Towards multi-scalar models for the co-evolution of transportation networks and territories

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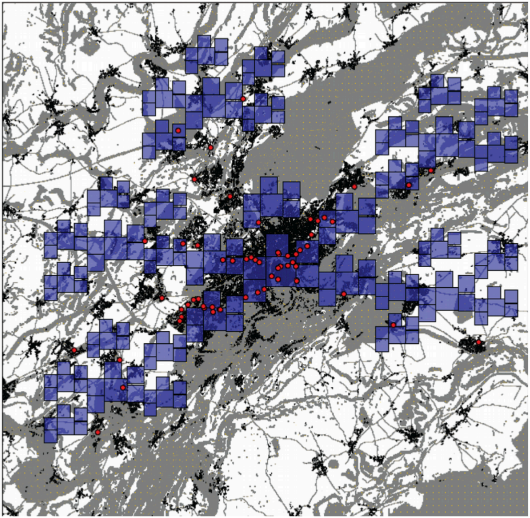
Interactions between networks and territories

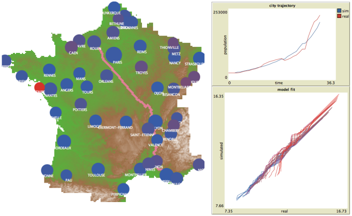
Central role of interactions between networks and territories in urban systems dynamics



Example: Multifractal planning for the city of Besancon [Tannier, 2017]

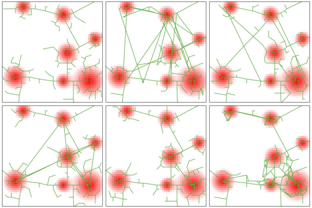
Models with different ontologies and scales [Raimbault, 2018a]

Macroscopic

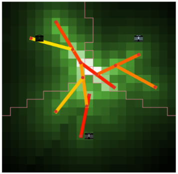


Interaction model

Mesoscopic



Urban morphogenesis



Transportation governance

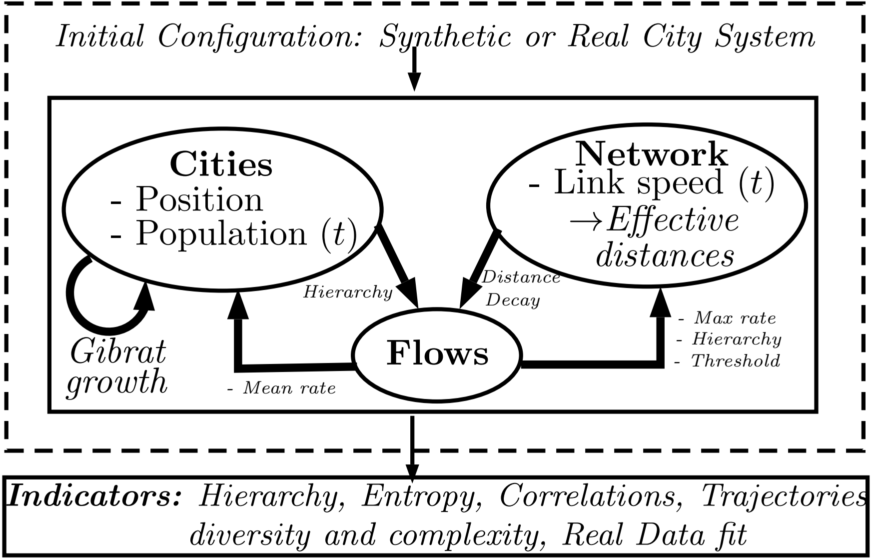
Towards multi-scalar models

$\rightarrow$ Processes included depend on the scale (urban form and function, interactions between cities)

