

Urban Morphogenesis and the co-evolution of Transportation Networks and Territories

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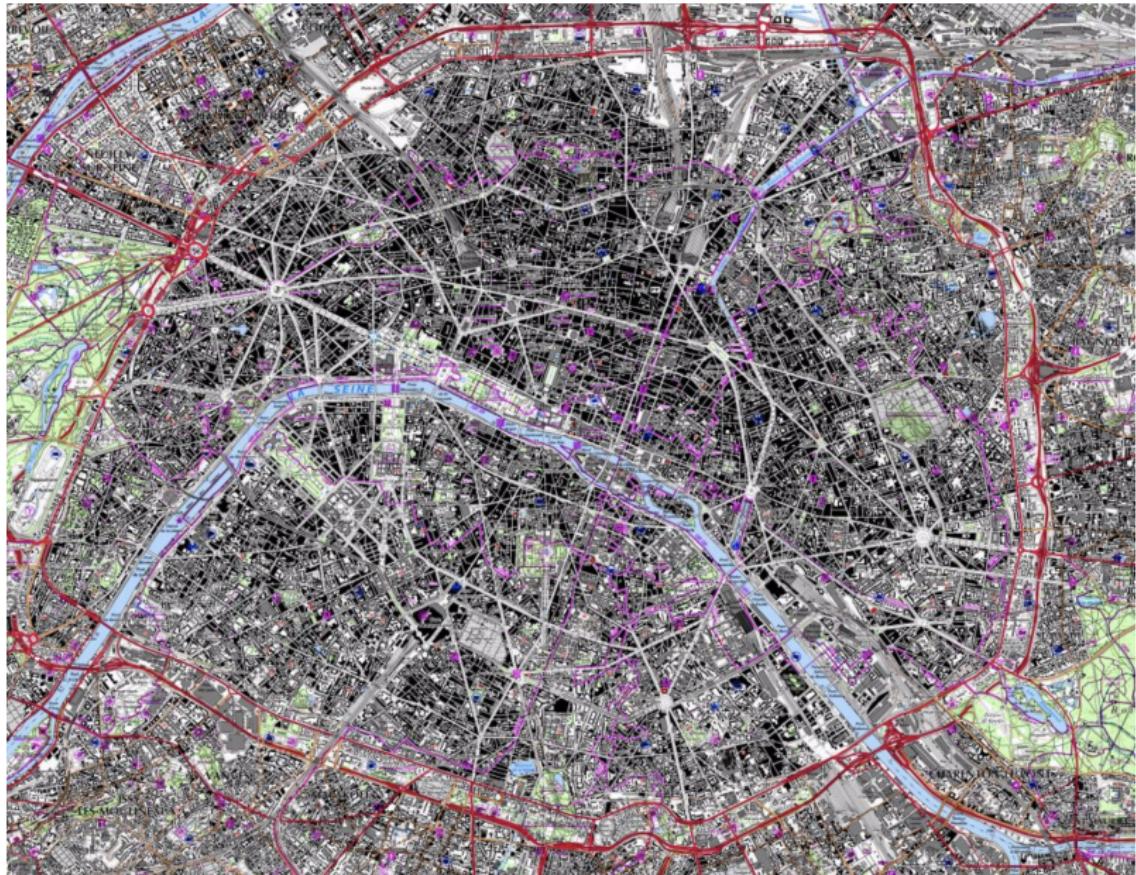
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Complex processes of Urban Morphogenesis



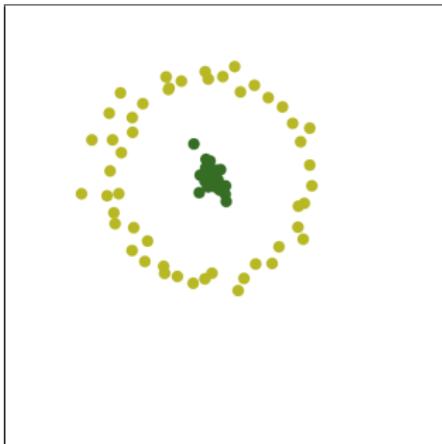
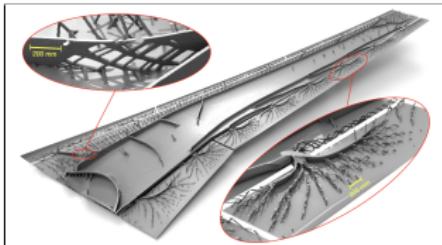
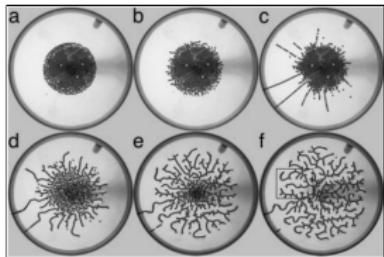
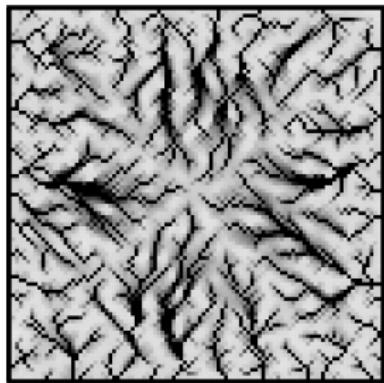
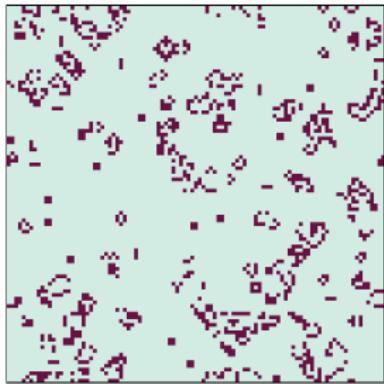
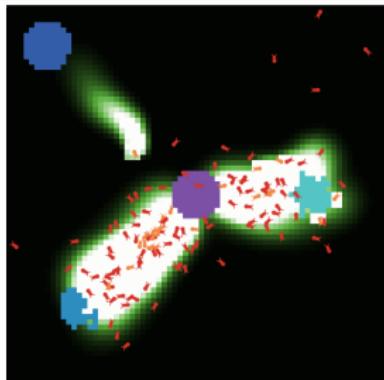
Source: Geoportal

