Modeling the Co-evolution of Urban Form and Transportation Networks

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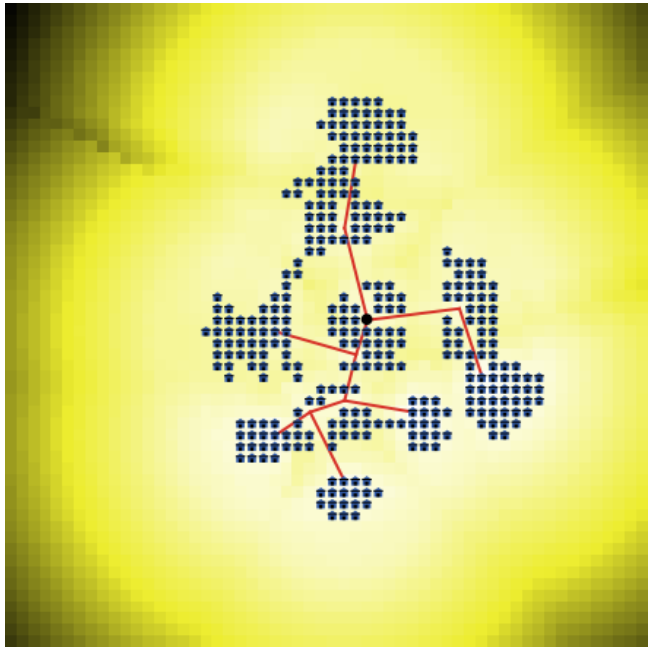
Complex processes of Urban Morphogenesis

Source: Google maps

Modeling Urban Morphogenesis



Source:
[Raimbault et al., 2014]

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

$\rightarrow$ Co-evolution of Transportation Networks and Urban Settlements plays a specific role in real Urban Morphogenetic processes

Research Objective : Study a morphogenetic model at an intermediate scale, based on the co-evolution between a transportation network and population distribution.

Model : Rationale

→ 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)

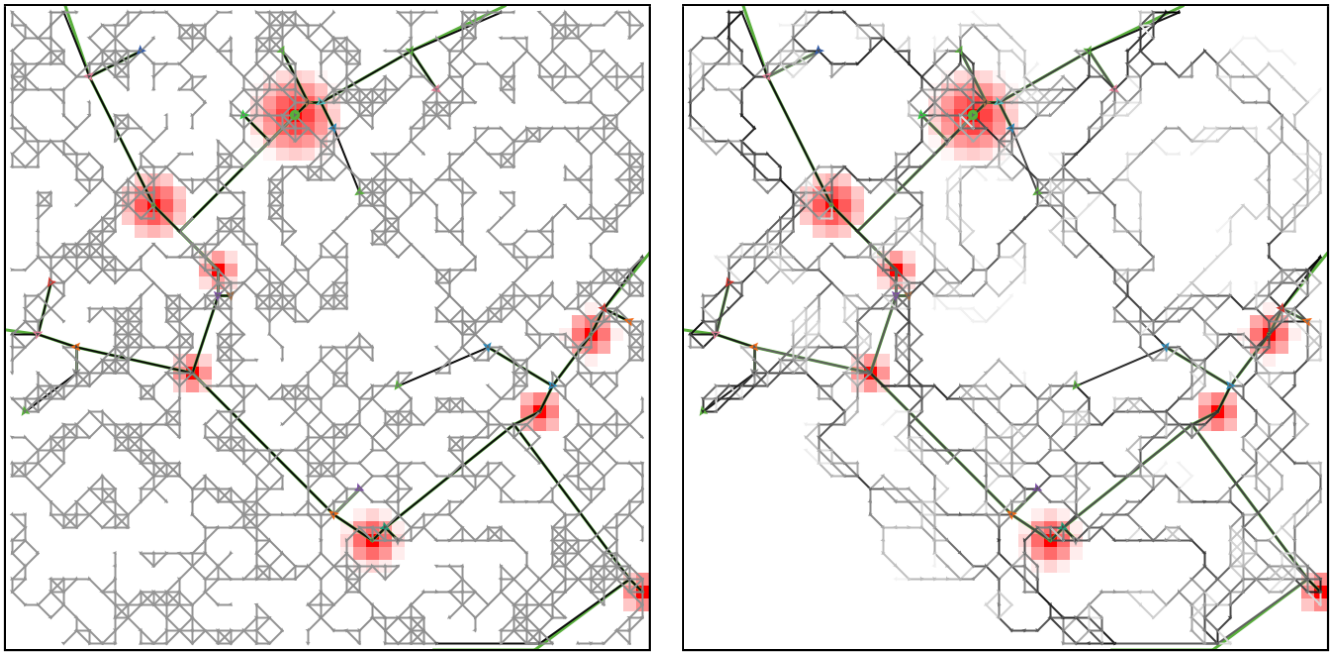
Local variables and network properties induce feedback on both, thus a strong coupling capturing the ***co-evolution***