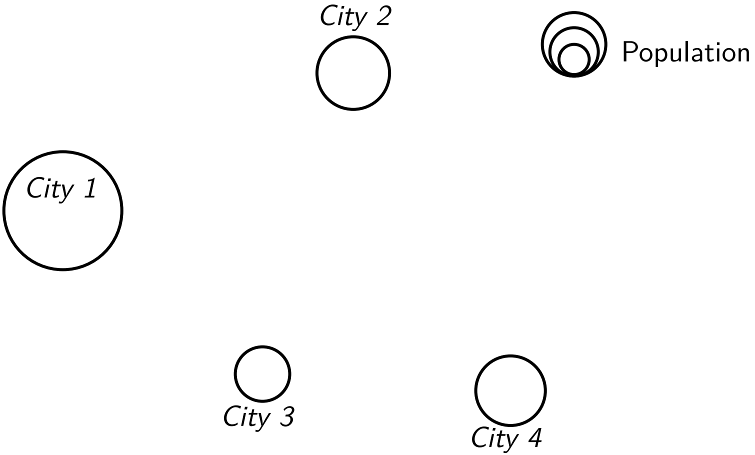
$\rightarrow$ Truly multi-scale models (coupling different ontologies and not just geographical ranges, and with a strong coupling between scales) are very rare (inexistent ?), despite a strong need for these [Rozenblat and Pumain, 2018]

Research objective: *Investigate an hybrid co-evolution model coupling macroscopic city dynamics and mescoscopic network dynamics*

