowing, etc.), which affect the temporal evolution of its vegetation structure. From time to time, it is affected by fires that destroy some of its vegetation and trigger a new vegetation dynamics.

Herdsmen and their herds see the forest as a resource area defined by the fodder potential determined by the plant formations, the crop management sequence, the climatic conditions, and the number of pasture zones capable of feeding the herd for at least ten days. Herdsmen undertake to remain in the area for at least 250 days a year, and are paid if the effect of their herds helps to reduce the risk of fire.

Foresters manage a protection and recreation area defined by the patrimonial value linked to the dominant species and the type of stand, and by the fire risk determined by the plant formations. They need to break down the forest into enclosures of a sufficient size to be able to apply silvicultural rules and ensure effective protection against fires. Their aim is therefore to minimize the fire risk at the lowest possible cost, while ensuring the persistence of the forest and fostering the diversity of structures and species, within the framework of a 20-year management plan.

12.6.2 The Role Game

The Sylvopast role game was developed once the development of the MAS finished in order to support silvopastoral training programs. However, it rapidly became a means of enriching and improving the representations within the MAS of the negotiations and interactions between livestock farmers and foresters. Numerous adaptations have been made, some of which are specific to the creation of a teaching aid with a fun aspect: it proved necessary to make the playing time as short as possible, look for a substitute for the computer tool used, and simplify the rules, without fundamentally altering the MAS. Other adaptations were necessitated by the need to simplify the representations: it was necessary to work with smaller areas, shorter time lapses, and indicators that were easy for the players to measure. Finally, it soon became necessary to replace the graphic interfaces in CORMAS with appropriate 'scorecards' so as to keep track of the progress of the game easily.

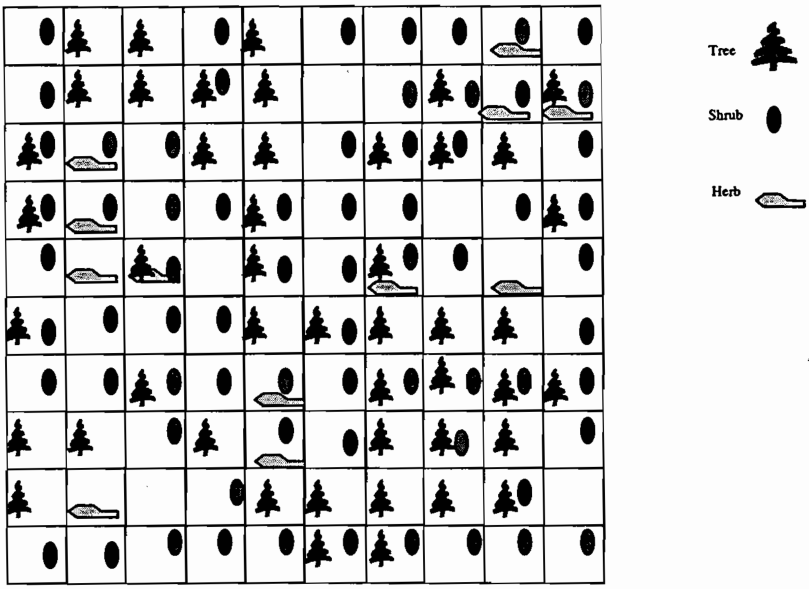

Figure 12.4: The interface of the Sylvopast model and role game adapted for publication. In the real game, specific colors correspond to combinations of land cover. The initial state presented in this figure is calibrated: proportions of each vegetation structure are respected and forest cells are grouped.

The change in the rules regarding vegetation dynamics primarily concerned long-term processes such as the encroachment in abandoned areas by trees or the substitution of forest species, which were not included in the role game. However, the negotiating methods were left entirely open, with the only constraint being the need to develop a way of recording the sequence of actions on the part of each agent. The method consisting of asking each player to justify each of his or her actions in writing was abandoned since it excessively reduced spontaneity. The new method chosen involves a confrontation between two pairs of players who are required to explain their choices and discuss them with their partner, under the watchful eye of an observer. The observer also has a computerized version of the role game, which facilitates monitoring, carries out automatic calculations, and keeps a full record of all the plays made and their sequence.

12.6.3 Some Conclusions

The role game was developed with a view to three objectives adapted to three different targets:

- In playing with managers, the aim was to create a teaching aid to enable forestry practitioners to appreciate the constraints on herdsmen, and vice versa. The game thus enabled players to put themselves in the other players' shoes and better appreciate their needs and difficulties.
- In playing with technicians, the aim was to 'switch' the development operation based on a broad sample to an area they were used to managing or evaluating. In this case, the game served to identify the main spatial organization strategies developed and to establish a typology of the negotiating tactics used.
- In playing with amateurs with no knowledge of either animal production or forestry, the aim was to test the clarity of the rules of the game, their ease of application, and their ability to express the problem of silvopastoral development clearly. The game in this case served to make players aware of the complexity of forest development, and was a means of teaching everyone to test, and even improve, their own natural resource management capacities.

