From a Conceptual Model to its Artifacts: Building on Experiments using the SHADOC Model

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Abstract: Experiments using simulation tools based on the same conceptual model of irrigated systems dynamics in the Senegal River Valley lead to an analysis of Multi-Agent Systems (MAS) as relevant conceptual models for the dynamics of renewable resources use. These experiments are compared with theoretical frameworks in computer science and cognitive science: the translation chain of simulation modelling and cognitive levels involved in computer mediation of group interactions. They are based on three artifacts, two computer based MAS and one Role Playing Game (RPG). These are successive translations of an implicit conceptual model, SHADOC, representing the dynamics using an irrigated system according to coordination patterns among stakeholders, as well as the dynamics of access to and use of water and credit. Content and goals of the conceptual model and the three artifacts are described. The consequences of using MAS as a Group Decision Support System and collaborative planning are then discussed. MAS are suitable conceptual models since they result in a variety of artifacts able to fit to their specific uses.

Keywords: Multi-Agent System; Simulation; Irrigated System; Role Playing Game; Negotiation Support

1. INTRODUCTION

The use of computer models and other artifacts is spreading rapidly in the field of renewable resources management. They have different purposes and various formats, which are usually poorly accomodated to one another.

The purpose of this paper is to specify the relationships between artifacts and their cognitive objectives. It states that a MAS should first and foremost be considered a conceptual model whose translation into an artifact may be fitted to specific goals. It is based on experiments with an agent-based model of irrigated systems in the Senegal River Valley, SHADOC. The form of this tool can be changed to fit different needs. Theoretically, it is related to the simulation modelling translation chain as well as cognitive levels in Group Decision Support.

The issue of irrigated systems viability in the Senegal River Valley, and the resulting conceptual agent-based model, as well as some corresponding artifacts, are presented. Then the implications for using MAS to simulate the dynamics of complex systems are discussed.

2. VIABILITY OF IRRIGATED SYSTEMS IN SENEGAL

The development of an agent-based model for irrigated system stems from the acknowledgement of a relative failure of irrigation development in the Senegal River Valley as pointed out by several categories of people and organizations: farmers, NGOs, SAED[1] officials, researchers and others with conflicting interests.

2.1 Irrigated Systems in Senegal

Irrigation in the middle Senegal River Valley developed rapidly from the mid-seventies and especially during the eighties. Most schemes that have been developed since then have now been abandoned or redesigned at least once. Moreover, they are underused in relation to their design standards. The initial targets for irrigation

[1] Acronym for Société d'aménagement et d'exploitation des terres du Delta et de la vallée du Sénégal et de la Falémé, the regional territory planning company which had a major role in the development of irrigation in the Senegal River Valley.

development in the Valley have by no means been reached. Lastly, the systems which do work are only partially used for one cropping season instead of the two initially planned.

These problems led several experts and scientists to look into the situation. Depending on their area of expertise as well as the orientation of interview, they proposed several explanations: flaws in the lending system, low level of loan recovery, overuse of water, low yield levels, low cultivation rates, etc. All these diagnostics tackle the same issue: viability of irrigated systems, i.e. its capacity to keep functioning under given initial conditions in a given context.

2.2 Our Interests in the Issue

This issue is important to many people with varying interests: reaching stated objectives of production; helping farmers make irrigation valuable for them; making huge investments profitable; developing autonomous and profitable agriculture in the Valley. Our objectives are threefold:

- understanding how different coordination patterns among farmers influence viability;
- encouraging discussion of their systems' dynamics among stakeholders;
- supporting the improvement of coordination within irrigated systems.

The first objective stems from the nature of an irrigated system as a place for many interactions through various channels.
The second builds upon the experience of many researchers who state that facilitating dialog is a key element in any Group Decision Support System or negotiation process [Babin et al., 1999].
The third aims at improving the viability of irrigated systems assuming a positive role of co-ordination level.

2.3 Specific Tools for Each Objective

For each of these, specific tools with a common base are needed to represent the dynamics of an irrigated system. Dealing with viability and coordination patterns involves the use of a simulation tool: a virtual irrigated system. It should be capable of exploring scenarios based on individual behavior patterns and collective rules, and the resulting consequences on the longevity of irrigated systems. The goal is to build a model that facilitates the pooling of several facets and points of view [Bland, 1999]. We argue in this paper that this should be done at the conceptual level. Executable models, or artifacts, should be adapted to their specific uses. In practice, however, specificity of tools is seldom applied to their intended use when dealing with complex systems, especially if a representation is already accepted and available. It is a fairly common flaw in complex management as well as in building works planning [Gardiner and Ritchie, 1999].