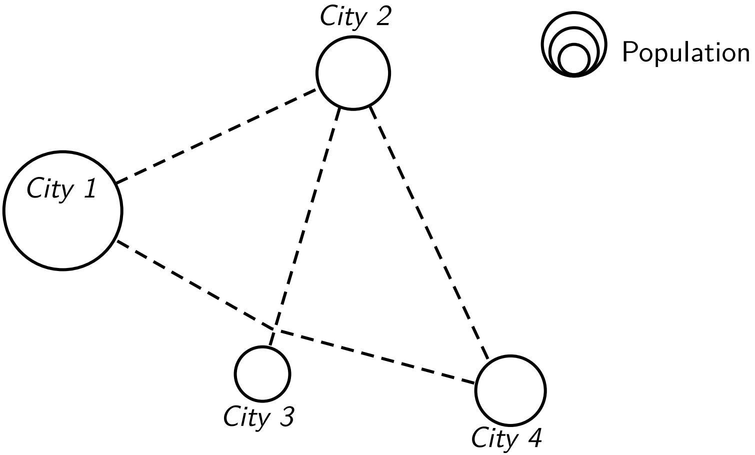
Generic description of the model



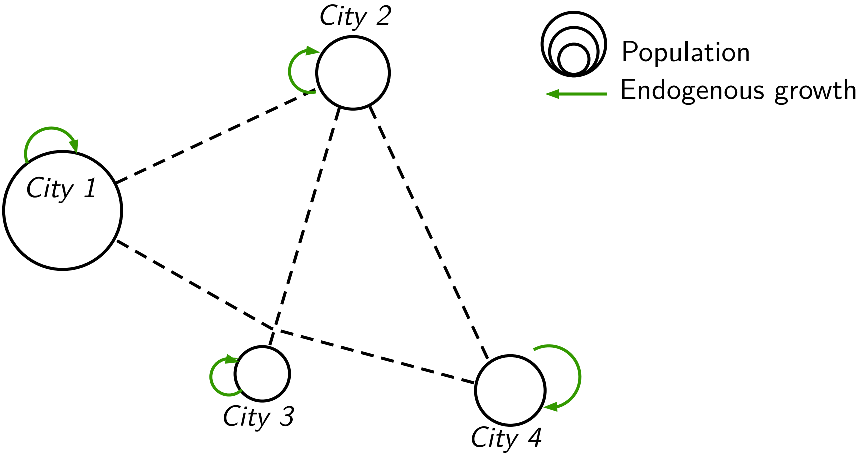
Macroscopic interaction model



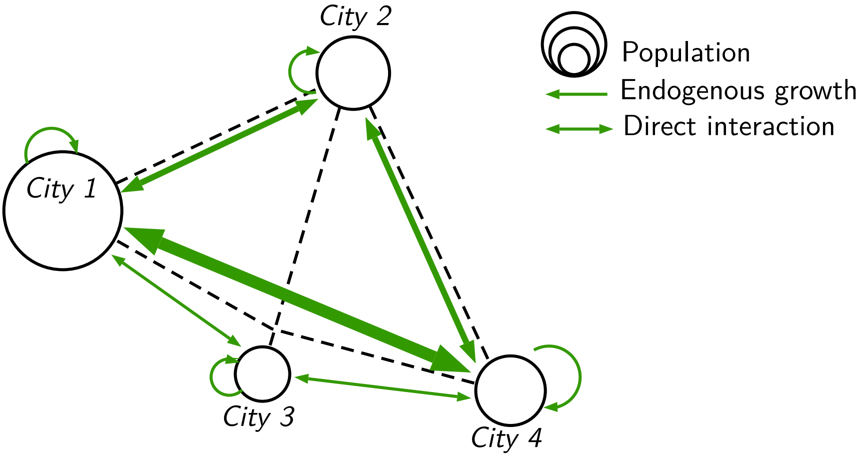
Macroscopic interaction model

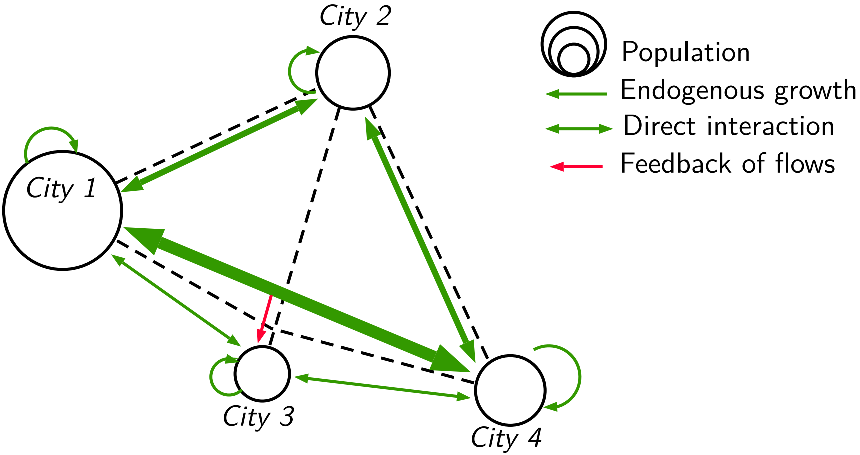


Macroscopic interaction model

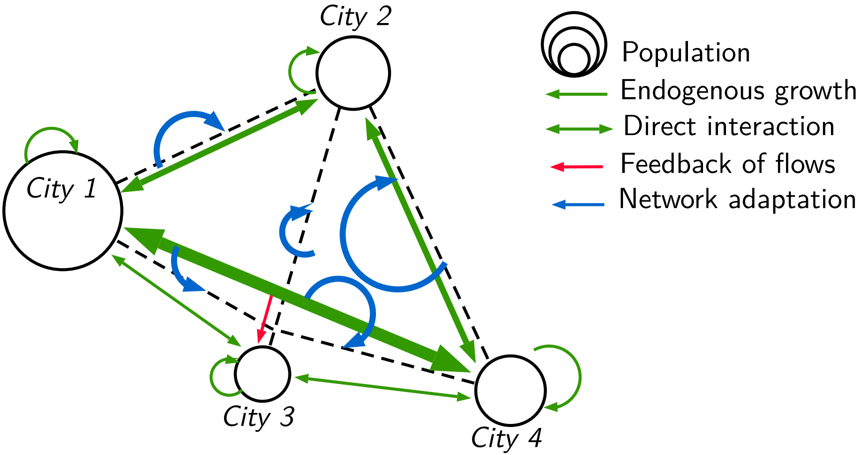


Macroscopic interaction model




City 2
City 1
City 3
City 4
Population
Endogenous growth
Direct interaction
Feedback of flows

Macroscopic interaction model



Making the model hybrid: physical network specification with explicit topology and geographical distribution; link capacity evolution with self-reinforcement