Many positive points showed that some of the objectives of the role game had been achieved. The fact that the players understood the rules quickly and easily adopted the markers provided demonstrated that they obtained a satisfactory representation of their reality. The fact that they commonly used, for discussing and negotiating, the codes proposed as a way to set up a shared representation of the land pointed out the effectiveness of translating multiple resources into a common language. The fact that the stimulation of the negotiation process by gaming led to a set of satisfactory final solutions proved that role games help to achieve reasonable collective solutions to collectively shared problems.

However, several questions remain. Is it better to use tokens that are seen as fun (playing cards, coins, pawns, dice, etc.), which stimulate the desire to win rather than the desire to act appropriately? Even if it is less fun to play, isn't the computerized version more explicit in terms of the shared constraints and processes? For the categories of players, should each game be played by players with the same level of knowledge, or should the categories be mixed to increase the range of experience and rationales? In searching for a socially satisfactory solution, isn't it necessary to replay a game whose final result was unsatisfactory for one of the two players? Alternatively, should a single person play both roles at once to find out what should be the best compromise for him or her?

12.7. MEJAN

The Mejan model was developed to simulate contrasting scenarios of behavior in front of the encroachment of conifers in natural ecosystems with high patrimonial stakes. Its main two aims were to compare management scenarios and enable the different categories of protagonists to exchange their views on an ecological process over which they have little control. If successful, the approach can enable the development of joint management strategies for natural areas. An initial MAS serves to represent the system based on scientific knowledge of the ecological processes in play and the practices with which the agents are familiar. A simplified MAS is then drawn up to make this formal expression accessible to agents and to share the representation of the system with them. The simplified MAS is then used in support of a role game that serves to make all agents aware of the ecological process and react to its overspreading. The role game permits putting the agents in a virtual context that is neutral enough to minimize local social tensions but sufficiently similar to their reality to push them to anticipate the probable changes in their practices as a result of the spatial dynamics likely to occur in the near future.

12.7.1 The Model

The basic principle behind the design of the MAS is that the different categories of agents found in the isolated area constituted by the South of France Causse Méjan (farmers, foresters, and conservationists) are all involved in managing a natural area affected by the strong encroachment of Scotch pines and Austrian pines, but on very different temporal and spatial scales. All three categories are concerned about this biological process, which affects their development objectives (meat or milk production, timber production, conservation, and preservation of open spaces) in different ways.

The natural resources available are defined by vegetation structure, topographical position, land tenure status, and patrimonial value (fauna, flora, and landscape). This land, which was represented by rasterizing a real vectorial map, evolves as a result of the natural spread of conifers and the range management and timber harvesting regimes (Figure 12.5).

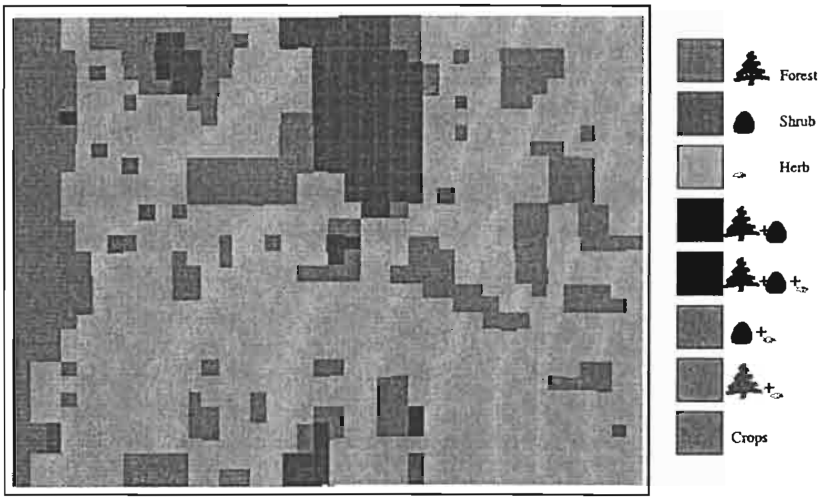

Figure 12.5: Map of land cover

Agro-pastoral strategies depend on the ratio of cultivated land to rangelands, grazing pressure, the position of the livestock farm, and the farmer's degree of ecological awareness. Forest management strategies depend on land tenure status and on whether the area is covered by specific regulations. Faced with the effect of the combination of these multiple strategies on conifer dynamics, the conservationists asked for a MAS to test different intervention scenarios in support of, in addition to, and even in opposition to the operations conducted by farmers and foresters.