Complex processes of Urban Morphogenesis



Source: Geoportail

What is Morphogenesis ?



Sources (in order by column). Ants, Erosion, Game of Life: NetLogo Library ; Arbotron [Jun and Hübler, 2005]; Industrial design [Aage et al., 2017]; Swarm chemistry [Sayama, 2007]

Defining Morphogenesis

Construction of an interdisciplinary definition in [Antelope et al., 2016]

Imbricated notions:

Self-organization ⊂ Morphogenesis ⊂ Autopoiesis ⊂ Life

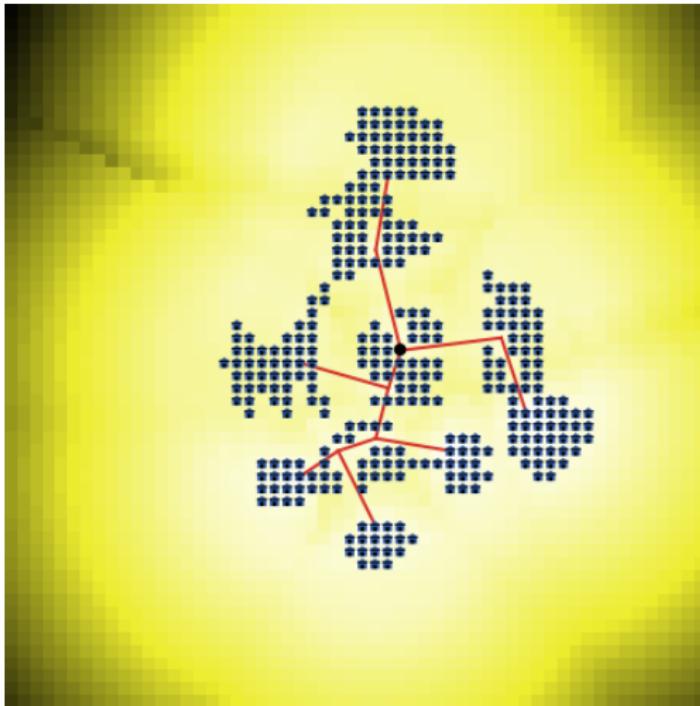
Properties:

- Architecture links form and function
- Emergence strength [Bedau, 2002] diminishing with depth, whereas bifurcations increase [Thom, 1974]

Morphogenesis : *Emergence of the form and the function in a strongly coupled manner, producing an emergent architecture [Doursat et al., 2012]*

Modeling Urban Morphogenesis

Which models for Urban Morphogenesis ?



