Spatial links specifications in the APILand simulation approach: an application to the coupling of a farm model and a carabid population model

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Abstract: The coupling of models is one way to realise simulation models. In that kind of modelling, there are three ways of managing the spatial dimension. The first is implicit, the second is dealing the space as a data and the third manages the landscape as a specific model. APILand is a JAVA™ object-oriented library conceived to manage dynamic landscape elements and so implement spatial simulation models in that last way.

As in the GIS domain, the landscape model is defined as a set of overlapped layers. In the APILand approach, each element of a layer can be dynamic in structure and composition.

At this point, three kinds of spatial links between external models have been used through APILand simulation experience: i) the sharing is used when models have the same definition of “what is the landscape”, ii) the translation is used when the landscape representation of a model comes from another representation and iii) the inclusion is used when two models have partially the same definition of “what is the landscape”.

A coupling example of a farm management model to a carabid population model shows that managing the landscape as a specific model allows a lower dependency between external models, permits an easier reuse of a part of the model in different contexts and helps the expression of spatial pattern emergence.

Keywords: object-oriented modelling; landscape model; dynamic layer; spatial link; low coupling; JAVA

Introduction

In the domain of simulation, the coupling of models is useful for reusability and assessment of existing models, but also to respect specialisations of experts. Basically, in that kind of formalism, the output of one model is the input of another one (Ziegler, 2000). A special issue is also the management of space in those modelling practices. Moreover, the management of landscape is really specific because it is a very particular object, indeed:

- Different scales; external "actors" of the landscape have actions at different levels (Burel and Baudry, 2003).
- Different views; each actor could see the landscape in a particular way (Vannier et al., 2009).
- Spatio-temporal; landscape element shapes are moving, their states are changing, everything is dynamic (Kleyer et al., 2007).
- Historical; previous landscape states are very influent on the present state (Ove et al., 2002).

In this paper, we will see three main ways to represent space/landscape information in model coupling. Then we will focus on a software experience of one of them; a JAVA library called APILand. To finish, we will show a case study presenting a specific model coupling using this tool.

1. Three types of space representation

We can distinguish three ways of including a spatial dimension into a coupling of models with advantages and disadvantages for each one (Table 1).

The first way is the implicit one. Models exchange variables without knowing where they explicitly make sense. For example, if a carabid model has to know the percentage of grassland in a territory in order to calculate the carabid population dynamics, this variable can be transmitted by a farm management model that calculate the percentage of grassland depending on various factors. This kind of coupling is rather simple to implement and allows to reuse models in different contexts. But it doesn't allow making spatial structures emerge by definition.

The second way is to manage the space as a specific data that is passed through models. It is the case of the LANDIS/RAMAS (Akçakaya et al., 2004) approach. The landscape representation created and emitted by LANDIS model matches with the representation waited by RAMAS model which translates it specifically in a second time. This kind of coupling is called "high coupling" because it involves a strong interdependency between models. This interdependency prevents models flexibility and reusability.

The third approach is to define the landscape as a model by itself (fig.1), a sort of common kernel, a centralised interface of space. This way is more complex to implement because the developer has to create a new model just to ensure space/landscape information. However, this last approach allows to make other models less dependent from each other and thus is compatible with a "low coupling". We chose to develop a JAVA library (APILand) to make easier the use of such a coupling and this approach is described in the following sections.

Table 1: Advantages and disadvantages of the three space representations

space/landscape representation	implicit	explicit data	explicit model
Easiness to implement	++	+	-
Spatial structure emergence	-	+	++
Flexibility and reusability	+	-	++

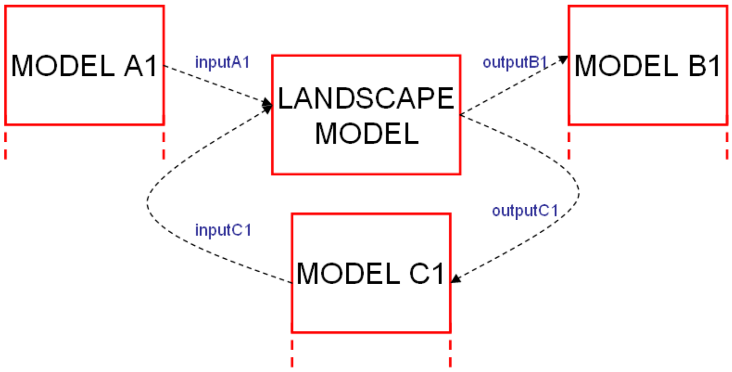

Figure 1: Schematic representation of the coupling of models using a landscape model