12.7.2 The Role Game

The Mejan role game sets out to make farmers, foresters, and conservationists (the Cevennes National Park staff) react to spatial dynamics likely to occur in the near future. It is based on a representation of a natural area sufficiently close to reality for players to be able to relate to it, but sufficiently distant from it for the game to take place in a neutral context, with no preconceptions. The role game relies on a combination of a simplified MAS and a GIS, enabling the rapid production of updated thematic cartographic representations on different scales.

The temporal and spatial scales are different from those of the MAS model, with the rules of conifer dynamics and plant and animal sensitivity to changes in their habitat remaining the same. The participants playing the role of farmers have a limited view of the area, reduced to the area covered by their farm. Within that area, they distribute their animals according to their livestock production system and the cover of conifers on their farm. They also cultivate all the flat lands. The participants playing the role of conservationists (Figure 12.6a) have an overall view of the natural area, in the form of a patchwork of holdings used for farming, forestry, or hunting. From several patrimonial viewpoints (fauna, flora, landscape), they can define the plots with priority patrimonial stakes and develop a control strategy of pine encroachment. The participants playing the role of foresters define the priority objectives for the forest holdings and propose a management and exploitation plan for those holdings. At the end of each round, negotiations occur concerning the technique to control pine encroachment, the location of the plot to be cleared, and the labor required. A cartographic representation of the effect of the practices adopted by the players on natural resource dynamics and land occupation in each agricultural holding is produced for use in the following round (Figure 12.6b).

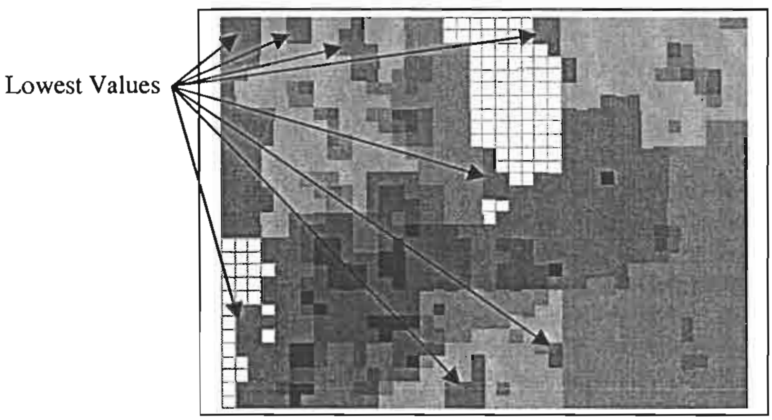

Figure 12.6a: The map of the conservationist (full area): lowest values are indicated; the darker the patch, the higher the value

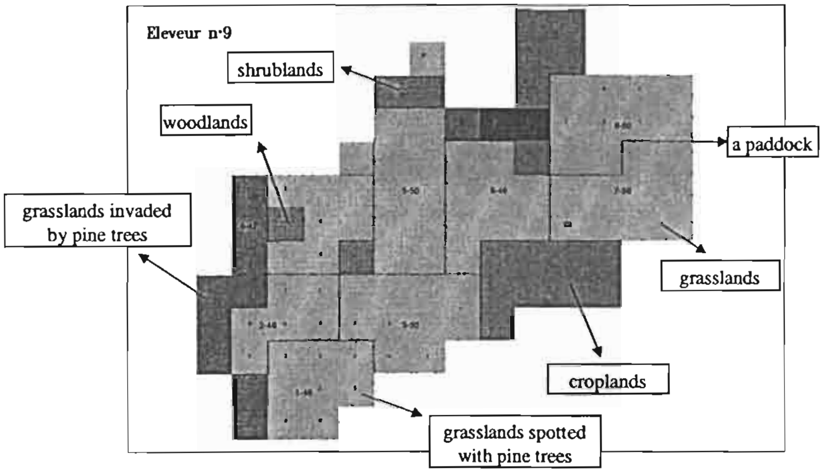

Figure 12.6b: The map of a farmer

The minimum number of players is four farmers, two conservationists, and two foresters. It can be played only by local managers playing their own role, which means that the players playing farmers have to include representatives of each of the main livestock production systems included in the model. Likewise, it is important that the fauna viewpoint and the flora viewpoint be clearly dissociated by being played by two different conservationists. However, the role game makes it easy to formalize the functioning of the interactions among agents and makes it possible to produce a representation of the conifer establishment process rapidly, to be shared with them. Above all, it gives free rein to the players' inventiveness in developing a strategy for action or negotiations, both for agents at the origin of the process and for those subject to it.

12.7.3 Some Conclusions

The MAS entirely fulfils its role as an aid in testing different scenarios of intervention on natural dynamics and in representing different types of collaboration among conservationists, farmers, and foresters. It is innovative in that it shows how agents adapt their behavior according to the changes in the areas concerning them, as a result of both natural dynamics and day-to-day management of those dynamics.

