Landscape Abstractions for Agent-based Biodiversity Simulation

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Abstract In this paper we present a multi-agent model that uses representations of the simulated landscapes on different levels of abstraction. We investigate species richness in agricultural landscapes with an agent-based population model. In the model we can either import raster data from GIS or create artificial landscapes and overlay a landscape fragmentation. Based on this use of landscape abstraction, a predictive model of biodiversity becomes practicable.

1 Introduction

Modeling and simulation form a well-known method for studying a system. If the abstraction of the real world into a model is done in a correct and valid way, the resulting model can be used instead of the original system to answer relevant questions.

In a spatially explicit multi-agent model the environmental component consists of a landscape and the dynamics of its elements that are not part of the modeled MAS itself. The realism of this part of the model is mainly responsible for the quality of answers produced by the overall model and thus for the way the model fulfils its purpose.

We present some thoughts about the role of the environment in MASim in general and our ecological model in particular. The main part of the paper is Section 4, where the landscape representation, abstraction, and ways for its configuration are presented. The paper ends with a short conclusion and some aspects of further work.

2 Related Work and Relevance of the Environment in MASim

The focus on environments used in MASim is in fact important, but relatively new [4]. Almost every individual-based simulation in ecology is spatially explicit (for a rather old review see [2]). Discrete maps, often in the form of Cellular Automata, are very popular. The same can be stated for MASims in different domains. Ecological, socio-technical and socio-ecological simulations can be seen as the main application areas for this form of modeling and simulation in which the focus lies on the interaction between agents and between agents and their environment.

By now the number of agent-based models employing spatially explicit environmental models (EM) is too high to allow a meaningful short review. Basically one may distinguish between randomly generated, greatly simplified ones and models that are based on real-world data for producing simulated landscapes.

The simulated environment in a MASim represents the environment of the real-world system. This makes multi-agent models highly dependent on the EM. It constraints the complete behavioral model of the agents, as it determines what the agents may perceive and also what they are able to manipulate. It does not need to possess a correspondence which can be compared to the agents, but may be modeled more or less abstractly. It contains abstractions of all relevant active and passive elements and forms the conceptual framework for the overall model abstraction. Thus, its richness and complexity determine the level of detail of the simulated MAS. This is especially important in adaptive and evolutionary simulations. Agents may learn on the basis of reward or similar feedback produced by the environment. Also selection is often implemented by the environment. The role of the simulated environment is to frame and constrain the behavior of the simulated agents.

The required level of detail for a simulation model is generally determined by the question that needs to be answered in the simulation study. Abstract questions may be answered by abstract simulation models with an abstract simulated environment. Questions that aim at predictions, or that are very specific regarding some details of the original system, require models with a certain level of detail. The problem with more realistic and complex simulated environments and MAS is that they are hard to control and analyze. A valid configuration of the possibly large number of model parameters cannot be determined a priori and requires the integration of real-world data into the design and calibration process [9]. In general the design of a realistic environment forms an especially important step in the simulation design process, because the realism and validity of the environmental simulation places constraints on the validity of the rest of the simulation system.

In the following sections, an ecological example is used for presenting a solution for the aspects addressed in this section. As in the current status of the model, environmental dynamics are not tackled; the focus is on the configuration of the landscape.

3 Ecological Example

The extent to which species richness in local communities is determined by regional and historical processes is not well understood [1]. The continuous expansion of agriculture over the last centuries created open landscapes with new habitats and led to an increase in biodiversity. Therefore, biodiversity of Central Europe depends on agriculture. Industrialization of agricultural production and intensification of land use in recent decades has led to enormous habitat destruction and thereby to a decrease in biodiversity. Here, we investigate which characteristics of landscape structure determine the species richness due to dispersal ability and habitat preferences of the investigated species.

Our spatially explicit multi-agent model MOBILE-AT was developed within the interdisciplinary project BIOPLEX as part of the BIOLOG-programme funded by the German BMBF . The latest version is implemented in the MASim environment SeSAm [10] and consists of a landscape module, an agent behaviour module and a set of model-species.

