

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

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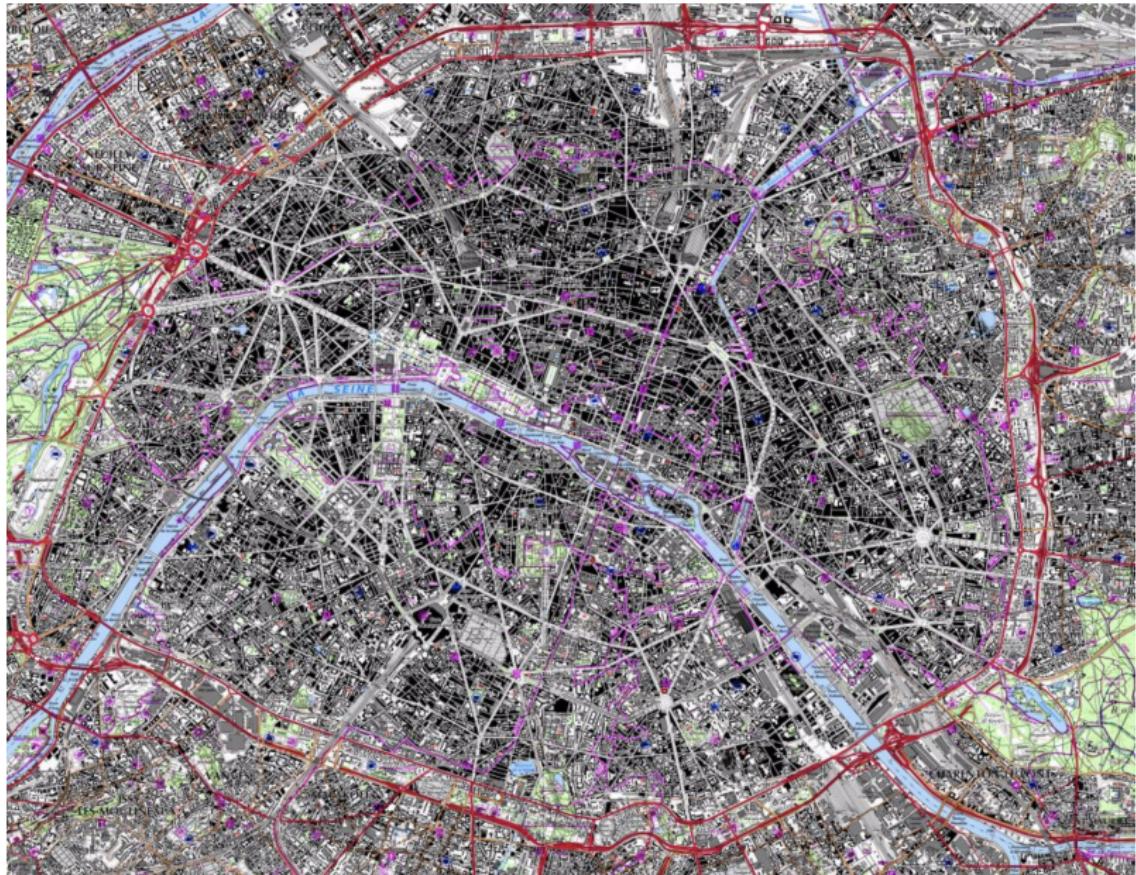
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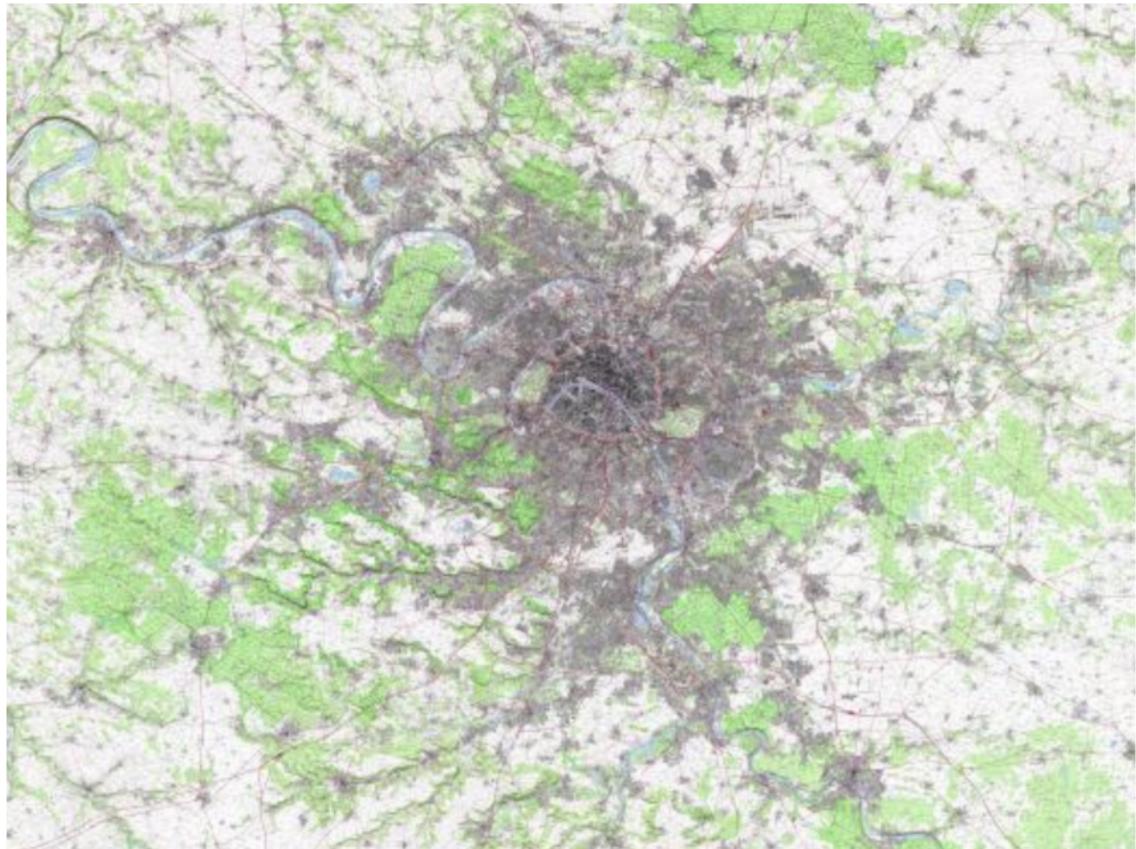
October 20th 2017