2. APILand for Application Programming Interface Landscape

2.1. APILand specifications

APILand (Boussard, 2008) is an open-source JAVA library made to manage dynamic landscape elements. APILand was done to help designers/developers to deal with the specific aspects of this complex object that is the "landscape". It's a reusable toolbox with a specific architecture (fig.2) that has the willingness to allow programmers:

i) To manage landscape data ; this is about the integration of shape files, the initialization of virtual landscapes, the data persistence or also the exportation of maps,

ii) To implement specific landscape analyses ; this is about spatial, temporal or more, spatio-temporal analyses,

iii) To develop landscape simulators.

This paper focuses on the APILand simulation approach. Externals models are connected to a central landscape model and the simulator enveloping them distribute times of action. Each model can have its own specific time step except the landscape model which is passive and waits for other models to modify it.

What are the mechanisms of the space interface? How is the communication between external models performed? And first, how is this landscape model structured?

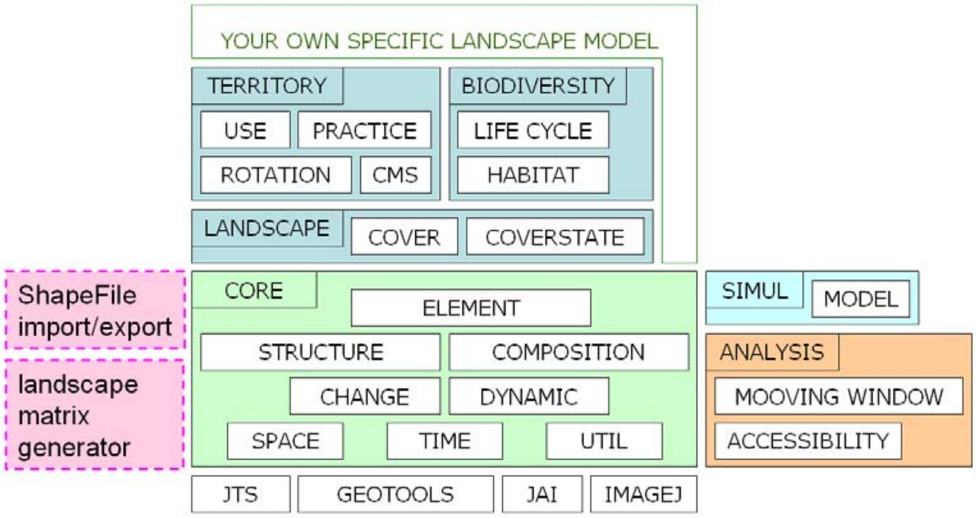

Figure 2: The APILand v0.4 architecture is based on existing and robust libraries

2.2. The GIS experience of overlapped thematic layers

The domain of Geomatics has shown us through experience of geographic information systems software (GIS) until the beginning of the eighties, that the best way to manage space is to split the different types of thematic information on overlapped layers. In the real world, layers are related to the notion of representation which is defined by the actor perception of landscape. Faced to a single hedgerow, a farmer would see a territory element that he has to manage, a carabid would catch a potential habitat, a child would invent a place to play, etc. Actually, there are as many representations for a single landscape element as there are different actor perceptions: in a certain degree, GIS layers and landscape representations are the same. These elements motivated the choice of using a set of overlapped layers in the APILand simulation approach.

2.3. The dynamic layers

The representation of the landscape in the real world can be static or dynamic in terms of structure, composition and perception. These dynamics induce that shapes and attributes which define the state of the modelled landscape elements change over time and this is not possible with the GIS released until now. This led us to define into APILand a new design of dynamic layer which allows dealing with both space and time aspects of each landscape elements (fig.3).

