Towards a Theory of Co-evolutive Networked Territorial Systems: Insights from Transportation Governance Modeling in Pearl River Delta, China

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Medium Project Seminar

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New pathways for sustainable urban development in China's medium-sized cities

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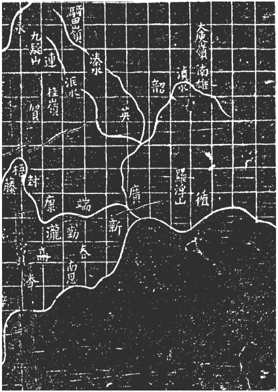
Complex Urban Systems



Source : Wikipedia

Complex Systems Approaches in Science

→ Failure of reductionism already highlighted by Anderson in 1972 [Anderson, 1972]

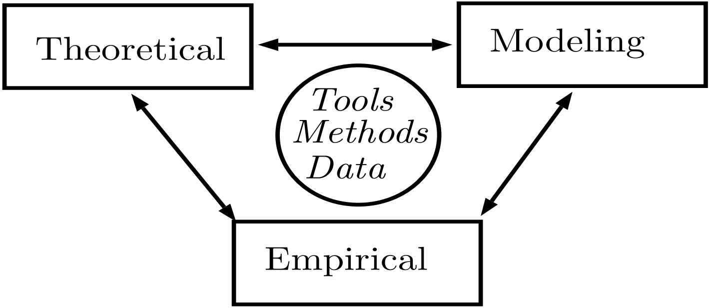
→ Yet few domains with Integrative Theories : see e.g. Economics [Farmer and Foley, 2009], Urban Science [Portugali, 2012]

→ Even physics begins to realize the potential of this "New Kind of Science [Wolfram, 2002] : Quantum coherence paradox solved through computational complexity [Bolotin, 2014] ; Very recent theory of emergent gravity solves Dark Matter issue [Verlinde, 2016]

→ Towards Complex Systems Sciences aiming at vertical integration (integrative disciplines) and horizontal integration (interdisciplinary transversal problems) : see e.g. CS roadmap [Bourgine et al., 2009]

Theoretical and Quantitative Geography

An extended framework for TQG [Livet et al., 2010]



To go further : speculative embedding of this scheme into a meta-modeling framework [Raimbault, 2016d]

Complex Urban Systems

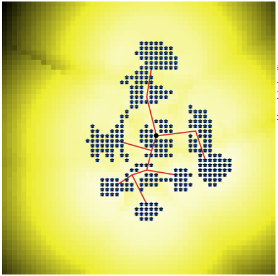
Research Context : *Investigate relations between Networks and Territories, in particular through the construction of models of co-evolution between land-use and transportation network, strangely absent in the literature [Raimbault, 2015].*

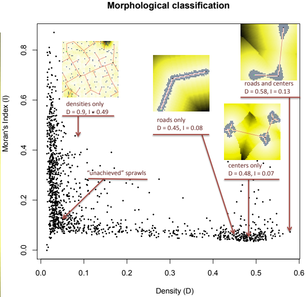
→ Collection of evidences from previous research ; proposition of a geographical theory

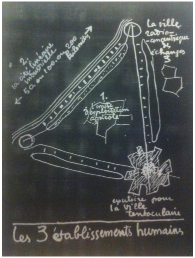
→ Application to Transportation Governance Modeling ; potential insights from application to Pearl River Delta

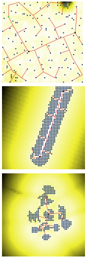
Meso-scale Coupled Growth

Simple co-evolutionary dynamics produce stylized urban forms at a mesoscopic scale [Raimbault et al., 2014]



