INTEGRATION OF VIABILITY MODELS IN A SERIOUS GAME FOR THE MANAGEMENT OF PROTECTED AREAS

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ABSTRACT

Participatory management is considered to be a very important challenge, in particular for the management of renewable resources and biodiversity conservation. In the framework of computer support for participatory management of protected areas, we present in this paper a component of a serious game, devoted to the viability study of the decision proposed by the stakeholders. Mathematical viability theory allows to identify the policies that can retain or restore desirable properties of a dynamical system. The objective of the viability expert is to provide the players with information about the efficiency of management policy . In this paper we present briefly the SimParc project, and we introduce the concepts of the mathematical viability theory. We then describe the viability expert agent architecture and possibility of use, in particular the fact that negotiation focuses on constraints rather than on the management decision itself. We also present the type of information given by the expert agent. In particular the fact that negotiation focuses on constraints rather than on the management decision itself.

KEYWORDS

Computer assisted management, Serious game, Viability theory.

1. INTRODUCTION

Participatory methods are now considered as a promising research field to support sustainable development, management of natural resources or protected areas [Lynam et al. 2007], [Van Asselt Marjolein et al, 2002]. In this context, role-playing or serious games are a new approach to explore and test possibilities of negotiations in a realistic context. This approach is effective with neither high costs nor risks [Michael, D. and Chen, S.L., 2005]. Actually, these games are an interesting substitute to experience directly in the real world or on the real infrastructure [Warmerdam, J. et al, 2006]. The SimParc project [Sordoni et al, 2010], is based on a computerised role-playing game, in which participants playing stakeholders negotiate their management decision about a national park or a protected area . The present objective is to help the participant to understand the issues of a park, the conflicts, and the importance of negotiation in order to achieve shared decisions. In this framework we add a viability support tool which can propose answers to players' requests about the efficiency of management strategies. The mathematical viability theory has been developed for twenty years [Aubin, 1991]. It provides methods and tools to analyse the compatibility between system dynamics and constraint sets. In practical terms, with such an approach, the system analysis allows answering questions such as: given an initial situation, is there at least one future evolution that satisfies the constraints indefinitely or during a given time (such an evolution is called "viable")? And especially, what are the control rules that insure this "viability". Viability algorithms [Saint-Pierre, 1994]; [Deffuant et al., 2007] have been developed to provide numerical response to these questions. This theory shows a great potential to give a mathematical ground to the concept of resilience in ecology. It has been applied to several fields, in particular bio-economic and ecology (see for instance [Bene, C. et al, 2001], [Mullon, C. et al, 2004], [Bonneuil, N., 2003]).

The paper is organized as follow. In section 2 we describe the SimParc project. In section 3 we present the theoretical bases of the viability expert agent. In section 4 we present and discuss interesting information that the viability expert agent can provide to the players.

2. THE SIMPARC PROJECT

The SimParc project is an ongoing research project concerned with exploring computer support for participatory management of protected areas. Its purpose is to help stakeholders to understand the conflicts in the park management and to negotiate their strategy. The initial inspiration of this research on techniques of participatory management is the companion modeling approach (ComMod) [Barreteau, O., 2003]. They pioneer method, called MAS/RPG, consists in coupling multi-agent simulation (MAS) of the environment resources and role-playing games (RPG) by the stakeholders.

2.1 The SimParc Role-Playing Game

Current SimParc game is based on a negotiation process that takes place within the park council. The game is structured along six steps (see more details in [Briot, J.P. et al, 2011]):

1. Study and incorporation of roles and general and domain information about the park.
2. Individual proposal for the land use type for each landscape unit of the conservation area.
3. Negotiation along participants, aiming at their role's goals.
4. Revision of the initial proposal based on the negotiation process and agreements.
5. Manager decision and presentation of individual indicators of performance.
6. Presentation of the effects of the decision making based on players' attitude.

A new negotiation cycle may then start, authorizing a kind of learning cycle. This game can help each player to understand the various factors and perspectives involved and how they are correlative; to negotiate with the other players; to try to reach a group consensus and to understand cause-effect relations based on the decisions.