The role game makes an essential contribution to the MAS in that it helps to determine the range of possible strategies through which farmers and conservationists can adapt to a process with which they have not yet been confronted. It also helps to explain and share issues that arise on different temporal and spatial scales.

Although the spatial environmental characteristics are much more closely linked to the local level than in Sylvopast, the overall structure of the model and the way in which it is simplified into a role game can be transposed to many other resource-sharing simulations. Moreover, the generic value of the problem posed (the threat to patrimonial stakes by pine encroachment) permits users to easily adapt the approach to similar ecological situations. Finally, the potential for using the approach under the developing trend of contractualizing the interactions between agricultural practices and environmental protection is particularly promising.

12.8 SAMBA

The 'Regional' component[4] of the SAM (Mountain Agrarian System) program is working in the mountainous area of Bac Kan Province in northern Vietnam. It aims at understanding agricultural dynamics and their consequences on land-use systems in order to promote more sustainable natural resource management from the village to the regional level. In this framework, several methodologies have been combined using and/or developing different tools from traditional fieldwork using on-farm surveys to remote-sensing data interpretation through computer modeling and role games. These various tools, methodologies, and the way they are used pursue different objectives, especially in the relationship between researchers and their objects of investigation, as well as between researchers and stakeholders (Castella *et al.*, 2001a, Castella *et al.*, 2001b).

A first multi-agent model called SAMBA has been developed for testing hypotheses about the differentiation of households at the end of the cooperative period in Xuat Hoa commune, Bac Kan Province (Castella *et al.*, 2001b). The way this model has been developed could be seen as 'armchair modeling'[5] as it was built upon data collected in the field but was constructed and run without interaction with stakeholders. This kind of model serves as a tool for representing, testing, sharing, and discussing hypotheses among researchers from different disciplines and thus having different representations of the world.

The problems experienced in validating this kind of model (Axelrod, 1997) led us to adopt a new methodology in the process of building a model and sharing it with stakeholders. Following a previously described experiment in Senegal (cf. Section 12.9), we adopted role games similar to gaming-simulations (Greenblat and Duke, 1981) as a way to collect information and 'feed' a second multi-agent model that is subsequently presented to stakeholders for validation and discussion.

12.8.1 Role Game and Model

This methodology, which is still under development, follows four steps that take place over a one-week period:

Step 1: collection of preliminary information and selection of participants (one day)
From one to three villages in a commune of Bac Kan Province are selected based on their original characteristics and the topic pursued.[6] Village headmen are interviewed to collect some basic information and identify participants representing the diversity of the village.
Step 2: role-playing (one day)
The 'SAMBA' role game is conducted around a game board composed of 1,600 wooden cubes, each one having six colors representing different land uses. The aim was to use an environment as close as possible to the one in the SAMBA multi-agent computer model developed under the CORMAS simulation platform (Figure 12.7). Around ten players and a few observers (e.g., village headmen, forest wardens) usually participate in the role game. The players draw household cards describing the composition of their virtual household and thus their food needs and available labor force. They also get an initial endowment of lowland rice fields and buffaloes. Then, the players have to propose and manage activities in order to feed their family and develop their own strategy. Actions of the players are situated on the board game and registered by facilitators. During the one-day sessions we have already organized, players could simulate around six years (i.e., six rounds of play). The meetings ended with a debriefing session during which the sequence of the game was analysed by both participants and facilitators.
Step 3: individual interviews and model construction (three days)
During the third step, two activities are carried out in parallel. On the one hand, a multi-agent model aimed at representing the sequence of the role game is developed. On the other, individual interviews are conducted with participants in the role game session (step 2). These individual interviews build upon the actions of the players during the role game. Through a comparison with the real situation, the surveyors investigate the individual behaviors of the players and the various strategies developed during the role game.

Step 4: participatory computer simulation (one day)
A new meeting with participants in the role game is organized and the model constructed during the third step is presented. The similarities of the environments in the role game and in the model help participants get comfortable with the computer. A first simulation similar to the role game session is easily described by the participants. Inconsistencies with and/or alternatives to this first model can thus be discussed for possible simulations.

12.8.2 Some Conclusions

The methodology described here serves several interrelated objectives. First, the role game is used to gather information on selected topics. It does this very efficiently. More traditional interviews usually face problems of confidence between the researchers and the stakeholders, with the interviewees sometimes being reluctant to give information requested in a formal way. On the contrary, the gaming aspect of the role game helps create a more natural and friendly environment, which in turn facilitates communication. Information can then be collected at two levels: (1) when the players are playing on the board, questions can be asked about their actions, and (2) through direct observation of conversations and interactions among participants in a more ethnographic way. Information gathered during the role game is completed by subsequent individual interviews and discussions around the computer model. Such information is used to explore the evolution of land-use systems.