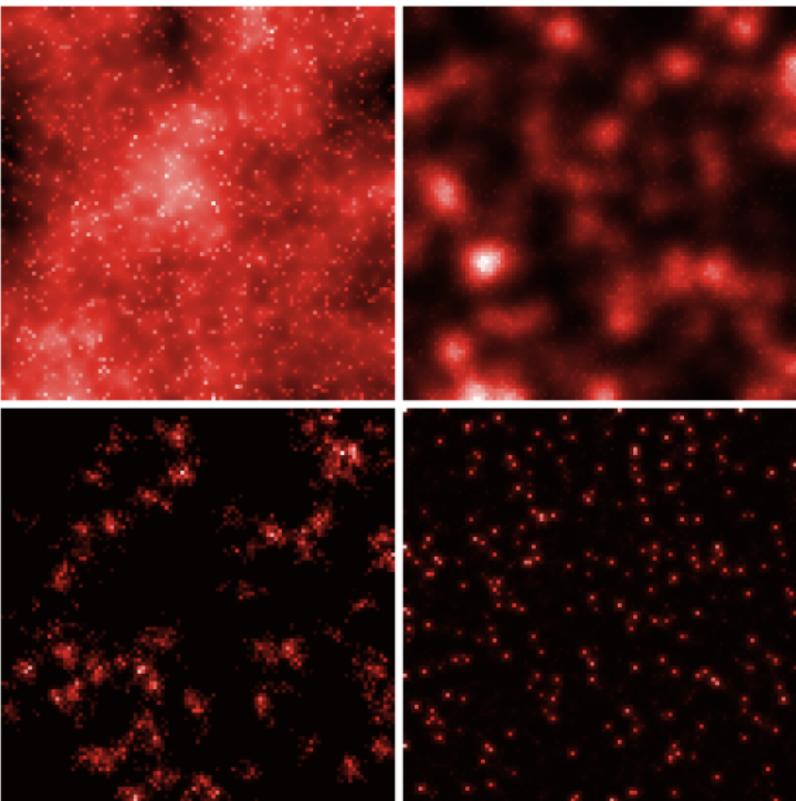
Example: a basic hybrid model based on elementary processes [Raimbault et al., 2014]

A simple Aggregation-diffusion model

Model Formalization

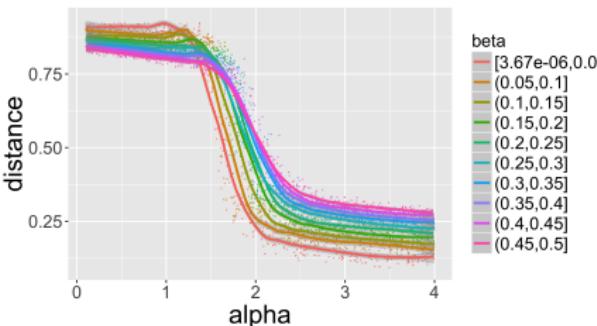
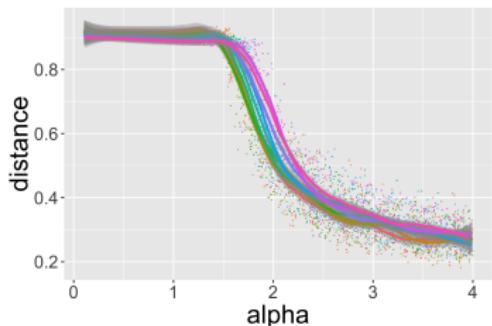
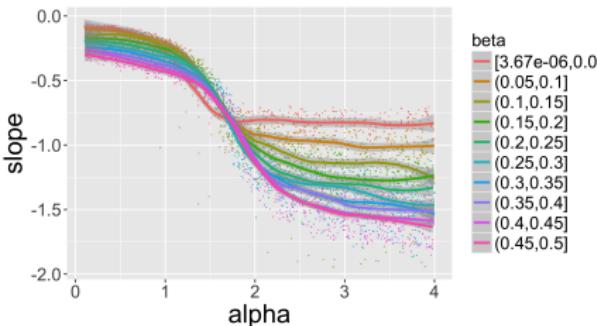
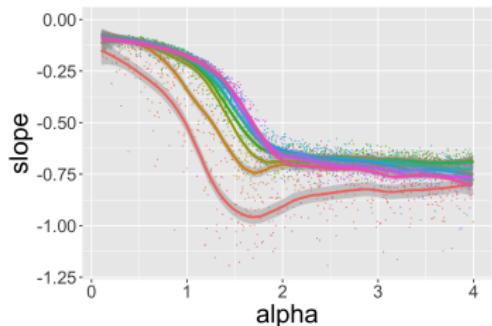
- Grid world with cell populations $(P_i(t))_{1 \leq i \leq N^2}$.
- At each time step:
 - ➊ Total population is increased by a fixed number N_G (growth rate).
Each population unit is attributed independently to a cell following a preferential attachment of strength α
 - ➋ A fraction β of population is diffused n_d times to cell neighborhood
- Stopping criterion fixed maximal population P_m .
- Output measured by morphological indicators: Moran index, average distance, rank-size hierarchy, entropy.