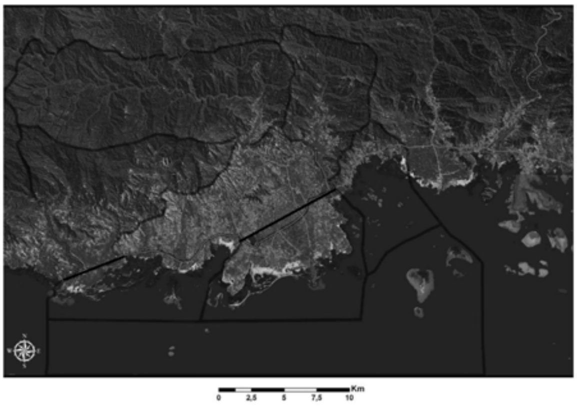


Figure 1. Map of the different areas of the park.

Actually, the game relies on a park in Brazil (figure 1). The Park is subdivided into eight landscape units. Players have to give a decision for each landscape unit. SimParc offers nine management modes, according to the Brazilian regulation: *Intangible* where no activity is permitted; *Primitive,* where the first concern is the high quality of the environment, which implies few access for tourist activity, typically for hunters; *Cultural Historical* area possesses cultural or historical sight spot, access to tourists, but pay attention to the quality of the environment; *Intensive* is tourist area, open to tourists; *Slight Use* is a typical tourist area that usually includes animals or vegetation which need protection, so the number of tourists is limited compared with *Intensive mode*; *Occupation* is a provisional zone that contains considerably disturbed areas, the objective is to stop the degradation of resources or to restore the area, this zone can be open to public but only for education purpose; *Temporary Occupation* processes densely populated urban zone, waiting for reapportionment, *Conflicts Use* is an area located in a protected zone, it has the infrastructure such as gas pipelines, transmission lines, antennas, water dams, roads and other equipment that are in conflict with environment conservation, the objective is here to minimize impacts on the protected areas; *Special mode* contains areas necessary to the administration, maintenance and service of the park, houses, workshops and others, its objectives is also to minimize the impacts.

All of these management modes are predefined in a list. Players have to select one mode as their management decision. But players from different backgrounds would put different interpretations on the same case. People rarely reach an absolute consensus on a controversial issue. In addition, the set of possible policy actions is very limited (regulatory limitation), so the negotiation between players could turn into confrontation with little progress. For this reason, we introduced the viability expert agent.

2.2 The SimParc Game Support Architecture with Artificial Agents

Figure 2 presents the general architecture and communication structure of SimParc current prototype (see more details in [Vasconcelos, G. et al, 2009.]). Distributed users (the players and the park manager) execute instructions with the system mediated internally by communication broker agents (CBA). The CBA is abstract, so each role may be played by a human or by an artificial agent. CBA may pass messages to each other, a CBA also transmits user messages in http format into multi-agent KQML format and vice versa to request assistance or to analysis. During the negotiation phase, players (human or artificial) negotiate among themselves to try to reach an agreement about the type of use for each landscape unit (sub-area) of the park. The artificial agents include: artificial players to replace some of the human players; assistant agents to assist them. We now design the expert agents to provide the players with technical information about the viability of their proposal.

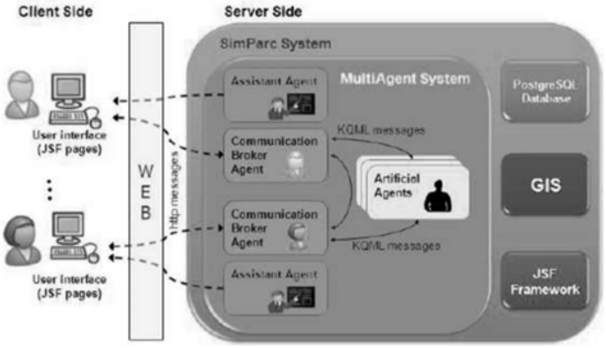


Figure 2. SimParc general architecture.