Model : Specification

Network Generation

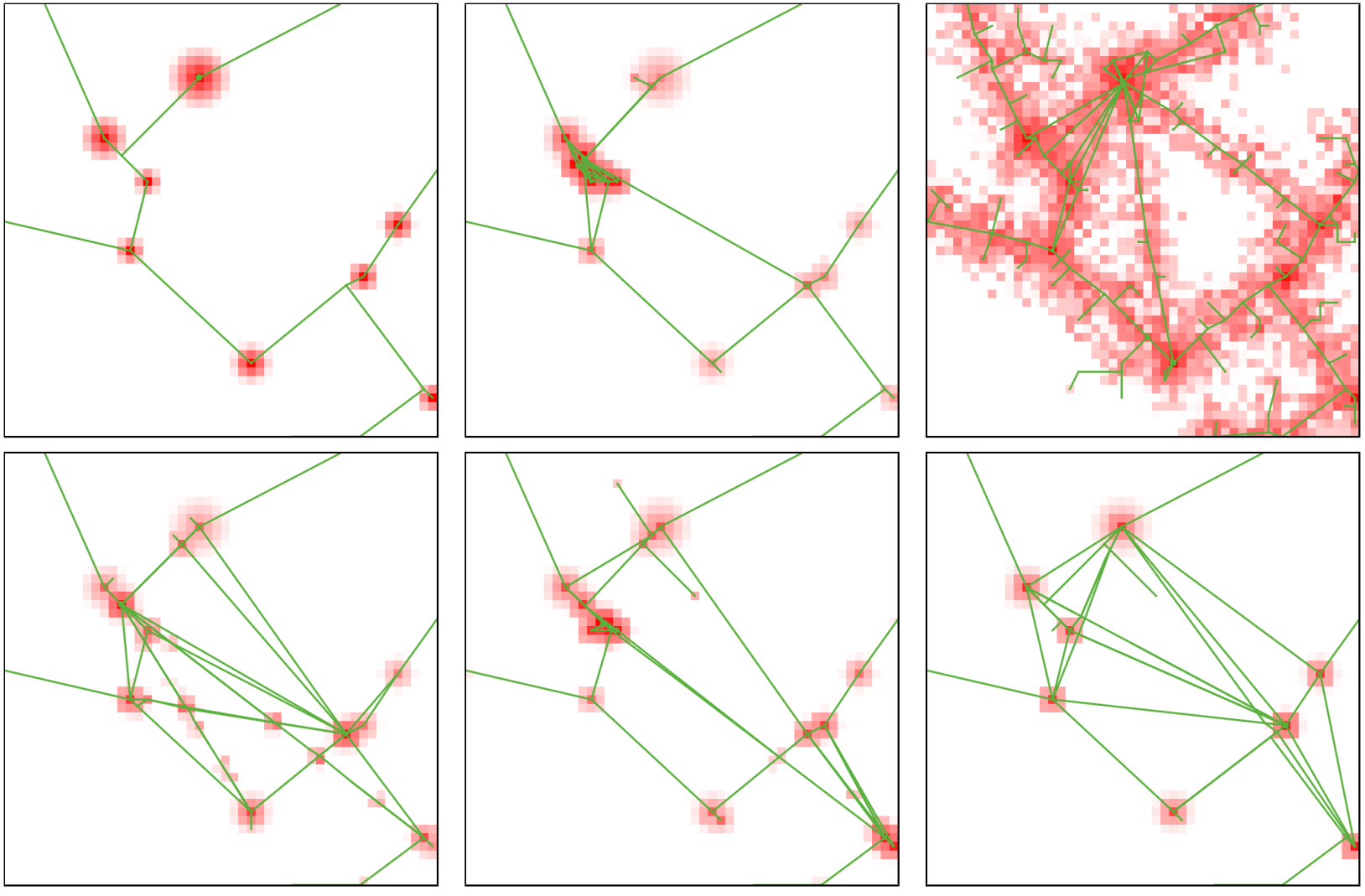
At fixed time steps :

