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An Agent-Group-Role based modelling framework for participative water management support

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Abstract:

Agent-based modelling can be used as a tool for participative water management support. Within this framework, we want to develop architectural features that can improve system understanding at the collective and individual levels. We present a modelling framework which aims at bringing particular insights into the interrelations between temporal, spatial and social scales of the resource management process. To study these links, we adopt an approach based on the notions of role, group and agent: roles represent the functions of agents as members of a group; a group consists of a set of agents that interact in a process through their roles. In this way, groups describe collective structures through behavior types given by roles. Agents executing roles modulate these collective behavior types through their individual features. Agents carrying out several roles undertake a superposition of behaviors induced by collective dynamics. The Agent-Group-Role structure building process is carried out by developing models within a research project that supports a co-decision procedure taking place in the French Drôme River basin. We validate the features of our framework through regular field testing of the models we build on top of it. We extend and enhance our framework through progressive complexity augmentation of these models. In conclusion, we aim at demonstrating the suitability of the Agent-Group-Role formalism for the resolution of the duality between individual and collective levels of a system.

Keywords: agent-based modelling; organizational levels; roles; modelling framework; water management support

1 INTRODUCTION

For the past few years, Cemagref and other French agricultural research institutes have been exploring the use of agent-based modelling as a tool for participative renewable resources management support [Bousquet et al., 1998; Barreteau and Bousquet, 2000; Lardon et al., 2000]. The approach, referred to as "companion modelling", is based on an incremental and interactive modelling process that supports the researcher in the building and testing of its hypothesis, and may create a medium to support the discussion with and between players [Bousquet et al., 1999], and favor co-decision. It has been quite intensively tested for the study of irrigated systems viability in the Senegal River valley [Barreteau and Bousquet, 2000]. Within this general framework, our research aims at developing new architectural features to improve companion modelling for Integrated Natural Resources Management (INRM). Interrelations between temporal, spatial and social scales, and the assessment of influences of various organizational levels are particularly at stake for INRM [Lovell et al., 2002]. This paper proposes a multi-agent modelling framework based on the notions of agent, group and role, seeking enhancement of co-evolution modelling in organizational levels. It will be tested in the French Drôme River basin where a participative process is under way[1].

Section 2 presents our methodology, mainly based on the work of Gutknecht [2001]. Section 2.1 explains his approach, which aims at supporting heterogeneous languages, applications or architec-

[1] In France, we refer to "concertation", defined as a "partially negotiated preparation of a decision that will be made by an administrative or political authority" (from [Mermet, 1998])

tures in the design of complex multi-agent software. Multi-agent systems are described on the basis of social structures built from groups and roles, independently from the actual nature of the agents. The system is analyzed, 'from the outside'.

In section 2.2, we explain how we want to use these concepts for a water management modelling application. We define an organizational level as a coherent set of interaction, coherent in the sense of: Time range, process type, spatial scale, viewpoint.
For instance, water circulating inside an irrigation system with a specific spatial scale or boundary with a specified hydrologic process defines one organizational level. We define organizational levels from the real system as groups in the model, and the functions that components process as roles.
In section 2.3, we explain the implementation of the Agent-Group-Role framework we are developing. This is a core entry of our research.

In section 3, we use the Drôme basin in southern France to exemplify three levels of interest of this organizational approach:
- a global level, where behavior types are defined by the set of roles and their relationships in the organizational levels (3.1)
- an individual level, where agents execute and interpret the roles they are playing (3.2)
- a co-evolution level, where simultaneous dynamics of organizational levels interact through roles and agents (3.3).
In this way, we show how the Agent-Group-Role approach appears to be able to tackle both individual and collective aspects of a system.

2 AN ORGANIZATIONAL MODELLING FRAMEWORK

2.1 Foundation: the Aalaadin Agent-Group-Role (AGR) model

Our approach is based on the organizational model of Ferber and Gutknecht [Ferber and Gutknecht, 1998; Gutknecht, 2001], called Aalaadin, of which core concepts are Agent, Group and Role:

- An agent is defined as an active communicating entity, no constraints other than those triggered by the ability to play a role or not.
- A group is defined as a set of agents.
- A role is defined as "an abstract representation of an agent function, service or identification within a group": the role encapsulates the way an agent should act within a group. Roles are local to groups.

An agent can simultaneously play different roles in different groups: groups can freely overlap. An agent can enter or leave groups by acquiring or resigning a role: groups are dynamic structures. Groups represent organizational levels and roles represent functions within these levels; through the roles it is handling, an entity gathers information from the different processes it is involved in without concern about eventual scale or time heterogeneity of these processes.