# Complex processes of Urban Morphogenesis



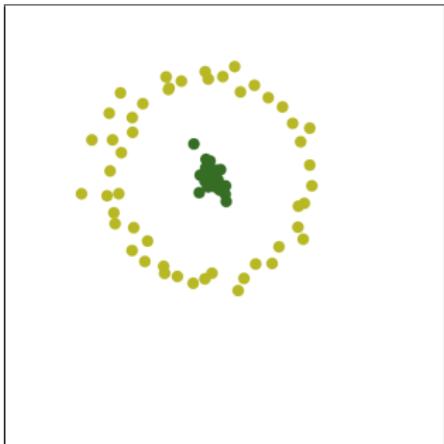
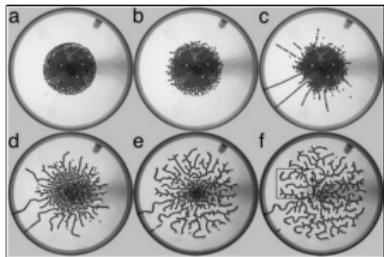
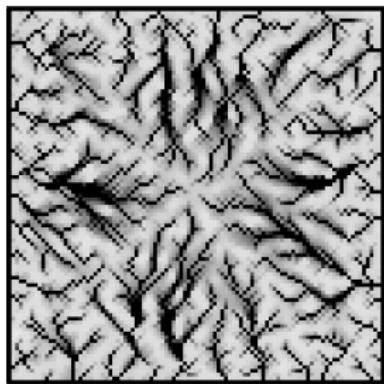
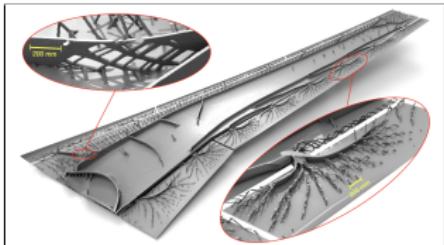
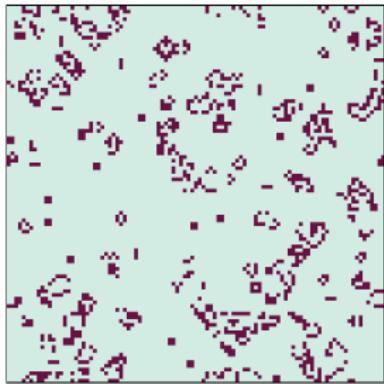
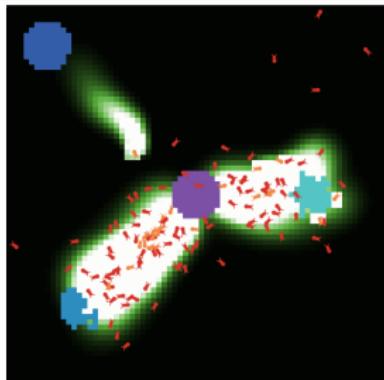
Source: Geoportal

# 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

[Antelope et al., 2016]