3. THE EXPERT AGENT

The viability expert agent is a type of artificial agents, which provides information about the efficiency of a given park management policy, to help the players to make a decision. Mathematical viability theory [Aubin, 1991] allows to identify the policies that can retain or restore desirable properties of a dynamical system, as it has been shown for Lake Eutrophication [Martin, S. 2004]. The viability expert agent helps the players to define what they consider to be the desirable set of states of the park, and the possible actions. It then computes the viability kernel corresponding to these constraints, and provides a viability analysis of the system.

3.1 Viability Theory

We consider the dynamical system (as in [Perko, L. 2001]) defined by its state $\vec{x}(t) \in X \subset R^n$ and we suppose its evolution can be influenced by a control $\vec{u}(t)$, with the following equation:

$$\begin{cases} \vec{x}'(t)=\varphi(\vec{x}(t),\vec{u}(t)) \\ \vec{u}(t)\in U(\vec{x}(t)) \end{cases} \quad (1)$$

The set of admissible controls can depend on the state of the system, $\vec{u}(t)$ x is chosen from a subset $U(\vec{x}(t)) \subset R^q$ (q dimensions, $q \in N$).

The set of constraints of viability is a subset of X noted K. The viability kernel of k for the dynamical system defined by (1) is:

$$Viab(K) = \left\{ \vec{x} \in K \middle| \exists \vec{u}(\cdot) \ \middle| \vec{x}(t) \in K, \forall t \in [0,+\infty] \right\} \quad (2)$$

Figure 3 shows an example of viability kernel. For all the points in the dark domain exists at least a control which allows the system to remain in the set of constraints. One interest of the viability theory is that the constraints can be adapted to the environment (defined as a set of variables submitted to the constraints of viability).

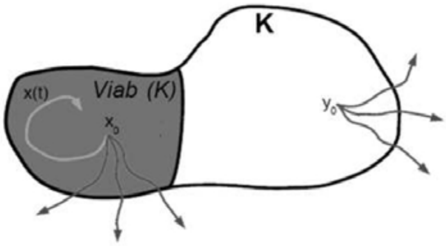


Figure 3. Example of viability kernel. The light color trajectory correspond to a viable action policy, dark trajectories are no viable, they leave the constraint set K. The dark domain is the viability kernel of the set of constraints *K*.

3.2 Operating the Viability Theory

3.2.1 Shifting the Problem away from the Restricting Decision Choice

According to viability theory, the players who want to operate the viability expert agent are invited to define what they would call the set of desirable state for the park or protected area. The choice of the state variables and the definition of the possible evolution of the park are also defined by the player, among a set of possible choice. The player should also decide what he / she considers to be the possible controls that can be used to modify the state of the park (rather than just let the park evolves by itself). For instance, in a park, several courses of actions are possible: investment, cleanup, plantation, etc.

Table 1. Correspondence between management decision and desirable state of the park given by the game designer expert committee.

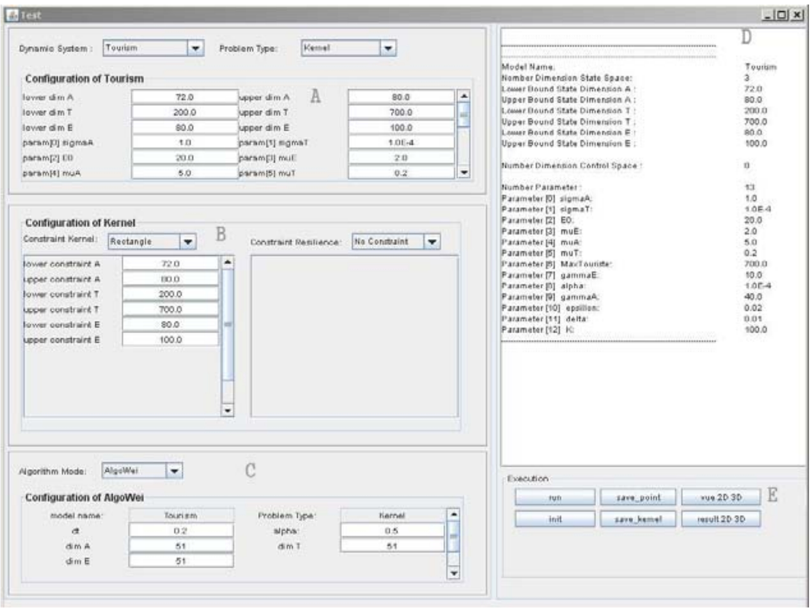
Mode / Variable	Intangible	Primitive	Cultural Historical	Use slight	Intensive	Occupation	Use conflicts
Tourists	0	<200	400~1500	200~700	1500~3000	0~1000	0~1000
Environment	100%	>90%	>70%	>80%	>60%	>70%	>70%
Animals	100%	>95%	>85%	>90%	>80%	>85%	>85%