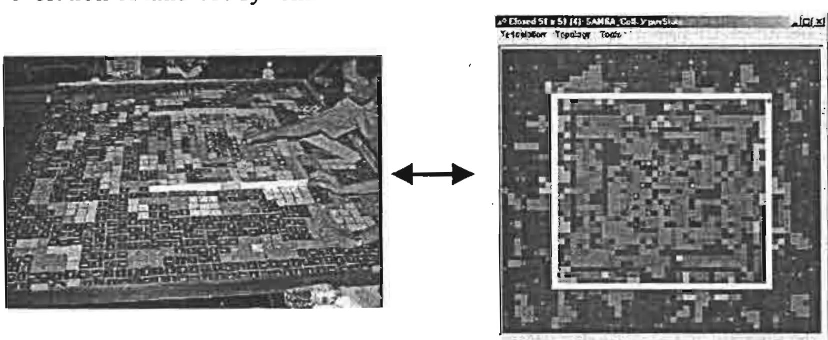

Figure 12.7: Similarity between the SAMBA computer model (right) and SAMBA role-play (left) environments. The white boundaries of the square are the limits of an area protected from unattended livestock. The limits were set during the game and reproduced in the model.

The second objective is to enable the rules (the behavior of the players) to change and new rules to emerge. When conducting the role game, an initial situation is assigned to the players but no rules, especially social rules, are predefined. These rules have to be set by the players themselves in the course of play, whenever they feel the need for them. The players may, for example, ask for the election of a village headman or organize collective pasture areas. Thus, if such rules are enacted, one can say that they are emerging from the convergence of individual actions in a particular environment. Emergence is also a basic principle of multi-agent modeling, where macro-phenomena are seen as emerging from micro-actions following a bottom-up approach. The combination of role games and multi-agent modeling thus appears to be a powerful tool for studying the emergence of collective rules that can be identified in the role game and more precisely explored by the computer model (Boissau, in prep).

Finally, through the information gathered and the discussions with participants, problems faced by local people in their production systems can be identified. Role games and multi-agent systems can then be used as communication platforms for the introduction of technical innovations. The need for accompanying organizational changes is explored through the construction of scenarios to ensure successful diffusion of the proposed innovations.

12.9 SELFCORMAS

The third experiment has been under way since 1998 at the POAS (Plan d'Occupation et d'Affectation des Sols) experimental unit in northern Senegal. In support of a local decentralization policy, the aim is to test simulations that will help local rural authorities and the people under their jurisdiction to organize sustainable land management, taking into account the different forms of land use (agriculture, animal production, the environment, etc.). The management scale considered is around 2,500 km² and 40,000 people. The simulation developed needs to help stakeholders at every stage of the decision-making process: when zoning the area, identifying rules of access to a given type of area, and evaluating possible social and environmental effects. It should also make it possible to forecast the different possible options, and therefore needs to be flexible.

Two precise objectives were set right at the start of the experiment. The first was to test the direct design of the MAS model by the stakeholders from the very first stage (unlike the SHADOC process), with as little prior design work by the modeler as possible, hence the 'self' added to the CORMAS name. This means that upstream modeling work had to concentrate on producing an environment enabling the stakeholders to express themselves in designing their model. The second objective was to test the use of a GIS managed by the region's public development company,[7] to sustain the decision-making process and modeling work regularly if necessary.

Rather than developing a specific model, the modelers developed tools within and around CORMAS (cf. role game, GIS, etc.) to formalize as accurately as possible the knowledge and views expressed by the stakeholders (including the GIS) during the continuous collective decision-making process.

12.9.1 The Role Game and Model

The 'self-design' experiment was organized in the form of discussion workshops. Three three-day workshops were organized by the rural council for the village of Ross-Béthio, a local partner that volunteered for the experiment. The first workshop, in French, concerned a group of source-persons from the rural community, chosen directly by it (a teacher, a young person who had moved back to the village, etc.). The other two workshops were a test, in the local Wolof language, conducted directly with illiterate members of the local population. The subject, which was chosen by the local stakeholders, was coordination between the crop and animal farming in the area. Each workshop set out to have the stakeholders construct and then test a model enabling them to make progress in solving this local management problem. The modelers, who attended the workshops as mere spectators to the discussions, were then to model the progress of the discussions in terms of the collective construction of the model, change and regulatory scenarios, hypotheses as to changes in external factors, etc.