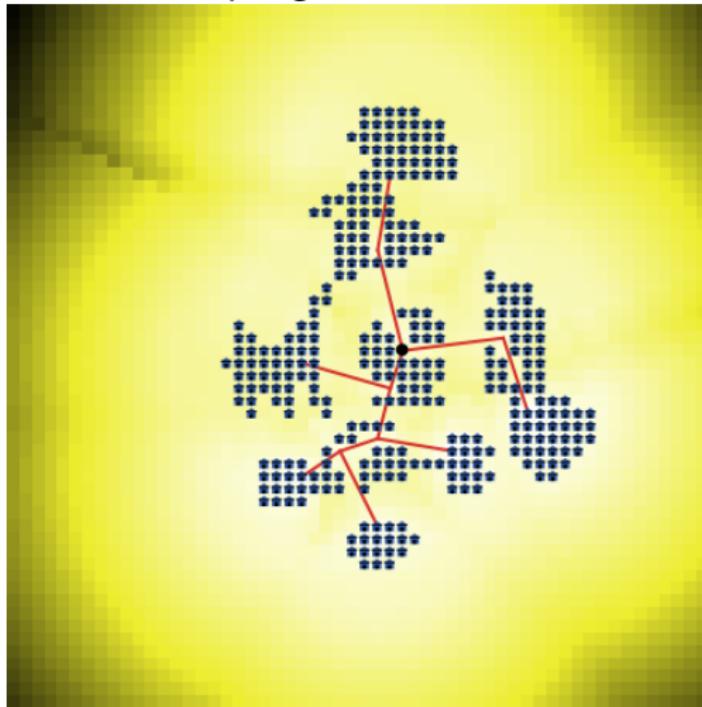
Self-organization  $\supseteq$  Morphogenesis  $\supseteq$  Autopoiesis  $\supseteq$  Life

- 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 ?*



*Source: [Raimbault et al., 2014]*

# A simple Aggregation-diffusion model

# Model Formalization

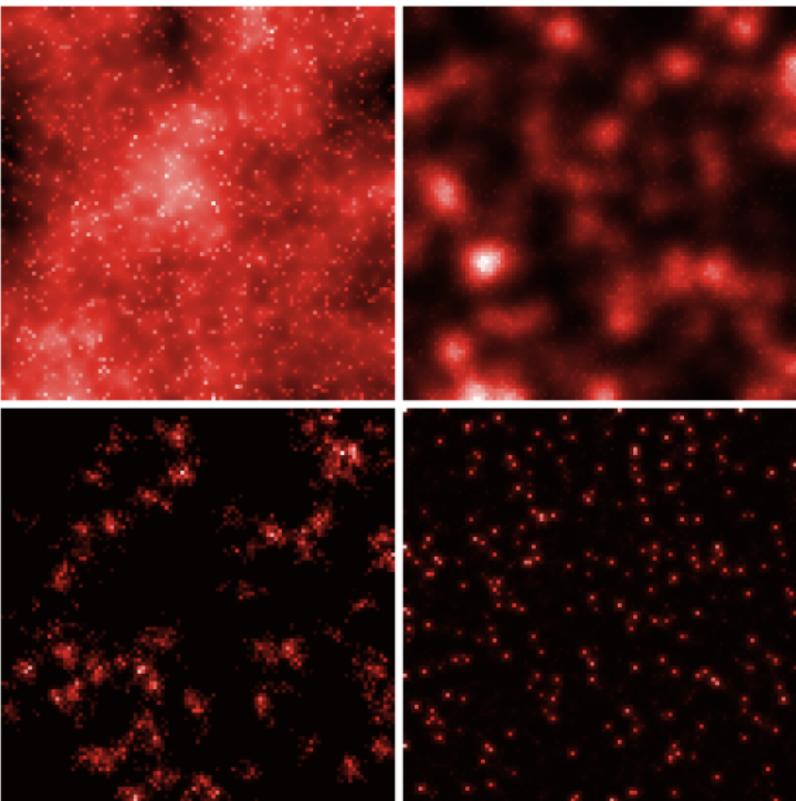
We formalize now the model and its parameters. The world is a square grid of width  $N$ , in which each cell is characterized by its population  $(P_i(t))_{1 \leq i \leq N^2}$ . We consider the grid initially empty, i.e.  $P_i(0) = 0$ , but the model can be easily generalized to any initial population distribution. The population distribution is updated in an iterative way.

At each time step:

- ① 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  $\alpha$
- ② A fraction  $\beta$  of population is diffused  $n_d$  times to cell neighborhood