Generating Population Distributions



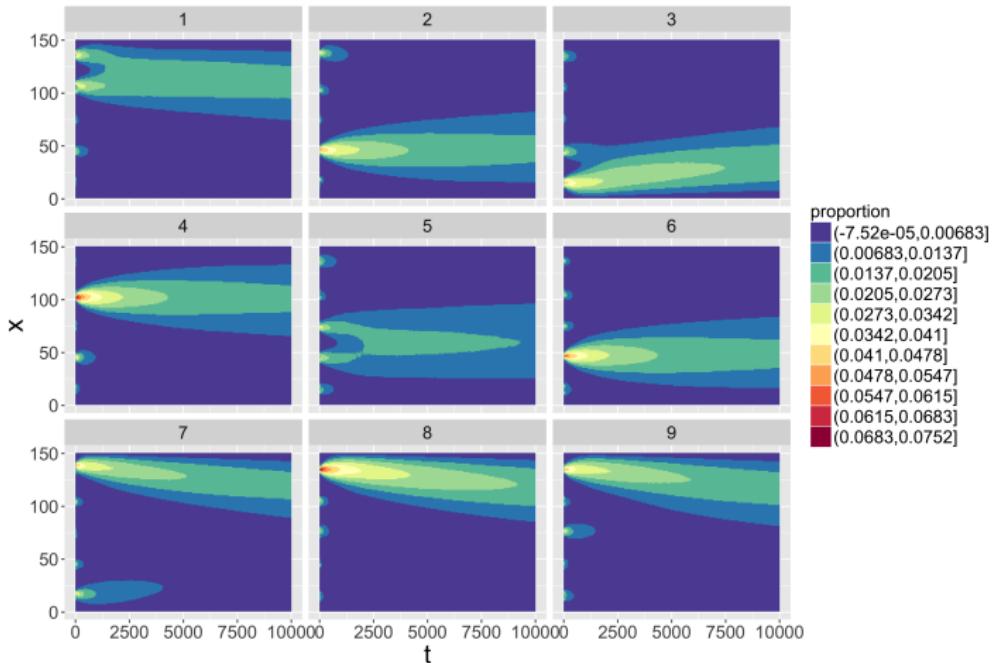
Examples of generated territorial shapes

Model behavior

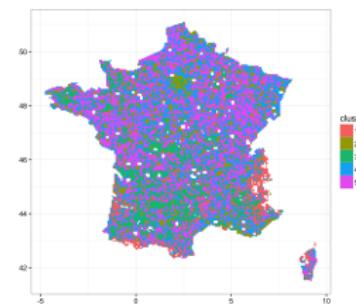
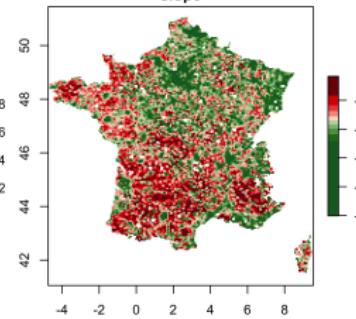
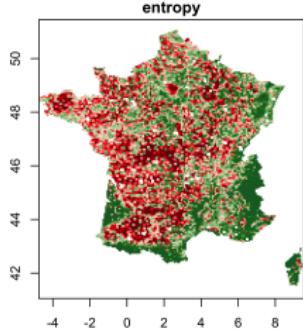
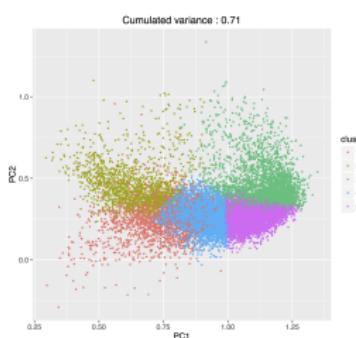
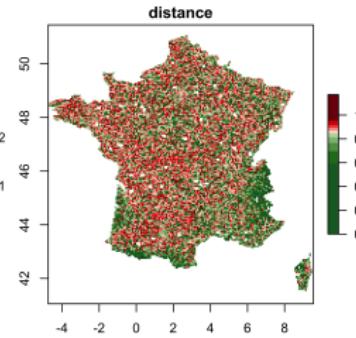
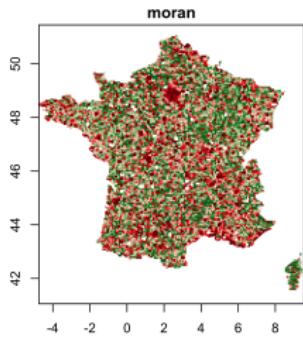


Phase transitions and non-monotonous behavior of indicators unveiled by intensive exploration of the parameter space

