A macroscale cellular automata model for simulating urban change in regional urban systems

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1. Introduction

Cellular Automata (CA) models are among the most popular models for simulating spatial change and they have been developed and applied intensively during the past two decades. Two main features made CA interesting for urban studies, ever since they were introduced by Waldo Tobler in the late 1970s (Tobler, 1979): first, their inherent spatiality which suits the simulation of a wide range of geographic phenomena; second, the possibility of simulating complex patterns of, for example, land use starting from a simple conceptual framework that includes the definition of a cell space (form), a neighborhood (interaction), and a finite set of transition rules (behaviors) applied to a finite set of cell states (land uses). This conjugation of form and function make CA models suitable for capturing the contribution of different phenomena to the complex processes of urban change.

These models are commonly used to simulate land use change at a regional or metropolitan level considering land use dynamics at a local level (Barredo and Demicheli, 2003, Silva and Clarke, 2005). They consider increasingly smaller cells, making use of the high resolution of today's remotely sensed images to capture many interactions that occur at a very large scale. Regular cells are used at the local scale (pixels) and at a regional scale, as aggregations of smaller cells (Van Vliet et al., 2009).

We address these issues of scale and cell form by proposing a macroscale CA model that tries to capture aggregated land use change at a regional level. We use administrative units – municipalities or similar units, varying with the national context – as irregular cells to simulate land use change considering population and employment growth and accessibility measures at a regional scale. The use of irregular cells, regardless of the scale, is scarce in the literature (Stevens and Dragicevic, 2007, Moreno et al., 2008). It ensures a good link between form and reliable data, an approach that has been successfully applied at the local scale (Norte Pinto and Pais Antunes, 2010).

Scale has been debated over the years. The evolution of computation allowed researchers to downscale from the typical large scale models of the 1950s and 1960s to the high resolution models of our decade. The debate over modeling scale started with the famous *Requiem for large-scale models* (Lee, 1973), and continued over the years, with a new moment in the mid 1990s when again the issue was brought to the agenda (Lee, 1994, Klosterman, 1994). Recently, there is again a new interest on scale, focusing also on CA models (Ménard and Marceau, 2005, Benesson, 2007, White, 2007, Briassoulis, 2008, Verburg et al., 2008).

2. Macroscale CA model

The model uses municipalities (or similar administrative units) as cells. Cell states are classified into a finite set of artificial land area, accounted as a percentage of the total cell area. Land use interactions take place within a variable neighborhood which distance value is determined through model calibration. Transition rules intend to simulate spatial interaction based on a transition potential functional that depends on the population, the employment, and a function of distance over the road network, calculated by the following expression:

$$V_i = \frac{\alpha_P \times P_i \times E_j}{{d_{ij}}^{\beta}}, \forall i \in \mathrm{C}, j \in \mathrm{C} \tag{1}$$

where, for each cell i from the set of cells C, V_i is the transition potential for cell i, P_i is the number of residents in cell i, E_i is the number of registered employees in cell i, $d_{i,j}$ is the distance between cells i and j (from the set of cells C) measured by the road network, α_P is a calibration parameter and β is the accessibility calibration parameter. In each time step, cells are selected by the model for urbanization though a measure of its relative probability (taking into consideration all cells) regarding the transition potential value, calculated through an application of the *logit* model as follows:

$$U_i = \frac{e^{\alpha_L \times V_i}}{\sum_j \left(e^{\alpha_L \times V_j} \right)}, \forall i \in \mathrm{C}, j \in \mathrm{C} \tag{2}$$

where, for each cell i from the set of cells C, U_i is the relative probability value of cell i, V_i is the transition potential for cell i, and α_L is the calibration parameter of the *logit* model.

The model is calibrated through an optimization procedure based on the particle swarm (PS) algorithm that uses as fitness measure the *kappa* index for contingency matrixes. PS makes use of a swarm of p particles that will fly through the solution space during n iterations. Each particle has D dimensions: in our CA model each calibration parameter is represented by a PS dimension. The algorithm retains the position and the velocity of each particle in every iteration, calculating their new values considering the group leader and their individual best positions. Note that CA are an embedded process that is called as many times as the number of PS iterations multiplied by the number of particles.

3. Application to the Metropolitan Area of Barcelona

The Metropolitan Area of Barcelona (MAB) is composed by 164 municipalities which vary considerably in area, population, and employment. The city of Barcelona heads a complex set of mid-size and small urban systems which group urban areas and their hinterlands with their own functional relationships.

The model was applied to MAB in order to simulate the allocation of urbanized land over the municipalities, considering an aggregate value of population and employment density as limits for land demand. The model was calibrated using data from the censuses of 1991 and 2001 for population and employment and using aggregated land use information derived from Corine Land Cover for the same years. The model reached a value of *kappa* of 0.427 which represents a moderate agreement.

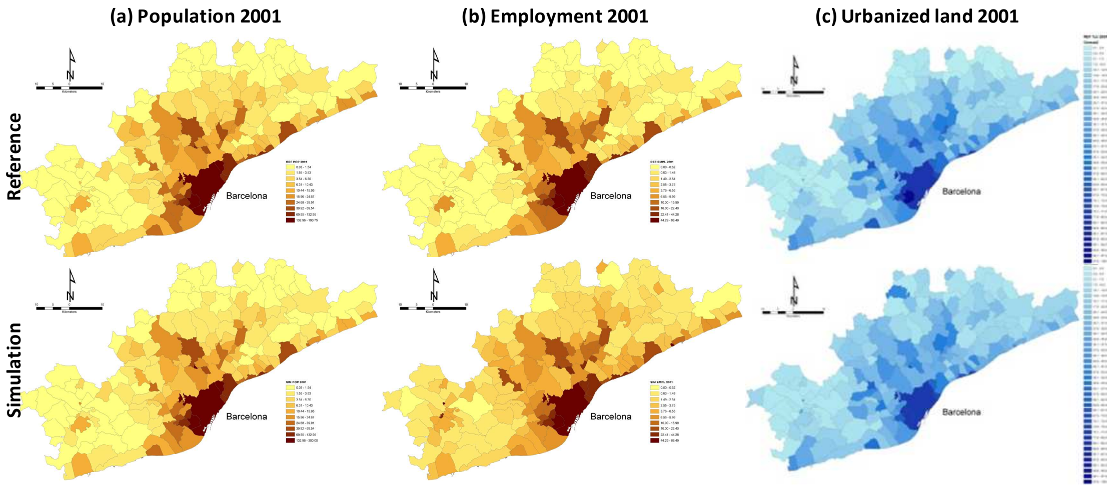

Figure 1. Model results for the MAB for population, employment, and urbanized areas.

4. Concluding remarks

This macroscale CA model is part of an integrated multiscale CA model that aims to capture different phenomena that occur at different spatial and time scales. The macroscale model aims to simulate the evolution of land use demand by modeling the areas of urbanized land at the municipality level as a function of the location of population and employment, considering accessibility. The values of urbanized land will be considered as land use demand at the microscale, and will be used as a constraint to a more traditional, local scale CA model

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