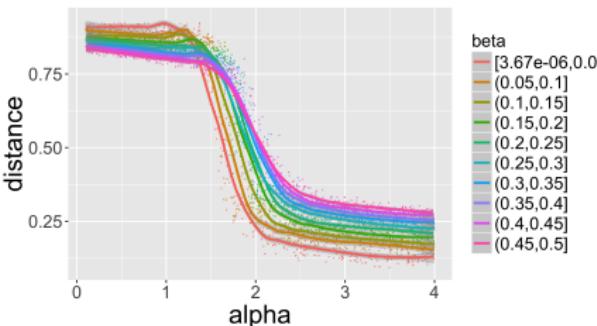
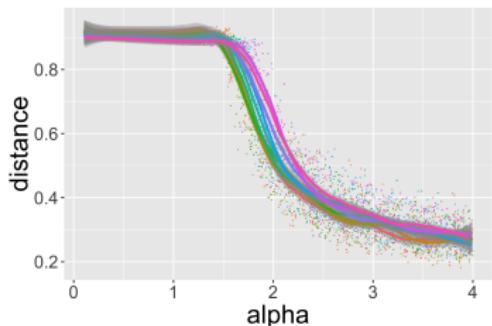
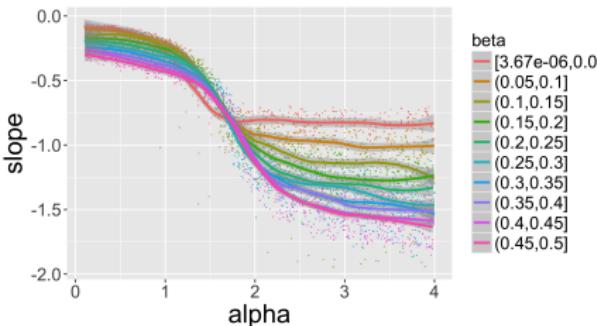
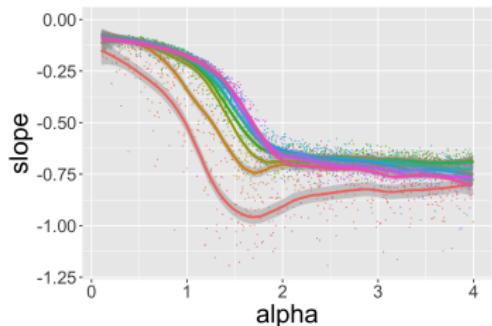
The model stops when total population reaches a fixed parameter  $P_m$ .

# Generating Population Distributions



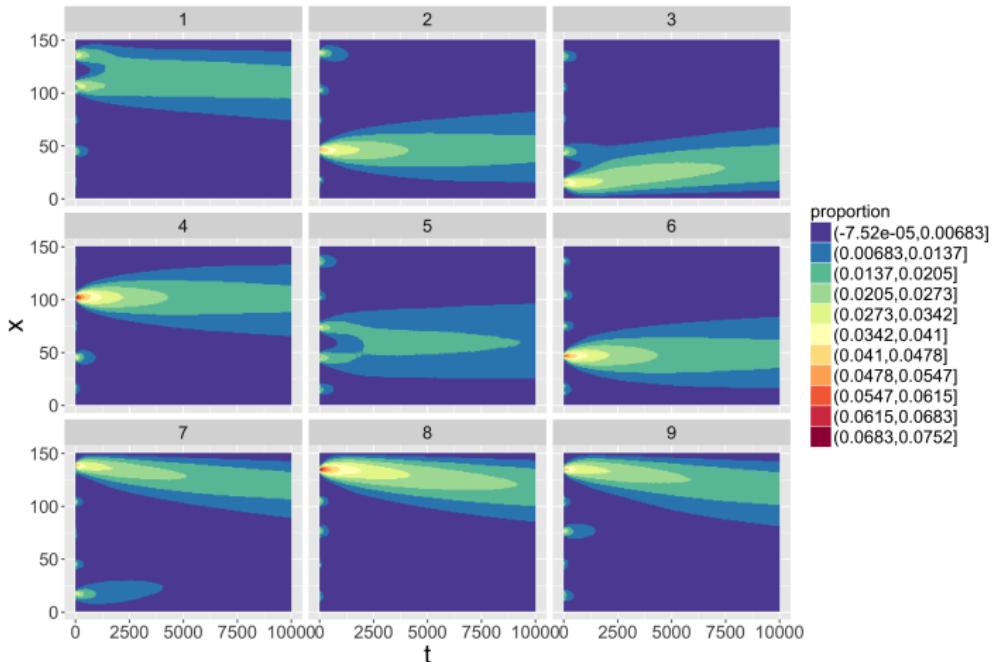
*Examples of generated territorial shapes*

# Model behavior

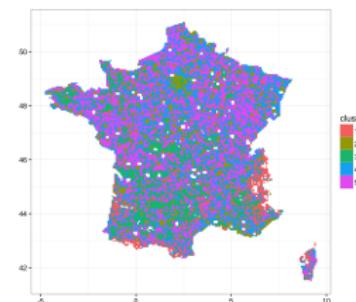
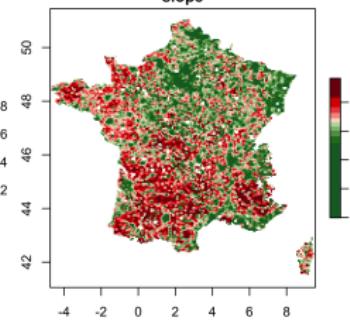
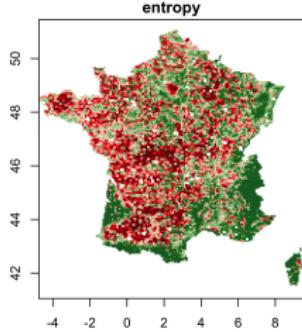
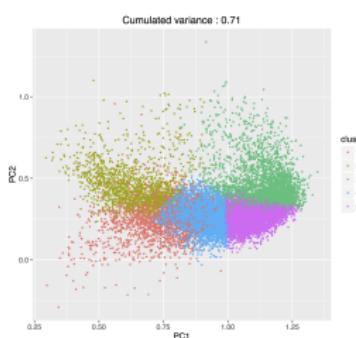
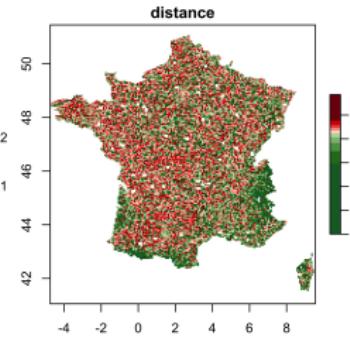
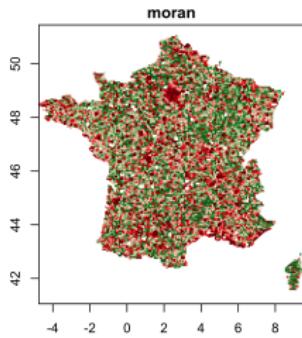


