Using Dynamics Spatial Entities in Agent-Based Simulations

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Abstract: Dealing with multiple scales is often a key question in renewable resources management. In some cases, the decision to incorporate a spatial entity is influenced by the fact that information is available at this level. In other cases, the system dynamics is intrinsically linked to a specific spatial entity. Nevertheless, it is important to have the possibility to manipulate and to incorporate into the same model spatial entities defined at different hierarchical levels. Multi-Agent Systems (MAS) are potentially suitable for linking several hierarchical levels. Cormas is a multi-agent simulation platform specially designed for renewable resource management. It provides the framework for building models of interactions between individuals and groups sharing natural resources. With Cormas, the design of the spatial support rests on spatial entities, which are themselves a category of agents. Cormas enables connections with Geographic Information Systems (GIS) to design realistic artificial landscapes. Following a general overview of the Cormas simulation platform, examples of models built by using this toolkit are presented, by emphasizing the overlapping of their multiple hierarchical scales.

Keywords: Agent-based simulation; Geographic Information System; Landscape dynamics; Multiple scales

1. INTRODUCTION

There is a trend in ecological modelling to define spatially-explicit individual-based models [Grimm, 1999]. One of the main challenges is to connect landscape patterns to population processes [Kareiva and Wennergren, 1995]. In this way towards a behavioural ecology of ecological landscapes, the major problem to face deals with scale, as different levels of aggregation are classically used by ecologists and behaviourists [Lima and Zollner, 1996]. In the meanwhile the ecological modelling community has shown a growing interest about the relations among scales [Wu and Levin, 1997]. Ecological systems viewed as hierarchical dynamic mosaics of patches are thus generated and maintained by processes of patch formation, patch development and disappearance. Mainly based on object-oriented conception, several software frameworks have implemented such hierarchically structured spatial environments. Liu and Ashton [1998] have developed a landscape model (Formosaic) for simulating forest dynamics based on four spatial scales: the landscape, made of forests, a forest being made of 10x10 grid cells, a cell containing many individual trees located at the point level. Ecotalk [Baceco and Lingeman, 1992] and Hobo [Lhotka, 1994] are simulation systems based on Smalltalk with an overall space structure being a tree-like configuration that facilitates specification of various spatial organisations. Ecosim [Lorek and Sonnenschein, 1999] is a C++ framework in which the basic spatial unit is a discrete cell, hierarchical environments being defined by structuring the cells using topologies.

The need to define realistic virtual landscapes is strengthened when human activities (agriculture, hunting, forestry, ...) are part of the system and when the goal of the model is to understand the interactions between natural and social dynamics to give some insights about renewable resources management. We present in this paper an agent-based simulation framework involving multi-agent system [Ferber, 1999; Weiss, 1999] in order to understand the complexity of these interactions. Models of this type have been developed for irrigated land management in Senegal [Barreteau and Bousquet, 2000], hunting wild meat in

Eastern Cameroon [Bousquet et al., 2001]. We have developed a simulation framework called Cormas[1] [Bousquet et al., 1998] that provides some facilities to incorporate data from a Geographic Information System (GIS) into what we call "spatial entities".

The aim of this paper is to introduce these facilities and to illustrate their usefulness in the field of natural resources management. Following a general description of Cormas, three examples of applications are given. To introduce the idea of incorporating dynamics processes inside spatial entities themselves, a first example, purely didactic and theoretical, is described. The second one illustrates how to incorporate GIS data existing at different spatial scales (individual cells of 3 ha on which the animals are moving, and hunter's hunting localities of different size) to design a realistic virtual landscape of a model of duiker's hunting in Eastern Cameroon. Finally, the last example illustrates the usefulness of dynamics spatial entities in representing specific viewpoints of agents using in different ways the same ecosystem.

2. THE CORMAS FRAMEWORK

2. 1 Why Another Agent-Based Simulation Toolkit ?

For several years now, multi-agent simulation softwares are developed. User groups (including ecologists and sociologists) are organized around generic tools that facilitate the construction of models and offer facilities ("virtual laboratories") for monitoring and analysing simulation trials. The example of Swarm[2] [Minar et al., 1996] clearly reflects the current trend. Since the launch of the project at the Santa Fe Institute in 1994, groups using Swarm have joined forces to try and resolve common problems. As a result, new softwares based on Swarm, with specific applications for different disciplinary fields have been developed. Among them, Echo [Hraber et al., 1997] is based on the fact that evolution is built in as a fundamental components of the system. Sugarscape [Epstein and Axtell, 1996] is focusing on artificial societies by putting emphasise into exchanges of goods between agents.