Implementation is based on Fishwick's "translation chain": progressing from a conceptual model to an executable model and then to the set {formalism, program} [Fishwick, 1998]. The conceptual model adapts to several purposes, whereas the executable model is more specific to each use. In the following discussion we will assimilate an executable model and its translation in any formalism or computer application, as an artifact. This highlights the fact that any (conceptual) model may be expressed in different ways: computer codes, role games, etc. [Hanneman, 1995], which may contribute to the reconciliation of social science and modelling.

The above-mentioned distinction makes it possible to consider our representation at the three different cognitive levels stated by Whitworth in his C3P model: information and task, interpersonal relationships, group level [Whitworth et al., 2000], which are well-adapted to our three objectives in the issue of irrigated systems viability. The understanding of the system behavior addresses the information level, the facilitation of discussion is related to the inter-personal relationships and the improvement of coordination deals with the group level. This strengthens the necessity of employing different artifacts, since each level makes different demands upon the interaction environment [Whitworth et al., 2000].

3. A MULTI-AGENT SYSTEM AS AN EVOLVING CONCEPTUAL MODEL

The occurrence of many entities, social and physical, interacting with their environment and co-evolving, are characteristics of irrigated systems. MAS, as sets of autonomous entities with their own goals situated and co-evolving in an environment, are suitable to represent such systems, as far as social modelling [Kohler, 1999] and renewable resources management issues [Lansing and Kremer, 1994; Bousquet et al., 1999] are concerned. Here the computer-based theory of agent-based modelling is extended from the executable to the conceptual level.

The variety of artifacts are a synchronous pluralistic expression of a model. We also had a diachronic pluralism in the design of the conceptual model itself, which we called a companion modelling [Bousquet et al., 1999]. This approach is first explained, then the conceptual model generated is described.

3.1 A Companion Modelling Approach

Generally speaking, system approaches are used to view models as representations of current knowledge of a system. They are also predictive tools for identifying key intervention points or activities and key gaps in understanding. They may also be used for communication and mediation in a collective decision-making process. Companion modelling is a means of designing a model for this purpose, in interaction with field studies [Bousquet et al., 1999]. It is based on a three-stage cycle which may be repeated as many times as needed:

- field studies and bibliography, which supply information and hypotheses for modelling and raise questions to be tackled with the model;
- modelling, i.e. converting current knowledge to a formal tool to be used as a simulator;
- simulations, done according to an experimental protocol, challenge former understanding of the system and raise new questions for a new batch of field studies.

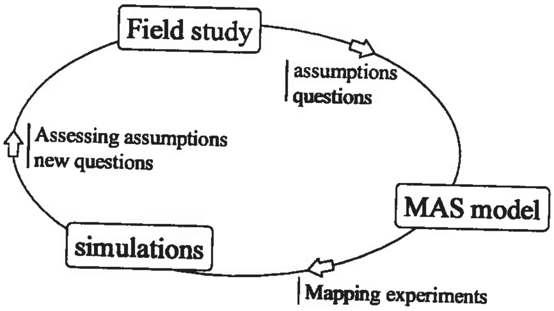

Figure 1. Companion modelling cycle

We completed this cycle three times over roughly two years, corresponding to three different issues involving irrigated systems:

- importance of water management in irrigated system dynamics;
- importance of cropping season preparation and debt circulation in system dynamics;
- assessment of cropping seasons by farmers.

Each cycle leads either to a modification or replacement of a current conceptual model. Such models may be considered as disposable, specific to an issue and a context. Each of these successive conceptual models needs the mediation of at least one artifact in order to be tested and discussed.

Such three-step methodology is common, whereas the circularity accompanying the changes in perception (each cycle leading either to a modification or replacement of a current conceptual model) is more innovative. Moreover, the model is a shared representation of the social process. Although models may not play a direct role in the resulting actions themselves, they do form the stimulus-response framework, which guides the nature of the actions and their implementation. Models play an important role in devising monitoring protocols as well as in providing a useful set of evaluative tools to suggest when critical thresholds or conditions are likely to be reached or exceeded. Though developed independently, this approach is a sort of extension of the Evolutionary System Design framework [Shakun, 1996]. While ESD is specific to the Group Decision Support System, companion modelling is also suitable at the conceptual level, whatever the desired tool may be.