Path-dependence and frozen accidents

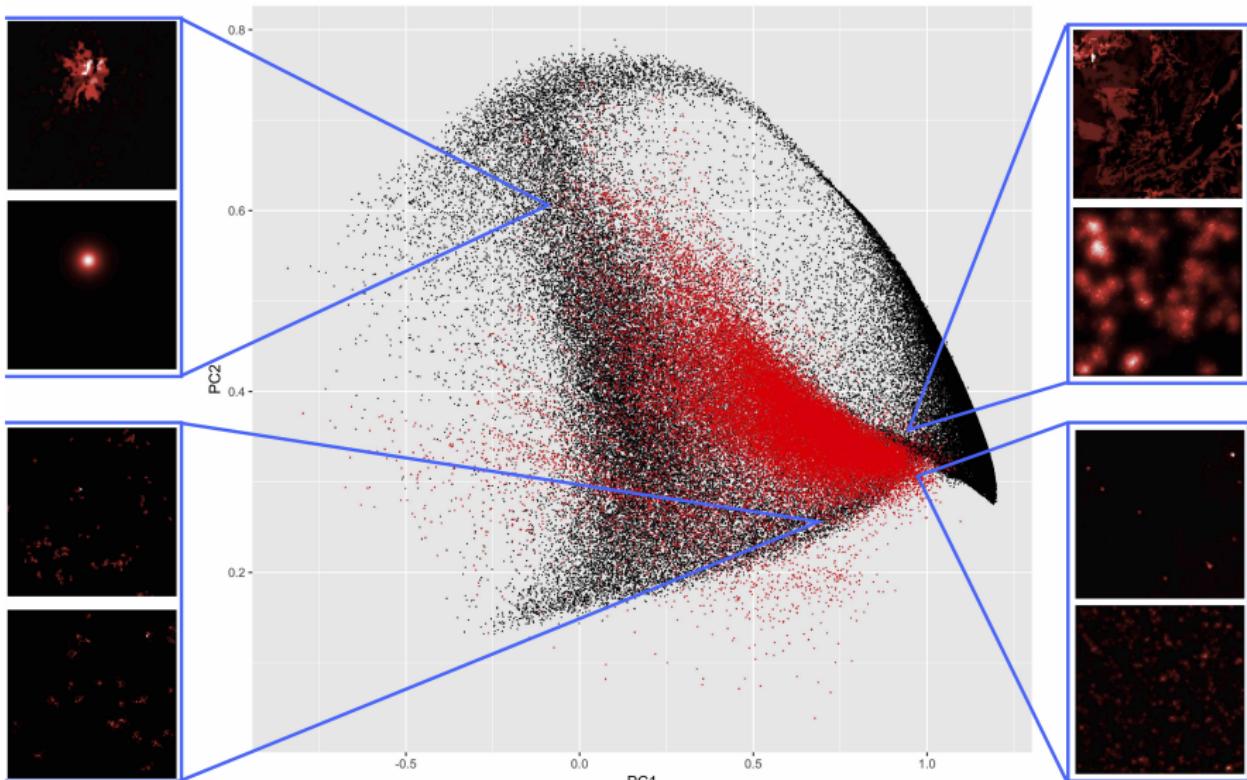


Real Data



Computation of morphological indicators on real data for Europe (shown here on France), morphological classification.

Model Calibration



Brute force calibration by exploring the parameter space. Reproduction of most existing configuration in the morphological sense (here in principal plan).

Including more complex processes ?

Interactions between Networks and Territories

Complex co-evolutive processes between Territories and Transportation Networks



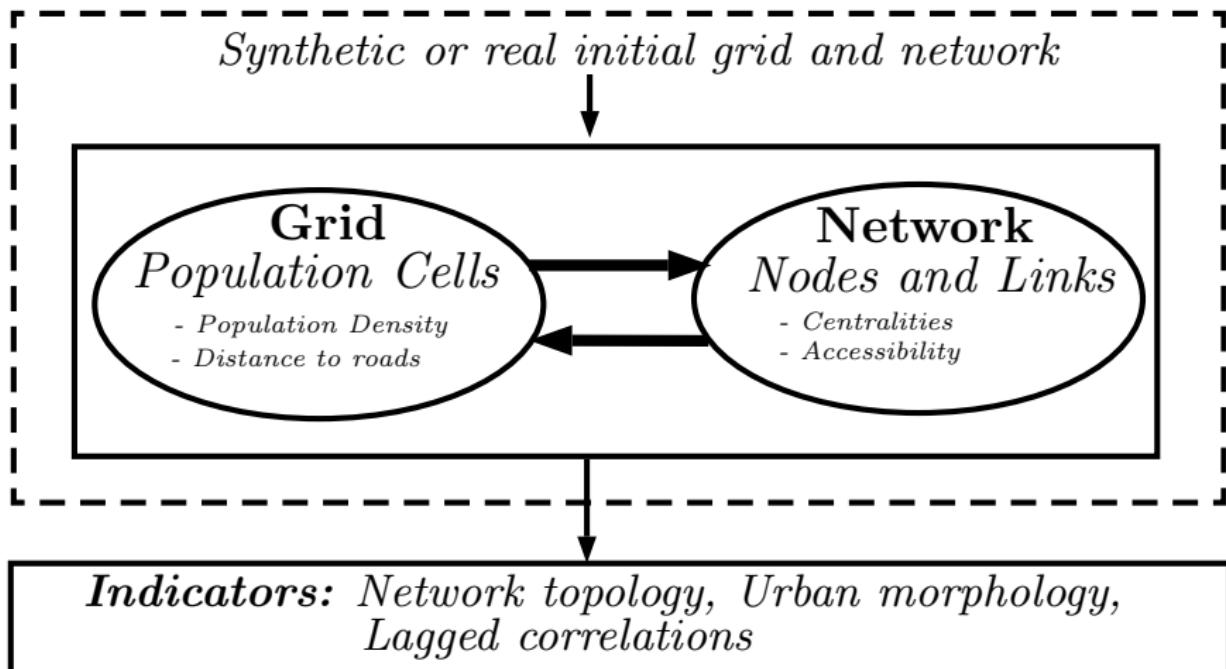
Expanding HSR network in China and ambiguous effects (Source : fieldwork survey)