As claimed by Resnick [1996], new computational tools can be useful to develop heuristics and metaphors to help people think about decentralised systems in a new way. Following this idea, Cormas (acronym for **Co**mmon-pool **R**esources and **M**ulti-**A**gent **S**ystems) provides a set a heuristics for thinking about common-pool resources management in a decentralised and distributed way. Cormas aims at being a modeling tool specific to the field of natural resources management, especially when different land-uses may lead to situations of conflict because of direct or indirect (externalities) interactions. As the "environment" is one of the key-concept in MAS but also in ecology, facilities to design realistic spatial supports (among them, connections with GIS) have been a priority since the beginning of Cormas development. Reschke [2001], in a recent comparative review of the available agent-based simulation toolkits, describes Cormas as a framework to build models of social dynamics in a spatially-explicit context. The recent rise of agent-based models being connected with GIS indicates that there will be an increasing need for this kind of simulation tools [Gimblett, 2001].

2.2 Cormas Main Principles

Cormas is based on the software VisualWorks, and is freely distributed. Cormas provides a set of Smalltalk classes that are representing generic social entities and that are encoding the behaviours classically exhibited by actors exploiting natural resources. Cormas also provides generic spatial entities organised in a hierarchical way.

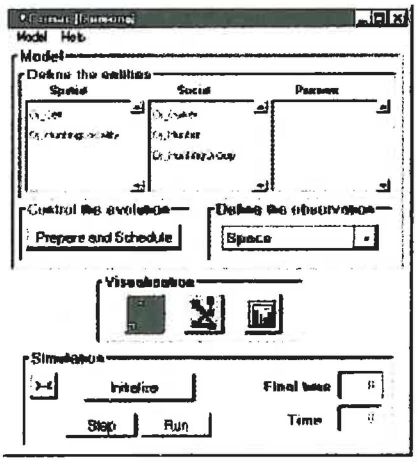


Figure 1. Cormas main interface.

The architecture of the main interface of the platform (Figure 1) has been designed to guide the

[1] http://cormas.cirad.fr

[2] http://www.swarm.org

user of Cormas during the modelling process. The organisation of the modeling group box in the upper part suggests three successive steps.

The first one consists in defining the entities of the model into three categories (spatial, social, passive). These categories are simply a way to group the Cormas superclasses. When creating a new entity to build a model, the user has to choose one of these generic classes to make its specific entity inheriting from it. Every methods has then to be written in Smalltalk, taking advantage of the pre-defined one. For instance, requesting actions to be performed has been set as the basic behaviour of the Cormas root entity. It is particularly useful when dealing with the share of common-pool resources. Two main rules have been implemented for sharing the resources, either to account for an asynchronous mode ("first asking, first served") or to account for a synchronous mode (each agent receives an amount proportional to its request).

The second step consists in defining the control and the scheduling of the model. The scheduling of the agents has to be specified (again by writing a smalltalk method which can itself use pre-defined methods) in a "step" method which is automatically executed at each time-step of the model. This time-step being used to schedule all the entities of the model, it has to be defined as the shortest unit of time during which an entity of the model evolve.

The last step allows the user to open some specific tools to define viewpoints on the entities of the model. A point of view is a Smalltalk method -to be implemented by the observer- that makes associations between the "state" of the entity and a colored image that will represent the "visual state" of this entity on the spatial grid.

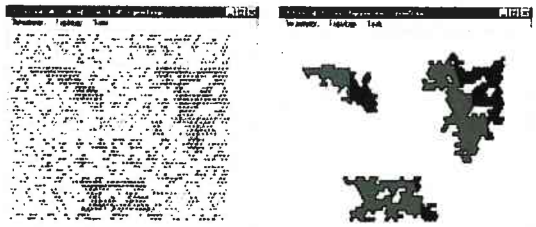
2.3 Building Artificial Landscapes with Cormas

By default, a regular spatial grid made of 10x10 cells is opening when clicking on the left icon of the visualisation group box in the Cormas main interface (see Figure 1). The configuration of the spatial grid can be done through its menu. Cormas can represent the space as regular grids or irregular tesselation. Regular ("raster") grids can be created either automatically, either by loading a specific matrix of cells from a text file with a particular format. Irregular grids will require special programmes to generate or load polygons exported as text files from Geographical Information System (GIS) softwares like MapInfo or ArcView. Some of the applications built with Cormas are using this facility. Some others, such as the second and last examples of the next session, are based on a pre-processing of the spatial data using GIS facilities to build raster grid from maps.

