Thesis Progress Meeting

J. Raimbault[1,2]

[1]Géographie-cités (UMR 8504 CNRS)
[2]LVMT (UMR-T 9403 IFSTTAR)

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Achieved Work (by projects)

- Biblio/Meetings/Organisation [0.7w]
- Conference [0.7w]
- Reading Records (*Synergetics* [Sanders, 1992]) [0.2w]
- Monitorat [1,3w]
- Cybergeo Project [1w]
- Correlated Synthetic data [3w]
- Theory construction (communication JIG) [0.2w]
- BP Case Study / Spatial Econometrics [0,3w]

Context

[Introduction at Rochebrune] : imagine a model of simulation describing skiers/ snowboarders relations, measures to improve situation ? NO conclusion without model exploration, including sensitivity to ressort station spatial configuration, or to population structure, even at second order → Necessity in that case (among others) to generate synthetic data controlled at second order.

Def. : *Synthetic Data* are output of generative models (and possibly inputs of models using them).

Methodology used in various fields, e.g. therapeutic evaluation [Abadie et al., 20 territorial systems analysis [Moeckel et al., 2003, Pritchard and Miller, 2009], machine learning [Bolón-Canedo et al., 2013] or bio-informatics [Van den Bulcke

Few examples at the second order : specific examples as [Ye, 2011] for discrete choices ; methods that can be interpreted this way : generation of complex networks [Newman, 2003].

Generic Method

$\vec{X}_I$ multidimensional stochastic process, $\mathbf{X} = (X_{i,j})$ realizations.

Aim : Generate a statistical population $\tilde{\mathbf{X}} = \tilde{X}_{i,j}$ such that:

1. proximity to data : given a precision ε and an indicator f, $\|f(\mathbf{X}) - f(\tilde{\mathbf{X}})\| < \varepsilon$
2. control of the estimated correlation structure : $\hat{\mathrm{Var}}\left[(\tilde{X}_i)\right] = \Sigma R$ with R fixed.

Geographical data : Context

- In geography, generation of synthetic populations for agent-based models [Pritchard and Miller, 2009].
- Generation of spatial synthetic configuration not used (Geo. Weighted Regression [Brunsdon et al., 1998] can be interpreted this way) ; however crucial for abstract models [Schmitt, 2014]
- [Cottineau et al., 2015] recently proposed to estimate the sensitivity of spatial models of simulation to initial configuration (application to Schelling model).
- Case study : city-transportation interactions, complex to understood quantitatively [Offner, 1993, Bretagnolle, 2009] $\rightarrow$ simple model of population density and transportation network morphogenesis.

Model

Simple coupling between

- Iterative generation of a density grid by preferential attachment/diffusion [Raimbault, 2016] calibrated on morphological objectives on european density grid.

- Heuristic network generation conditional to density :
  - Distribution of a fixed number of centers preferentially following density
  - Deterministic percolation between closest neighbors
  - Breaking of interaction potentials

$$V_{ij}(d) = \left[(1-k_h) + k_h \cdot \left(\frac{P_i P_j}{P^2}\right)^{\gamma}\right] \cdot \exp\left(-\frac{d}{r_g(1+d/d_0)}\right)$$

    for a fixed number of couples N_L such that $V_{ij}(d_N)/V_{ij}(d_{ij})$ is minimal among $K \cdot N_L$ strongest euclidian potentials ($K=5$ fixed)
  - Planarization

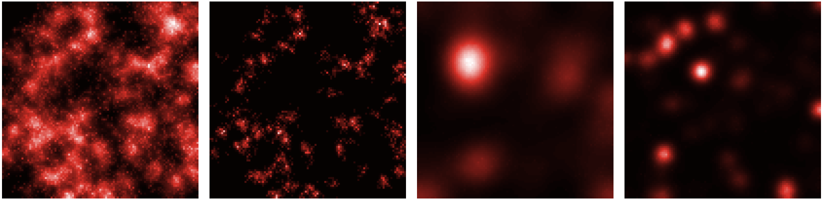
Indicators : morphology [Le Néchet, 2015] (Moran, mean distance, entropy, hierarchy) and network (centrality, mean width, speed, diameter).