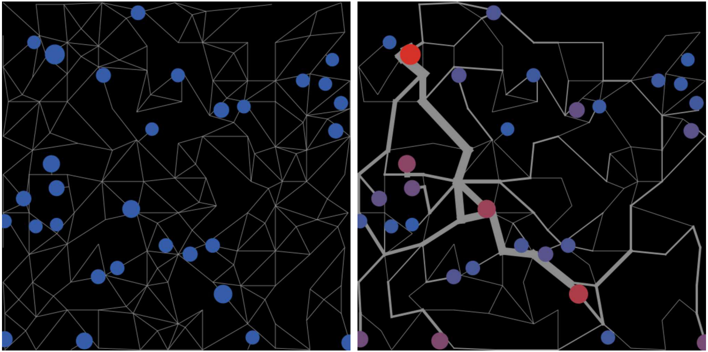
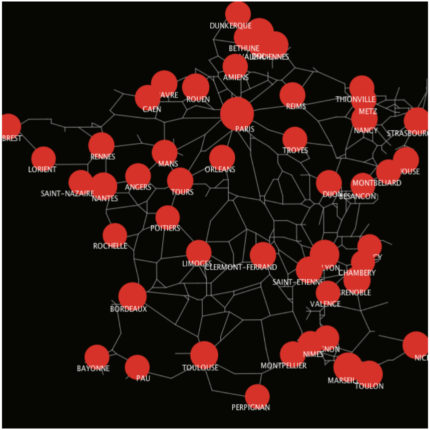
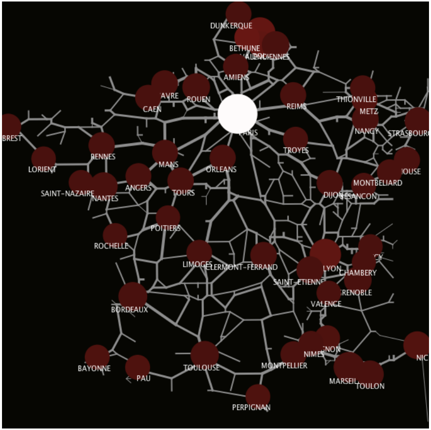


Illustration on a synthetic system of cities

Parametrisation on the French system of cities with temporal windows (see [Raimbault, 2018b]); train network data from [Mimeur et al., 2017]





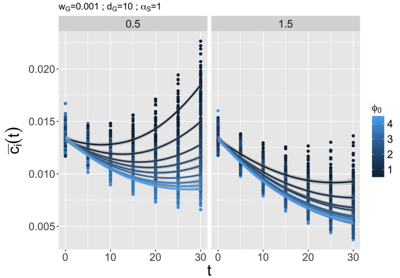
Model exploration and calibration

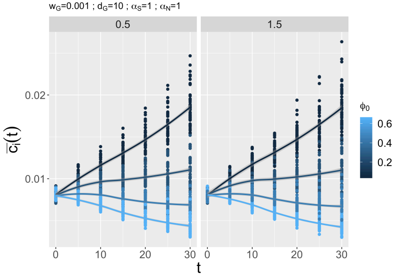
Large experience plan and bi-objective calibration on 9 periods $\rightarrow$ use of genetic algorithms on grid, made smooth with the OpenMOLE software `https://next.openmole.org/`

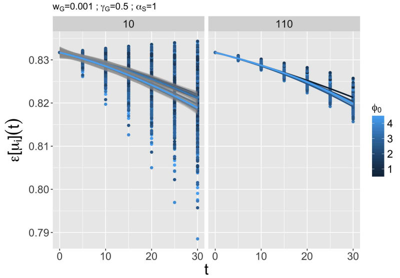
OpenMOLE: (i) embed any model as a black box; (ii) transparent access to main High Performance Computing environments; (iii) model exploration and calibration methods.

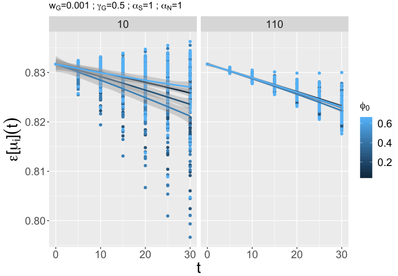
Come to the demonstration tomorrow, and save the date for the next summer school (2020) ! `https://exmodelo.org/`