3. USING CORMAS SPATIAL ENTITIES

3.1 Aggregated Spatial Entities With Scale-specific Dynamics Processes

In Cormas, there are pre-defined methods to aggregate lower-level spatial entities and thus to create compound spatial entities whose components are defined as sets of contiguous elementary spatial entities sharing a same condition.



(a) (b)

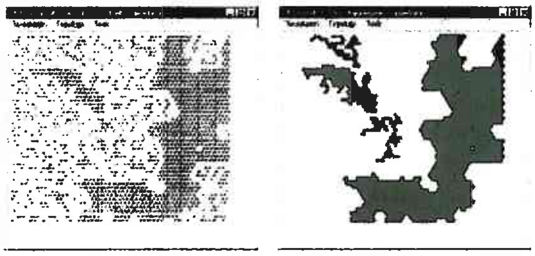
Figure 2. Initial configuration of the landscape, (a) from a cellular (tree) point of view; (b) from an aggregative (forest) point of view.

The starting point of this model[3] is to load a spatial grid made of 50*50 cells from a file (see Figure 2a). Each cell has either #tree (gray colored) or #empty (white colored) as value of its "context" attribute. The effective creations of the compound spatial entities are submitted to an additional constraint about a minimum number (set to 25) of contiguous components verifying the aggregation condition. Initially, only three "forests" entities are created, (see Figure 2b, the darker they appear, the bigger they are). To let co-exist in the same model several spatial entities defined at different levels gives a great flexibility to write the dynamics of the landscape. Some of the processes are more easily described at the cellular level, as for some others, the aggregated level is more suitable. In this didactic and simplistic example, each cell has a fixed (very low) probability to switch its "context" attribute value. This may correspond to the balance

[3] http://cormas.cirad.fr/en/applica/tse.htm

between natural mortality of individual trees and colonization by seeds' dispersal.

At the level of the aggregates, a spreading process from the edges is written like this: a given number (corresponding to the hundredth of the total number of components of the forestry entity) of cells at the outside edge are going to be aggregated to the forest. In order to keep a high compacity to the forestry entities, a priority is given to the cells that are surrounded by the highest number of already aggregated cells. After 50 time-steps, the result is shown in Figure 3. There are now 4 forests in the landscape, and they are as much compact as they are big. The biggest one is a mixing from two initial forests. Two additional forests have been created, from the individual process. Now that they exist as aggregative entities, the spreading process will also be at work.



(a) (b)

Figure 3. Configuration of the landscape after 50 time-steps, (a) from a cellular (tree) point of view; (b) from an aggregative (forest) point of view..

3.2 Spatial Entities Loaded From a GIS

The model described [Bousquet et al., 2001] is based on a study of blue duiker hunting (a small antelope) in Djemiong, a forest village in eastern Cameroon[4]. The model was built based on the life history of the blue-duiker and on the inhabitants' hunting behaviour and incorporates raster data from a GIS. Once blue duikers have reached maturity and found a mate, they demarcate their territory (about 3 ha) where they remain until they die. Each cell on the spatial grid represents an area of 3 ha. The GIS is divided into three layers: roads, rivers and hunting localities. On Figure 4, cells with water are dark gray, cells with a road are black. The small dark gray dots represent adult duikers with a mate and the small white dots represent juveniles or single adults. The perception range of a duiker agent is defined as a 3-order recursive function based on the 4-connex neighbourhood of the cell where it is located. In a weekly time step, a duiker agent can visit any of the 25 cells that make up this area. When a single adult male meets a single mature female, they look for a suitable cell (empty, no water, no road) within their common perception range where they can settle.

Figure 4. The Djemiong artificial landscape in Cormas.

The cell was then the space unit appropriate to build the individual-based duikers population model. To deal with the hunting activity, we had to work with spatial entities defined at a higher level. During the hunting season, each hunter sets traps along a path in the forest (trap network). The hunting localities have been determined from surveys on the field. Their limits have been defined on a map in consultation with the inhabitants. Twenty-nine hunting localities were identified from the spatial information collected in the survey (see Figure 5).

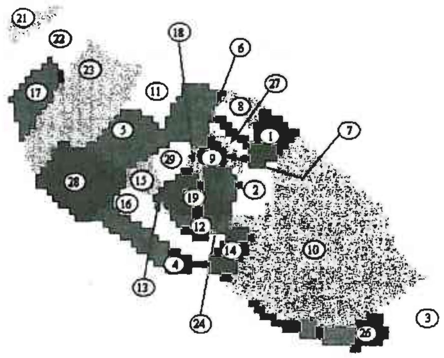


Figure 5. The 27 hunting localities used in the Djemiong model are each identified by a number.

