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Toward a coupling between GIS and agent simulation: USM, an OrbisGIS extension to model urban evolution at a large scale

Frederic Rousseaux, Erwan Bocher**, Antoine Gourlay**, Gwendall Petit***

**UMR LIENSS, **Atelier SIG-IRSTV*

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Introduction and context

The modeling of a city's evolution is one of the most exciting fields in urban studies research. The interest of such a model lies more in the past than the future: understanding how a city was made rather as opposed to how it might evolve. Such a model can necessitate expertise from numerous fields. From urban network analysis to spatial organisation and social patterning, modeling is a matter of choice. Our model simulates a set of alternative planning scenarios and urban development options. City growth reveals important issues to be taken into account in the city planning process and in territorial diagnoses, and analysis of potential alternatives is an essential step for both technicians and policy makers.

Using a spatio-dynamic urban evolution model, we discuss the implementation of agent-based modeling in an open-source geographical information system (GIS). Our model simulates the evolution of urban structures as a function of different scenarios at the city block scale in Nantes-Métropole, France.

From an agent-based paradigm to a GIS representation

A spatial simulation necessarily describes a given phenomenon and the space in which it is embedded. This description requires appropriate (and often very specialized) software. One of the main technical challenges is to link geographical information systems with simulation platforms. GIS, with the richness of related tools--geographical databases, spatial analysis, cartographic representations--are needed to realistically describe the spatial environment of the simulation, but do not possess dynamic capabilities. On the other hand, agent-based modeling platforms allow simulation of phenomena in a dynamic context but lack geographic and spatial analysis tools. Agent-based models have an individual-centric structure that identifies the active entities (the agents) and defines their behaviour, which can be influenced by interactions with other agents as well as the environment. "*The environmental model is critical for the Multi-Agent System as it strongly affects the agents' decision making and behaviour.*" [1]

Coupling spatial capabilities (e.g., managing georeferenced vector data) and agent based simulation platforms (e.g., assigning behaviour and rules to geographic features) has already been implemented in open-source toolkits such as REPAST S, based on the geotools library [2], GAMA [3], or the simpler NETLOGO [4] and its GIS extension. In this paper, we

propose the description of an agent-based model implementation in the open-source GIS platform OrbisGIS (Bocher & Petit, 2012). This platform is characterised by high-performance processing, easy handling on important geographical databases as well as complete cartographic representation capabilities. OrbisGIS stores geographical data in a GDMS database and performs spatial analysis chains using its own language [5].

Description of the Urban Simulation Model (USM)

First, we describe in our model a geographic environment (Nantes-Métropole) at the city block scale by means of a large-scale database (BD TOPO, IGN). The model includes road networks, amenities, land-use characterizations, planning rules, and cadastral plots.

In our model we characterize two classes of agents which have their own behaviour and are capable of evolving in both time and space. Using geographic vector data in an agent-based model allows us to consider a geographical object as agent [3].

The first type of agent is linked to the cadastral plot, and is characterized as an evolving homogeneous urban structure. Each plot agent is identified with a method based on a remote sensing classification. Five categories of urban structures are defined based on density of buildings, ranging from very low to very high (Figure 1). The plot is determined according to specific evolutionary rules, based on planning rules and attractiveness. As an example, a given zone can evolve from a non-building structure to a building structure or from an existing building structure to a denser building structure depending on local urban rules and the number of households it contains.