A Morphogenesis Model of co-evolution

- Coupled grid population distribution and vector transportation network, following the core of [Raimbault et al., 2014]
- Local morphological and functional variables determine a patch-value, driving new population attribution through preferential attachment ; combined to population diffusion (aggregation-diffusion processes studied in [?])
- Network growth is also driven by morphological, functional and local network measures, following diverse heuristics corresponding to different processes (multi-modeling)

*Local variables and network properties induce feedback on both, thus a strong coupling capturing the **co-evolution***

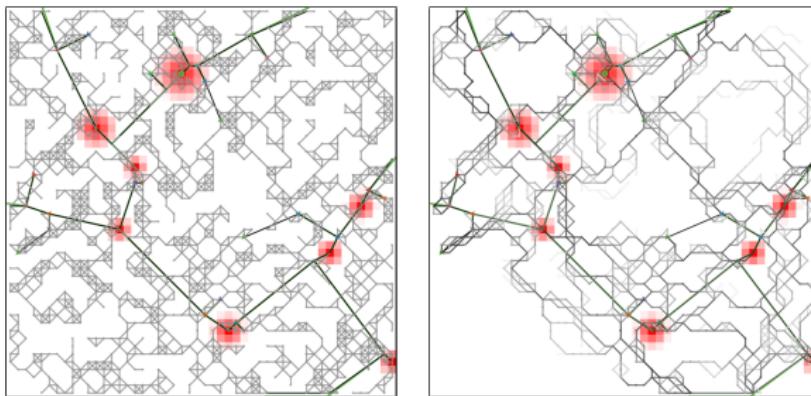
Model : Specification



Network Generation

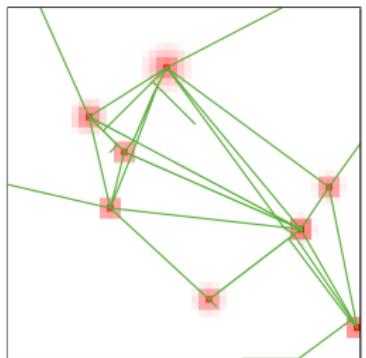
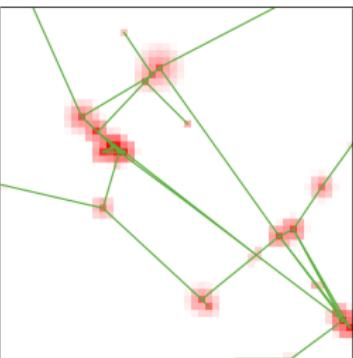
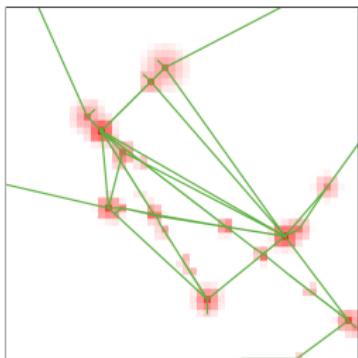
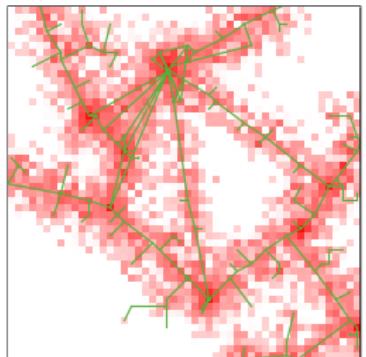
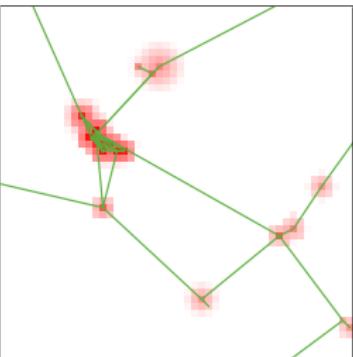
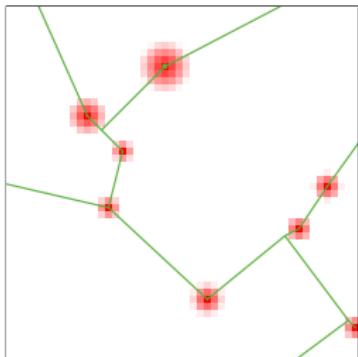
At fixed time steps :

- ① Add new nodes preferentially to new population and connect them
- ② Variable heuristic for new links, among: nothing, random, gravity-based deterministic breakdown, gravity-based random breakdown (from [Schmitt, 2014]), cost-benefits (from [Louf et al., 2013]), biological network generation (based on [Tero et al., 2010])