In practice, a family of dynamical systems is built in advance. The players can choose between models, they can question the accuracy of the model, or define the value of the parameters to improve the models. Moreover, the players provide their constraints on the variables. Presently we work with a model that deals with the problem of the interaction between tourism, environment and animal at an abstract level. Table 1 shows a set of the constraints of the different management modes that are recommended by the committee as reference for each player. During the game (see section 2.1), each player proposes his constraints for each landscape unit. Players can also ask the expert agent to make a viability analysis. If the players get positives results, they are able to use these results to discuss with others at step three. Possibly players do not obtain the result they want: Several players can get an empty kernel, which means that the park cannot stay in a state within the constraint set they choose. The expert agent can propose a relaxation of the constraints. During step four, the park manager reviews the proposals and commits themselves to a final proposal for each landscape unit. The use of the viability expert allows the player to discuss directly on the constraints. The negotiation between players revolves around the definition of the desirable area, which is a continuous space. During the tests it appeared that it was easier to discuss the position of the boundary rather than directly the choice of restricting management mode.

3.2.2 User Interface

In the previous section, we've already let the players turn their attention to the constraints. But in this role-game [Briot, J.P. et al, 2011] support participatory management, players are encouraged to reflect across different domains of the protected area, and the game consists of two phases of negotiation rather consequent. This leads players to use the expert agents repeatedly, with substantial modifications of constraints and eventually the models parameters.

An interface is proposed to facilitate the manipulation. It is shown at figure 4. In this interface, players can select the model (all models are predefined, each model corresponds to a zone of park); define the constraints (just to enter the values); select an algorithm to solve the problem (each algorithm has a different usefulness); execute the problem; analyzes and observe the results; save results. This interface allows to consider separate component for the model definition, the constraint and the algorithm. Its advantage is that when we add or delete a model (resp. constraint, algorithm) it will not affect other components. If we want to build a new model or implement a new algorithm, we just need to create the new object then integrate it in this interface, which is very easy.



Dynamic System : Tourism
Problem Type: Kernel

Configuration of Tourism

lower dim A 72.0
upper dim A 80.0
lower dim T 200.0
upper dim T 700.0
lower dim E 80.0
upper dim E 100.0
param[0] sigmaA 1.0
param[1] sigmaT 1.0E-4
param[2] E0 20.0
param[3] muE 2.0
param[4] muA 5.0
param[5] muT 0.2

Configuration of Kernel

Constraint Kernel: Rectangle
Constraint Resilience: No Constraint
lower constraint A 72.0
upper constraint A 80.0
lower constraint T 200.0
upper constraint T 700.0
lower constraint E 80.0
upper constraint E 100.0