[4] http://cormas.cirad.fr/en/applica/djemiong.htm

From a practical point of view, it was very convenient to be able to let the two levels of spatial entities co-exist in the model, because we were able to incorporate directly the available information . But as a consequence, we had to make assumptions about the precise locations of traps paths within a given hunting locality. Several simulation scenarios have been defined on this basis and then compared by running the model [Bousquet et al., 2001].

Defining spatial entities at several levels may not only be a useful way to incorporate pre-existing data. It is also very fruitful to take into account the specific perceptions of a commonly-used environment that each kind of agent will use to make its decisions.

3.3 Pine Encroachment in the Mejan Causse

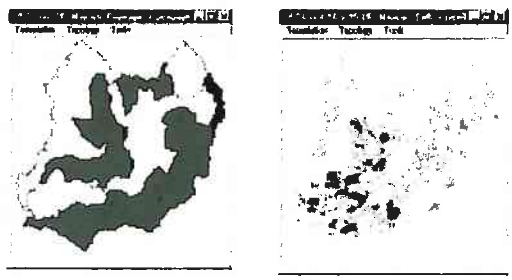
The Mejan causse is a limestone plateau in south-central France. It is a natural open-land area, delimited by high cliffs. Because of high wildlife interests, the Mejan causse is part of a national park, but it is also used by shepherds and foresters. Mejan is a model[5] which simulates contrasting management behaviour in the face of pine (*Pinus sylvestris* and *P. nigra*) encroachment. Three agents representing the different land-uses have been defined: a shepherd agent, a forester agent, and a national park agent. All the agents are concerned by the global pine encroachment process although it affects their management goals in very different ways. The global landscape dynamics is resulting from a combination of the natural vegetation dynamics processes and the actions of the three kind of agents :

- The sheep farmer can adjust the size of its grazing pastures to the animal needs. This has a direct consequence on the pine encroachment process as young pines can not resist above a given grazing pressure.
- The forester, whose specific objective is to produce timber, is able to harvest its plantations (to cut the trees when they are big enough).
- The national park, whose specific objective is to maintain an "open landscape" to preserve wild fauna and flora, has to take care of places with high patrimonial interest.

[5] http://cormas.cirad.fr/en/applica/mejan.htm

The natural resources are defined by the vegetation types according to the combination of vegetation layers (tree, shrub or grass), the topographic position, land tenure and conservation value (fauna, flora, landscape). The causse is represented by a grid made from the rasterization of a real vectorial map built with the MapInfo® GIS. Each of the 96*95 cells represents 4 ha (see Figure 6b).

The natural dynamics of the vegetation has two driving forces. There is a pioneer front at the border of any mature forest. There is also a dispersal process from isolated adult trees, within a portion of space being defined as the intersection between an ellipsoid around the isolated tree and the dispersal basin to which it belongs.



(a) (b)

Figure 6. The causse Mejean virtual landscape, from the national park point of view. (a) Scenery units. (b) Wild fauna and flora interest. In both cases, the more dark, the more valuable.

In this model, spatial entities defined at different levels are also needed to build the specific perception of the ecosystem that each agent uses to determine its actions. We just give here an example relative to the national park agent (see Figure 6). As said before, the national park agent has to find places with high patrimonial interest. The national park rangers working in the Mejan causse have pointed out several criteria to be taken into account. Among them, a very subjective one has been expressed at an intermediate space level by defining "scenery units", which are portions of space with a specific scenic view (Figure 6a). On the other hand, very precisely located botanical stations are of great importance because of the presence of rare species. This information is stored at the level of the 4 ha cells (see Figure 6b). Moreover, at the level of the whole landscape, the suitability of the habitat for endangered species of birds of prey is directly related to a global index of pine encroachment. It is very convenient to be able to define all the corresponding spatial entities and to let the national park agent refer to them when it needs to perform its actions, according to the management scenario to be tested.

The two main goals of this model are precisely to compare contrasting management scenarios and to use directly the model with the actors to allow them to exchange their perceptions of the process of pine encroachment. If this approach is successful, it may help to find ways to conciliate agricultural and forestry activities on a space with high wildlife interests.

4. CONCLUSION

Rather than raising the question of scale transfer, the methodology that we propose beyond the use of the Cormas simulation framework enables us to focus on relationships among dynamic processes at several levels. The Cormas spatial structure may prove useful in trying to slice the "layer cake" of ecological systems diagonally, as Allen et al. [1987] have stressed to be one of the most interesting point to focus on in ecological modelling. This research direction is promising but also challenging: Being able to connect several spatial levels by using dynamics spatial entities asks new questions about controlling the reciprocal influence of the dynamics.

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