Complex Systems Made Simple
Project final report

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Generative coupled model for Urban configuration optimisation

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Abstract

We describe an hybrid agent-based model coupling a cellular automata and a dynamic network, for the simulation of urban growth. Heterogeneous aspects of urban systems are taken into account in the sense that morphologic structure but also functional properties of the city are implied in the evolution. Classic measures of description and performances for generated configuration are used to classify and explore generated patterns, and we also propose an economic evaluation of the structure using sensitivity of segregation models to spatial configuration. We can apply the model to a real-world situation, proposing an optimisation of the repartition of activities in a zoning context.

1 Introduction

Recent progress in many discipline linked directly or indirectly to Urban Planning can be interpreted as the development of a "new urban science" as Batty stands in [**?**]. From agent-based modeling in quantitative geography, which achievements are reviewed in [**?**], and for which the best example of promising results are the series of Simpop models ([**?**]), to other approaches of the field that Portugali present as "Complexity theories of cities" ([**?**]) that can involve scientists such as physicists as Haken on information theory ([**?**]) or architects as Hillier with Space Syntax theory ([**?**]), the field is broad but is strongly consistent through the common view of urban systems as complex systems.

2 Model description

Our model is adapted from the work of Moreno & *al.* ([**?**, **?**]), that proposed to integrate network effects in a CA model for modeling urban morphology. Their aim was to test the effects of physical proximity on urban shape, introducing the modeling of urban mobility through a network which evolution is coupled with the evolution of the urban shape. We generalise the model, allowing to take into account functional properties of the urban environment.

2.1 Agents and rules

The world is a square lattice $(P_{i,j})_{1\leq i,j\leq N}$ constitued of cells that can be occupied or not (that will be denoted by a function $\delta(i,j,t)$, time being defined on a standard time scale $\mathbb{T}$ which definition is introduced in [**?**], and for which we will take $\tau\mathbb{N}$, $\tau > 0$ to simplify). Among these fixed agents evolves an euclidian network which agents are roads: $N(t) = (V(t), E(t))$ whith V finite part of the world (set of points). At initial time, no cell is occupied and the initial network is fixed: $N(0) = (V_0, E_0)$. In order to translate functional mechanisms in the growth of the city, we suppose that a part of initial nodes are city centers C_0 for each an activity is defined by $a : C_0 \to [|1; a_{max}|]$.

Giving these settings and variables, the evolution of the system for one time step is the following:

- New cell values are calculated
- N new cells are built

Note that the process is stochastic since it depends on the random order on which the new cell are built.

2.2 Evaluation functions

Morphology We qualify the morphologic structure of a configuration by projecting on a plan corresponding to the following indicators:

- The integrated local density, calculated by integration with a norm-p of the densities in circular neighborhood of each cell (with same radius parameter as for the run). We have, with $p_d \in [1; +\infty[$

$$D(t) = \left[\frac{1}{\sum_{i,j} \delta(i,j,t)} \cdot \sum_{\delta(i,j,t)\neq 0} d(i,j,t)^{p_d} \right]^{1/p_d}$$

- The Moran index, defined in [?] and used a lot in quantitative geography such as in [?], is used to quantify the polycentric character of the distribution of populated cells.

Network performance Because of the way it evolves, the only loops in the network are the initial ones. Therefore, it has no sense to evaluate robustess or clustering coefficient of the network. However, since the generated network is supposed to simulate the mobility network, we can evaluate as suggested in [?] its performance through its relative speed, i. e. the quantity of detours it obliges to make.

Functional accessibility

Economic performance It has been shown by Banos in [?] that the Schelling segregation model, a basic model for socio-economic segregation introduced in [?], was highly sensitive to the spatial structure in which one can embed it (the segregation laws are in that case also influenced by spatial proximity). That justify the use of such a model as an evaluation function for the spatial structure regarding "economic performance", in the sense of how much does the structure influence segregation. We implement a model for residential dynamics based on the model proposed in [?]. The output function is a segregation index calculated on residential patterns obtained from a distribution of constructed patches. Detailed description of the model is provided in supplementary material S1.

3 Results

The model was implemented in NetLogo 5.2 ([?]). Plots and charts are managed with R after export into standardised data ([?]). Primary treatment of GIS Data (for most hand vectorization of simple raster data) is handled with QGIS ([?]). See supplementary material S2 for implementation details needed for exact reproducibility.

3.1 Generation of urban patterns

Typical patterns Different configurations of the weights allow to generate very different structures.

Classification of structures

3.2 Sensitivity analysis and exploration of the parameter space

Sensitivity to initial conditions To determine the magnitude of repetitions useful to get meaningful values of output functions and to ensure some validity in the results, it is necessary to investigate the sensitivity of the model to initial conditions of the spatial configuration. Indeed, if the conclusions that can be drawn in a particular case are significantly modified by small changes in the spatial configuration, one will differently apply the model than in a case where abstract topology of activities has more influence: one will obviously elaborate totally different exploration heuristics to proceed to optimisation.

Therefore, we launched large number of simulations with same parameter values but different initial configurations, in order to get statistical distributions of outputs at fixed parameters. Standard deviations were calculated for samples of the parameter space (around 20 samples) and the distributions were each time of same amplitude and same deviation. Fig. 3 shows these distributions for the sample corresponding to equal weights to each parameter. Given the numerical values of deviations (each time around 0.1 times the amplitude of the function), we can conclude that outputs are significantly less sensitive to spatial positions than to topology of activities and parameters values (as the exploration of parameter space results show in the following). That justify the small number of repetition needed to have reasonnable values.

Sensitivity to update type The generated structures seem to be quite sensible to the type of update that is done at each time step, i. e. to the number of cells that are built at each time step. We can explore a grid of the main parameter space,

Exploration of the parameter space We explored a grid of the 4-dimensional space of the "main" parameters, the relative weights of variables.

3.3 Concrete application

Since we have shown that outputs on which we want to optimise, such as accessibility to activities or network performance, are significantly more sensible to initial configuration of activities than to spatial distribution, we can apply the model to the optimisation of activities repartition, given an existing spatial structure. That situation can occur in a planning problem, then one has to decide possible landuses of predefined zones.

4 Discussion

The reproduction of existing urban facts (in the sense of the morphological structures) and the possible applications showed that the implemented model may be useful for evidence-based decision-making in urban planning. However, many aspects can be discussed as they raise crucial questions and would need further explorations.

Conclusion

Supplementary materials

S1 Description of coupled ABM for economic evaluation.

S2 Core source code of the NetLogo implementation of the model, sample of data used for applications, source code for generation of plots and charts.