1. Fixed process for new nodes and connectivity
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])



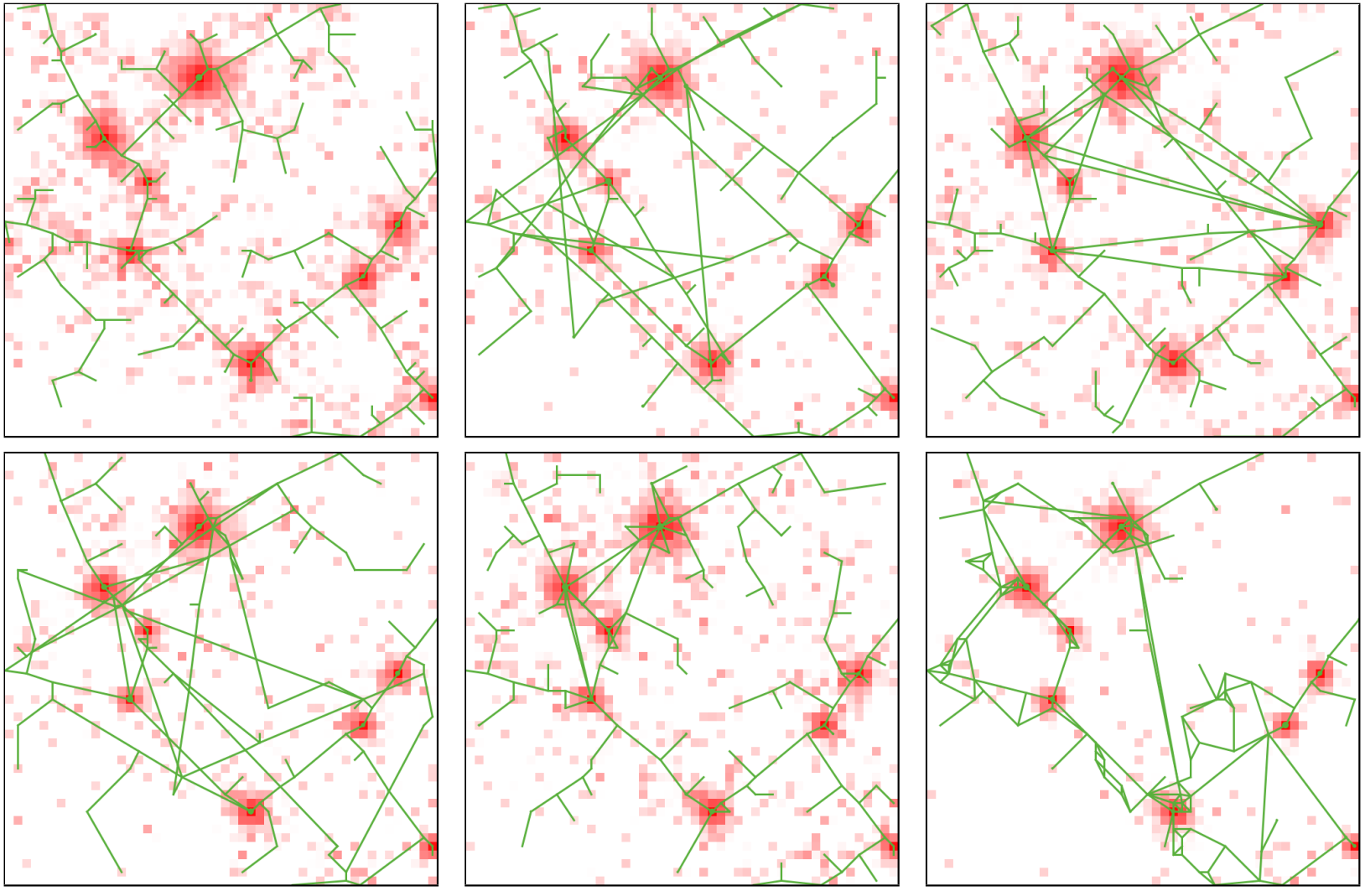
Intermediate stage for biological network generation

