Complex Systems Made Simple
Project description

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Generative coupled model for urban configuration optimisation

Abstract

We describe briefly the context and the proposal for a project which aims to extend and apply to concrete cases a generative Cellular Automata model. The original model will be coupled with an agent-based model (we have to find out if the coupling will be simple or complex) in order to add some properties that cannot be translated into the CA model.

1 General context

Cellular Automata (CA) models have been extendly studied and used in quantitative geography and in a more indirect way in Urban Planning and Design. Batty sums up in [3] the basis of toy models based on CA to explore self-organized patterns typical of urban systems. A review of existing applications of CA models in geography is done by Iltanen in [8] in the frame of a general review of recent methods and practices linked to agent-based modeling in the field ([7]). Direct applications are Urban sprawl simulations, but other concrete example can be general models for landuse simulation (e. g. [18]) or also more precise applications as in [19] for sustainable development.

In [9], Moreno & al. propose to couple a cellular automata with a dynamic euclidian network in order to test the influence of distances and proximity in the sprawl phenomena. The model was based on a previous work ([10]) which aim was morphological reproduction and analysis of urban structures. Considering the development of the transportation network in common with the development of urban patterns showed to reproduce in a better way typical patterns. Furthermore, it allowed to include properties of the urban system such as transportation time within the network. We work in that frame in the following.

2 Project description

2.1 Previous work

In a previous work ([12]), we generalized the formal description of the model proposed in [9]. The model works roughly as follows.

The world is composed of a cellular automaton in which an euclidian network is embedded. A cell can be constructed or not.

The automaton and the network evolve as follows:

- at each time step, N new cells of the automaton have to be constructed
- therefore, a score (depending on the state of the world) for each cell is calculated, depending on some variables that we can choose and for which we can tune the influence on the score through prameters (for example, distance to the town center which is a fixed node of the network, or distance to the nearest road, i. e. to the network, or density in a Moore neighborhood, what creates a direct feedback), and the best N cells for this score are constructed.
- New roads are constructed: if a new constructed cell is over a fixed distance, it is connected to the network following an heuristic (generally connected to the orthogonal projection on the nearest road).

In that project, sensitivity analysis, exploration of the parameter space and possible calibration were only overflown. Furthermore, we would like to rethink completely the model and the possible applications.

2.2 Aims of the extension and generalisation

The aim of this project will thereby be to rethink, extend and make the model more robust. We will try to correct the imprecisions, give more sense to parameters (too much abstract parameters makes the model less coherent) and extend it by coupling. We will explore in a more rigourous way the parameter space of the new model, using possibly evolutionnary algorithms ([1], we may however not be able to parallelize because of technical means) if an quasi-exhaustive heuristic exploration is not possible. The final aim is to apply the model to the concrete case of the optimisation of the configuration of a new district (for the real parameters that the model will translate).

3 Important points

3.1 Epistemological framework

Reviewing in the current state of art in the Complexity Theories of Cities, Portugali argues in [11] that a misunderstanding on the role of quantitative simulation models in urban system modeling has lead to a loss of sense in the application of these models. It appears that our work could easily fall in that trap, because of the application of abstract generative model to real cases. We will beware to have a coherent correspondance between the abstract model and the real world, and if not we will stay careful in the statement of the results.

3.2 Coherent evaluation functions

We need to find more realistic functions for evaluation of performances of the generated urban structures.

Morphological analysis A fine morphological classification of the generated structure is needed in order to better understand the model. However, direct calculation on a configuration has no real sense since indicators such as Moran index (defined for example in [16]) can be very sensitive to local perturbation that have in fact no strong impact in the general urban form, and the extraction of the morphological enveloppe of the urban structure appears to be a good solution that we will implement at is proposed in [15, 6]. Using that, better descriptor of urban morphology than simple density (e. g. Moran Index mentioned before) will be used to evaluate one output of the model.

Network properties The evaluation of the network properties stayed abstract and static. We would like to use actual distribution of inhabitants that will result from the ABM (see next paragraph) to compute more realistic index of robustness ([14]) or of performance ([2]).

Other indicators New indicators as economic ones will come from the extension that is described just after (e. g. spatial distribution of wealth, segregation, etc.)

3.3 Economic properties of the form: coupling with an ABM

The core part of our work will be the coupling with an agent-based model in order to model economic evolution of the generated urban form. That means adding function to the form, what is one crucial question in urban system modeling.

The idea comes from [5] where a micro-economic model of urban sprawl is developped. That way, we will add mobile agents that will represent households or companies that want to invest the new built cells. That would also mean that cells are dwellings or workplaces. The population can come progressively, what is quite adapted to the type of application we want to proceed to (see e. g. the application in the previous work, that was the optimization of the configuration of a new district). We will use relations between agents close to the model described by Benenson in [4] (simulation of residential dynamics), with an emphasis on immigrants regarding internal move (different time scale could be use to do that).

In the following, propositions are not formal but more to give an idea on the type of feedbacks in the ABM.

The question of the type of coupling will be crucial:

- a simple coupling would consist in a "serial" process: structure is generated through CA-network model, then the ABM takes the configuration as inputs and make the people choose their places, with evolution of rents. Rents are a function of the wealth of people, and feedback is done through correspondance wealth/rent. (beware that too simple relations would give the Schelling segregation model ([13]), we may not want to have caricatural effects). People can move if their wealth change or they find a rent that suits them better.

- complex coupling will be a "parallel" process: new people come at each time step of the development of the CA, they wealth has an influence on rents, rents have an influence on new constructions, which have a feedback on the choice of the new place by people and on the possible moves within former arrivants.

Note that the distinction "simple/complex" relies on the underlying complexity of the global model: a simple coupling of two complex models of complex systems leads to "predictive" behaviors, in the sense that the knowledge of the beahvior the two models will able us to predict the beahvior of the simple coupling, whereas the complex coupling will be an impredictible complex model of a complex system (see [17] for a formalisation of the notion of complexity between models and systems).

3.4 Sensitivity analysis and exploration of the parameter space

After having generalised our model with the constraint of the minimization of abstract parameters ("real" parameters that can be inputed from real data, estimations or proxy will be fixed), we will proceed to sensitivity analysis of the model to different parameters, but also to initial situation. We will try to see if implementation bias has a non-neglectible influence on the behavior of the model. We will proceed to an exploration of the parameter space as explained before. The appropriated output functions will be used to describe the beahvior of the model in the parameter space.

3.5 Application of the model

Last point will be the focus on the application on a real case. We may consider the same example or a similar one as in previous work, indeed that type of situation suits well the conceptual frame of the model as we claimed before.

Depending on the time we have, we may collect finer GIS Data for spatial configuration and IRIS data for possible population configuration. The application should be quite the same, i. e. the optimization of the configuration of a new district in regard to some real parameters that have a translation in the model.

4 Objectives and schedule

Considering the amount of work already put in the previous work on the subject, i. e. that for example the heavy code parts are already written, so we can have more time on theoretical considerations, exploration and application of the model, our aim is to obtain at the end of the project a publishable paper.

The detailed scheduled is the following:

- Review of old work, review of litterature: already done
- Theoretical extension and revision: 2 weeks (due 27/10)
- Implementation: 1 week (due 03/11) – should be quick because core part is already implemented and utility functions also
- Exploration, results, collect of data, discussion: 2,5 weeks (due 21/11)
- Redaction of the paper: 1 week (due 27/11 – begun in previous step)

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