NANTES METROPOLE, 2010
Initial step of the simulation

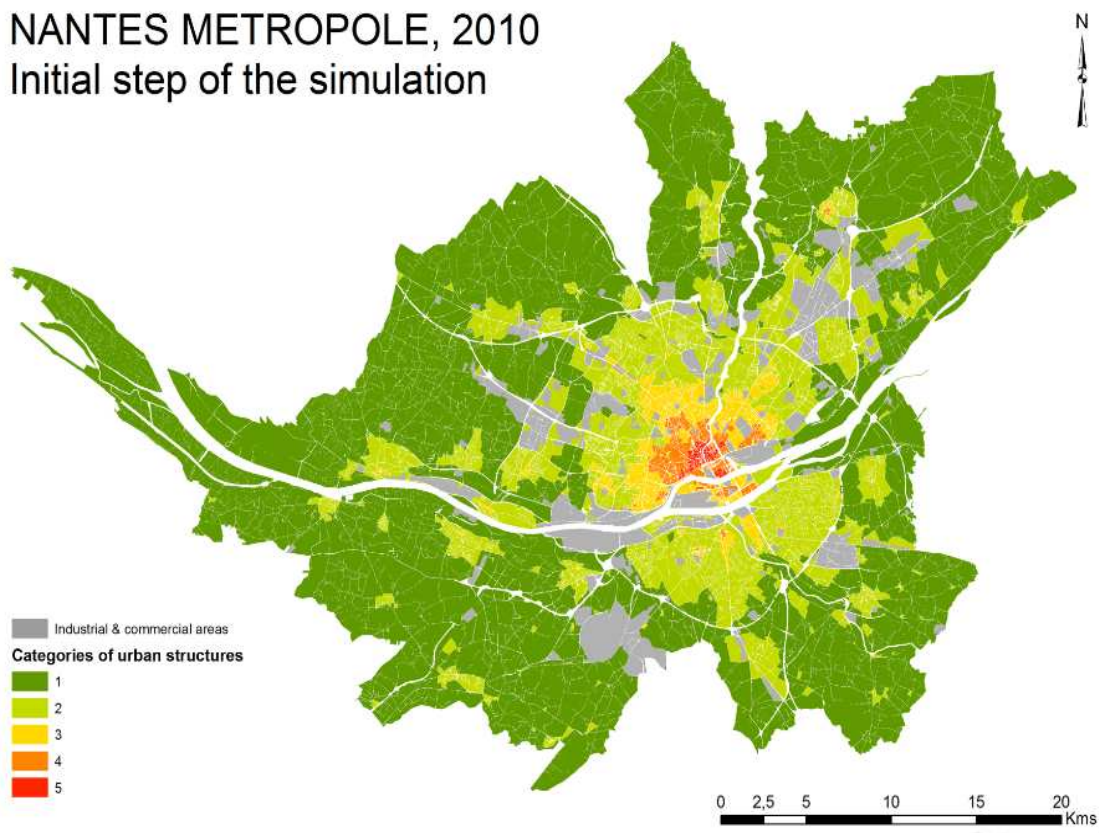


Figure 1: Initial step of the simulation

Households are the second type of agent. This agent is described by average age and income, factors which influence the need for space and the corresponding type of urban structure (e.g., house with a garden or building). Each household searches for a satisfactory plot to settle, considering the housing category and neighbourhood corresponding to similar incomes and the social segregation model [6]. If a given plot is not suitable, the household moves on and tries another plot. The more attractive and easier build a plot is, the faster the urban structure becomes dense.

The massive number of agents in the model (100 000 households, 60 000 plots) and the high level of geographical environment detail require a very high-performance platform with complete GIS capabilities. We developed our model from scratch as a plugin in OrbisGIS.

USM, an OrbisGIS plugin

OrbisGIS is an open-source GIS written in Java and developed at the IRSTV (Institut de Recherche Sciences et Techniques de la Ville) in Nantes, France since 2007 [5]. The power of OrbisGIS lies in its GDMS (Generic DataSource Management System) library, which offers its own SQL language and an abstract data layer to read, write and process huge amounts of data [7]. GDMS implements the Simple Feature SQL standard to perform data processing with spatial operators (`ST_Buffer`, `ST_Intersects`, etc.). All spatial analysis methods are expressed with SQL functions, just as in PostGIS#. Moreover, GDMS offers an application programming interface (API), and OrbisGIS is a graphical interface that allows creating custom processes and user interfaces. The USM model takes advantage of these two aspects. It is structured in two main components:

- The first part is an object-oriented implementation of the model described above, using GDMS files to store results, to read input configuration files and data as well as to run all geographic processes. Its API can be used directly to run simulations and also allows users to provide custom algorithms for some parts of the computation.
- The second part is a graphical interface accessible through OrbisGIS using the Java Swing GUI library. The USM user interface allows one to configure the model or open a previously configured one, and then to run it (Figure 2).