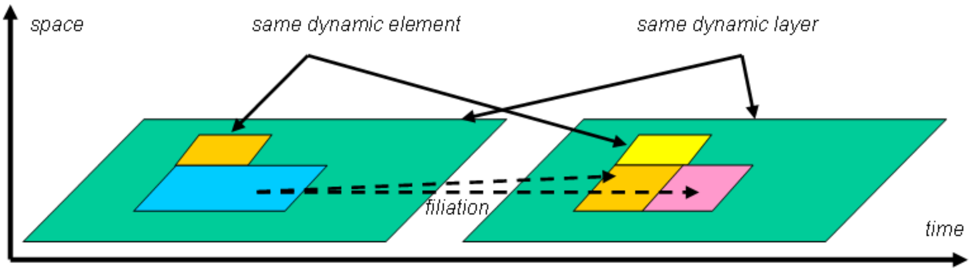

Figure 3: each element of a dynamic layer can be dynamic in structure and in composition

The other important difference between GIS layer and real representation is that those different thematic representations are strongly linked to each other. Indeed, if the farmer weeds its hedgerow with some herbicide, the carabid may not still consider that hedgerow as a potential habitat.

So, to construct a landscape simulation model, it is not enough to be able to define representations which compose it, but also to specify the dependencies between them. What kinds of links are possible?

2.4. Different types of spatial links identified

Until now, we have identified three types of spatial links between two models through the APILand experience that we call sharing, translation and inclusion.

The simplest case is the sharing of representation (fig. 4).This is used when the two models (A and B on figures) have the same definition of “what is the landscape”. It could be two types of farm management model working on the same territory, or two models of population dynamics of two species having the same ecological requirements. Basically, this kind of shared representation could be used to develop specific Agent Based Model (ABM).

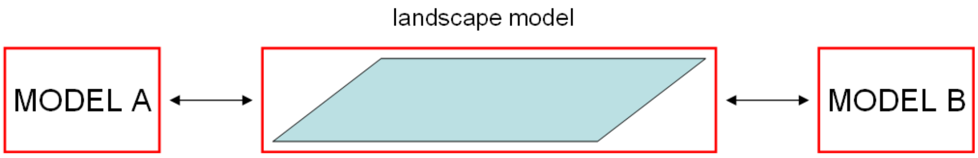

Figure 4: the sharing of representation

The second case is the translation of a model representation to another model representation (fig.5). In that case, there is a one-way hierarchy communication between externals models because “model A” actions on its own representation could have effect on “model B” representation and the inverse is wrong. Basically, a translation can be a treatment like a raster to vector conversion, an analysis like presence-absence interpretation or a filtering of some information. It could be also a bit more complex like a dynamic creation of a heterogeneity map using a moving window analysis (Joannon et al., 2009).

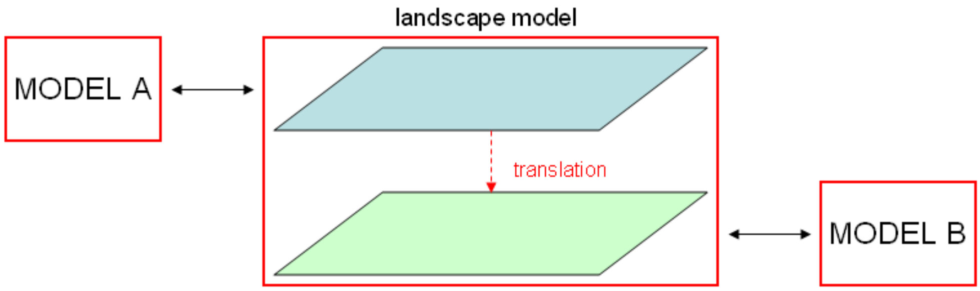

Figure 5: the translation of representation

The third case is the inclusion of a model representation into another model representation (fig.6). This operation is used when the two external models have partially the same definition of "what is a landscape". In the figure, each landscape element composing the representation of model B contains one landscape element coming from the representation of model A. This idea leans on the design pattern called "decorator" (Gamma et al., 1995, Freeman et al., 2005) which allows an object to add some characteristics (attributes or methods) to another object without modifying it. So the model B representation is an extension of the model A representation. Notice that this case could support not only a one-way communication, but a real double communication of the external models. Indeed, both representations have some attributes in common and both external models could modify them and thus influence the other model.