2.2 Implications in the modelling process

This software design oriented formalism brings three main potentially useful insights for the description and modelling of social and spatial structures of a real system:

Organizational levels are first-class citizens of the model. Thinking about the system in terms of organizational levels means thinking first about its global activities. This brings temporal consistency in the modelling process. Each of these global activities is described by the positions of the agents within these activities, and by the patterns of interaction of these positions. These positions are the roles. They do not exist by themselves and they are linked to a viewpoint of the system, which is an organizational level. Finally, the individual dynamics of agents are triggered by a combination of the dynamics of its different roles, which are linked to the collective dynamics of the system [Durand, 1996]. The agent still models individuality and communication support, but it expresses it through its interventions in the organizational levels of the system. The role concentrates on the phenomena occurring at the group level.

Superposition of organizational levels is implicit. The link between the different groups is held by single agents playing roles in each of these groups - the agent acts as a medium for information between the different levels, so that the superposition of organizational levels of the systems is implicitly modelled.

Collective and individual features of an entity are differentiated. The role defines the position and function of an entity within an organizational level "from the outside", independently of its internal structure. The enforcement of a role is modulated by each entity's internal parameters. Modelling of the function is thus separated from modelling of the actual execution of the function. Groups and roles represent an ”ideal” system isolated from its environmental and individual constraints. This ideal system is modulated by the way the agents play their roles: The influence of individual factors on social rules is a first-class parameter of the models.

Thus, the Agent-Group-Role formalism makes it possible to model on the one hand organizational levels and individual behaviors they define by the means of roles, and, on the other hand, how these roles are identified and executed by the individuals. This is, as Rouchier et al. [1998] point to, a means of resolving the duality between collective and individual points of view on a social system [Boltanski and Thévenot, 1991].

2.3 Implementation of the Agent-Group-Role structure

In most of the multi-agent systems where Agent-Group-Role concepts exist, they are used solely for software engineering design and analysis, but are not actually implemented [Kendall, 1999; Wooldridge et al., 2000]. In the field of multi-agent simulation, Durand [1996] implements roles and organizational structures as a way of dividing the system complexity into organizational levels or application domains. In this sense his approach is similar to ours. The difference lies in the concept of role: It is a set of activities linked to a single entity for Durand; for us, it is a representation within a group of the function of any entity able to hold the role.

Our use of the AGR architecture aims at dealing with relations among several organizational levels. We use the object-oriented Smalltalk, and work on top of an existing multi-agent platform dedicated to natural resources modelling, Cormas [Bousquet et al., 1998]. We do not claim to reach the level of genericity of Gutknecht [2001] whose platform kernel is organizational. We first want to test the concept on a simplified system. So, we just inserted the AGR structure inside the Cormas entities hierarchy.

Hierarchy Like Fowler [1997], we use parallel hierarchies of roles and entities holding roles. Figure 1 shows how we inserted `EntityWithRole` (class of the entities able to hold roles) and `Roles` into the Cormas entities hierarchy[2]. All entities (ac-

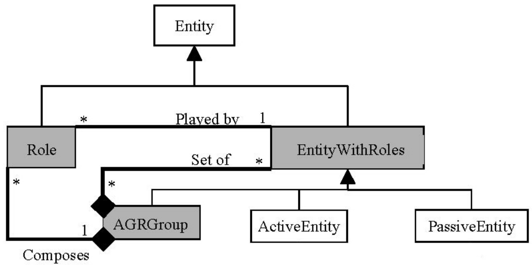

Figure 1: UML class diagram of the AGR formalism. White boxes are the classes that were already part of the agent platform. Thick lines represent relations between instances of the classes and diamond shaped symbols represent aggregation relations

tive, but also passive ones, for which roles consolidate points of view) are able to hold roles. Roles are also entities (roles can transmit agent communications or interact with resources).

Role properties As they express interactions within a particular organizational level, roles are local to groups. Roles cannot exist by themselves: They have to be held by an entity subclassifying `EntityWithRoles`. As a classic entity, a role can accomplish communication or actions with others (entity or roles), but never by itself: its actions and communications are either triggered by its environment and forwarded to its holder, or vice versa triggered by its holder and transmitted to its environment. That is why the role is not an active entity.

A key question about role is the bilateral definition of its relationship to its holder. On the role side, it mainly consists of transferring information to and from the entity. The major part of the relationship actually relies on the entity: Just as the way one decides to deal with his positions/obligations in society is individual and internal, it is the entity's business to manage role conflicts and interpret its roles. This raises major issues for our entities architecture:

- **ability to synchronize its roles:** When a role is acting, it refers to internal methods of its holder. This holder must be able to coordinate simultaneous solicitations from different roles. For example, if an entity `farmer` is in his field because of his `irrigant` role, he must be able to refuse or postpone solicitations from his `beekeeper` role to go and check his hives, and to raise priorities if he has to choose between two solicitations. Thus, particular care must be taken in the indexing and management of resources shared by different roles.