Generated Urban Shapes: Urban Form



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

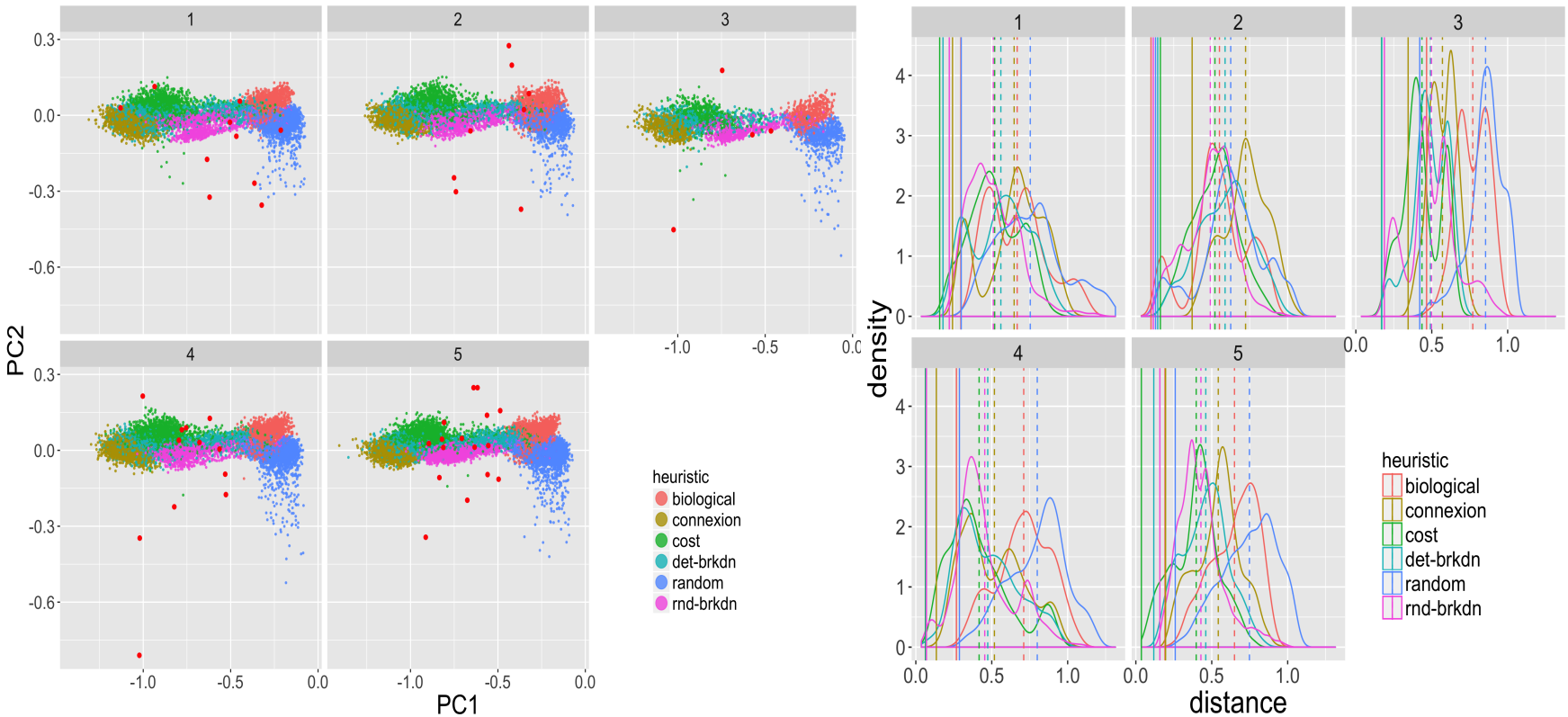
Generated Urban Shapes: Network



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

Results : Network Heuristics

