A comparison of simple models for urban morphogenesis

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Abstract

The spatial distribution of population and activities within urban areas, or urban form at the mesoscopic scale, is the outcome of multiple antagonist processes. We propose in this paper to benchmark different models of urban morphogenesis, to systematically compare the urban forms they can produce. Different types of approaches are included, such as a reaction-diffusion model, a gravity-based model, and correlated percolation. Applying a diversity search algorithm, we estimate the feasible space of each model within a space of urban form indicators, in comparison of empirical values for worldwide urban areas. We find a complementarity of the different types of processes, advocating for a plurality of urban models.

Introduction

Understanding the dynamics of cities is an increasing issue for sustainability, since the proportion of the world population expected to live in cities will grow to a large majority in the next decades, and that cities combine both positive and negative externalities on most aspects. Their complexity implies that quantitative and qualitative predictions are not relevant, but planners can *invent future cities* [1], what requires though a knowledge of key urban processes which can be acted upon. In that context, the growth of *urban form* in its different definition and scales, is essential [2]. Considering urban form at a mesoscopic scale, i.e. roughly the scale of urban areas, it can be understood as the spatial distribution of activities. More particularly the distribution of population density has a strong impact on commuting, energy consumption and emissions [3]. Being able to link microscopic processes with the growth of different types of urban form is thus important for a long term planning of sustainable urban systems.

Urban modeling at the mesoscopic scale is the subject of diverse approaches and disciplines. Intra-urban urban economic models, building on classic works such as the Alonso-Mills-Muth model or the Fujita-Ogawa model, propose models linking land-use with land and building markets, which are spatially explicit to different degrees [4]. Transportation and Urban Planning also have a long history in urban dynamics models, including Land-use transport interaction models [5]. Spatial interaction models can also be used in a similar manner to study urban dynamics and as a by-product urban form [6]. Cellular automata models of urban growth are also a privileged approach to study the growth of urban form from a data-driven perspective [7].

At the interface of physics, artificial life and quantitative geography, a few approaches propose simple models to explain the growth of urban form, and generally rely on an unidimensional description of urban form, namely the distribution of population or of the built environment. In that context, the correlated percolation model introduced by [8] was a precursor. Such models can rely on abstract physical processes but also on agent behavior, such as in the Sugarscape model which according to [9] can be considered as a model for human settlements. [10] use migration between cities at multiple scales to simulate urban growth. Diffusion-limited aggregation (DLA) is an other approach transferred from physics to urban modeling [11] and has shown relevant to reproduce fractal urban structures and urban migration processes [12]. [13] combines DLA with percolation to obtain more realistic urban forms. Closer to the idea of urban morphogenesis, [14] proposes a reaction-diffusion model to capture fundamental urban growth processes. [15] describes an urban growth model based on geographical processes, namely an aggregation of population driven by spatial interaction. All these works have in common to model urban growth in synthetic settings, at a mesoscopic scale, considering population distribution only, and in a stylized way. They furthermore consider diverse processes, remaining simple in their structure although they lead to the emergence of a complex behavior. We will in this paper focus on such models, referring to them as *models of urban morphogenesis*.

Exhibiting models with a few number of parameters and processes is useful from an explanative viewpoint, when these can reproduce real world configurations. Having multiple concurrent models which include diverse, complementary or contradictory processes, is furthermore useful for the construction of integrated urban theories, since concurrent explanations can be benchmarked, compared and possibly integrated into multi-modeling approaches. This plurality in urban modeling is intrinsic to a literature with multiple disciplines focusing on a same object of study [16].

We propose thus in this paper to benchmark several simple models of urban morphogenesis, in order to understand the potentialities of some of these models to exhibit a complex behavior and reproduce existing urban forms, and compare them in a systematic way. More precisely, our contributions are as follows: (i) we integrate four different models (correlated percolation, reaction-diffusion, gravity and exponential mixture) into a single software framework; (ii) we compute measures of urban form for urban areas worldwide; (iii) we apply a novelty search algorithm to the models in order to determine their feasible morphological space, and compare these to real urban form values. This contributes to a general understanding of the complementarity of urban models, more particularly for urban morphogenesis at this scale.

The rest of this paper is organized as follows:

Materials and methods

Urban morphogenesis models

Gravity-based model

[15]

Reaction-diffusion

[14]

Correlated percolation

[8]

The method to generate a spatial field exhibiting long range correlations was introduced for problems in physics by [17].

Kernel mixtures

Finally, to provide some kind of null model to understand the advantages of each approach compared to a simple description of population distribution, we also include urban forms generated as kernel mixtures. We consider in particular exponential mixtures [18], written as

Measures of urban form

Quantitative measures of urban form

Results

Implementation

The models are implemented in `scala` and integrated into the `spatialdata` library for spatial sensitivity analysis [19]. The library is bundled as an OpenMOLE plugin for the numerical experiments. OpenMOLE is an open source software for model exploration and validation [20] combining model embedding with state-of-the-art exploration methods (including for example sensitivity analysis, design of experiments, calibration with genetic algorithms) and a transparent distribution of computations on high performance computing environments. In our case, we use its workflow system and an integrated algorithm to determine the feasible space of models.

