Models of growth for system of cities : Back to the simple

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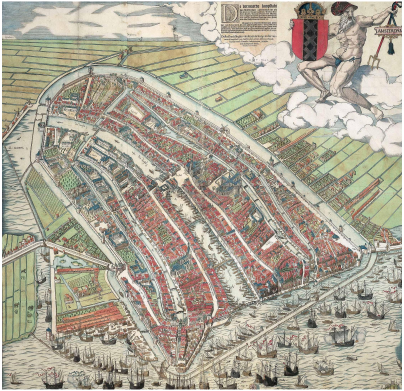
CCS 2016 - Amsterdam

Session Urban 3

22th September 2016

Modeling Urban Growth

Growth in Urban Systems : multi-scalar, heterogeneous drivers, bifurcations and path-dependancy



Source : Wikipedia

Spatial Interaction and Urban Growth

Role of spatial interactions in Urban Growth ?

→ gravity-based flows influence population growth in a synergetic formulation [Sanders, 1992]

→ Simpop models (from Simpop1 to SimpopLocal) [Pumain, 2012] : agent-based approaches ; more recently Marius [Cottineau et al., 2015] closer to system dynamics

→ Simple random growth (Gibrat model) becomes quickly complex by adding spatial interaction [Bretagnolle et al., 2000] ; refined extension with waves of innovation in [Favaro and Pumain, 2011]

Research Objective

→ *Between complex ABM and non-geographical models in economics/physics, what place for simple models of growth in Urban Systems ?*

→ *Modulation of simple mechanisms to check for necessity/sufficiency : multi-modeling in models of simulation*

Research Objective : Extend Gibrat simple model of growth in system of cities with spatial interactions and feedbacks through physical networks ; Explore systematically and calibrate such families of models

Model Rationale

Rationale : extend an interaction model for system of cities by including physical network as an additional carrier of spatial interactions (see [Raimbault, 2016b] for developed theoretical context)

$\rightarrow$ 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 $\vec{\mu}(t+1) = f(\vec{\mu}(t))$

Model Formulation

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

Model specified by

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

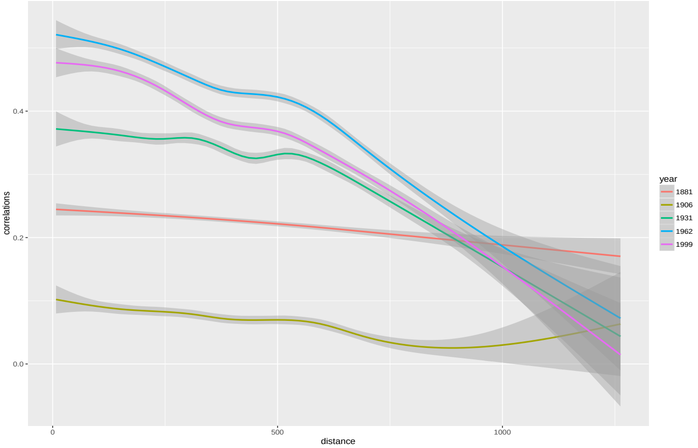
with

- $G_{ij} = w_G \cdot \frac{V_{ij}}{<V_{ij}>}$ 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 $\alpha_0 \simeq 3)$

Data : stylized facts

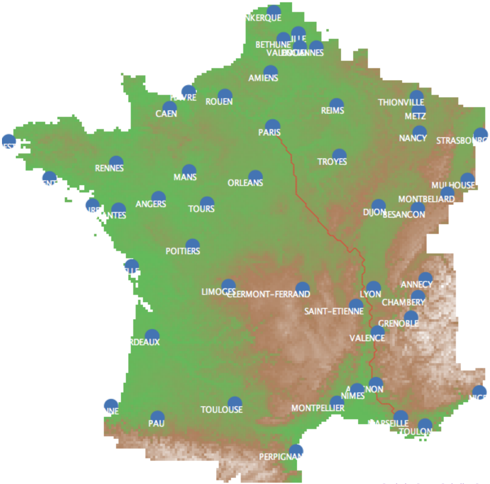
Population data for French-cities (Pumain-INED database : 1831-1999)