Comparison of feasible space for network indicators with fixed density

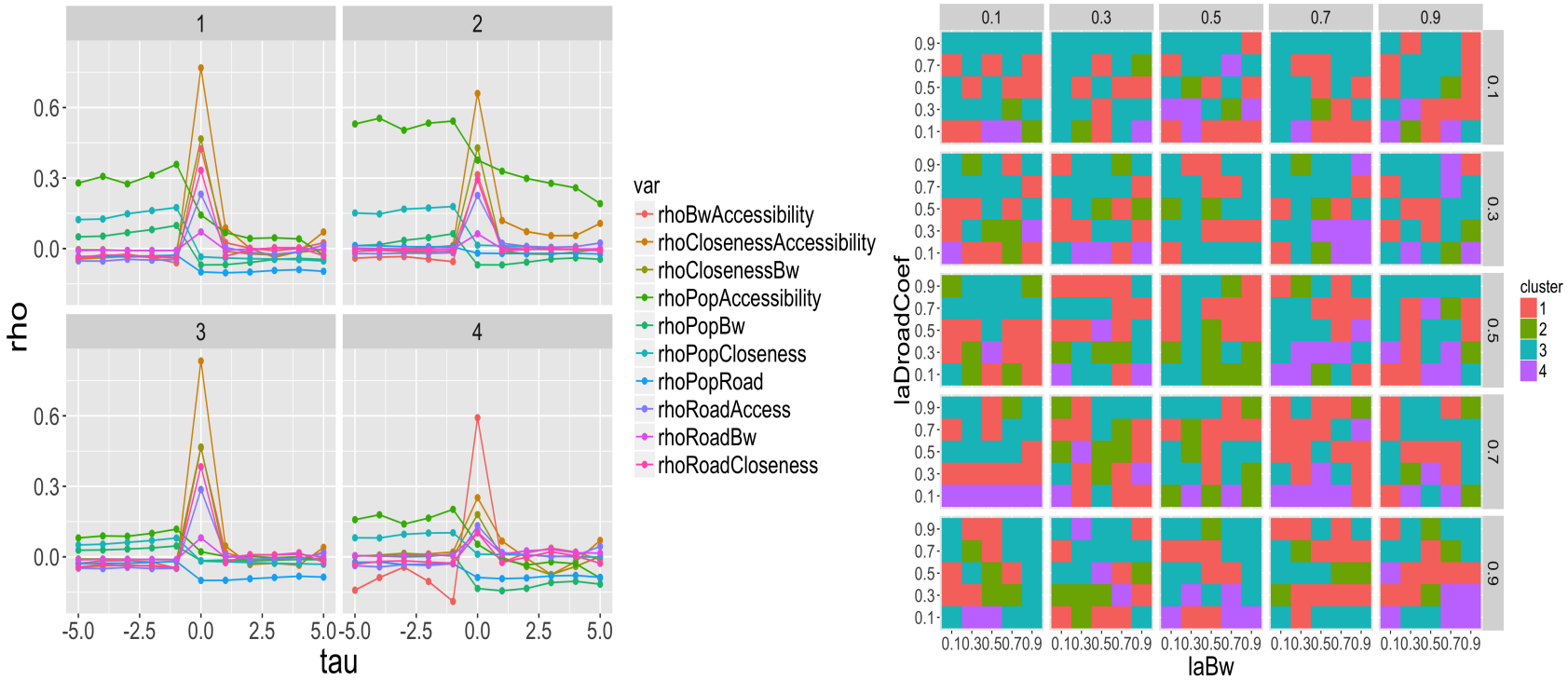


(Left) Feasible spaces by morphological class and network heuristic; (Right) Distribution of distances to topologies of real networks