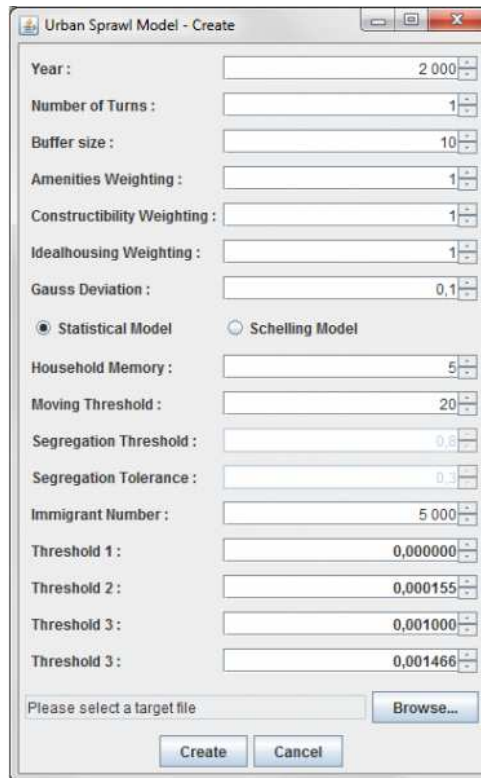


Figure 2: Frame to setup the USM configuration parameters

During the simulation execution, the state of several key parameters is visible using dynamic charts, including the number of incoming, outgoing and total households (Figure 3). Each step is stored in a separate GDMS file and can be linked to the input parcel data to display the result of the simulation as a thematic map. For users, a complete visual wizard interface has been developed. All the parameters of the model's configuration can be saved. After the simulation, the user can display each step of the process in OrbisGIS, access all GIS primitives and use them for spatial analysis or dynamic cartography.

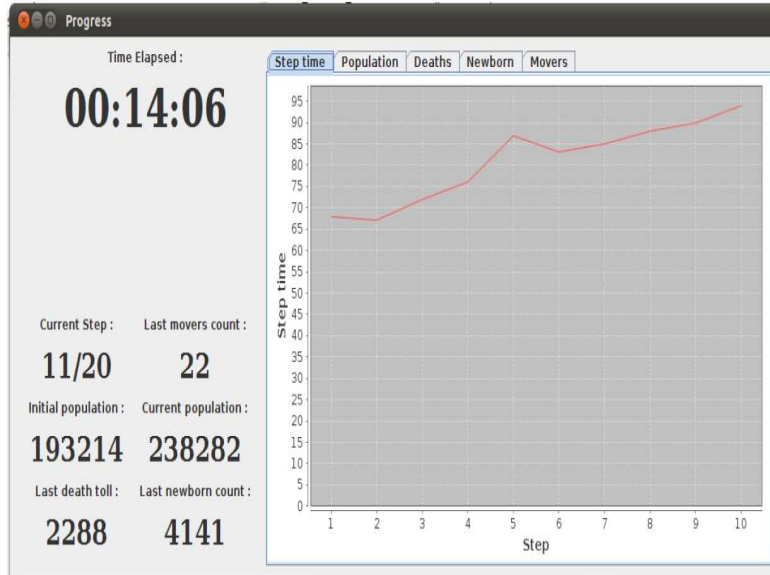


Figure 3: Dynamics charts are showing each step of the simulation

Results and further work

Our plugin's processing time is very short considering the large number of agents. Most of the processing time is linked to the movement of agents. The model can treat very large sets of geographic data (more than 100 000 parcels) without significant increase in processing time. Nevertheless, the number of movers can increase it, albeit lightly. As an example, 5 000 agents takes 10 minutes of computation.