- **ability to modulate its roles:** entities must be able to influence the execution of their roles, and create a gap between what they are supposed to do

[2]an `Entity` is able to communicate and interact with other entities; an `ActiveEntity` is an entity with a proactive dynamic; a `PassiveEntity` dynamic is only triggered by external events.

and what they are actually doing. For instance, if the `irrigant` role compels the farmer to use his pumps ten hours a day, the farmer can decide how much he respects this constraint. This can be done specially dedicating some of the entities attributes or methods to role modulation.

These two points raise an important constraint: entity methods and attributes accessed by a role must be carefully documented. This is a necessary condition for role modulation and synchronization to be portable between entities of different types.

Group properties Groups are sets of agents holding roles, but they are also subclasses of `EntityWithRole` : they are in charge of the global management of the organizational level, and notably of the time management aspects. As subclasses of `EntityWithRole` , they are also able to hold roles and become members of other groups. This is a possibility we keep open and that we will have to test in the future. Group admission issues are also set aside for the moment.

3 APPLYING AGR ARCHITECTURE TO A MULTI-AGENT MODEL FOR WATER MANAGEMENT

A simplified ideal system is used as a basis for testing and developing our AGR meta-model. Farmers behaviors are taken from a survey report on agricultural water uses in the Drôme basin in southern France [Zanker, 1999].

3.1 Example system description

We will consider a portion of the catchment where the water is used only by agriculture. Farms consist of a set of parcels for corn growing, and farmers can get water individually, pumping from the river, or from one of the three irrigated systems in the area. These options are not exclusive and a single farmer can have parcels in several irrigated systems and also own pumps. Individual irrigation is not organized and is subject to possible administrative interdictions during the dry period. Irrigated systems have a leader that can be one of the farmers. He is an intermediary between farmers and higher levels of decision / dialog. Irrigated systems are also subject to administrative restrictions during dry periods, but they are free to adapt their internal organization to respect the restrictions.

Four of the organizational levels we modelled are

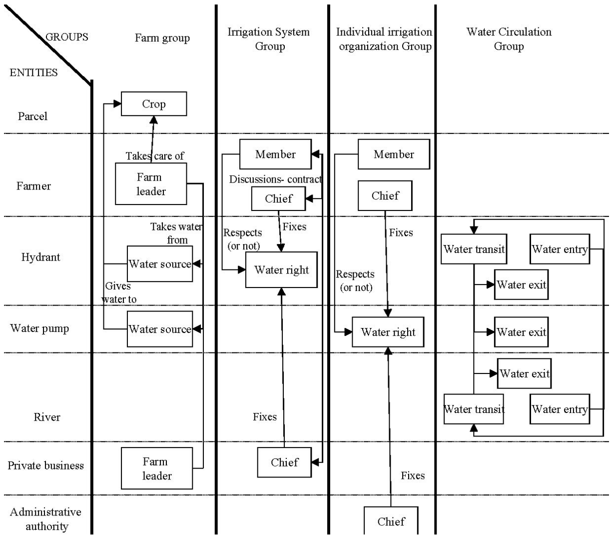

Figure 2: ”Swimlanes diagram” [Parunak and Odell, 2001].
First column are the entities, first line are the groups and the roles are in boxes.
Lines show the different roles an entity can hold and columns show the different roles that can exist within a group, and their main relationship

represented in Figure 2. This sketch represents the class description level of the model, i.e. the type of groups, roles and relations that can be instantiated during simulations. `Farm Group`, `Irrigation System Group` and `Individual Irrigation Organization Group` describe water management as regards the farm, the irrigation system, and the individual irrigation coordination respectively. Another group that describes water management at the level of the catchment is not present on the sketch. Finally, the last column shows how the AGR formalism can also describe physical processes such as water circulation. This particular aspect will not be developed further in the paper. We will now detail how we use the AGR formalism to model the distance between function and execution of the function, and to study the superposition of different organizational levels.

3.2 Individual level: role modulation by an entity

We will now take a closer look at `Farm group`. It must deal with decisions and actions as regards the farm, mainly irrigated crop rotation choice and upkeep. Its different roles :

- `Farm leader`, could be held by a farmer (player whose income depends on his farm) or a private company for instance. In any case, this farm leader is defined by a set of parcels and hydrants, and by a crop irrigation rotation calendar, and he accomplishes the action of implementing his calendar during the irrigation campaign. These are attributes and methods of the `farm leader` role, that can be seen from outside at the farm level. An entity holding this role modulates it with individual attributes such as concern over water economy, farm objectives or level of respect of interdictions.