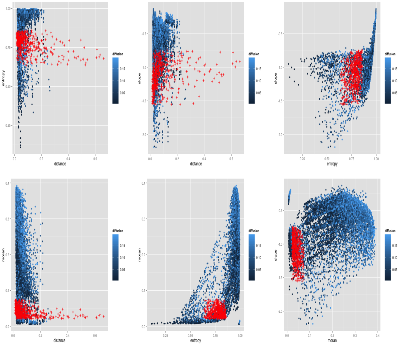
Implementation and Exploration

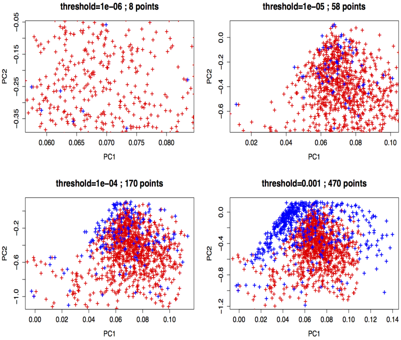
$\rightarrow$ Formal and Operational coupling : modular implementation (`scala/NetLogo`
encapsulated by `OpenMole` [Reuillon et al., 2013]

$\rightarrow$ Exploration by intensive computation on grid via `OpenMole` : calibration of density model alone ($\sim 1.5 \cdot 10^6$ runs) ; brutal exploration by LHS sampling for feasible correlations ($\sim 5 \cdot 10^4$ runs)