*Phase transitions and non-monotonous behavior of indicators unveiled by intensive exploration of the parameter space*

# Path-dependence and frozen accidents

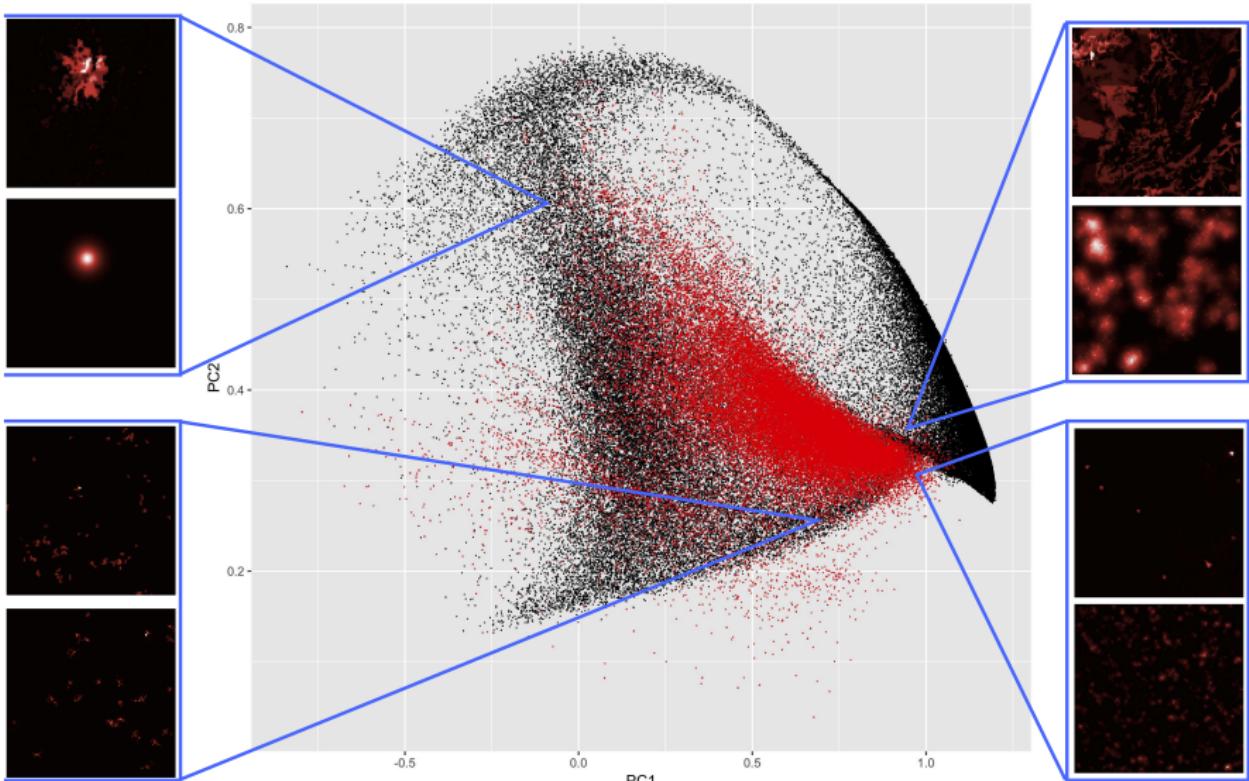


# Real Data



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

# Model Calibration



*Brute force calibration*

# Including more complex processes ?

# Interactions between Networks and Territories

*Complex co-evolutive processes between Territories and Transportation Networks*



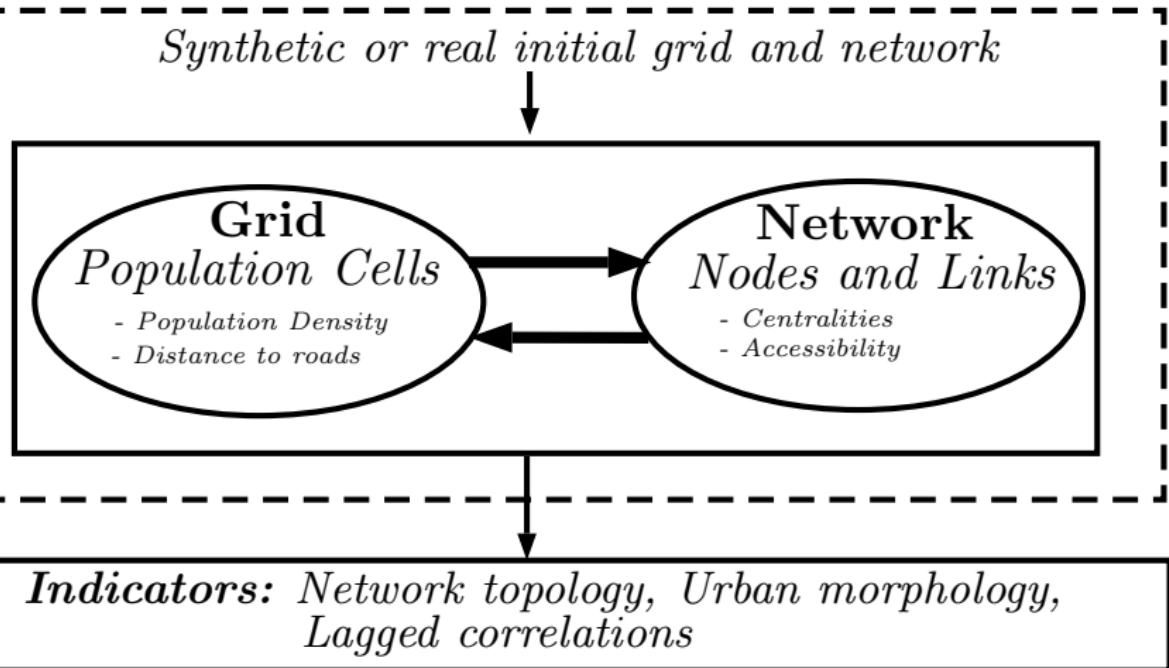