Non-stationarity of log-returns correlations function of distance



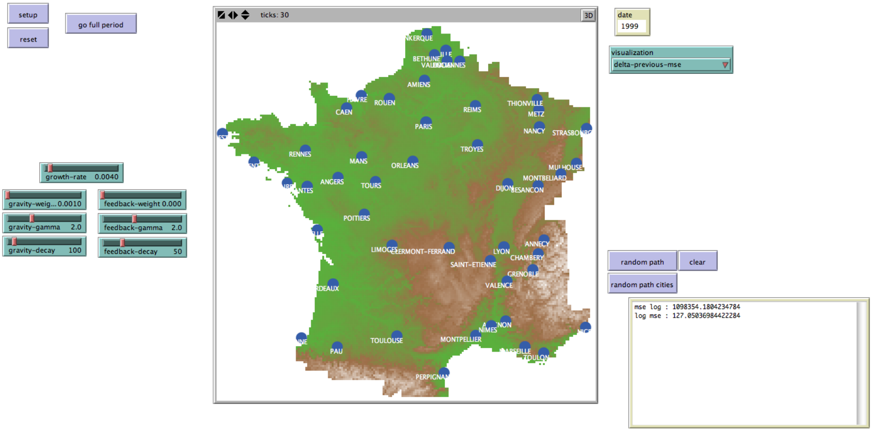
Data : geographic abstract network

Physical transportation network abstracted through a geographical shortest path network



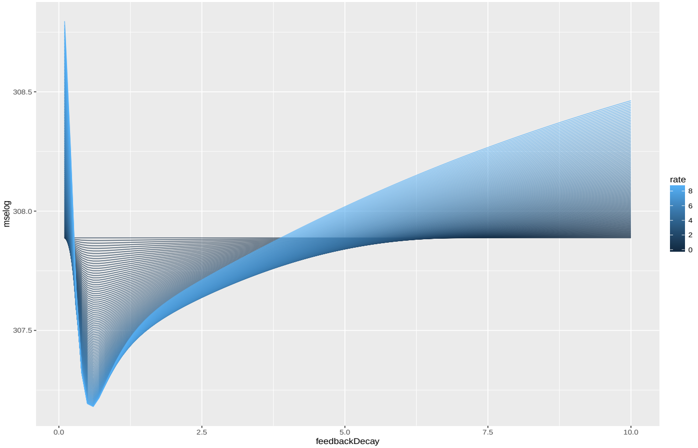
Implementation

On the importance of visualization in spatial models : complementary implementations in NetLogo/R/Scala



Results : model exploration

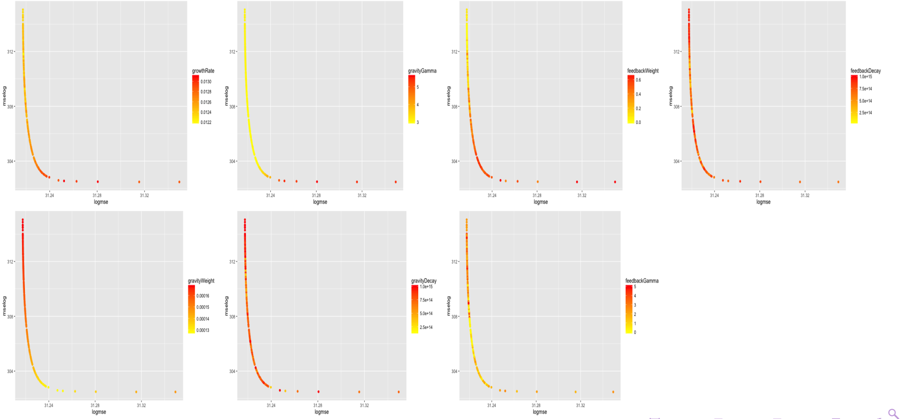
Evidence of physical network effects : fit improve through feedback at fixed gravity