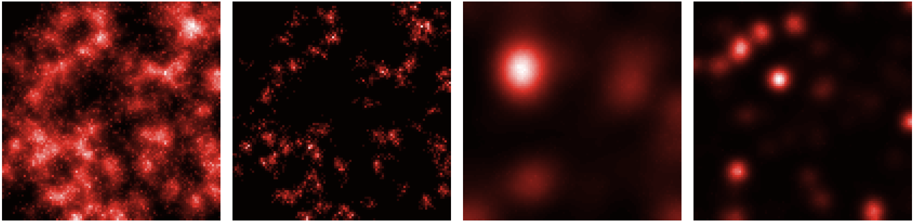


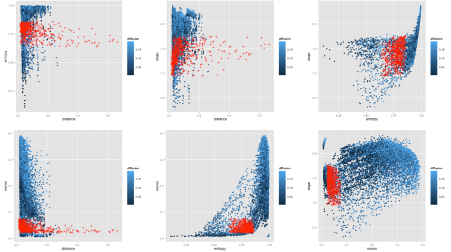


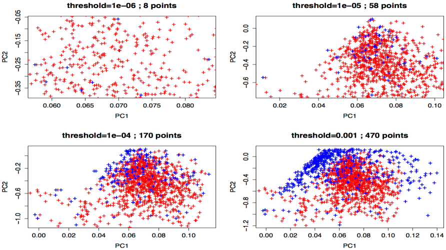


Aggregation-diffusion Urban Growth

Evidence of autonomous Morphogenetic processes : morphological calibration of an Aggregation-diffusion growth model







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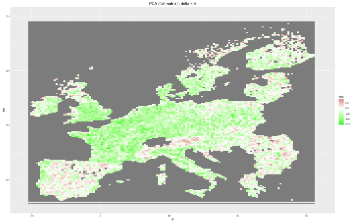
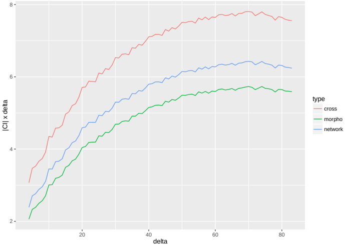
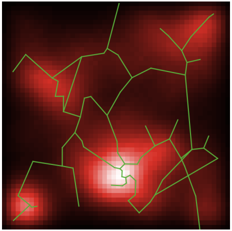
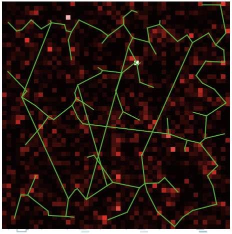
Coupled Growth and Correlations

Spatial non-stationarity of correlation matrix between urban morphology and network topology [Raimbault, 2016a] ; coupled growth model yield a large range of potential correlations [Raimbault, 2016b]



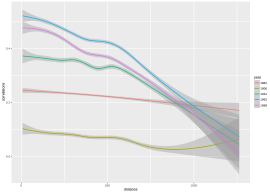


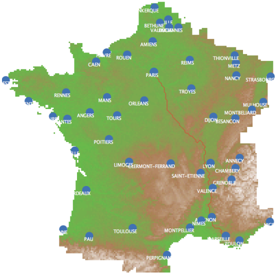


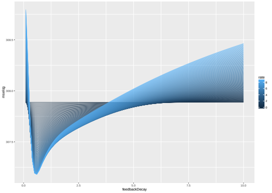


Macro-scale Growth and Network Necessity

Macro-scale population growth model reveals physical network effects in French System of Cities [Raimbault, 2016c]







Theory : Pillars

1. *Networked Human Territories* → Raffestin approach to territory combined with Dupuy theory of networks.
2. *Evolutive Urban Theory* → City Systems as complex Adaptive systems, applied to human settlements in general and thus territorial systems.
3. *Urban Morphogenesis* → Morphogenesis as autonomous rules to explain growth of urban form. Used as the provider of modular decompositions.
4. *Boundaries and Co-evolution* → Co-evolution as the existence of *niche*, consequence of boundary patterns.

Theory : Specification

Definition : Territorial systems are networked Human Territories. They are multi-level complex adaptive systems following Evolutive Urban Theory.

Hypothesis : The existence of Morphogenetic processes in which networks are essential drivers is equivalent to the existence of co-evolutive niches in territorial systems. We call thus these *Co-evolutive Networked Territorial Systems*.

The LUTECIA Model : Rationale

Mega-city Regions [Hall and Pain, 2006] exhibit new qualitative regimes of urban systems ?

→ A LUTI + infrastructure provision model (LUTECIA)

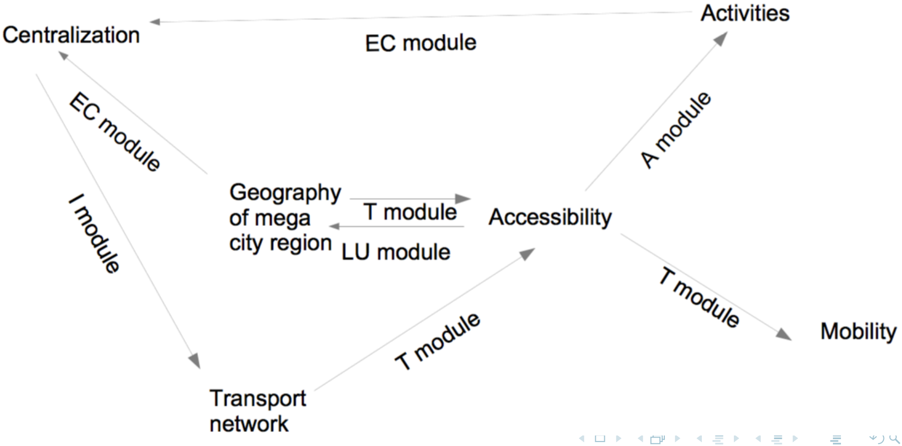
→ Coevolution transport / urbanism (LUTI model with endogeneous transport infrastructure provision)