Qualitatively similar trajectories in time



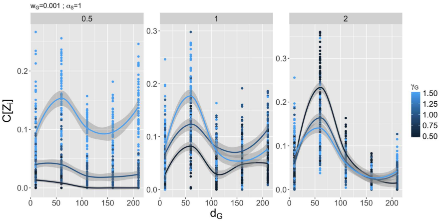


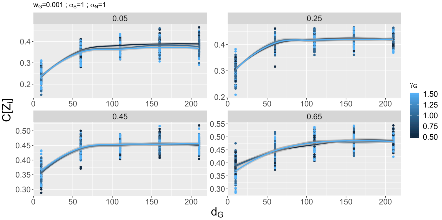


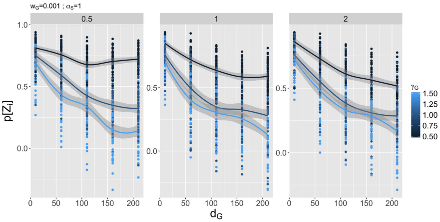


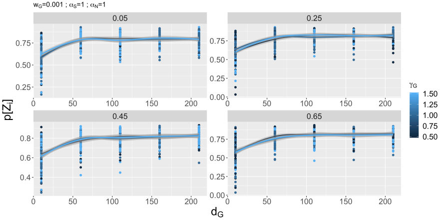
Model behavior

Strongly different qualitative behavior for aggregated indicators



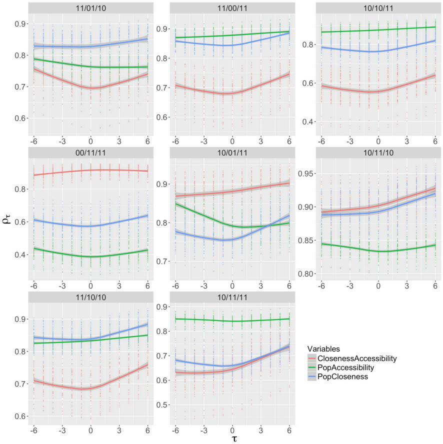


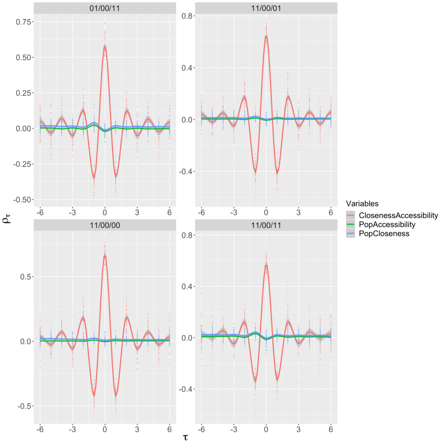




Interaction regimes

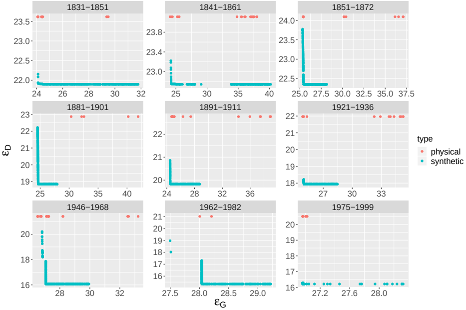
Less co-evolution regimes: similar results than [Raimbault, 2018f] which explored the SimpopNet model (only 3 against 19 co-evolutive regimes)