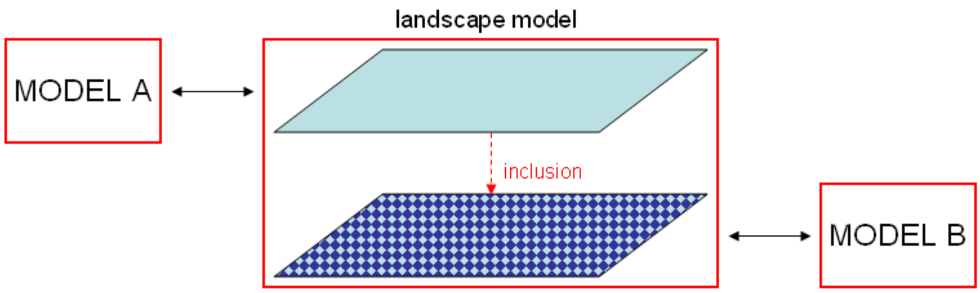

Figure 6: the inclusion of representation

3. Application to a coupling of a farm management model and a carabid population model

In order to respond to research questions such as the impacts of practice management systems on carabid metapopulation viability and structure, we defined two externals models.

3.1. Specification of the external models

The first model is a farm management model which allocates land uses and crop management sequences according to rotations. So the outputs of this model are spatial practices that have effects on land covers and their states. The time step of this model is discrete events because practices act at their own specific dates. The occurrence of this model is single; there is one farm management model for the whole landscape that we consider.

The second model is a spatially explicit carabid population model that simulates the local demography and the dispersion in the landscape. The time step of this model is each ten days. The occurrence of this model is multiple because patch population are defined at landscape element level and each element can potentially be a patch.

To spatially link those two models, we defined a specific landscape model composed of four dynamic layers (fig.7).

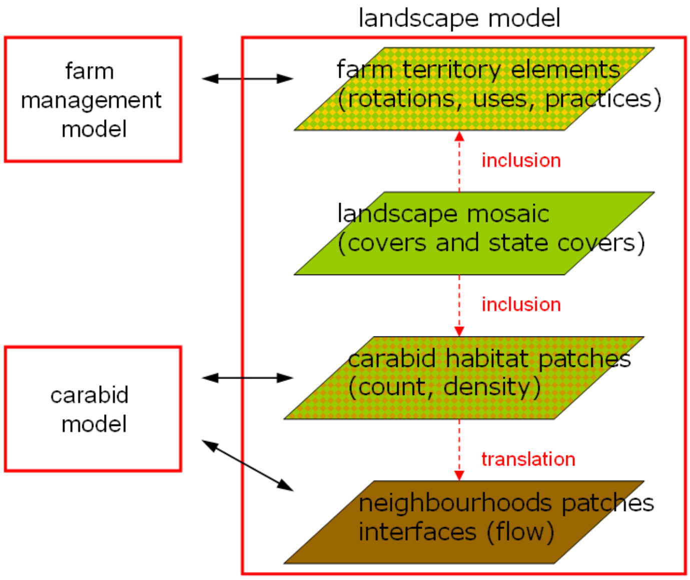

Figure 7: example of coupling with a landscape model

3.2. Use of APILand

The first one is the « landscape mosaic » layer; it is the common landscape representation of both external models. Each landscape element of this layer is defined by a cover and a state of cover at a precise time.

The second layer is the « farm territory elements » layer. Each landscape element of this layer is defined by a rotation, a land use and practices, but also by a cover and a state of cover because this layer is an inclusion of the « landscape mosaic » layer. This layer is linked to the farm management model which modifies it.

The third layer is the « carabid habitat patches » layer. Each landscape element of this layer is defined by a count of the population and its density, but also by a cover and a state of cover because it is an inclusion of the « landscape mosaic » layer too. Each landscape element of this layer is linked to a carabid population model which modifies it.