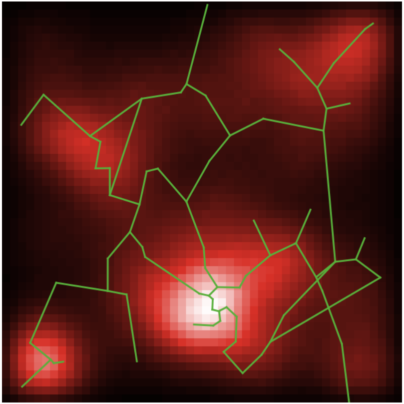
Results : Density Model alone

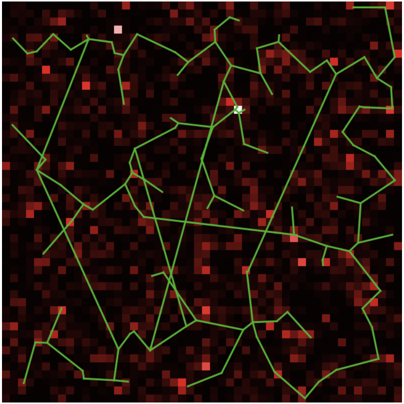




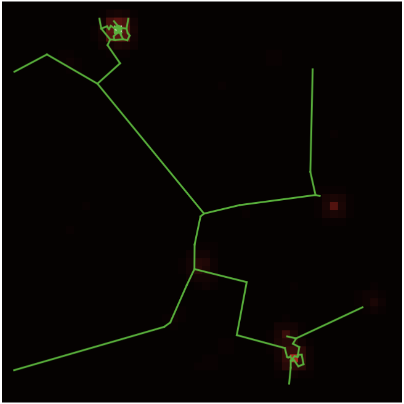


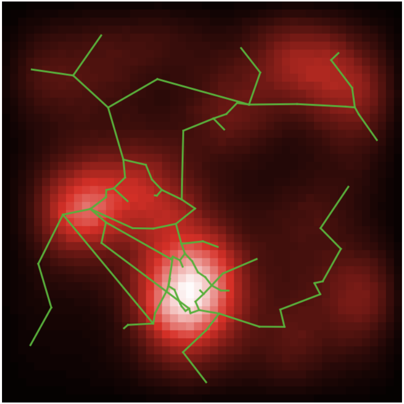
Results : examples of configurations



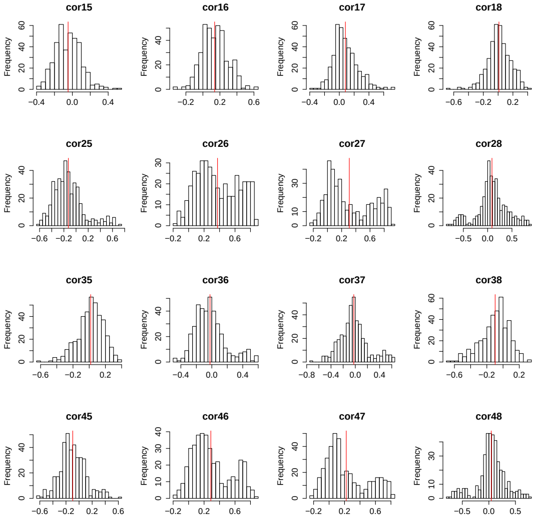


Results : examples of configurations



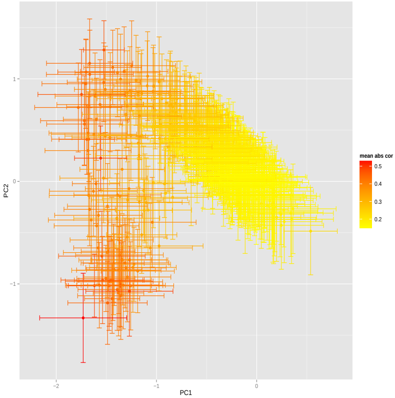


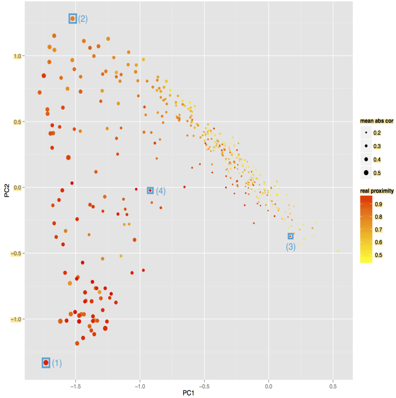
Results : cross-correlations



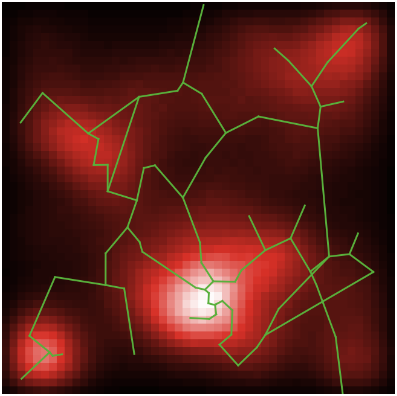
Results : feasible correlations

Mean matrices in a principal plan

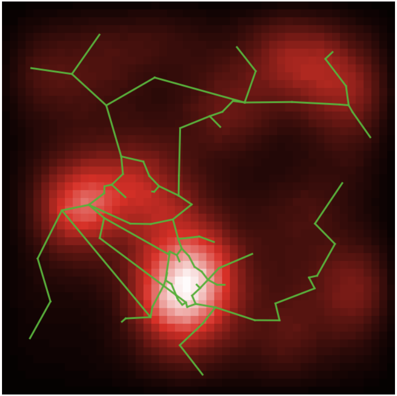




Results : exemples of correlations



$\rho[\bar{d}, \bar{c}] \simeq 0.34$



$\rho[\bar{d}, \bar{c}] \simeq -0.41$

$\rightarrow$ *gravity hierarchy more important in (1)* $\gamma = 3.9, k_h = 0.7$ *against* $\gamma = 1.07, k_h = 0.25$ *for (2)*

Applications

1. Calibration of the coupled model, street network data (edge effects!)
   $\rightarrow$ generation of correlated synthetic data corresponding to a given urban system
   $\rightarrow$ intrinsic correlations to be compared to estimated correlations between different states : non-ergodicity of urban systems [Pumain, 2012]).

2. Dynamical correlations in a strongly coupled model / spatio-temporal correlations in a strong spatial coupling.

Case study : Context

Database by Florent : main road network (route 120) in extended *Bassin Parisien* with opening dates for highways ; census data : population and employment of *communes* at dates [other data such as rail network and train timetables not used for now].