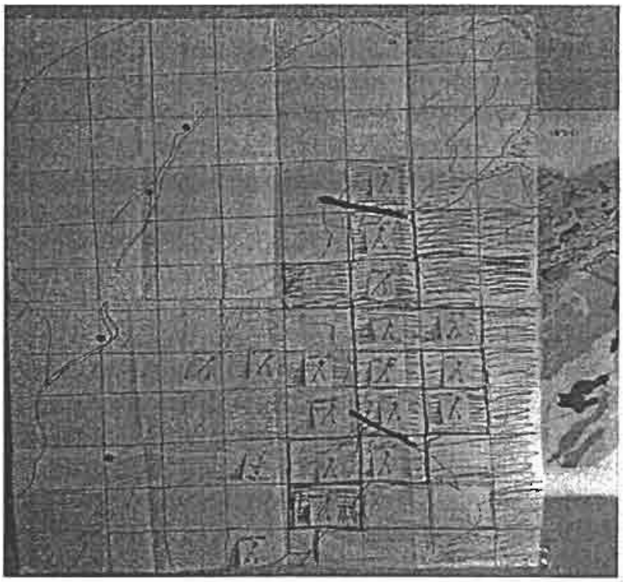

Figure 12.8: The initial map of Ngnith

Around 25 people attended each of the workshops, which were held over three days as follows:

Day one:

The first stage was the identification by the participants of the different stakeholders' requirements in terms of crop and animal farming (soil quality, water salinity, distance from a water supply, distance between plots, etc.), in other words, the definition and above all the collective approval or *legitimization* of the minimum requirements of each stakeholder. This was also the first stage in the design of the MAS model, the form of which was thus dictated to the modelers by the stakeholders.

The second part of the day was given over to the introduction of the cartographic support: the representation of the 'resources' in the zone concerned, with resources defined from criteria chosen by the stakeholders in the previous stage. Maps were produced based on the farmers' perceptions in the first stage, using data from the SAED GIS. Data were amended and approved jointly.

Day two:

A role game was proposed to represent the dynamics of the model designed the previous day. The cartographic support was based on the maps produced the day before, but broken down into regular rectangular polygons (Figure 12.8). In the game, month after month, all players decide on their activity and position within an area they know well, according to a definition of their requirements established jointly on day one. To show their position at every time lapse (a month), all players use a post-it note that they move around the map. After several rounds, a discussion is held to analyse significant phenomena and events that have occurred during the game (conflicts, resource degradation or shortages, dissatisfaction of a particular stakeholder, etc.). The discussion then turns to the joint definition of possible futures (scenarios) in the form of either trends (for instance, population growth) or events (for instance, the digging of new canals).

Day three:

Between days two and three, the multi-agent model corresponding to the role game is programmed for presentation on day three. The first simulation concerns the role game played the day before (Figure 12.9). After that, the scenarios identified the previous day and the new ones that have emerged since are simulated and discussed.

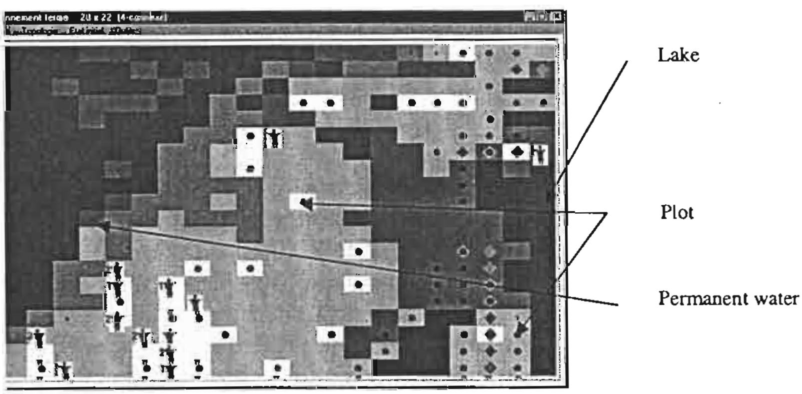

Figure 12.9: The map at the end of the simulation. Zones in which the resource has been consumed are shown in white. This screen shows that the livestock farmers who do not have access to water move west.

12.9.2 Some Conclusions

A good deal of information can be drawn from this experiment, which is continuing. Developing a role game in conjunction with stakeholders seems to be an interesting way of enabling novice stakeholders to play an active part in designing a multi-agent model. The role game serves in this case as a sort of dialogue interface between computer modeling, the 'machine', and stakeholders.[8] It enables them to interpret the behaviors and interactions in the simulation correctly. The stakeholders who developed and played the game were fully capable of interpreting the results of the model and linking them with reality. As they were themselves the initial designers of the simulations carried out, they were also aware of the distance between the model and reality, and of the way in which simulation results should be used. Having largely designed the model, they were well aware that it was not a black box capable of seeing into the future.

Simulation made it possible to go much farther than the role game. For one thing, it would have been physically impossible without computer simulation to 'play' the different scenarios selected by the stakeholders and to observe their multiple effects over sufficiently long time lapses. Furthermore, a sufficiently flexible modeling platform offers many more possibilities of modifying the rules on request than cumbersome game sessions. Simulation thus multiplies the effectiveness of the role game and can take the decision-making process much farther by taking into account the long-term future or through the feasibility of the decisions made. Concerning this last point, the permanent link with a GIS for data restitution and their precise mapping enabled the local stakeholders to shift from a mere exercise to a heated discussion of the future of each area (and of each stakeholder) in a zone they knew well. The satisfaction expressed by the participants largely stems from this return to a precise local reality, using a GIS fed with quite detailed relevant information.