Algorithm Mode: AlgoWei

Configuration of AlgoWei

model name: Tourism
Problem Type: Kernel
dt 0.2
alpha: 0.5
dim A 51
dim T 51
dim E 51

```
Model Name:                                  Tourism
Nomber Dimension State Space:                3
Lower Bound State Dimension A :              72.0
Upper Bound State Dimension A :              80.0
Lower Bound State Dimension T :              200.0
Upper Bound State Dimension T :              700.0
Lower Bound State Dimension E :              80.0
Upper Bound State Dimension E :              100.0

Number Dimension Control Space :             0

Number Parameter :                           13
Parameter [0]  sigmaA:                       1.0
Parameter [1]  sigmaT:                       1.0E-4
Parameter [2]  E0:                           20.0
Parameter [3]  muE:                          2.0
Parameter [4]  muA:                          5.0
Parameter [5]  muT:                          0.2
Parameter [6]  MaxTouriste:                  700.0
Parameter [7]  gammaE:                       10.0
Parameter [8]  alpha:                        1.0E-4
Parameter [9]  gammaA:                       40.0
Parameter [10]  epsilon:                     0.02
Parameter [11]  delta:                       0.01
Parameter [12]  K:                           100.0
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Figure 4. The expert agents interface.

3.2.3 Computing an Approximation of the Viability Kernel

In the context of the tool of support participatory management, players do not want to wait too long, so the expert agents need to provide the results as soon as possible, even if the approximation is rather rough. We could not use the algorithms that are available to compute the viability kernels because of the specific constraints we experiment in a serious game: Speed, reactivity to model change, easy parameterization. None of the available algorithms could answer these constraints in a satisfactory way (Saint-Pierre, P. [1994] and Coquelin and al. [2007] algorithm is embedded with the model; Kviar, from Deffuant G. and al. [2007] uses Support Vector Machines (SVMs), which reduce the sample size to keep in memory, but it terribly increases the runtime). For these reasons, we use the algorithm from [Wei, W. et al. 2012], which uses the classification procedure based on the method of Nearest Neighbor Search. The algorithm satisfies the conditions of convergence from [Deffuant, G. and al. 2007]. This algorithm gives very good results in the case of theoretic models (TVK) that could be calculated (the model of population growth on a limited space [Aubin, J.P. and Saint-Pierre, P.] and the model of consumption problem [Aubin, J.P. 1992]). In both cases, the fidelity (number of points common in Approximation of algorithm and in TVK / number of points of approximation) is more than 90% and increases with the number of points. Running time is much lower than that of Kviar when the number of points increases: 3 times faster for 100.000 points to 10 times faster for one million points.

4. RESULTS PROVIDED BY VIABILITY EXPERT AGENTS

To test the interest of the viability approach, we work with a 3-dimensional model: tourists (T), environmental quality (E) and Animals (A). The animals (A) develop according to a Verhulst law with the net growth rate γ_A. The carrying capacity $\sigma_A(E-E_0)$ takes into account the environment (when the environment is better, the capacity is higher). And animals may be killed with probability σ_T when they encounter a tourist. The variation of tourists (T) depends on the attractiveness of environment and on animal with coefficient ω_E, ω_A, and tourists are mutually exclusive with coefficient ω_T. The quality of the environment (E) is described by a classical logistic equation, the net growth rate γ_E, and the carrying capacity *K*. αT represents the flow of damages induced by tourism. And *u* is the control parameter which represents the investment rate to restore the environment. In conclusion, our simple model turns out to be:

$$A' = A*(\gamma_A(\sigma_A(E-E_0)-A)-\sigma_T T)$$
$$T' = T*(\omega_E E + \omega_A A - \omega_T T)$$
$$E' = E*(\gamma_E(1-\frac{E}{K})-\alpha T)+u(K-E)$$

We use the parameters $\gamma_A = \sigma_A = 1$, $E_0 = 10$, $\omega_E = \omega_T = 0.1$, $\omega_A = 3$, $\gamma_E = 10$, $\sigma_T = \alpha = 0.001$, *K*=100 and *u* between 0 and 0.5.

4.1 Viability Kernel Visualization