→ Game theory framework to predict emergence of centralized decision within a polycentric region

→ Importance of accessibility at MCR scale

The LUTECIA Model : Structure

LU : Land Use module ; T : Transport module ; EC : Evaluation of Centralized decision module ; I : Infrastructure provision module ; A : Agglomeration economies module



Governance Modeling

Matrix of actors utilities, depending on respective choices

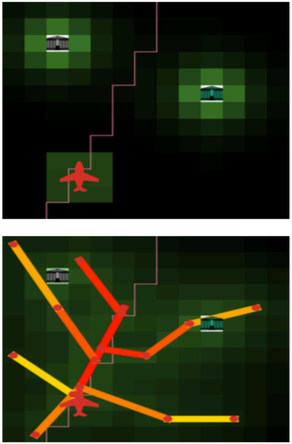
1 | 2	C	A
C	$U_i = \kappa \cdot \Delta X_i(Z_C^*) - I - \frac{\delta I}{2}$	$\begin{cases} U_1 = \kappa \cdot \Delta X_1(Z_1^*) - I \\ U_2 = \kappa \cdot \Delta X_2(Z_2^*) - I - \frac{\delta I}{2} \end{cases}$
A	$\begin{cases} U_1 = \kappa \cdot \Delta X_1(Z_1^*) - I - \frac{\delta I}{2} \\ U_2 = \kappa \cdot \Delta X_2(Z_2^*) - I \end{cases}$	$U_i = \kappa \cdot \Delta X_i(Z_i^*) - I$

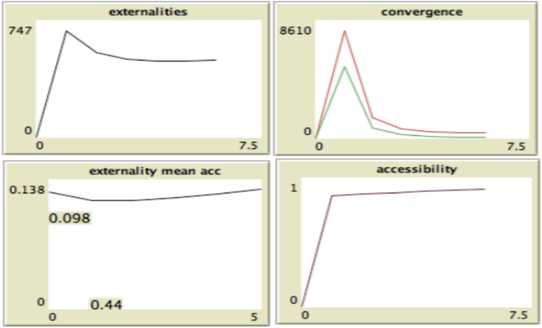
Two types of games implemented :

- Mixed Nash equilibrium, where actors compete
- One Rational Discrete Choice equilibrium

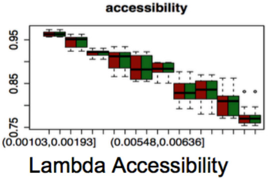
Model Output : Examples

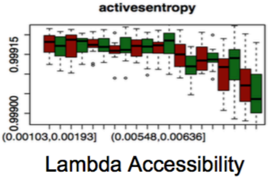
Implementation : Netlogo ; particular treatment for dynamical programming computation of network shortest distances. Exploration with High Performance Computing on grid with `OpenMole` [Reuillon et al., 2013]

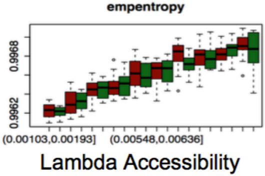


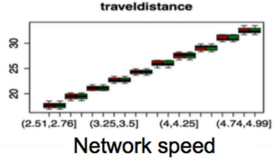


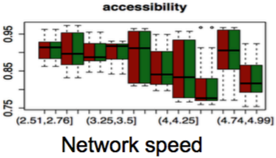
Model Exploration : Examples



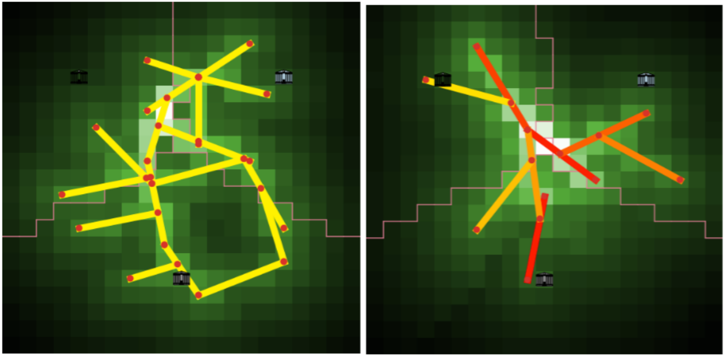








Long Time Limits for Transportation Networks



Application to Pearl River Delta Mega-city Region

Stylized characteristics of Pearl River Delta make a perfect candidate for model application