*Expanding HSR network in China and ambiguous effects (Source : fieldwork survey)*

# 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 [Raimbault, 2017])
- 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***

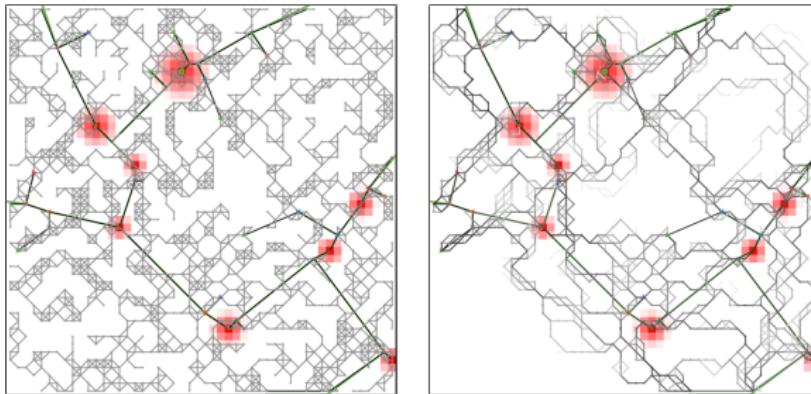
# Model : Specification



# Network Generation

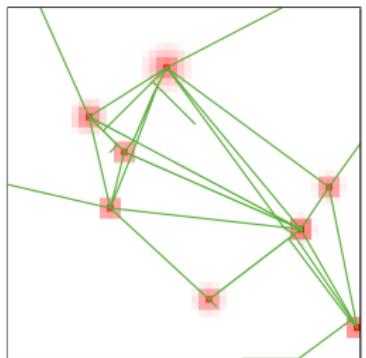
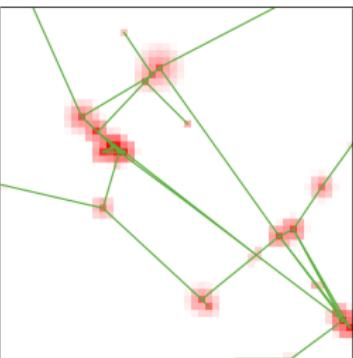
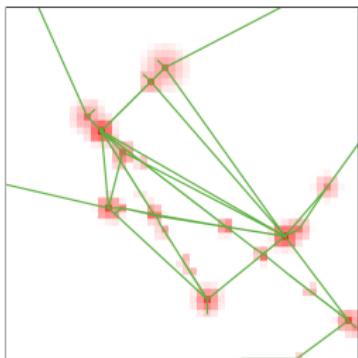
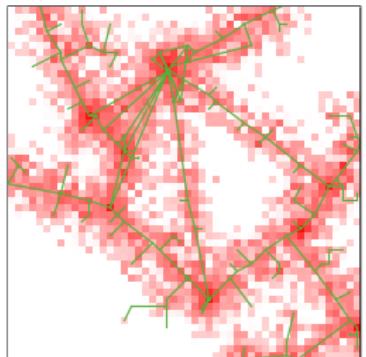
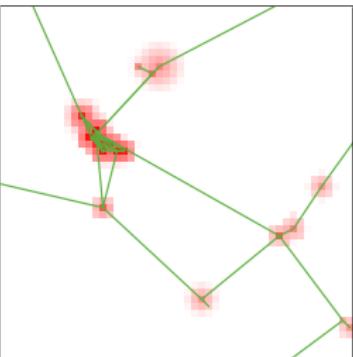
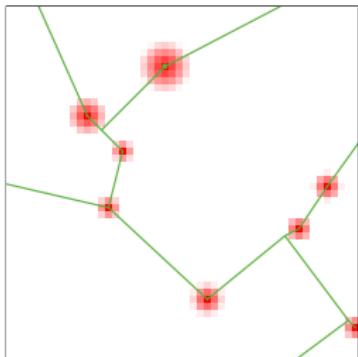
At fixed time steps :