– **Landscape Module**
  In general, landscapes differ in land-use (habitat) composition, their configuration (arrangement), and their anthropogenic fragmentation. With MOBILE-AT we analyze approximately 40.96 km^2 of landscapes found in central Germany [8].
  The most important habitat (land-use) types are arable land, meadow, and fallow, as we are simulating species typical for open landscapes only. The simulated species depend on these habitat types during different life stages such as hibernation or reproduction. To simulate less abstract (more realistic) landscapes additional land-use types like forest, settlements, and water bodies can be included.
  Anthropogenic fragmentation of landscapes is known as a major reason for loss of biodiversity. It is important to represent the effect caused by roads, railway lines, etc. on the dispersal of species. For comparing the fragmentation of regions with different total size we use the effective mesh size (m) [3].
– **Agent Behavior Module**
  The modeled species represent carabids (Coleoptera: Carabidae) since they are a taxonomically and ecologically well-studied group and sensitive to anthropogenic changes in habitat quality [6]. The set of model-species represents a range of mobility and habitat characteristics.

This paper deals with the basic question of landscape usage in the model. The particular agent model is not concerned here. Before useful results can be obtained from simulation runs, an EM has to be developed that is applicable to the research question of interest.

4 Landscape Configuration

4.1 Concepts

The goal of the ecological example is to analyze the dependence between particular landscapes, or landscape types, and species frequencies in the landscape. Thus, the representation and configuration of the landscape is particularly important as it is part of the research question and forms a quasi input value to the experiments. Real-world landscape data are commonly governed and abstracted using a GIS system. The resulting raster maps can be imported into our model and represent the highest quality and lowest abstraction of a simulated environment. This provides the optimum for predictive simulations. The landscape composition and configuration can be quantified by metrics and indices and may affect ecological processes independently and interactively. The same metrics and indices can be used to create artificial landscapes. The fewer habitats are considered, the higher is the degree of abstraction obtained. An additional layer that overlays the simulated landscape incorporates the landscape fragmentation caused by roads, railway lines, etc.

4.2 Landscape Representations

The simulated landscape in our model is based on a grid that represents a 2-dimensional discrete map. The grid cells form the smallest spatial units and represent 25m x 25m in the real world. For simplification, agent movement is restricted to discrete movement between cells. The representation as a grid facilitates efficient computation concerning positioning and enables the import of raster data from a GIS. The scale of grid units and thus the level of details representable in the landscape can readily be changed.

There are three scales of observation in our model: the landscape, the habitat, and the single-cell scale. A landscape is composed of habitat patches as discrete clusters of cells with the same type of land use. Each of them has a distinct shape and size. On the basis of their preferences for certain habitats agents can disperse from one habitat to another by moving between single cells. An agent that prefers to stay in the current habitat will not leave the current habitat. An agent must not walk (but may fly) from one cell to a cell belonging to a different isolated fragment. The information for landscape fragmentation is stored separately from other cell properties. Hence, the same configuration of habitats may be tested with different fragmentation information, such as road construction scenarios.

5 Landscape Classes

The simulated landscapes may be grouped and compared by specific metrics and indices. By exporting the artificial landscapes from our model into a file, we are able to compare them with real GIS maps. This enables us to group real and artificial landscapes into a common landscape class. Landscape classes allow the transferal of simulation results generated for one landscape configuration to other landscapes within the same class. Consequently, it is possible to transfer results from artificial landscapes to GIS maps of real landscapes.

The selection of useful properties and indicators is delicate: Using too many makes such a generation unnecessarily complex. Using fewer leads to a high abstraction of the landscape and to the loss of predictive power of the simulation. The five metrics we use in this work are the possible land-use types (for each habitat), the percentage of land-use type (for each habitat), the possible sizes for habitat patches, an aggregation index (for each habitat) and the effective mesh size of the simulated area.