附图2　珠三角高快速路布局规划图

Source : Guangdong Province Government

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Application to Pearl River Delta

Specific characteristics :

- Regional Governance new level of State action ; Mega-city region roughly at regional scale.
- Large development of infrastructures in a relatively short time
- Local and Regional Transportation masterplans at different dates
- Bridges across the delta : expensive infrastructure, require difficult collaboration
- High economic competition between cities ; particular role of Hong-Kong and Macao

Application : Experience plan and Expected Results

Requirements :

- Thematic model adaptation
- Technical model adjustments

Experience plan :

- Conditions for emergence of the functional MCR
- Calibrate model retrospectively : unveil governance processes
- Calibrate model on planned infrastructure : collaboration patterns equivalent to a central planning
- Calibrate model on optimal infrastructure (multi-objectives to be determined) : what are corresponding "optimal" governance structures ?

Conclusion

→ From this particular model and the case study, theory should be confirmed/informed/refined/etc. (ex. : network plays indeed a crucial role in governance bifurcations, territorial systems should include explicit agents, etc.)

→ Knowledge production process is itself a metaphor of studied geographical processes : co-evolutive and complex.

→ Vertical and Horizontal integration : Interdisciplinarity beyond qualitative/quantitative artificial distinctions

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

Reserve Slides

Governance Game Specification

Mixed Nash equilibrium probability :

$$p_i = \frac{J}{\Delta X_{\bar{i}} Z^\star_C - \Delta X_{\bar{i}} Z^\star_{\bar{i}}}$$

Discrete Choice model :

$$U_i(C) - U_i(NC) = p_{\bar{i}}(\Delta X_i Z^\star_C - \Delta X_i Z^\star_i) - J$$

then

$$p_i = \frac{1}{1 + \exp\left(-\beta_{DC} \cdot \left(\frac{\Delta X_i Z^\star_C - \Delta X_i Z^\star_i}{1+\exp\left(-\beta_{DC}(p_i \cdot (\Delta X_{\bar{i}} Z^\star_C - \Delta X_{\bar{i}} Z^\star_{\bar{i}}) - J)\right)} - J\right)\right)}$$

Lutetia : default parameter values

$A_{max} = E_{max} = 500; r_A = 1; r_E = 0.8; \gamma_E = 0.9; \gamma_A = 0.65; \beta_I = 1.8; \lambda = 0.005; r_0 = 2$

$N_{expl} = 25; I = 0.001; J = 0.0001; \nu = 5; E_{ext}(t_0) = 3E_{max}; t_f = 4$

Lutetia : Land-use Initialization

Initial distribution of Actives and Employments around governance centers at positions $\vec{x}_i$ by

$$A(\vec{x}) = A_{max} \cdot \exp\left(\frac{\|\vec{x} - \vec{x}_i\|}{r_A}\right); E(\vec{x}) = E_{max} \cdot \exp\left(\frac{\|\vec{x} - \vec{x}_i\|}{r_E}\right)$$

Lutetia : Transportation

Transportation module : computation of flows ϕ_{ij} by solving on p_i, q_j by a fixed point method (Furness algorithm), the system of gravital flows

$$\begin{cases} \phi_{ij} = p_i q_j A_i E_j \exp\left(-\lambda_{tr} d_{ij}\right) \\ \sum_k \phi_{kj} = E_j ; \sum_k \phi_{ik} = A_i \\ p_i = \frac{1}{\sum_k q_k E_k \exp\left(-\lambda_{tr} d_{ik}\right)} ; q_j = \frac{1}{\sum_k p_k A_k \exp\left(-\lambda_{tr} d_{kj}\right)} \end{cases}$$

Trajectories then attributed by effective shortest path, and corresponding congestion c obtained (no Wardrop equilibrium).
Speed of network given by BPR function $v(c) = v_0 \left(1 - \frac{c}{\kappa}\right)^{\gamma_c}$. Congestion not used in current studies (infinite capacity κ).