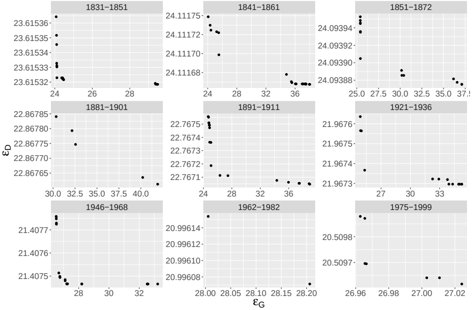




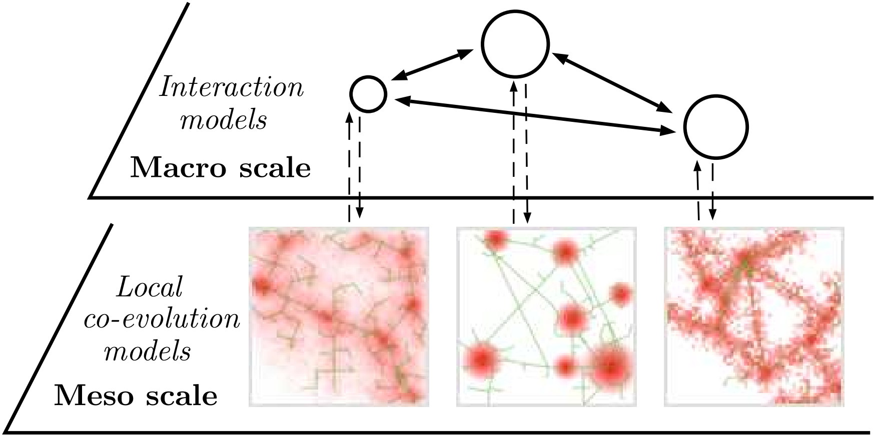
Comparison of regimes with strongest entanglement: auto-correlation bias with virtual network; apparent AR(1) behavior with physical network: sensitivity to indicators definition ?

Much more mediocre results for distance matrices, improvement for population fit on some time windows: converge with the difficulty to characterize co-evolution with the same data [Raimbault, 2019] ?





Theoretical proposal for a multi-scalar model



Several open questions: spatial non-stationarity, nature of inter-scale coupling, level of calibration, operationalization, . . .

Discussion

Implications

$\rightarrow$ Such hybrid models closer or further to the actual complexity of co-evolution ?

$\rightarrow$ Implications for planning still to be determined (two different policy type and level)

Developments

$\rightarrow$ Fair comparison of number of interaction regimes using PSE algorithm [Chérel et al., 2015]; fair comparison of calibrations taking into account number of parameters [Piou et al., 2009]

$\rightarrow$ Multi-modeling for network growth in the hybrid model, including topological evolution [Raimbault, 2018c]

$\rightarrow$ Towards the inclusion of governance processes in co-evolution models [Le Néchet and Raimbault, 2015]

Conclusion

→ Towards multi-scalar models and multi-models, calibrated on several systems of cities [Raimbault, 2018e]: foundations of integrative models for territorial systems

→ Towards an integration of complexities [Raimbault, 2018d] [Raimbault, 2019]: foundations of integrative theories of territorial systems

Some references

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- Code, data and results at
`https://github.com/JusteRaimbault/CoevolutionNwTerritories`

- Acknowledgements to the *European Grid Infrastructure* and its *National Grid Initiatives* (*France-Grilles* in particular) for the technical support and the infrastructure.

Reserve Slides

Macroscopic Interaction Model Rationale

Rationale : extend an interaction model for system of cities by including physical network as an additional carrier of spatial interactions

$\rightarrow$ Work under Gibrat independence assumptions, i.e. $\text{Cov}[P_i(t), P_j(t)] = 0$. If $\vec{P}(t+1) = \mathbf{R} \cdot \vec{P}(t)$ where $\mathbf{R}$ is also independent, then $\mathbb{E}\left[\vec{P}(t+1)\right] = \mathbb{E}[\mathbf{R}] \cdot \mathbb{E}\left[\vec{P}\right](t)$. Consider expectancies only (higher moments computable similarly)

$\rightarrow$ With $\vec{\mu}(t) = \mathbb{E}\left[\vec{P}(t)\right]$, we generalize this approach by taking $\vec{\mu}(t+1) = f(\vec{\mu}(t))$

Macroscopic Model Description

Let $\vec{\mu}(t) = \mathbb{E}\left[\vec{P}(t)\right]$ cities population and (d_{ij}) distance matrix

Model specified by

$$f(\vec{\mu}) = r_0 \cdot \mathbf{Id} \cdot \vec{\mu} + \mathbf{G} \cdot \mathbf{1} + \mathbf{N}$$

with

- $G_{ij} = w_G \cdot \frac{V_{ij}}{<V_{ij}>}$ and $V_{ij} = \left(\frac{\mu_i \mu_j}{\sum \mu_k{}^2}\right)^{\gamma_G} \exp\left(-d_{ij}/d_G\right)$
- $N_i = w_N \cdot \sum_{kl} \left(\frac{\mu_k \mu_l}{\sum \mu}\right)^{\gamma_N} \exp\left(-d_{kl,i}\right)/d_N$ where $d_{kl,i}$ is distance to shortest path between k, l computed with slope impedance $(Z = (1 + \alpha/\alpha_0)^{n_0}$ with $\alpha_0 \simeq 3)$