3.2 The SHADOC Conceptual Model

The irrigated systems of the Senegal River Valley are represented in an MAS called SHADOC[2]. This model is fully described elsewhere as a computerized executable model [Barreteau and Bousquet, 2000]. It assumes that irrigated system is mainly a place for acquisition and allocation of water and credit.

In this section, the terms farmer, group etc. stand for conceptual agents in the MAS. The simulated scheme is composed of a pumping station, which supplies water to a main canal, which then delivers water to watercourses along which plots are situated. Within the simulated society, each farmer belongs to three groups related to the irrigated system, one for water allocation among plots along the same watercourse, one for credit issues and one for pumping management. Each farmer has her own representation of the system among which are the imagined state of her plot, the imagined water availability and a list of other farmers with whom she is willing to cooperate. Each farmer also has a goal, which specifies the relative importance she gives to her plot in money as well as in time. Each group is also an autonomous agent and has a representation of the system, in which it keeps a record of its activities and transactions with other agents. Lastly, each agent, farmer or group has a set of rules which describes how it behaves. The purpose of each rule depends on the agent: individual rules for farmers, and, for groups,

[2] French acronym for hydro-agricultural simulator describing organization and coordination modes.

collective rules relating to their grounds. Among these rules, each agent has an assessment rule and one that enables it to modify the rules if it is not satisfied.

Dynamically, simulations are based on several time steps for agents to activate rules:

- a day for choice of activity;
- a point in cropping season for selecting a relevant set of rules;
- a whole cropping season for changing rules.

Such an archetypal model of irrigated systems in the Senegal River Valley is seen as providing insight into these irrigated systems with the help of simulation.

4. THREE ARTIFACTS

This conceptual model has been translated into three different artifacts, each one aimed at a specific purpose: understanding the system; communicating the content; exploring scenarios.

4.1 SHADOC: a Research Tool

For social scientists, simulation models are the most promising tools for producing theories about social systems, such as those dealing with renewable resources use, provided that they remain quite simple [Leik and Meeker, 1995]. This has been our first use of the SHADOC conceptual model, and the first translation into a computer based artifact, also called SHADOC. It was designed as a tool for simulating scenarios that synthesize hypotheses about rules in an irrigated system, whether collective, individual or inter-personal, and a few physical parameters. Hence, one may study the evolution of an irrigated system with different sets of rules. Scenarios can be chosen either through the model interface or through files of parameters.

Several indicators are available throughout a simulation, some at a day time step, others at a cropping season time step. They include: the number of plots cultivated each season; the evolution of water stressed plots; the evolution of farmer satisfaction; the payment rate of water fees; farmers' wealth; water consumption; and the population of rules.

The model uses several random values and some imposed thresholds. Hence, for one given scenario simulations must be repeated several times. They are mainly interpreted by comparing them with simulations using other scenarios.

4.2 The Role Playing Game: a Way to Communicate Content

The second translation is aimed at communicating the content of the conceptual model, first to get feedback on our representation and then to incite people to discuss their own representation of irrigated system dynamics on the basis of ours. It is meant to open SHADOC's black box.

RPG have already been used in experimental economics to test conceptual models [Ostrom et al., 1994] and as a prospective tool for regional development [Piveteau, 1995]. Their apparent structural similarities with an MAS [Barreteau et al., 2001] induced us to use them as an artifact.

To translate SHADOC into a playable RPG, a process of simplification was necessary:

- limit it to a dozen players or so,
- eliminate a few rules after consulting a local farmers association,
- divide a season into about eight time steps.

Players take the roles of farmers with each of them cultivating a plot in an irrigated scheme in the Senegal River Valley. They stay in a first room representing the villages, divided into two friendship groups. In this same room, two other individual tables represent the two groups in the game, which implement collective rules. On the basis of an "opportunity card" drawn randomly and on their goal card, players go to a second room where the scheme is illustrated on a board. In the beginning, each player randomly carries cards, which describe social status, goal for cultivating the plot, rule for reimbursement of credits. Cards are trilingual: Pulaar, Wolof, French. The Game has been played several times with farmers in villages of the Senegal River Valley. Each session fostered discussions among the players regarding the real system, while teaching us details about the way interactions may take place.

