Multi-Agent Modelling to support Decision in Water Management: A Case-Based Approach

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Abstract. Due to the disparity of interests associated with a shared resource, the political dimension of contemporary water management is an important factor in conflicts among stakeholders. In this sense, environmental decision-making takes place in a highly interconnected system, in which neither the decisional ramifications nor the complexity of its impacts, can be neglected. The Mediterranean Region is characterized by water scarcity. This problem is increasingly challenging human and more-than-human communities, developing the need of a dynamic support in complex decision-making processes. A Multi-Agent System approach and System Dynamics modelling can introduce unconventional alternatives that can combine physical and economical components, with the consequences of individual behaviors in the management of a common resource, namely water. The paper works on analysis carried out in the irrigation water management in the Apulia region and a case-based modelling approach is suggested.

Keywords: Water management; Aiding decision-making; Multiple agents; System Dynamics; Cooperative models; Interactions; Participatory modelling.

1 Introduction

The management of natural and renewable resources must take account of both resource and social dynamics, such as the existence of belief system and cultural norms [1]. Complex human behaviors and natural-artificial systems produce remarkable impacts on global environments [2]. Water supply systems often engage multiple stakeholders with conflicting interests [3]. In this sense, water management is a “messy” problem, as a result of various interests associated with a shared resource, originated from the failure to meet basic human needs, inappropriate or ineffective institutions and the inability to balance human needs with the needs of the natural world. Furthermore according to Ostrom [4], the tragedy of what economists call common-pool resources, could be avoided under the right conditions: local communities can manage shared resources sustainably and successfully. The

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importance of shared decision processes in water management derives from the awareness of the inadequacy of traditional engineering approaches in dealing with complex and ill-structured problems. It is becoming increasingly obvious that traditional problem solving and decision support techniques, based on optimization and factual knowledge, have to be combined with stakeholder based policy design and implementation [5]. New approaches to water planning and management that incorporate principles of sustainability and equity are required [6] and consequently, the environmental decision-making takes place in a highly interconnected system, in which it is not possible to ignore the decisional network or the complexity of its impacts. However, the participative decision process with public actors and public objects is an unpredictable scenario for the great variety of objects and for the competition between intervening actors. For this reason, in order to ensure the sustainable development of water resources and their dependent societies and environments, there is an increasingly recognized need for the development of improved approaches to aid multi-stakeholder decision-making in the water sector [7].

After this introduction, the next chapters explain briefly the modelling theories and the agent based framework carried out from the case study. The paper ends up with follow-ups.

2 Multi-paradigm modelling approach

The need for the involvement of a number of different agents during planning processes induced issues of: gathering and exchanging complex knowledge, representing structured concepts, supporting different formal/informal languages [8] and structuring architecture interactions. Environmental systems are being viewed in terms of a set of autonomous agent due to several factors: multiple decision-makers, competing interest, complex and highly distributed network, inoperative distribution of resources, environmental and social impacts and difficulties of building scenario in a dynamic system. Different approaches for agent-based simulation have already been discussed in the literature (e.g. [1, 9, 10, 11, 12]). These approaches seem interesting since they permit the coupling of environmental and social systems, thus allowing to model both disaggregated human decision making [13] and social structures of interaction in environmental management. In this framework, a Multi-Agent System (MAS) approach and System Dynamics (SD) modelling can introduce unconventional alternatives that can combine physical and economical components, with the consequences of individual behaviors in the management of a common resource, namely water. The use of a multiple-agent approach shows new potentials to support the complex scenarios embedded with the multifaceted problem of managing water and it is useful to formalize the behaviors of water users in the knowledge management structure [11, 9]. Combining MAS modeling and SD simulation allows to deal equally with structural and behavioral models [14]. Originated from the field of Distributed Artificial Intelligence, MAS are based on the principles of distribution and interaction [15, 16]. MAS is a set of agents in a certain environment that interact with an appropriate organization to coordinate their behavior
In such systems, not all agents are equal: each agent can have unique capabilities and objectives, representing its real-world counterpart. An Agent can be defined as an autonomous entity and it has the capacity to adapt itself when its environment changes [16]. Furthermore, System Dynamics is a powerful and versatile simulating tool for studying easily dynamic characteristics of large complex systems. SD was defined by J.W. Forrester [17] as a way of studying the behavior of systems to show how policies, decisions, structure, and delays are interrelated to influence growth and stability. SD can be helpful to elicit and integrate conceptual models and the core of this structure is composed of feedback loops (positive and negative) that integrate the three fundamental constituents: state, rate, and information [18].