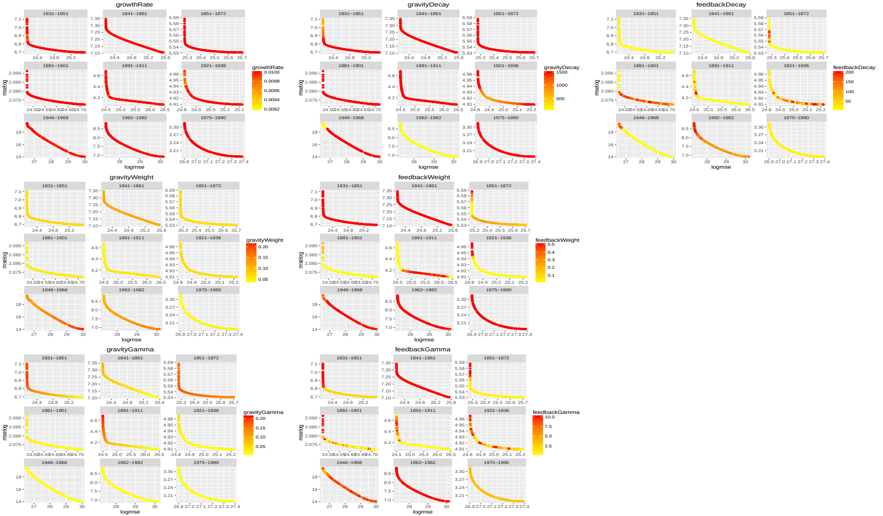
Results : model calibration

Model calibration using GA on computation grid, with software `OpenMole` [Reuillon et al., 2013]

Pareto front for full model calibration, objectives MSE and MSE on logs



Results : non-stationary model calibration



Quantifying overfitting : Empirical AIC

Not clear nor well theorized how to deal with overfitting in models of simulation. **Intuitive idea :** Approximate gain of information by approaching models of simulation by statistical models.

Let $M_k^* = M_k\left[\alpha_k^*\right]$ computational models heuristically fitted to the same dataset. With $S_k \simeq M_k^*$, we show that $\Delta D_{KL}\left(M_k^*, M_{k'}^*\right) \simeq \Delta D_{KL}\left(S_k, S_{k'}\right)$ if fits of S_k are negligible compared to fit difference between computational models and models have same parameter number.

Application M_1 : gravity only model with $(r_0 = 0.0133, w_G = 1.28e-4, \gamma_G = 3.82, d_G = 4e12)$; M_2 : full model with $(r_0 = 0.0128, w_G = 1.30e-4, \gamma_G = 3.80, d_G = 8.4e14, w_N = 0.603, \gamma_N = 1.148, d_N = 7.474)$
Fitting of independent polynomial models ($\tilde{P}_i(t) = Q\left[\tilde{P}_i(t-1)\right]$) with 4 and 7 parameters) gives $\Delta D_{KL} \simeq 19.7 \rightarrow$ fit improvement without overfitting

Discussion

Theoretical and Methodological Implications

→ Indirect confirmation of known stylized facts (such as *tunnel effect* through non-stationary calibration)

→ For a better integration of theory, empirical and modeling on network aspects in evolutive urban theories

→ Methodology : first steps for empirical AIC in multi-modeling

Further Developments

→ Need to validate the approach on other system/subsystem of cities [Pumain et al., 2015]

→ Add Real Network in a static/dynamic way : towards models of co-evolution of cities and network [Raimbault, 2016b]

→ Coupling with growth models at other level, as e.g. mesoscopic reaction-diffusion model [Raimbault, 2016a]

Conclusion

→ Simple models of complex systems can have strong explanatory power, and be used to test hypothesis/confront a theory

→ Crucial role of interdisciplinarity and integration theory/empirical and qualitative/quantitative

- All code and data available at `https://github.com/JusteRaimbault/CityNetwork/tree/master/Models/NetworkNecessity/InteractionGibrat`

Reserve slides

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Calibration with fixed gravity effects (iterative calibration)