When the players have described their viewpoint on the desirable states of the system, for instance the presence of tourists, the expert agent can provide the viability kernel of the intersection of players' desirable states. The fact that the intersection be non empty does not imply that the viability kernel corresponds to the whole intersection. If we choose the constraints of *Intensive mode* of the table 1, and use the previous parameters, the viability kernel is empty. However, with slight change in the constraints, we can get non empty viability kernels. The Figure 5 displays two constraint sets and their associated viability kernels. The constraints of the big box are $A \in [64,90], T \in [1400,300]$, $E \in [60,100]$, its volume of the viability kernel is about 64% of the big box volume. The constraints of the small box are $A \in [64,90]$, $T \in [1500,300]$, $E \in [80,100]$, the volume of viability kernel is about 97% of the small box volume. The big box includes the small box. The viability kernel of small box is obviously contained within the viability kernel of big box.

From any point inside the viability kernel there exists a way of controlling the investment rate *u* in order to maintain the state of the system inside the desirable set. Such information is easily received with visualizations such as Figure 5. Thanks to this information, the players can select among the viable strategies during a negotiation cycle (see 2.1) to reduce the set of conflicts.

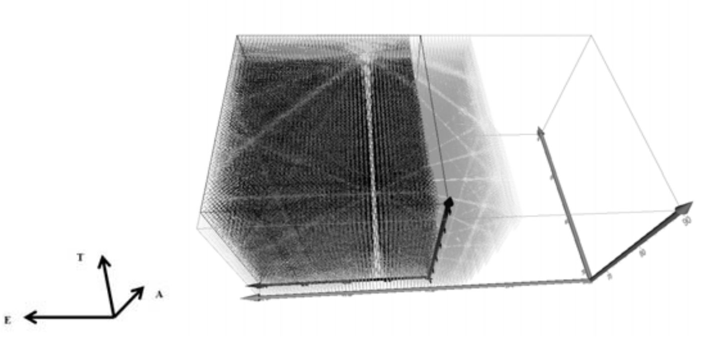

Figure 5. The viability kernel of the big box is colored light grey. The viability kernel of the small box is colored dark.

4.2 Viable Evolution and Control Functions Visualization

Once it is determined that a situation belongs to the viability kernel, the expert agent provide the players with real viable evolutions and the control functions that govern them. In Figure 6, the viability kernel is colored light grey. From a point belonging to this viability kernel, the grey trajectory represents a viable evolution. From the same initial point, the dark trajectory following the same evolution as the grey one in the kernel, and then leave the desirable set since a viable control has not been applied. Such information has two interests: from the one hand, it gives examples of viable control functions to the players; On the other hand it allows them to test the viability of the control functions they may propose.

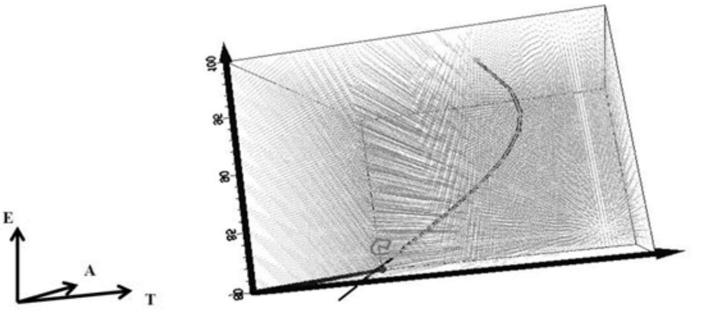

Figure 6. The set of constraints is the small box of the figure 5. The viability kernel is colored light grey. The two trajectories have the same starting point (A=80, T=2000, E=100) which belongs to the viability kernel. The grey trajectory is viable whereas the dark one leaves the desirable set.

5. CONCLUSION

We have presented the issue of integrating an artificial viability expert in a serious game for participatory management support: Providing the players with information about the possible viability of the system under discussion according to the constraint set they have defined. Actually, including viability concepts based on the study of the compatibility between dynamics and constraints allows the players to focus on the state sets of the system they consider as desirable. And such discussions appear to be fruitful in the framework of the SimParc project, a serious game about participatory management of protected areas. Using a model from the literature on socio-ecological tourism-based system, we have next illustrated the information given by the computation of the viability kernel that allows easily distinguishing situations from which the desirable set can be preserved. Moreover, we have shown the ability of providing the players with examples of viable evolutions and control functions, or the ability of checking the viability of the control functions they may propose. Such interesting results have been reached thanks to the development of an easy to use interface which can be handled by all players, and an efficient algorithm for viability kernel approximation. In the future we intend to test the viability expert in extensive sessions of the serious game, and to offer more possibilities to the players: change model choice, comparison of viewpoints, help to define indicators, computation of resilience in case of disturbances.

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