Given the flow ϕ in a link, its effective distance is updated following

1. For the thresholded case

$$d(t+1) = d(t) \cdot \left(1 + g_{max} \cdot \left[\frac{1 - \left(\frac{\phi}{\phi_0}\right)^{\gamma_s}}{1 + \left(\frac{\phi}{\phi_0}\right)^{\gamma_s}}\right]\right)$$

2. For the full growth case

$$d(t+1) = d(t) \cdot \left(1 + g_{max} \cdot \left[\frac{\phi}{\max \phi}\right]^{\gamma_s}\right)$$

where γ_s is a hierarchy parameter, ϕ_0 a threshold parameter and g_{max} the maximal growth rate easily adjustable to realistic values by computing $(1 + g_{max})^{t_f}$

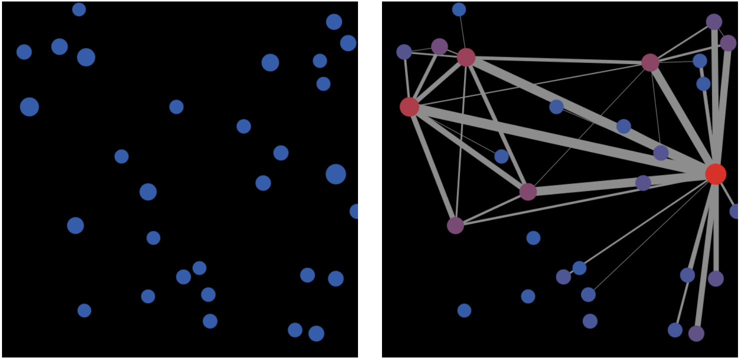
Model Description : Indicators

- Hierarchy, Entropy, Summary statistics in time
- Initial-final rank correlation (changes in the hierarchy) for variable X : $\rho\left[X_i(t=0), X_i(t=t_f)\right]$
- Trajectory diversity for variable X : with $\tilde{X}_i(t) \in [0;1]$ rescaled trajectories,

$$\frac{2}{N\cdot(N-1)}\sum_{i<j}\left(\frac{1}{T}\int_t\left(\tilde{X}_i(t)-\tilde{X}_j(t)\right)^2\right)^{\frac{1}{2}}$$

- Average trajectory complexity (number of inflexion points)
- Pearson correlations conditionally to distance $\hat{\rho}_d\left[(X(\vec{x}_1, Y(\vec{x}_2))\middle|\,||\vec{x}_1-\vec{x}_2|| \sim d\right]$
- Lagged return correlations $\hat{\rho}_\tau\left[\Delta X(t), \Delta Y(t-\tau)\right]$ (Granger causality)

Complete virtual network between cities, initialized with euclidian distances ; thresholded reinforcement of speeds as a function of flows.



Exemple of run ($t_f = 30$). Level of red gives overall growth and link width flows.

Synthetic system of cities

Generation of synthetic systems of cities for model exploration:

- Cities at random locations (farther from each other by a fixed radius $r_0 = 10$); population distribution with a scaling law $P_i = P_0 \cdot i^{-\alpha_S}$ (α_S parameter, $P_0 = 100000$, for $N = 30$ cities)
- Create a grid network with nodes at a fixed distance $r_N = 15$; remove a fixed proportion $p_l = 0.2$ of links; jitter node positions by $\pm r_N$ for each coordinate (avoids ties in shortest routes and oscillating behaviors e.g.)
- Connect cities to the network with euclidian projection to closest link

Applying the method of [Raimbault et al., 2018] for spatial sensitivity to the SimpopNet model, [Raimbault, 2018f] shows that the model is sensible to some (e.g. α_S) $\rightarrow$ remains to be checked here.

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