Spatial sensitivity analysis of social simulation models

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Validation of simulation models

Typology of **validation methods for simulation models** from a systematic review [Raimbault, 2023]

- prediction
- sensitivity analysis
- uncertainty
- multiple methods
- benchmark
- calibration
- optimisation
- visualisation
- Pattern Oriented Modelling
- participatory
- exploration
- mixed
- surrogate

Methods, standards and definitions strongly depend on disciplines and model functions [Raimbault, 2019b]

Specificities of socio-spatial systems

→ Spatio-temporal non-stationarity and non-ergodicity [Raimbault, 2019a] → Fuzzy and noisy data [Olteanu-Raimond et al., 2015] → Genericity/specifici of patterns and processes [Raimbault et al., 2020] → Modifiable Areal Unit Problem [Wong, 2004] → Multiscalar systems [Raimbault, 2021b]

Spatial sensitivity analysis

Spatial configurations are model parameters too

- "*Space matters*": impact of spatial configuration on model behavior
- Model behaviours which are robust to spatial configuration
- Model behaviours which are robust to noise in real datasets

$\Longrightarrow$ ***Construction of a generic library for spatial sensitivity analysis, including the generation of synthetic data, perturbation of real data and indicators***

Synthetic data: general context

$\rightarrow$ coupling models with spatial configuration generators (spatial synthetic data) gives model sensitivity to space through sensitivity analysis of the coupled model

$\rightarrow$ synthetic urban forms resembling real configurations

$\rightarrow$ at different scales: microscopic (buildings), mesoscopic (population distribution), macroscopic (system of cities)

Synthetic building layouts

At the microscopic scale (district): generating building layouts

Raimbault, J., & Perret, J. (2019, July). Generating urban morphologies at large scales. In Artificial Life Conference Proceedings (pp. 179-186). MIT Press.

- systematic comparison of simple processual generators
- introduction of morphological indicators
- calibration on sampled layouts from OpenStreetMap

Synthetic population grids

At the mesoscopic scale: population grids

- a reaction-diffusion model for population distributions
- urban form measures at the mesoscopic scale
- synthetic generators coupling population and road networks

Raimbault, J. (2018). Calibration of a density-based model of urban morphogenesis. PloS one, 13(9), e0203516.

Raimbault, J. (2019). An urban morphogenesis model capturing interactions between networks and territories. In The Mathematics of Urban Morphology (pp. 383-409). Birkhäuser, Cham.

Synthetic systems of cities

At the macroscopic scale: synthetic systems of cities

- Evolutive urban theory: systems of cities follow general stylised facts [Pumain, 2018]
- Rank-size law [Pumain et al., 2006]
- Central place theory

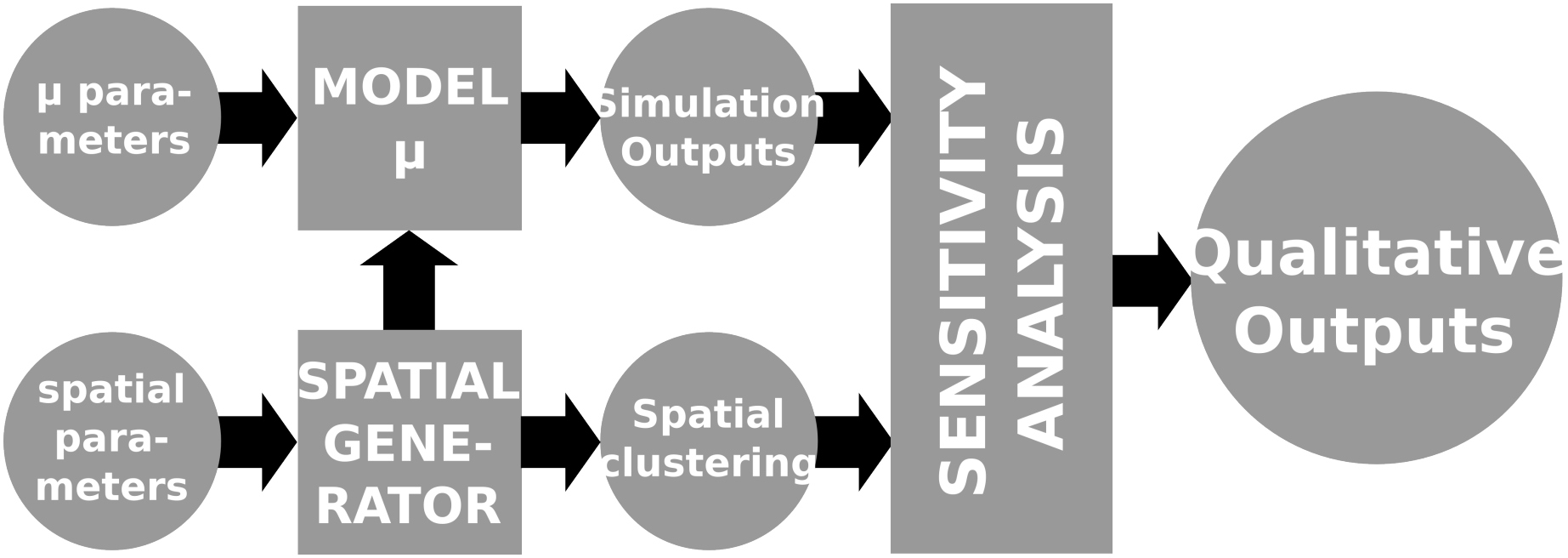
→ *Cities-network co-evolution model explored on synthetic systems of cities*

Raimbault, J. (2021). Modeling the co-evolution of cities and networks. In Handbook of Cities and Networks (pp. 166-193). E. Elgar.

Method flowchart

General workflow to test the spatial sensitivity of simulation models

Raimbault, J., Cottineau, C., Le Texier, M., Le Nechet, F., & Reuillon, R. (2019). Space Matters: Extending Sensitivity Analysis to Initial Spatial Conditions in Geosimulation Models. Journal of Artificial Societies and Social Simulation, 22(4).



Implementation: integration into OpenMOLE

Library implemented in `scala`: advantages of functional and object programming; Apache Spark; no widely used GIS library in scala.

`https://github.com/openmole/spatialdata`

$\rightarrow$ integration into the OpenMOLE model exploration open source software [?]

Enables seamlessly (i) model embedding; (ii) access to HPC resources; (iii) exploration and optimization algorithms

`https://openmole.org/`

Real data perturbation

→ *How does noise in real data impacts the result ?*

- Impact of missing elements
- Impact of imprecise coordinates or topology
- Optimal matching between spatial datasets

→ *How does perturbation of real data allows to explore scenario*

Examples:

- simulating urban projects by modifying population of areas with a given spatial correlation structure
- simulating network disruptions or new transportation lines

[Koo et al., 2020]

Discussion

Developments

- more spatial network generative models [?], correlated synthetic data [?]
- domain models: LUTI, urban dynamics
- other disciplines, ecology, geosciences [?]?
- interaction with data driven disciplines ? (planning, architecture, spatio-temporal datamining)
- genericity of some models? (reaction-diffusion)
- synthetic data generation methods (synthetic populations)
- synthetic data at the core of applied statistics methodology (less in spatial statistics?)
- port the library to more classic languages (python, R)

Conclusion

→ **Space matters:** relevance of spatially-explicit models and spatial sensitivity analysis.

→ **Synthetic data:** first experimental samplings included in OpenMOLE, soon more to come.

→ **Disciplinary context:** strong contingency on included models.

Get the library at `https://github.com/openmole/spatialdata`

Open issues at `https://github.com/openmole/spatialdata/issues`

References I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