Formalisation : Dynamic transportation network $n(\vec{x}, t)$ within a dynamic territorial landscape $\vec{T}(\vec{x}, t)$, which components are population $p(\vec{x}, t)$ and employments $e(\vec{x}, t)$, discretized in space and in time, i.e. the spatial field $\vec{T}$ is summarized by $\mathbf{T} = \left(\vec{T}(\vec{x}_i, t_j)\right)_{i,j}$ with $1 \leq i \leq N$ and $1 \leq j \leq T$. To simplify, network distances sampled at same times and spatial points (support extended if not the case), given by $\mathbf{N} = \left(\vec{d}_n(\vec{x}_i, t_j)\right)_{i,j}$.

On Accessibility

Is the notion of accessibility crucial for statistical analysis ?

Weibull has proposed an axiomatic approach to accessibility [Weibull, 1976], deriving a canonical decomposition for any *attraction-accessibility* function $A(a, d)$, assuming expected thematic axioms among others technical ones that are :

1. A is invariant regarding the order of the configuration
2. A decrease with distance at fixed attraction and increase with attraction at fixed distance
3. A is invariant when adding null attractions and constant configurations

Then A verifies these *iff* it is of the form

$$A\left[(a_i, d_i)\right] = T\left(\bigoplus_i z(d_i, a_i)\right)$$

where T is increasing with null origin, z is a *distance substitution function* (i.e. verifying axiom 2) and $\oplus$ a *standard composition* associating two attractions at zero distance to th corresponding unique one.
$\rightarrow$ *Well suited matrices of autocorrelation should capture accessibility in regressions ; or captured by non-linear regression on* $\mathbf{N}$

Accessibility as potential ?

Given any stationary dynamic for n, $\vec{T}$, Helmoltz theorem states that it derives from a potential (can be adapted to non-stationary dynamics with time-varying potential).

Statistical Analysis

Large set of analysis to be tested (non exhaustive) :

- On data :
  - Multivariate models $\mathcal{L}\left[\mathbf{T},\mathbf{N}\right] \sim \varepsilon$
  - Autocorrelated univariate models $(\mathbf{I} - \Sigma RW)\mathbf{X} \sim \varepsilon$
  - Autocorrelated multivariate models $(\mathcal{L}' - \Sigma RW)\left[\mathbf{T}+\mathbf{N}\right] \sim \varepsilon$
  - Geographically Weighted Regression [Brunsdon et al., 1998]

$$\mathcal{L}\left[\mathcal{G}\left(\mathbf{T},\mathbf{N}\right)\right] \sim \varepsilon$$

  - Granger causality tests : [Xie and Levinson, 2009] use Granger causality to link transit with land-use changes.
- On data returns :
  - Autoregressive multivariate models

$$\mathcal{L}\left[(\Delta\mathbf{T}(t_{j'}))_{j'\leq j},(\Delta\mathbf{N}(t_{j'}))_{j'\leq j}\right] \sim \varepsilon$$

  - Autoregressive autocorrelated multivariate models : idem with spatial autocorrelation term.
  - Synthetic Instrumental Variables : static territory and/or network ?

P. Bourgine framework for Complex Adaptive Systems

Bourgine has recently developed a framework to extract patterns of Complex Adaptive Systems, using a representation theorem : any discrete stationary process is a *Hidden Markow Model* (Knight, 1975)
Given the definition of a causal state as $\mathbb{P}[future|A] = \mathbb{P}[future|B]$, the partition of system states induced by the corresponding equivalence relations allows to derive a *Recurrent Network* that is enough to determine next state of the system, as it is a *deterministic* function of previous state and hidden states [Shalizi and Crutchfield, 2001] :

$$(x_{t+1}, s_{t+1}) = F\left[(x_t, s_t)\right]$$

$\rightarrow$ *Estimation of Hidden States and of the Recurrent Function thus captures through deep learning entirely dynamical patterns of the system, i.e. full information on its dynamics and internal processes.*

Some questions for an application to Geography :

- Can the stationarity assumption be tackled through augmentation of system states ?
- Can heterogeneous and asynchronous data be used to bootstrap long time-series necessary for a correct estimation of the neural network ?

Next steps (until February 15th 2016)

- Theory exemplification, paper finalization [1w]
- Spatial Econometrics / Case study [0.5w]
- Cybergeo [0.5w]
- Wrap everything within a 1-year Memoire [1w]

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