Results : Calibration

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

Implications

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Developments

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Conclusion

$\rightarrow$

- Code et data available at
`https://github.com/JusteRaimbault/CityNetwork`

Reserve slides

Reserve Slides

Defining co-evolution

No clear definition of co-evolution in the literature : [Bretagnolle, 2009] distinguishes "reciprocal adaptation" where a sense of causality can clearly be identified, from co-evolutive regimes

[Raimbault, 2017b] identifies multiple causality regimes in a simple strongly coupled growth model $\rightarrow$ to be put in perspective with a theoretical definition of co-evolution based on the conjunction of Morphogenesis and the Evolutive Urban Theory, summarised by [Raimbault, 2017a]

Data Processing

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Morphological Indicators

Urban morphology measured by:

- Spatial autocorrelation (Moran Index)
- Average distance
- Entropy
- Hierarchy (OLS slope for rank-size)

Network Indicators

Network Topology measured by:

- Betweenness and Closeness centralities: average and hierarchy
- Accessibility (weighted closeness)
- Efficiency (network pace relative to euclidian

Model specification

Patch utility given by $U_i = \sum_k w_k \cdot \tilde{x}_k$
Gravity interaction

Biological Network generation

Adding new links with biological heuristic:

1. Create network of potential new links, with existing network and randomly sampled diagonal lattice
2. Iterate for k increasing ($k \in \{1, 2, 4\}$ in practice) :
   - Using population distribution, iterate $k \cdot n_b$ times the slime mould model to compute new link capacities
   - Delete links with capacity under θ_d
   - Keep the largest connected component
3. Planarize and simplify final network