Concerning the case study, we tested two scenarios in Nantes-Métropole, a major metropolitan area, located near the west coast of France. Both scenarios propose a time scale of 2010 to 2030. Different categories of urban structures are numbered 1 to 5 in Figure 4. Each category is an indicator determined from a set of variables (density, building height, percent empty space, etc.). Commercial and industrial areas are a specific category that we ignore in this model due to very specific transition rules.



Figure 4: categories of urban structures

The first scenario (Figure 5) simulates a political desire to curb urban sprawl and favours densification. The second scenario (Figure 6) does not constrain urbanization and "let's the city

live". As a consequence, in 2030 the model shows important urban sprawl, to the detriment of agricultural and natural areas, especially on the northwest area of the city.

NANTES METROPOLE, 2030 Results of simulation, Scenario 1

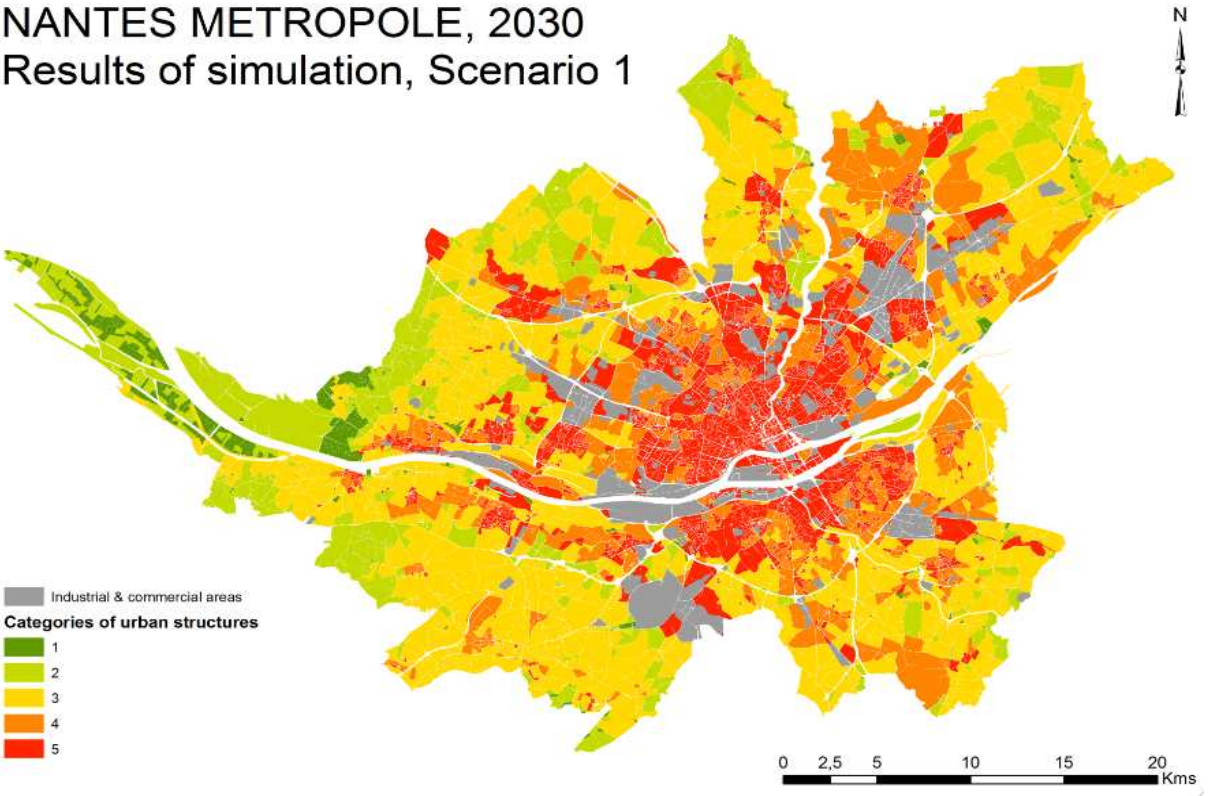


Figure 5: Results of scenario 1