This operation provided us with confirmation of the feasibility of using computers in such socio-cultural situations. By progressing gradually over three days, the stakeholders are capable of following the different scenarios on screen, discussing them, and proposing new ones. There is no need for sophisticated agents for the main land and resource management problems to appear easily in the simulation. As the simplifications were instigated by the stakeholders themselves, they reflect the most important aspects of actual behavior. As regards cartographic representation, we were surprised to see how easily the stakeholders adopted the concept and used it as a negotiating tool, even in the case of a simplified map in grid form (CORMAS), which was just as well received and used by the participants. As a result, if we measure the educational progress made, it is clear that a CORMAS-type simulation platform can be used with participants with a very limited level of schooling. As a result, in a nevertheless conflict-laden local context, our simulation enabled new progress to be made in local negotiations. For instance, at one workshop, the establishment of rangelands was debated, whereas it had previously been a taboo subject, and a decision was even made to ask the local technical services to talk about the issue. In another area, in which the problem was access to water, simulation resulted in an agreement on new collective regulations to protect animal production.

The emphasis placed on the flexibility of the platform also accounted for the progress made in the local decision-making process. For instance, it enabled a response to a wide range of situations. At one workshop, the problem posed and discussed was that of agricultural diversification and its consequences for animal production and environmental areas. At another, it was rangeland development, and, at another, water access regulations.

The model was not designed to provide solutions to problems, but to encourage discussion of the different alternatives, to improve the effectiveness of a collective decision-making process and even to change the behavior of local stakeholders with respect to their technical partners. In our approach, recourse to technical expertise is the stage that follows, and not that which precedes, the collective choice of scenarios that can 'reasonably' be envisaged by the community. Thus, for the project itself, one of the main achievements of this experiment is to have reversed the relations between local populations and technical staff. After the interactive simulations, the representatives of the local populations themselves identified the priority types of support they required within their decision-making proçess (information on rangeland development, appraisals of certain crops on sandy soils, etc.).

12.10 MAS MODELS AND ROLE GAMES: SOME PRELIMINARY LESSONS

Several conclusions can be drawn from this set of experiments. We start with some practical conclusions and propose a discussion on the different processes these tools can be involved in. The practical conclusions are the following:

- Confirmation of the results obtained by participatory GIS: people are capable of following simulations on a screen and interpreting and discussing them.
- The role-game simulation model seems to be appropriate to favor the involvement of the stakeholders in the exploration of scenarios (see SHADOC, SAMBA and SelfCORMAS). Through the game, participants gain an idea of what the model is. They are then capable of following simulations. Better still, they are able to understand the relation between the model and reality. Having played a role game, they measure the simplification of the process. The associated MAS model is then also considered a simplification. As a result, participants can better interpret the results of the simulations. As the aim is not to predict but to encourage

and enrich discussion, simulations and role games serve to identify and formalize problems for discussion.

- Usually, each actor plays his or her role in the game. In certain cases, it can be useful to switch the roles. Each actor playing the role of the other can better understand the constraints the other faces and the resulting behavior. This sometimes prepares the discussion very well.
- The environment of the MAS and the role game is often different from reality. It is structurally similar to reality (proportions, neighborhood), but we do not use the map of the case studied. The stakeholders have no difficulties with that; they are freer to discuss and this preserves some confidentiality on the knowledge.
- KISS ('keep it simple, stupid') is one of the principles of complex simulations: the interactions between simple processes are a result of complex dynamics. As a rule, the argument is that this principle is valid on paper, but is not operational. In this particular phase, the collective identification of problems, it appears that simplicity is required. For instance, when developing SHADOC, huge efforts were required to make the model simple enough to play. The same was true for the Sylvopast model. On the other hand, for SelfCORMAS, a collective discussion process was triggered based on a simple model (designed by the participants themselves), which increased in complexity as the discussions became deeper.
- The game has to be played with players of each level represented in the model. This aims at validating the behaviors and interaction processes. In the case of separated validations (with stakeholders belonging to different levels surveyed separately), it is better to start the validation process with the players at the lower level. Once validated, this part of the model can serve to implement the behaviors and interactions of the upper levels.