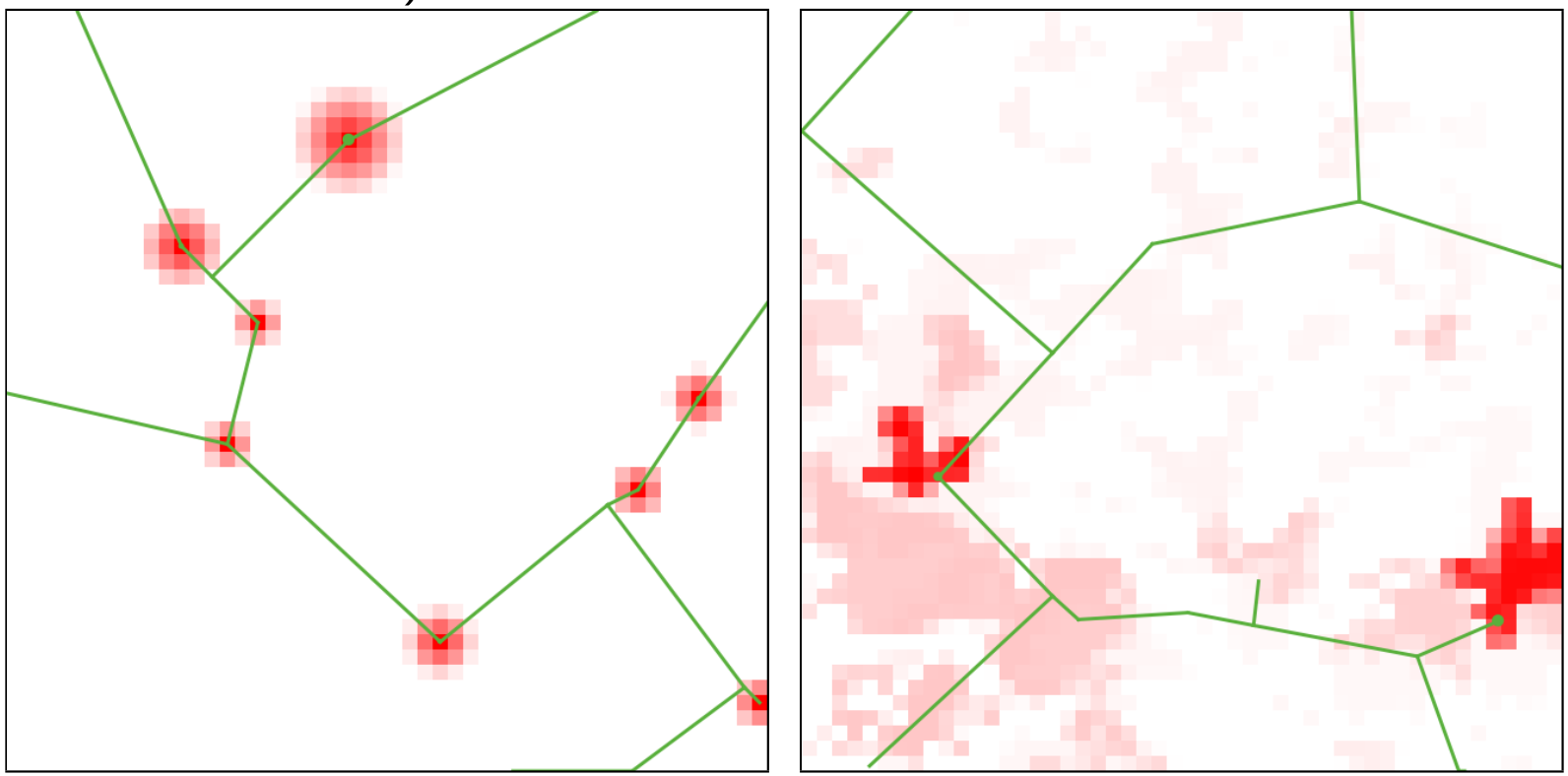
Model parameters

- Patch utility weights w_k
- General network generation parameters: growth time steps t_N, maximal additional links
- Gravity interactions : decay d_G and hierarchy α_G

Model setup

Synthetic setup: rank-sized monocentric cities, simple connection with bord nodes to avoid bord effects

Real setup: Population density raster at 500m resolution (European Union, from Eurostat)

