Spatial sensitivity analysis of social simulation models

Juste Raimbault[1] and Julien Perret[1]
[1]LASTIG, Univ. Gustave Eiffel, IGN-ENSG

Spatial simulation models for socio-technical systems require a thorough validation process in order to obtain actionable policy insights from their application. While the sensitivity to model parameters is usually well accounted for, it was shown recently by [1] that the variability of model outputs due to the spatial configuration could be as much as the variability due to model parameters, with an investigation on classical socio-spatial models such as the Schelling model. A scala library implementing generators of synthetic urban configurations at different scales (district, urban area, system of cities) was developed in that context [2]. Indeed, testing the effect of the spatial configuration can be done by sampling synthetic realistic urban systems for which the model phase space is obtained and compared.

This contribution proposes to summarise different ongoing streams of research extending and developing this new crucial component of the validation of socio-spatial simulation models.

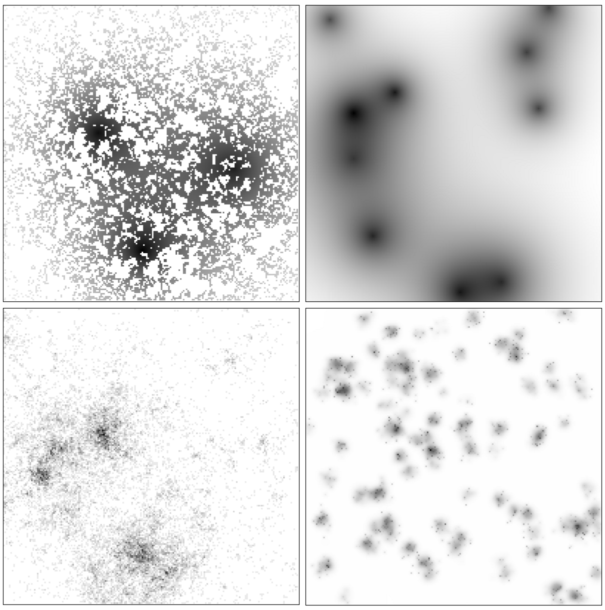

Fig. 1. Synthetic population grids at the urban area scales, generated by different models, in order from left to right and top to bottom: correlated percolation [3], kernel mixture, gravity-based model [4], and reaction-diffusion model.

First, the generator approach for synthetic urban configurations was further explored. At the mesoscopic scale of an urban area, a benchmark of generative models for population distribution was achieved, including models not investigated before such as a gravity-based model [4] and a correlated percolation model [3]. Examples of generated configurations are shown in Fig. 1. A diversity-search algorithm provides the feasible morphological space for each model, showing the complementarity of the different generative processes to cover different regions of urban forms.

Second, an approach based on noise propagation is being investigated [5], by exploring neighbour spatial configurations to existing ones. The main difficulty is to define small variations in the morphological space, as these do not follow standard distributions in most cases: for example in the case of a road network, moving uniformly or with a Gaussian noise coordinates of vertices will produce unrealistic configurations in terms of curvature. Similarly, angles of building polygons follow a very specific distribution with highly localised peaks. Some initial tests for generating realistic noises and linking these with the generative approach are being lead for building configurations.

Third, the open issue of indicators to quantify the variability due to space is being tackled by introducing variance-based indicators following the classical approach by [6]. For a correct statistical estimation of such indicators, the sampling of the morphological space must have a high discrepancy, what is not ensured by simply sampling the parameter space of synthetic generators. An approach based on diversity search for these generators is being tested and compared to a parameter sampling, in the case of population distribution generators and the Schelling model.

Finally, the link with other fields in which model sensitivity analysis and validation is much widely developed compared to computational social science, is investigated from a theoretical point of view. In environmental science, similar frameworks have been proposed such as the perturbation of spatial datasets described in [7].

These complementary research axis contribute to a more robust validation process for socio-spatial simulation models.

[1] J Raimbault, C Cottineau, M Le Texier, F Le Nechet, and R Reuillon. Space matters: Extending sensitivity analysis to initial spatial conditions in geosimulation models. *Journal of Artificial Societies and Social Simulation*, 22(4), 2019.

[2] J Raimbault, J Perret, and R Reuillon. A scala library for spatial sensitivity analysis. GISRUK, 2020.

[3] Hernán A Makse and al. Modeling urban growth patterns with correlated percolation. *Physical Review E*, 58(6):7054, 1998.

[4] Yunfei Li, Diego Rybski, and Jürgen P Kropp. Singularity cities. *Environment and Planning B: Urban Analytics and City Science*, 48(1):43–59, 2021.

[5] Juan M Pedraza and Alexander van Oudenaarden. Noise propagation in gene networks. *Science*, 307(5717):1965–1969, 2005.

[6] Andrea Saltelli and al. Variance based sensitivity analysis of model output. design and estimator for the total sensitivity index. *Computer physics communications*, 181(2):259–270, 2010.

[7] Hyeongmo Koo and al. Position paper: Sensitivity analysis of spatially distributed environmental models-a pragmatic framework for the exploration of uncertainty sources. *Environmental modelling & software*, 134:104857, 2020.