4.3 Njoobari Ilnoowo: a Way to Explore Scenarios with Stakeholders

The third artifact is aimed at testing the possibility of using SHADOC as a negotiation support tool, which may lead to discussions within a group involving the choice among several scenarios for collective rules. The tool should explore scenarios and their possible long-term outcomes [Robinson, 1991]. It must be a legitimate representation of the system so that the results of simulations might be accepted as arguments in the collective decision process [Funtowicz et al., 1999]. Thus we used another computerized translation of the conceptual model, based on the same RPG simplifications to which stakeholders had previously agreed, as well as an interface approaching the graphical elements of the game.

This new computer artifact has been named "Njoobari ilnoowo"[3] by participants. Even though most of them had never used a computer before, they were very active in selecting scenarios and discussing the results afterwards. They understood the model and were able to play with it.

5. DISCUSSION

These experiments bring new insights into using MAS as simulation tools for renewable resources management. This field is growing steadily, [Bousquet et al., 2001] mainly through empirical approaches.

These simulation tools assimilate conceptual and executable levels, as we had done with SHADOC in the early stages. Our experiments show that MAS are suitable at both conceptual and executable levels, as conceptual models or as computerized artifacts. Computer versions constitute various specific artifacts, but are not the only ones. RPG are other possibilities. Other methods are under study and seem promising, such as Petri Nets [Bakam et al., 2001].

This potential polymorphism paves the way for synergy among various artifacts: complementing and mutual supply. Here RPG opens the black box of an MAS allowing to understand the overall behavior of a system. The links between them still require further analysis.

In this example, it has been possible to communicate a given representation at different cognitive levels. An MAS is suitable, at least as a conceptual model, to be used as a basis for a Group Decision Support System dealing with renewable resources management. It entails problems encountered by every stakeholder but spread over time and space to become common knowledge. Shared representations mediate this evolution towards better cognitive capacities of stakeholders [Teulier-Bourgine, 1997].

Interactions between stakeholders in relation to natural resources management may follow several channels: indirect, (perception of the consequences of others' actions on the resource); or direct (either on a one to one basis or in institutionalized collective frameworks [Rouchier et al., 1998]). All these direct interactions are based on mediating objects. Each artifact thus constitutes such a mediating object inducing stakeholders to agree on a common representation of their joint natural resource system and making communication among them easier. They use a well-suited artifact coming from the same representation, constituting a common, well-understood reference, provided the translation process is transparent enough.

Interactions among stakeholders mediated by a representation delivered through an artifact may be threefold: direct, on a one to one basis; indirect, through a group which manages the interaction with the artifact; indirect, through each one's interaction with the artifact (Rousseau, pers. comm.). By separating conceptual and executable levels, the same representation can be used, strengthening its legitimacy and the formation of a shared knowledge, while tailoring it to the various kinds of interactions to be addressed. These three kinds of interaction correspond to the three cognitive levels stated above. These are related to three kinds of influence: informative; personal; or normative [Whitworth et al., 2000]. The choice of a specific translation results in the strengthening of one aspect or another. It enables improved external interventions in the negotiation process, in order to facilitate the needed participation of stakeholders in irrigated systems [Kolavalli and Brewer, 1999].

6. CONCLUSION

By using theoretical frameworks in computer science as well as in cognitive science, experiments with a family of simulation tools for studying coordination patterns and viability of irrigated systems in Senegal can be analyzed. The most important outcome is that MAS constitute interesting conceptual models that are both polymorphous and modifiable. It paves the way for responding to some of the constraints of collaborative planning in complex projects management: making available some tools common to each participant, but also specific to each individual point of view [Gardiner and Ritchie, 1999]. This is required for a legitimate and worthwhile assessment of renewable resources systems viability.

The next step is to explore in greater depth the various possible artifacts and their relationships. A review of communication and information tools in the field of environmental management may bring specific capabilities to integrate with the artifacts. Furthermore, it refers to the issue of ergonomics of models used in decision processes.

[3] "survival kit of irrigating farmer" (authors' translation from pulaar).

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