NANTES METROPOLE, 2030 Results of simulation, Scenario 2

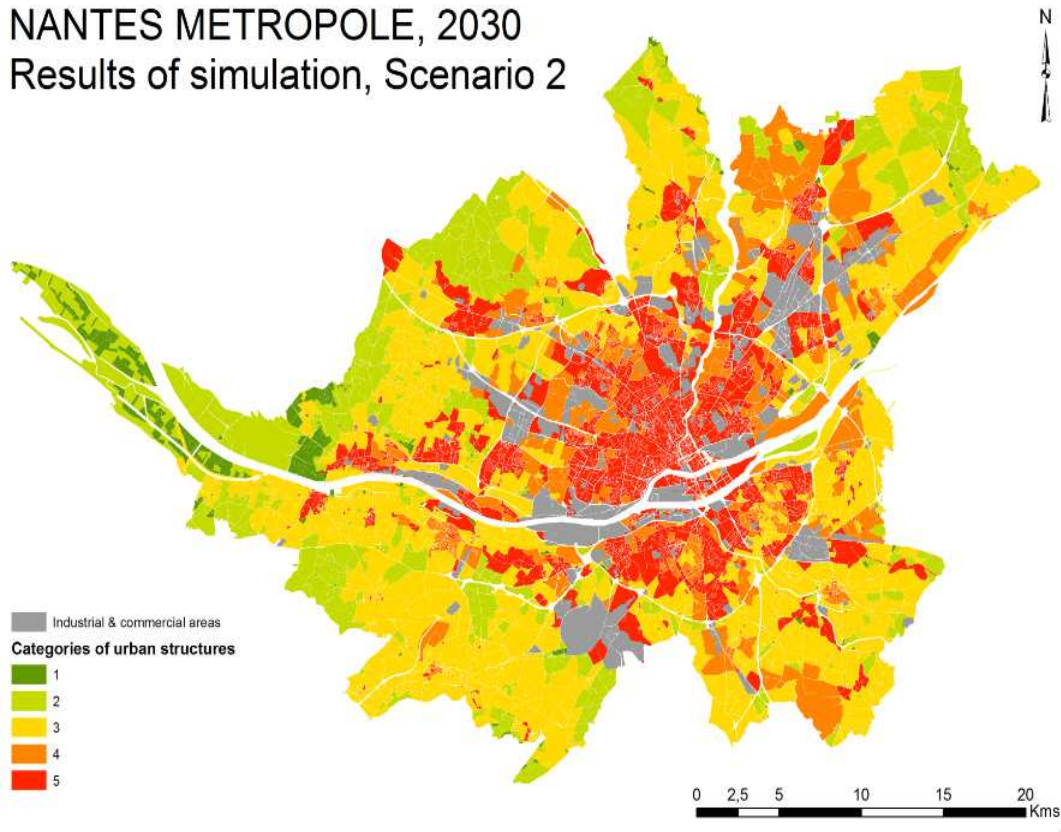


Figure 6: Results of scenario 2

Comparing the two maps reveals spatial disparities, particularly in the southwest area of the metropolis where the structure of the plot varies from high densities (mainly orange) to low densities (mainly yellow). A similar trend can be observed in the northwest where structures with lower densities appear. By contrast in the vicinity of the city center (located in the center of the map), structure plots are denser in scenario 1 as compared to scenario 2.

One of the major interests of this GIS model is to view the results of a simulation in light of demographic data or other spatial information (e.g., land uses, traffic network distribution). The relevance of the model can then be evaluated in relation to the territory and how it changes. This is the most interesting aspect of the model; the results of the simulation can be discussed and improved upon with city planners and urban engineers.

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