- `Water Source`, could be held by hydrants or water pumps. It is defined by its known outflow and by the parcels it is linked to. Real outflow is an internal characteristic of its role holder.

- `Crop` is held by parcels. It is characterized by what it is growing and how it is watered.

Initial state of the group The farm group is instantiated with one farm leader and several crops and water sources. We suppose that the irrigated crop rotation calendar is given in advance, and we just deal with what happens during the irrigation season.

Group dynamics At each step, `farm leader` checks his calendar and executes it by putting water in the parcels concerned. Here are a few possible modulations of this execution:

- `hydrant` can have a different actual outflow, so that the quantity of water actually put in the parcel is different from what it is supposed to be

- `farmer` can be busy when his role of `farm leader` asks him to operate the hydrant

- if an external event such as wind or restriction happens, `farm leader` is not supposed to irrigate and must reorganize his rotation. But if `farmer` does not care about wind or restriction, irrigation still takes place. If it is not possible to reorganize the rotation, `farm leader` chooses which crop not to irrigate, depending on the objectives of `farmer`.

Roles describe what is supposed to happen, and their interpretation by their holder entities determines what is actually happening.

3.3 Superposition of organizational levels

A main interest of the AGR architecture is to represent co-evolution of organizational levels. Figure 3 represents what happens when an alert is given for water restrictions in the catchment, and how decisions travel between the different organizational levels.

The action starts at the catchment level: the `restriction trigger` activates the `restrictor` (typically an administrative authority) who

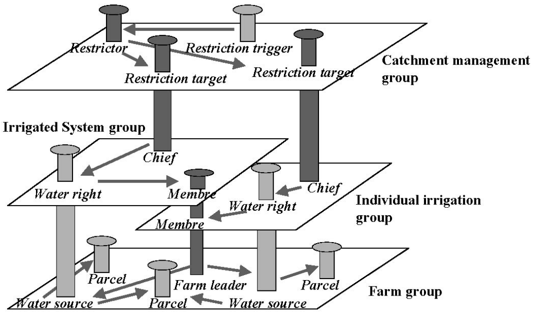

Figure 3: Organizational levels superposition during restriction rule activation (adapted from Ferber and Gutknecht [1998]).
This sketch represents the simulation level. Each plane represents a group with its currently active roles (in italics) and relationship among roles.
Pawns represent the agents holding the roles:
Pawns crossing several planes represent agents simultaneously playing roles in different groups

sends (possibly with some delay by agent modulation) a restriction signal to `restricted` roles.
Then it reaches the irrigated system level: the agent holding `restricted` role receives the restriction signal and forwards it to his concerned role, which is chief. `chief` role activates its restriction protocol [3]: `water right` roles of hydrants or pumps are updated, and `member` roles of farmers decide to respect the new water rights or not.
Then at the farm level: Hydrants and pumps transfer information from the above level into an availability on their `water source` role; `farm leader` faces this new availability and makes decisions regarding his farm to modify his rotation calendar.
Now we will have a closer look: if the individual irrigation level is not well organized, the `chief` role is not played by any `farmer` agent. It is held by default by an administrative authority who just relays the restriction to the irrigants. In this case, members of individual irrigation do not have effective control over the application of the restrictions (when members of irrigated systems face important social pressure) and cheat more easily (modulation). At the farm level, the farmer who possesses collective hydrants and some individual pumps might decide during restrictions to use pumps to irrigate a parcel he usually waters with hydrants (articulation of collective and individual dynamics).

4 CONCLUSION AND FUTURE WORK

Agent-Group-Role formalism is an attractive means of tackling issues concerning co-evolution of indi-

[3] given in advance; it could be negotiated at the catchment level and approved later at the irrigated system level

vidual and collective dynamics within a system: It can be used to model players "schizophrenia",e.g. the fact that a player can behave differently according to social context.

In this paper we focused on applications of the AGR formalism to social dynamics. Future developments will concentrate on spatial aspects of the system. The AGR approach can bring interesting insights: Disconnection of the topological aspects (spatial relationships among entities) and the representations (how it will appear on screen) of a spatial entity into different roles for instance. Subsequent reflection must be carried out about the status of space in our model: We must find ways to understand and formalize the relationships between social and spatial structures (e.g. Do social structures imply some boundaries in space, and how?), between processes and spatial scales... [Lovell et al., 2002]

Our Agent-Group-Role structure is a building site under construction. Our objective is to build up features that will best support modelling and understanding of socio-physical systems implied in participative management procedures. We will interact with real players of the Drôme River basin to discover how best to build models using the AGR structure, to test these models and then to expand them and enhance the structure in a step by step process. This collaborative development effort produces additional benefits - it provides for stronger understanding and support of the water management process through dialog with end users and strengthens the core model development process.

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