Lutetia : Land-use Evolution

Land-Use module : we assume that residential/employments relocations are at equilibrium at the time scale of a tick, that corresponds to transportation infrastructure evolution time scale which is much larger (Bretagnolle, 2009).
We take a Cobb-douglas function for utilities of actives/employments at a given cell

$$U_i(A) = X_i(A)^{\gamma_A} \cdot F_i(A)^{1-\gamma_A}; F_i(A) = \frac{1}{A_i E_i}$$

$$U_j(E) = X_j(E)^{\gamma_E} \cdot F_j(E)^{1-\gamma_E}; F_j(E) = 1$$

where $X_i(A) = A_i \cdot \sum_j E_j \exp\left(-\lambda \cdot d_{ij}\right)$ and $X_j(E) = E_j \cdot \sum_i A_i \exp\left(-\lambda \cdot d_{ij}\right)$.
Relocations are then done deterministically following a discrete choice model :

$$A_i(t+1) = \sum_i A_i(t) \cdot \frac{\exp\left(\beta U_i(A)\right)}{\sum_i \exp\left(\beta U_i(A)\right)}$$

$$E_j(t+1) = \sum_j E_j(t) \cdot \frac{\exp\left(\beta U_j(E)\right)}{\sum_j \exp\left(\beta U_j(E)\right)}$$

Lutetia : Network Distance Computation

Effective distances computation

- Euclidian distance matrix $d(i,j)$ computed analytically
- Network shortest paths between network intersections (rasterized network) updated in a dynamic way (addition of new paths and update/change of old paths if needed when a link is added), correspondance between network patches and closest intersection also updated dynamically ; $O(N_{inters}^3)$
- Weak component clusters and distance between clusters updated ; $O(N_{nw}^2)$
- Network distances between network patches updated, through the heuristic of only minimal connexions between clusters ; $O(N_{nw}^2)$
- Effective distances (taking paces/congestion into account) updated as minimum between euclidian time and $\min_{C,C'} d(i,C) + d_{nw}(p_C(i), p'_C(j)) + d(C',j)$; $O(N_{clusters}^2 \cdot N^2)$ [Approximed with $\min_C$ only in the implementation, consistent within the interaction ranges ~ 5 patches taken in the model].

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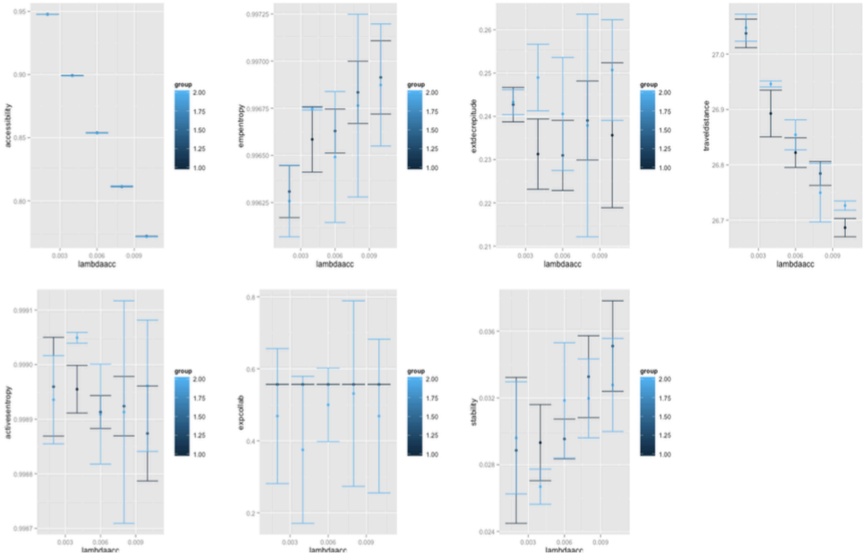
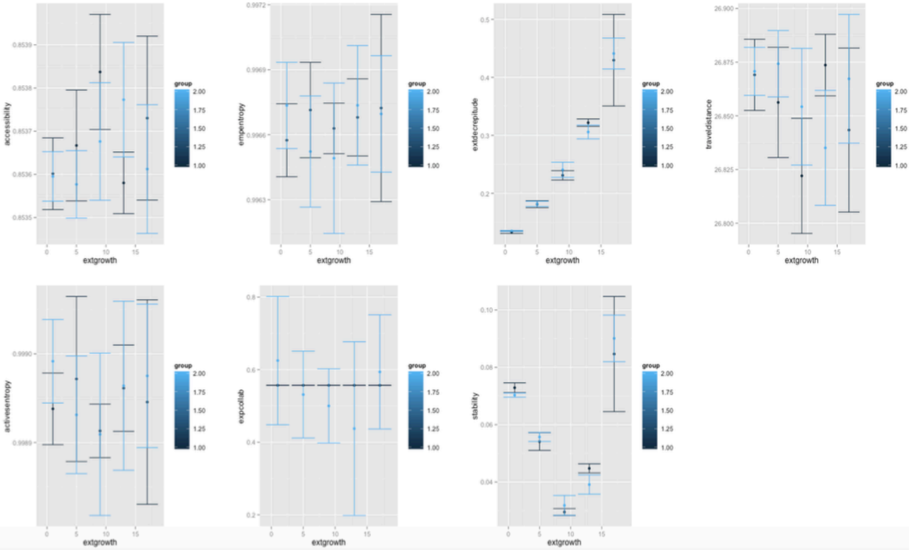
Lutecia : Exploration