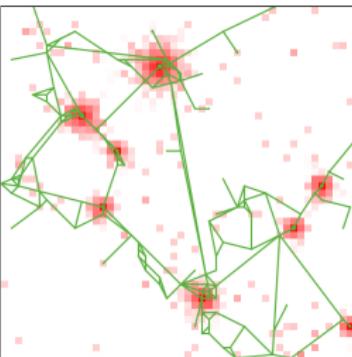
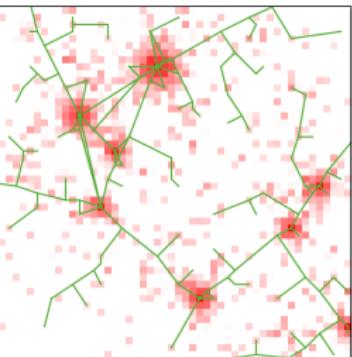
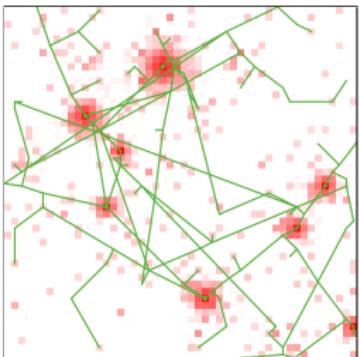
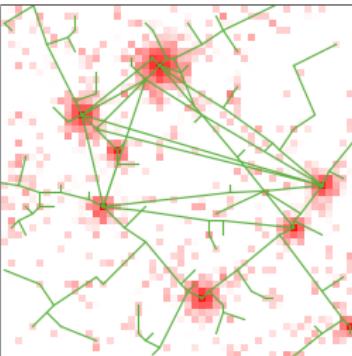
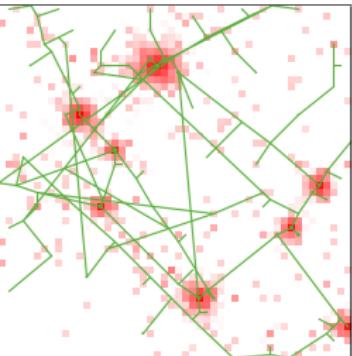
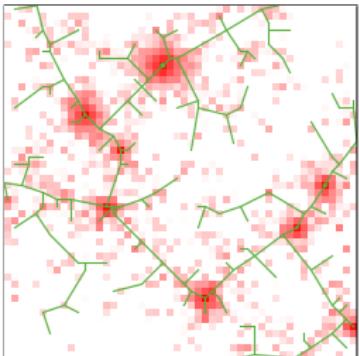
Intermediate stage for biological network generation

Generated Urban Shapes: Urban Form



In order: setup; accessibility driven; road distance driven; betweenness driven; closeness driven; population driven.

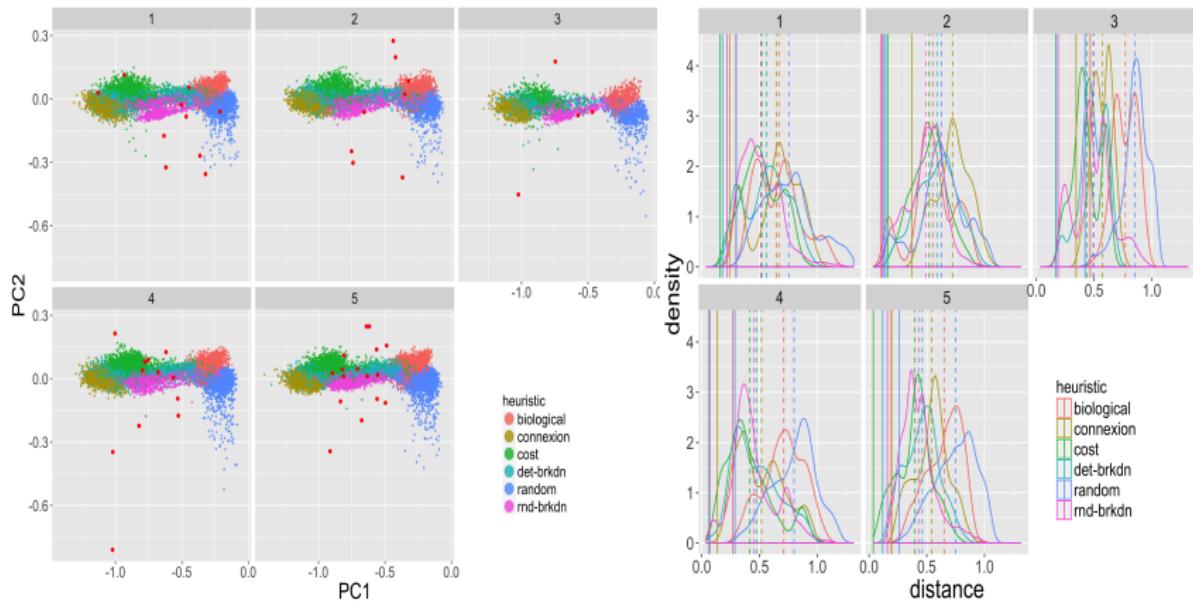
Generated Urban Shapes: Network



In order: connection; random; deterministic breakdown; random breakdown; cost-driven; biological.