The final aim of the current research activity is to support knowledge elicitation from different decision makers and to simulate future scenarios, both desirable or not, in a distributed and highly interconnected water management network. From the prescriptive point of view, the research activity has the objective of modelling and interpreting the architecture of interactions between involved agents, to formalize the behaviors of water users and the consequences of their actions on the system.

3 A Case-Based Modelling

The complexity of a water management situation is largely driven by: the number of uncertainties, the number of interrelations between agents and the number and level of conflicts present [7]. The paper works on analysis carried out in the irrigation water management in agricultural systems in the Apulia region (south Italy). The simulations of scenarios on this case-based approach are used to analyze the consequences of sets of actions made by agents as an issue of coherence among sets of rules in a given environment. Different agents with different roles and behaviors can affect the environment, while performing their single and/or collective activities. Simulation lead to describe the overall behavioral patterns of the virtual system, interpreted as theories for real irrigated systems and proposing new insights on irrigated systems.

Let us define the system as 5-plets \(\{E, O, A, R, S\}\) made of: an environment \(E\), a set of objects \(O\), an assembly of agents \(A\) which represent the active entities in the system, an assembly of relations \(R\) that link objects (and therefore agents) to one another and \(S\) a set of rules and strategies, making it possible for the agents to perceive, produce, transform and manipulate objects in \(O\). The taxonomy of agents, objects and the formal and informal interaction have been created through two steps of semi-structured interviews with the stakeholders, dealing with conflict identification and resolution in natural resource management to achieve the “shared vision of the problem” [19]. The validation of the model has been done with a focus group and single interviews. In this sense, defining the set of elements, the relations between the sets and the behavioural rules allow to build the final model. Within the case-study analysed, the stakeholders are: Farmers, Water managers (political and technical side), the Regional Authority and Analysts. The Water Manager Consortium of Capitanata has to deal with the scarcity of water of the region and with the request of water from each farmer. Farmers have to
Each Farmer in order to maximize his profits chooses the right mix crops with regard to the quantity of available water and the hectares of arable land. In dry season, farmers receive the information of the water lack with delay and they can choose different alternatives like paying for a water surplus or using the groundwater. The groundwater (GW) overexploitation brings about social and environmental problems and the regional Authority, the Apulia Region, needs to protect groundwater quality and to keep a high level of productivity of the agricultural sector. It is possible to identify two different level of decision: one problem is embedded within another. The first level concerns the decision of the Water Manager of available water for each farmer. The second level affects the farmers, their crop planning and management of available water and its price. The boundaries of this system are given by the assumption of the irrigated system is a place for acquisition and allocation of water and credit; the water allocation is the combination of actions which enable users to receive water according to a recognized system of rights and priorities. The characteristics of the system constraints are economical (i.e. water price, market rules) and associated to the volume of available water. For each farmer sets of attributes, strategies and relations have been defined through the identification of a large numbers of parameters (such as level of autonomy, social aptitudes, communication rules, distributed decision-making, ability to influence environment, coherence in sensing environment). In addition, the identification of the object hierarchy allow to understand how concrete or abstract objects are related to each other's. For example some objects are: expected water demand, farmers' perception of water availability, irrigation budget, irrigated area, GW availability, acceptability.

A general overview of the model is in the figure below. The final model shows that the macro behavior of a system is primarily determined by its internal microstructure. In detail, the constructive process pays particular attention to structuring a shared vision of the problems and the model-building process is aimed at directly allowing the stakeholder to make decisions for themselves, understanding the consequences on the system of their possible actions. With this aim, the case-based model develops an integrated methodology able to combine hydrological, socioeconomic and behavioral determinants of water use to support resource protection.

Fig. 1. General overview of the final model
4 Conclusions and final discussion

In complex and strongly interconnected systems as the water management system, it is important to analyze the ramifications of the decision-making processes and the interaction between involved agents. To this aim, methods and tools to elicit and structure the actors of the water management problem are particularly interesting. This paper shows the potentials of using an agent based framework to simulate environmental resource management and to manage complex knowledge involved in a multi-stakeholder behaviors system. A Multi Agent system architecture and System Dynamics simulation allow the enhancement of the interaction and the participation of water users in the governance process. This is due to their ability to explain the dynamism of a system by modelling the roles of social interaction and adaptive, disaggregated (micro-level) human decision-making in environmental management.

References