- 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])



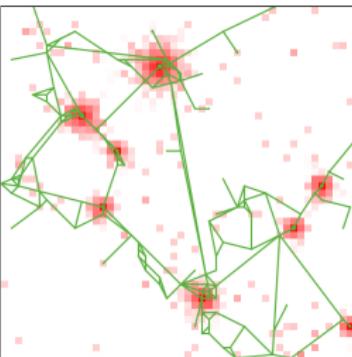
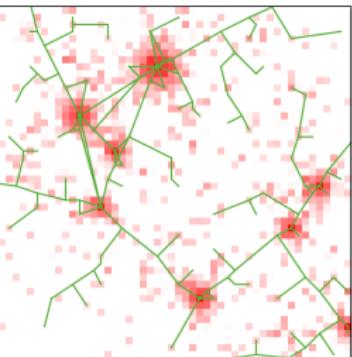
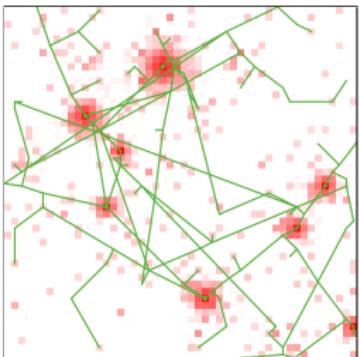
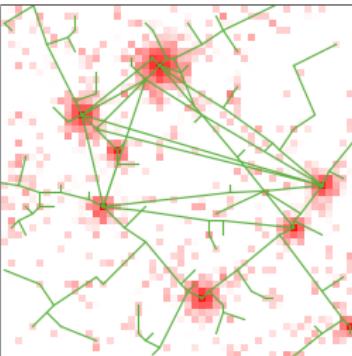
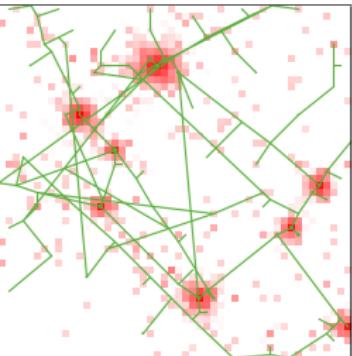
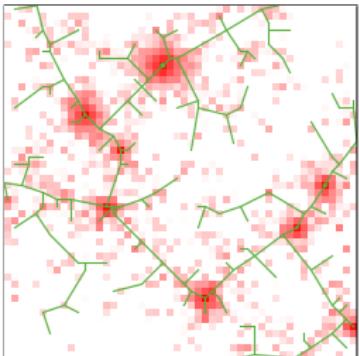
*Intermediate stage for biological network generation*