Lutecia : Exploration



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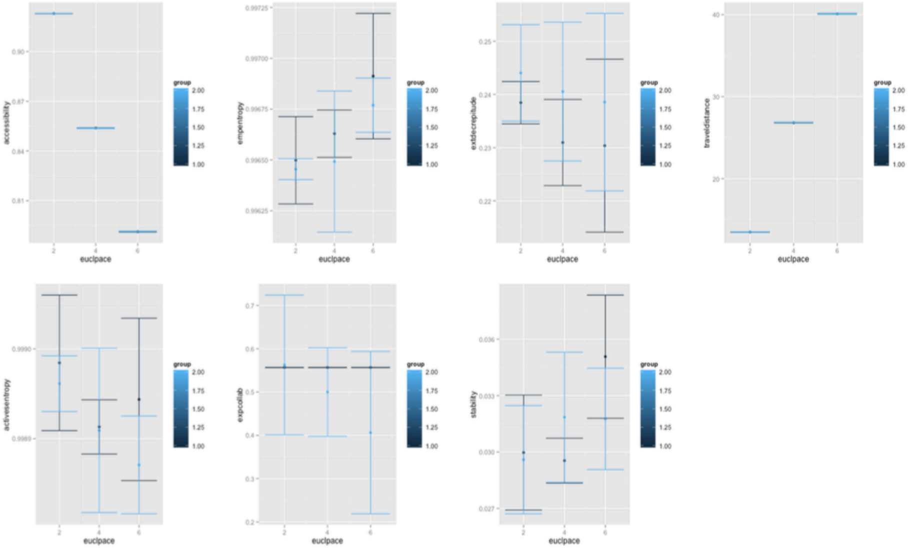
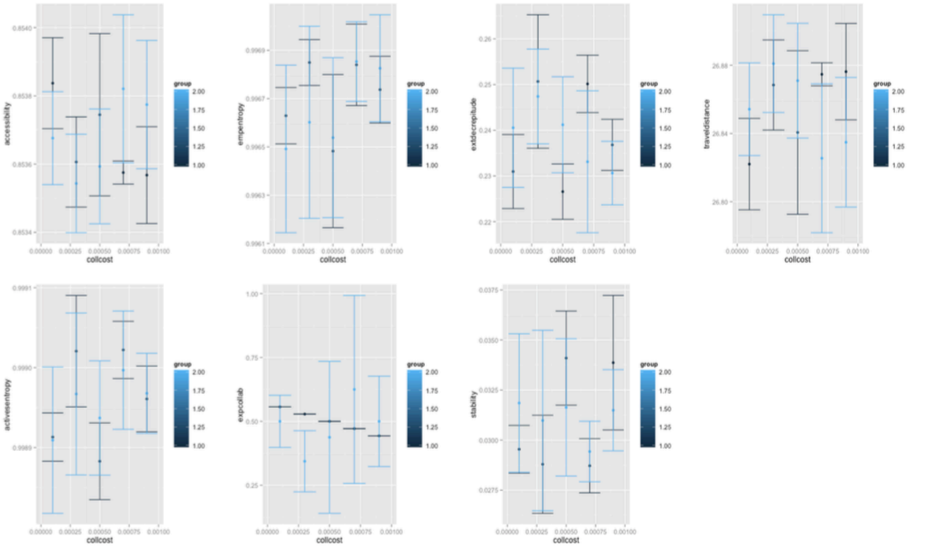


Lutecia : Exploration



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