Empirical data

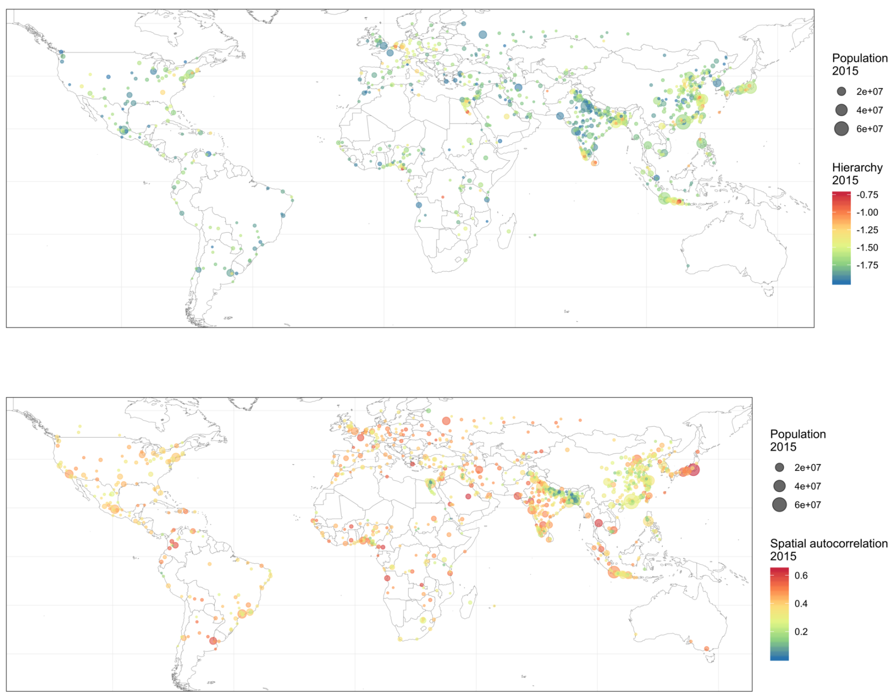

Fig 1. .

Feasible morphological spaces

Discussion

[21]

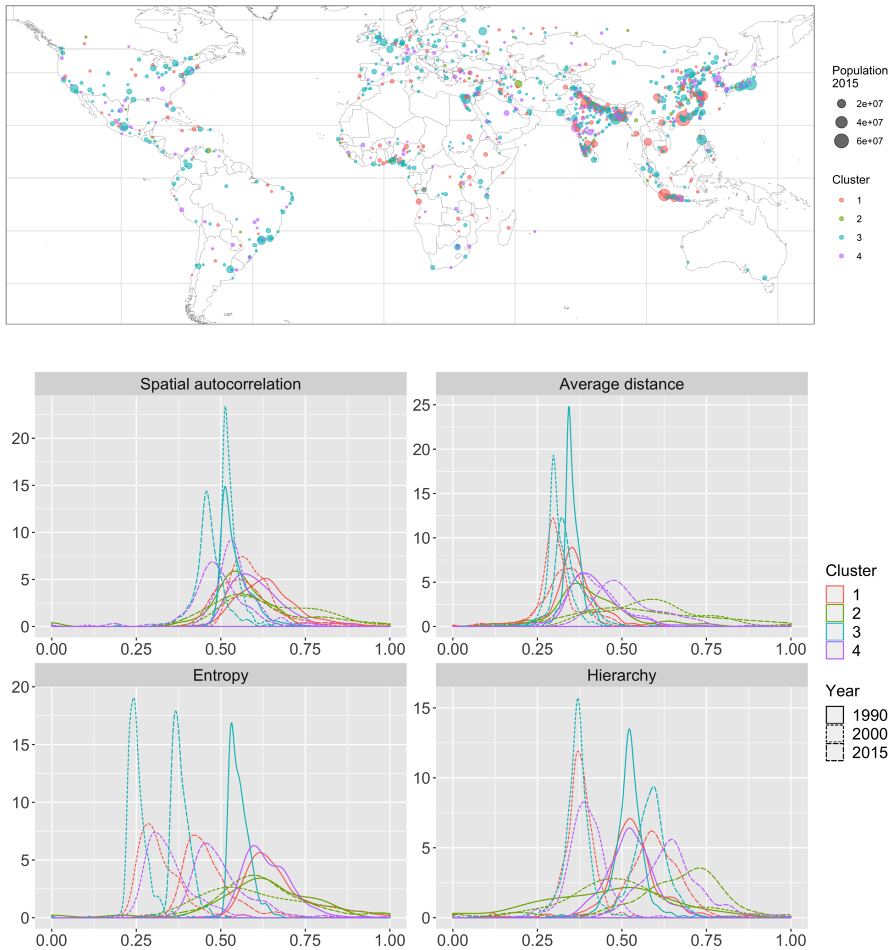

Fig 2. .

Conclusion

Acknowledgments

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