# Generated Urban Shapes: Urban Form



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

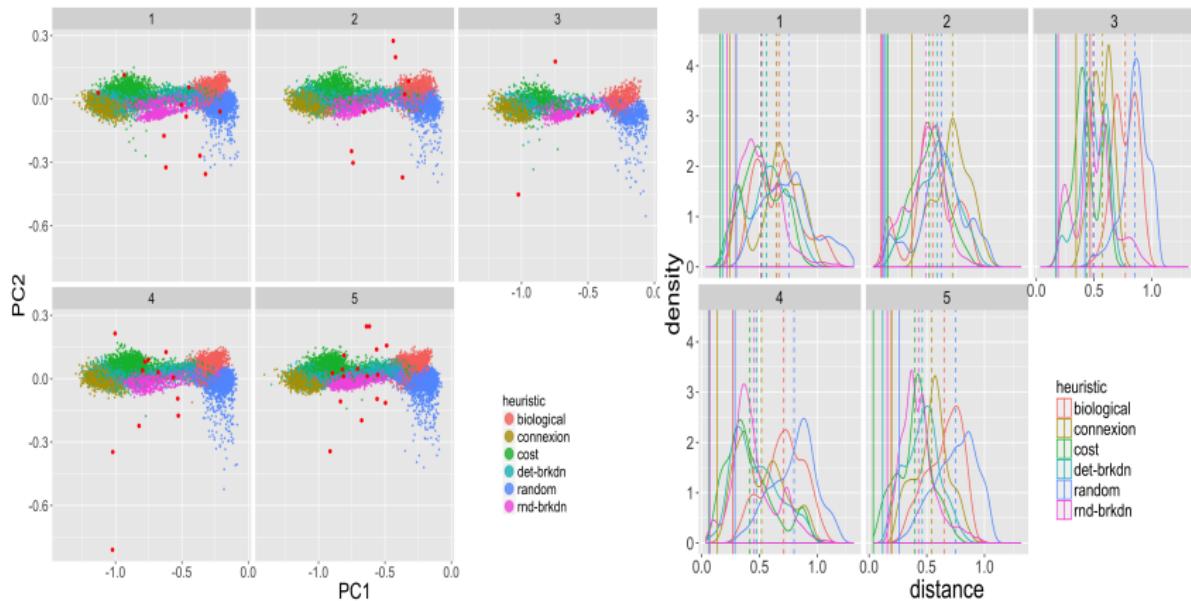
# Generated Urban Shapes: Network



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

# Results : Network Heuristics

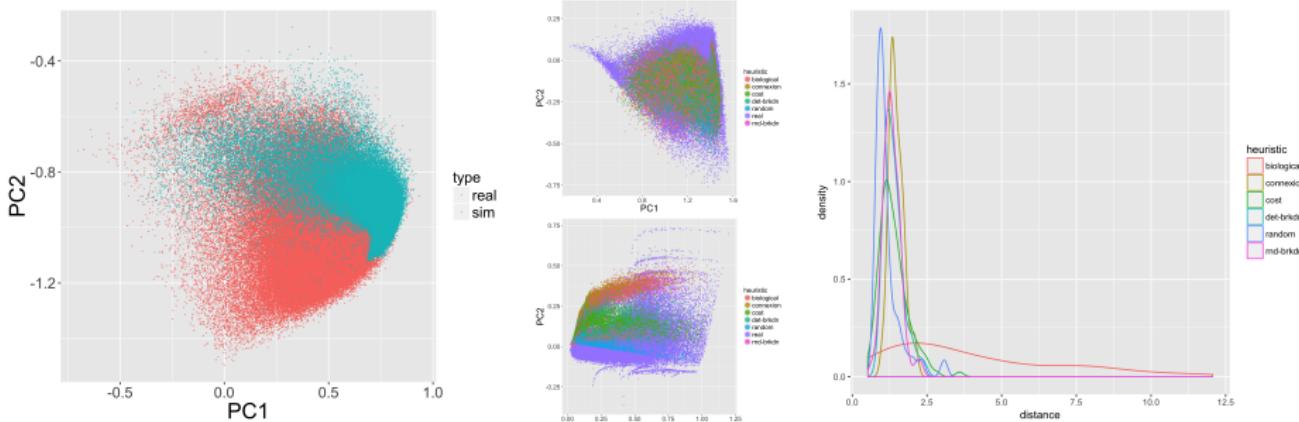
*Comparison of feasible space for network indicators with fixed density*



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

# Results : Calibration

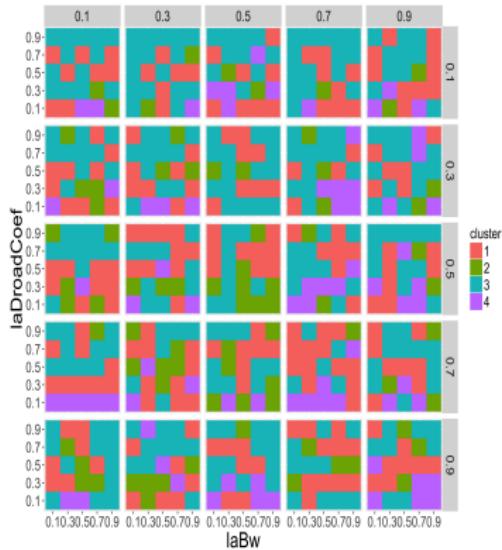
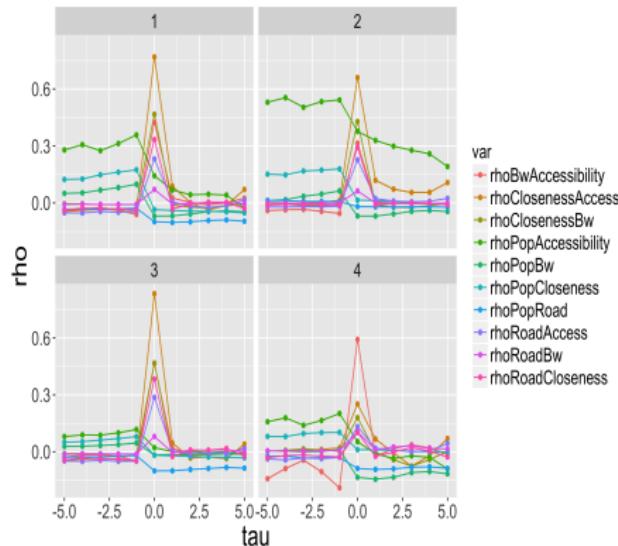
Calibration (model explored with OpenMole [Reuillon et al., 2013],  $\sim 10^6$  model runs) at the first order on morphological and topological objectives, and on correlations matrices.



(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

# Reserve Slides

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