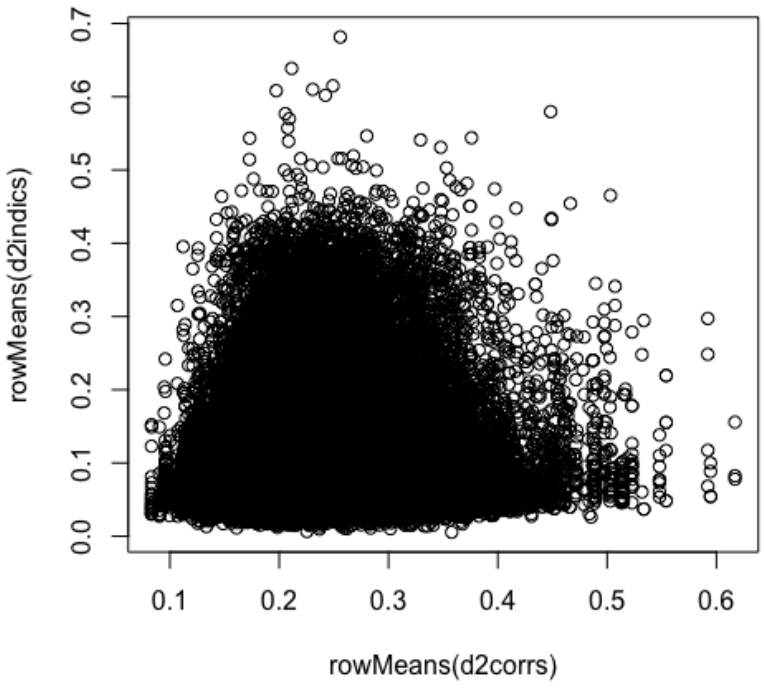


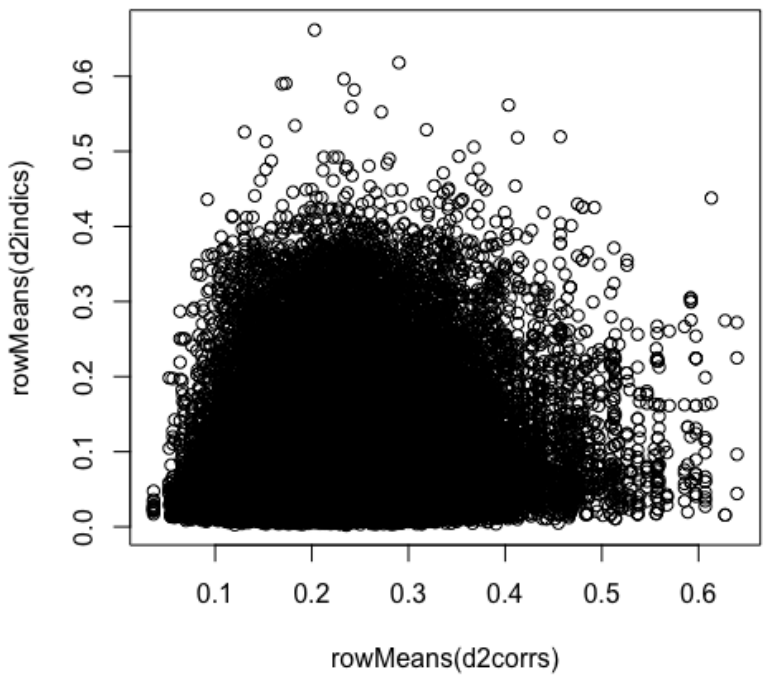
Stopping conditions: fixed final time; fixed total population; fixed network size

Calibration Method

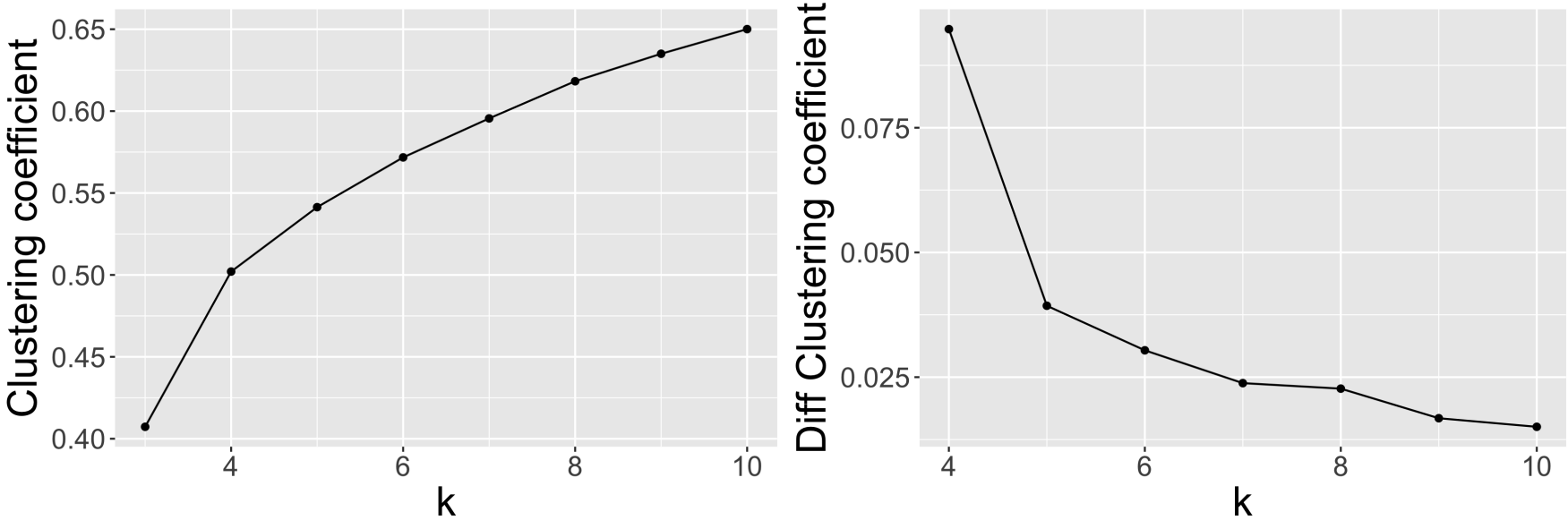
Brute force exploration of a LHS sampling

Calibration : optimal points





Causality regimes: clustering



Clustering coefficient (left) and its derivative (right) as a function of number of clusters

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