Although all authors of this chapter are using the role game and MAS for integrated NRM, some differences can be pointed out. We present some conclusions here and more can be found in Aquino *et al.* (2002) and Barreteau (2002). We think that the decision-making process for NRM can be viewed as a collective learning process. This process involving representations and emotions has been conceptualized by Varela *et al.* (1993) and Maturana (1996) and advocated by Röling (1996). The stakeholders, including the researchers, exchange their knowledge and generate new knowledge that is used to monitor or transform the environment. This is a constructivist approach in which an agreed representation is the objective. However, we experienced three possible modes of interaction:

1. Interactive modeling for the creation of a better model of the reality. The modeler, alternating modeling activities and field work, conceptualizes a model of the studied ecosystem. The knowledge is elicited with the stakeholders and the model is validated through role games, among other methods. The model is then used within the scientific community or for educational purposes. This is the case, for instance, for SHADOC or Sylvopast or Stratagenes. For example, the Sylvopast game on Forester-Herder negotiations has been played about 40 times. The scientist now has a classification of individual strategies correlated to the forms of negotiation.
2. Interactive modeling to give back the representation of the scientist. Scientists work on a model, often based on biophysical processes, and then return and share their results and conclusions with the other stakeholders. The scientists are pro-active in the decision-making process. This is the case, for instance, of the game Mejan, in which the objective is to help coordinate against pine invasion.
3. The model for mediation. Scientists act as mediators in a collective decision-making process. The model is one of their tools and they will develop their model accompanying the social process; more than an accurate model of reality, the purpose is to reach an agreement and models are used as a mediator toward this agreement. This is the case of the SelfCORMAS experiment.

The status of the modeler and the use of the model are different for each of these cases. They depend on the context. Sometimes, there is no need for intervention in a decision-making process, for instance, when institutions correctly regulate the use of resources or if there is no demand from the stakeholders at all. The model can be developed interactively for a better understanding of the dynamics of the system. In other cases, there will be a demand for the intervention of the scientist, either as an expert or as a mediator.

There is no strong relation between the status of the scientist and the linkage between role games and MAS. At first, we thought that the scientist who wanted to build a model for understanding should start with a model to be transformed into a role game. But we realized how much the role game was efficient in obtaining knowledge on social dynamics and even on individual decision-making (see experiment). At first, we thought that the mediation process would be facilitated if no previous model existed before the role game. But it happened that a role game based on a model could be used as a mediator tool to facilitate discussions and decisions in emerging organizations. This was the case for the SHADOC game.

As noticed by many other authors, it appears that the efficiency of the tools lies much more in the social process at stake rather than in the combination of tools. If institutions for mediation, also called platforms, already exist or are emerging, these tools are positively perceived and can be appropriated. Furthermore, placing these tools in such institutions lowers the risk of sidelining the responsibilities attributed to decision makers.

12.11 CONCLUSIONS

To conclude, the supportive approach on which all these experiments and CORMAS are based can be seen as a bottom-up rather than a top-down modeling method. These experiments enabled us to explore an interesting way of using MAS for better understanding of the decision-making process and, in some cases, in support of negotiations among stakeholders. A new horizon has now opened up and other applications are under way or are planned. Now that this feasibility has been demonstrated and the elements of a method are in place, it is important to study the contributions and effects of such tools over longer periods. How do the models evolve with a decision-making process? Do they disappear? Do they change status? It is now necessary to establish ways of monitoring such research-action dynamics, either in relation to their final purpose or, more generally, in relation to their effect on the local community (impact on stakeholders in the decision, ethics of intervention, etc.). New research is starting on this issue (Dare, 2002).

Because they allow users to consider agents of a very different nature with their own perceptions, modes of communication, and control, MAS have a considerable potential in integrated natural resource management research for the modeling and simulation of complex processes among stakeholders, as well as between social and ecological dynamics.

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NOTES

1. The various experiments described in this article, and some others still under way, originated from a process set in motion at CIRAD (Centre de cooperation internationale en recherche agronomique pour le développement) in 1994 by its 'Green' (Renewable resource management, Environment) research group. http://cormas.cirad.fr
2. Simulateur Hydro-Agricole Décrivant les modes d'Organisation et de Coordination
3. However, as far as the researchers were concerned, the more they specialized in a given issue concerning the viability of irrigated systems, the less comfortable they were with the representation in the model form, which they believed did not go far enough.
4. SAM-Regional is a joint research programme of the Vietnam Agricultural Science Institute (VASI, Vietnam), the Institut de Recherche pour le Développement (IRD, France), and the International Rice Research Institute (IRRI, Philippines).
5. In reference to the 'armchair economics' denounced by Herbert Simon (1986).
6. So far, topics have been the allocation of the labour force between paddy fields and upland crops, livestock management systems, the saturation of uplands, and the emergence of forest land as a scarce resource.
7. SAED, Société d'Aménagement et d'Exploitation des terres du Delta du Sénégal et des vallées du fleuve Sénégal et de la Falémé (a public regional development company).
8. The low educational level of the participants in the workshop (a very high rate of illiteracy) is no obstacle to the use of such computer simulations.

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