- **Using GIS Maps from Real World Landscapes**
  As described before, we are able to import each real world landscape represented in the GIS into the simulation system SeSAm. Different abstraction levels of the real world landscape can be created by merging the different land-use types (e.g. arable land, meadow or settlement) present in the GIS map, creating a mixture of real-world landscapes and artificial landscapes.
  Basing simulations on real-world landscapes enables a calibration of the agent model for a close correspondence to the field data.
- **Using Artificial Landscapes**
  Although the usage of real-world data for generating simulation environments with prediction capabilities is highly desirable in some cases, in other cases it may be

sufficient to use an artificial landscape with a higher abstraction level. Here, we use an algorithm to create artificial landscapes that are similar to the agricultural landscapes in Central Germany. They imitate the patchwork of rectangular fields in agricultural open landscapes.

At the beginning of the creation process a random percentage of arable land for the landscape to be created is defined. The landscape proportions for the other land-use types are derived on the basis of this arable land value. The next step consists of adding rows of parcels. For each new row of parcels a random height in cells is drawn, which remains constant for each habitat area in this row. Then the row is filled with cells from left to right. For each habitat area a random width is drawn and a land-use type based on the given land-use parameters is determined. This process is repeated until the artificial landscape is completely filled with cells. The result is a rectangular landscape structure of cells.

– **Using artificial landscape fragmentation**
  As mentioned above, we use an additional layer that represents the landscape fragmentation caused by roads, railway lines, etc. Given a desired number of equally sized fragmentation areas, our generation algorithm calculates the effective mesh size (m) and the corresponding number of cells. The shape of each area converges to a square and an unfragmented landscape consists of one area only. The algorithm could be further enhanced using random variation of the number and sizes of the areas, but this would reduce the comparability of the landscape fragmentation. Also, there seems to be no advantage in using real-world fragmentation, which would result in incomparable complex structures due to the difficulty of representing an 8-meter-wide road in a 25-m grid structure. In our representation the border lines are infinitely small and follow the discrete grid structure. The artificial landscape fragmentation overlays the GIS imported grid or the artificial landscape.
– **Using Changing Landscapes**
  In the real world, a landscape changes over time. Either the type of land use is changing due to changes in the agricultural practice or the landscape fragmentation is increasing due to new roads. Our model offers the option to analyze such a change dynamically with time. Using real-world data imported from GIS, the simplest way to deal with these changes is to import new grid files at appropriate times during a simulation run. For artificial landscapes a dynamic model has to be defined that takes the automatically generated configuration as input and modifies it in a reasonable way. Such a model is quite hard to specify in a valid form as it incorporates human decision making about deliberate changes in the landscape. A huge amount of research has already been done in this area (see [7])

6 Conclusion

An important question in landscape ecology is how to evaluate the complex structure of a landscape. In conservation ecology it is necessary to assess the impact of changes in the landscape structure. Beyond these application domains, landscape models form central aspects in many multi-agent simulations. Our results concerning the usage of landscape models can be generalized:

Valid agent-based models should be based on empirical data from a particular real-world environment. A model of such an environment is necessary in order to develop an appropriate agent model as all necessary details for agent perception and manipulation are provided by this artificial environment. Ideally, an existing data base should be used for the model. Thus, our approach offers the potential of using a GIS grid file within a MASim model as simulation environment.

However, general statements cannot be derived from a specific model and its environmental context. Here, an abstract model is more useful. Also, in situations when no sufficiently detailed data is available, alternative approaches have to be used that allow working with an abstract, yet realistic map configuration. We presented a method for generating artificial landscapes based on high-level properties and indicators derived from real world maps. In this way, it is possible to examine classes of landscapes instead of particular areas. Tackling classes instead of particular configurations also supports the possibility to make general statements about the modeled agent systems.

Acknowledgement

The original C++ version of MOBILE with the plain model structure and artificial landscape algorithm was developed by Kerstin Wiegand. We thank Tobias Purtauf, Jens Dauber, and Carsten Thies for the productive collaboration within the BIOPLEX (01LC0020A) project funded by the BMBF.

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