The carabid metapopulation model also needs the explicit knowledge of the "neighbourhood patch interfaces" layer for its dispersal process. Each landscape elements of this linear layer is defined by a flow of individuals at each time step. This layer is a translation coming up from the "carabid habitat patches" layer.

So the two external models are spatially linked by a low coupling. Farm management model actions have impacts on carabid population models but they do not communicate directly together.

3.3. Results

In this example, two rotations were allocated in the landscape: permanent grasslands and a rotation with maize and wheat (fig.8). For the carabid species chosen in this example, the permanent grassland represents a stable but intermediate quality habitat whereas the crop rotation alternate crops representing temporarily good or very good habitats. In fact, wheat represents a good habitat for the larvae development and for the adult foraging and reproduction early in the season. On the contrary, maize represents an unfavourable habitat for larvae development but a good habitat for adults foraging and reproduction later in the season. Individuals need to complement habitat in space during the year to find refuge. Moreover they need to disperse just after emerging to recolonise crops that have shifted in the landscape. It makes the crop mosaic structure important to maintain the population viable. After ten years of simulation of the landscape dynamics, we can see that populations are not localised in fields of a particular crop or rotation but in distinct set of fields that combine different crops and rotations (fig.9). Interactions between spatial requirement of the carabid species and spatial configurations of dynamic crops at intermediate scale result in an emerging spatial structure of the carabid metapopulation at the landscape level.

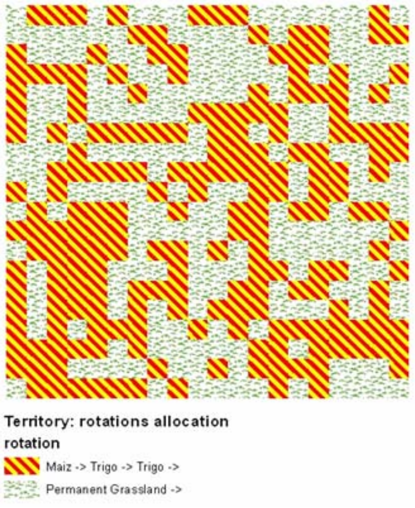

Figure 8: rotation allocations

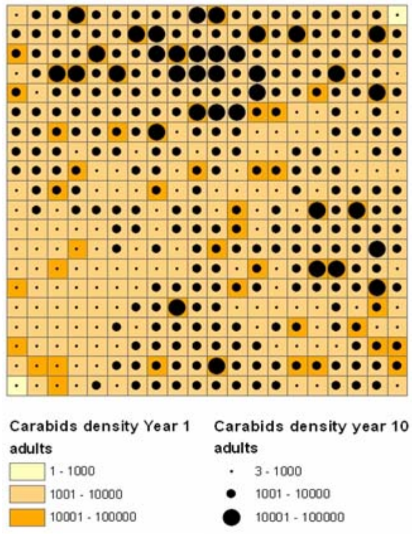

Figure 9: comparison of population abundances after ten years

Conclusion

APILand allows coupling at least two external JAVA models by managing explicitly the landscape as a specific model. This last approach is complex to construct but APILand, through its application programming interface (API), helps developers to model and to implement those types of coupling. The benefits are real because of:

- Reusability of external models; the two external models are low coupled so they do not know each other directly. We will test this generic aspect by replacing the simple "farm management" model by another agronomic model called "LandsFACTS" (Castellazi, 2007) which is able to allocate land uses according to organisation rules and crop and soil constraints. Technically, the issue is to launch a C++ model with an APILand simulator.
- Control of spatial and temporal information; managing the landscape model as a set of dynamic layers/representations is a good way to handle space-time information and specifications.
- Flexibility of the entire whole model; we plan now without modifying anything else to the existing models except the landscape model itself to couple a) a new external syrphid model linked to its own representation and b) a crop phenology model linked to the « landscape mosaic » layer.

In the model examples implemented with the APILand library, three types of spatial links between two external models have been identified at this point: the sharing, the translation and the inclusion. Through combinations of dynamics layers and those spatial links, a wide range of landscape simulation models can be built by APILand developers.

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Download APILand v0.4: http://www.rennes.inra.fr/sad/outils_informatiques/APILand

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