Results : Network Heuristics

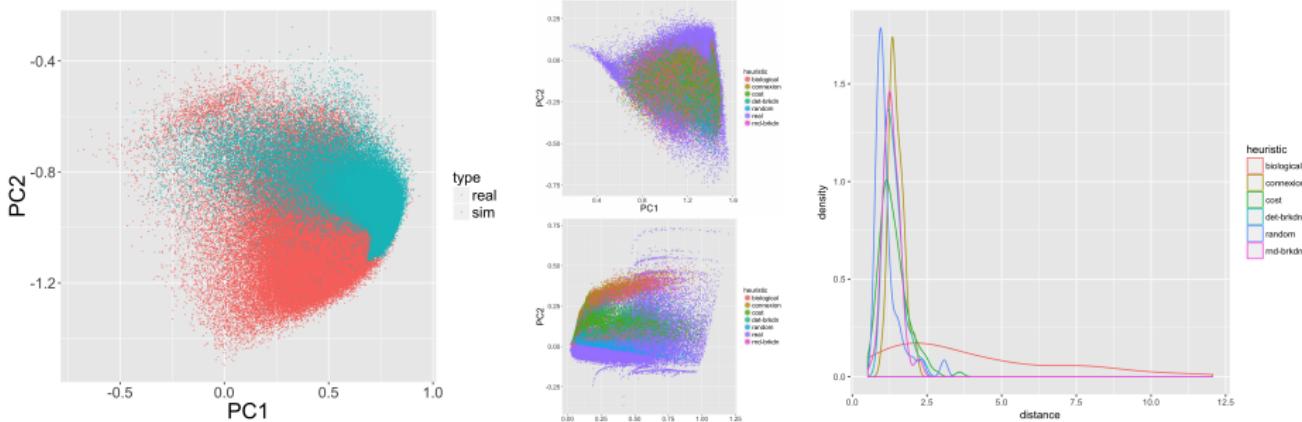
Comparison of feasible space for network indicators with fixed density



(Left) Feasible spaces by morphological class and network heuristic; (Right) Distribution of distances to topologies of real networks

Results : Calibration

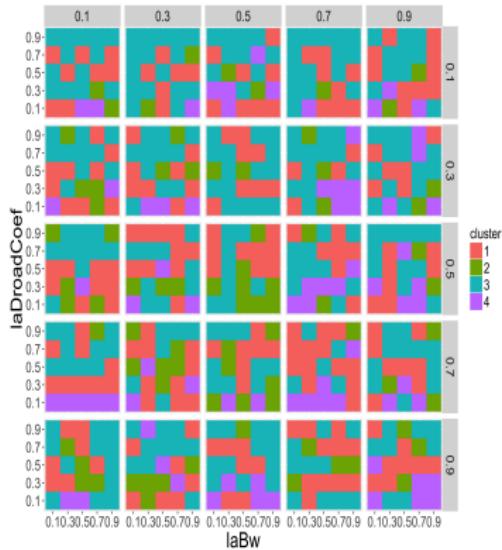
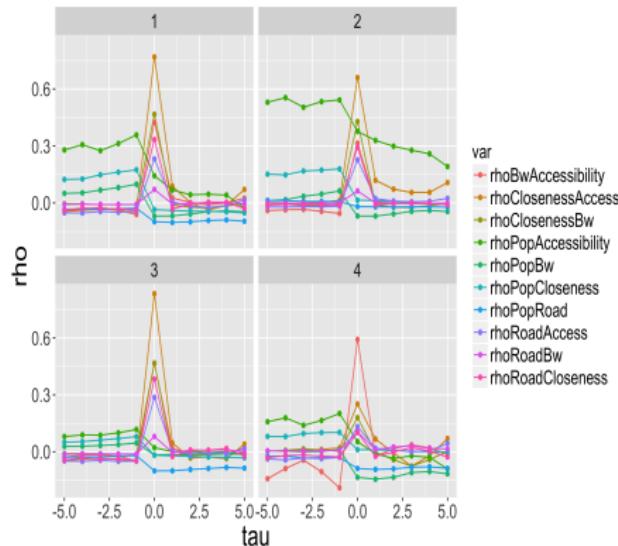
Calibration (model explored with OpenMole [Reuillon et al., 2013], $\sim 10^6$ model runs) at the first order on morphological and topological objectives, and on correlations matrices.



(Left) Full indicator space; (Middle) Morphological and Topology, by network heuristic;
(Right) Distance distribution for cumulated distance for indicators and correlations.

Results : Causality Regimes

Unsupervised learning on lagged correlations between local variables unveils a diversity of causality regimes



(Left) Lagged correlation profiles of cluster centers; (Right) Distribution of regimes across parameter space

Discussion

Conclusion

Reserve Slides

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