Towards Coupling Transportation Networks and City Growth in Complex Urban Systems Models

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Thesis Progress Meeting
March 10th 2015

Scientific Context

Interactions between urban development and transportation network are considered to be central in dynamics of complex urban systems at any spatial and temporal scale [Bretagnolle, 2009][Offner, 1993]. As many underlying time scales are involved in dynamics, very few modeling efforts have been done towards models simulating simultaneously both growths.

Such geographical models would have both

- theoretical interest, in understanding processes involved in coevolution
- direct practical applications (e.g. planning) in the case of partially data-driven models

Research Question

Research question (current and very general, will necessarily evolve):

Are there some scale and level of thematic genericity at which it is possible to construct models of simulation aiming to couple urban and network growth ? To what extent can these models be data-driven in the aim of application to case studies ?

Methods and Approach

- Broad Complex Systems point of view (from physics to geography, economy, etc).
- Multidisciplinary research teams, two laboratories at the best both thematically and technically (LVMT : transportation, urban economy), Géocits-Paris : quantitative geography, spatial integration
- Recent progress in numerical exploration of models, work will be based on a strong basis from technical point of view [Reuillon et al., 2013, Schmitt et al., 2014]

State of the Art

- Thematic literature on codevelopment [Bretagnolle, 2009, L'Hostis et al., 2012]
- Network growth literature : geometrical network growth [Barthélemy and Flammini, 2008], economic network growth (empirical micro and macro economic studies on stylized facts of transportation network growth) [Xie and Levinson, 2009], biological network growth [Adamatzky and Jones, 2010, Tero et al., 2010]
- LUTI models : influence of transportation on land-use change [Chang, 2006, Iacono et al., 2008]
- Various urban morphogenesis models [Achibet et al., 2014, Bonin et al., 201
- Spatial Econometrics studies, trying to find statistically significant relations (causalities or correlations), such as e.g. [Duranton and Turner, 2012, Levinson, 2008]
- Few studies from this various field propose to couple both growths : [Barthélemy and Flammini, 2009, Achibet et al., 2014, Raimbault et al., 201 Levinson et al., 2007]

Technical Tools

- Systematic use of `git` as a backup/transparency/reproducibility/etc. tool ; integrality of the work on a public repository
- Model/methods implementation : agnostic in languages and tools (NetLogo, R, Java, Python, Shell etc)
- Model exploration : use of OpenMole as soon as possible.
- Intensive computation : reasonnable tasks (max 4 weeks CPU-time) run on personnal remote 4-cores server (NetLogo, R, Java)

Model Coupling

Need for qualitative and quantitative considerations on modular model construction and validation $\rightarrow$ importance of model coupling.

Many literature on model construction :
iterative process in [Cottineau et al., 2015]
towards a meta-model in [Goldspink, 2000] ; etc.

Environments and formalisms for system integration (more from engineering backgroung) : [Golden et al., 2012] ; DEVS formalism [Zeigler, 1989], or Object-Process Methodology [Dori, 2002].

Towards a Quantification of Model Coupling

Intuitive formulation

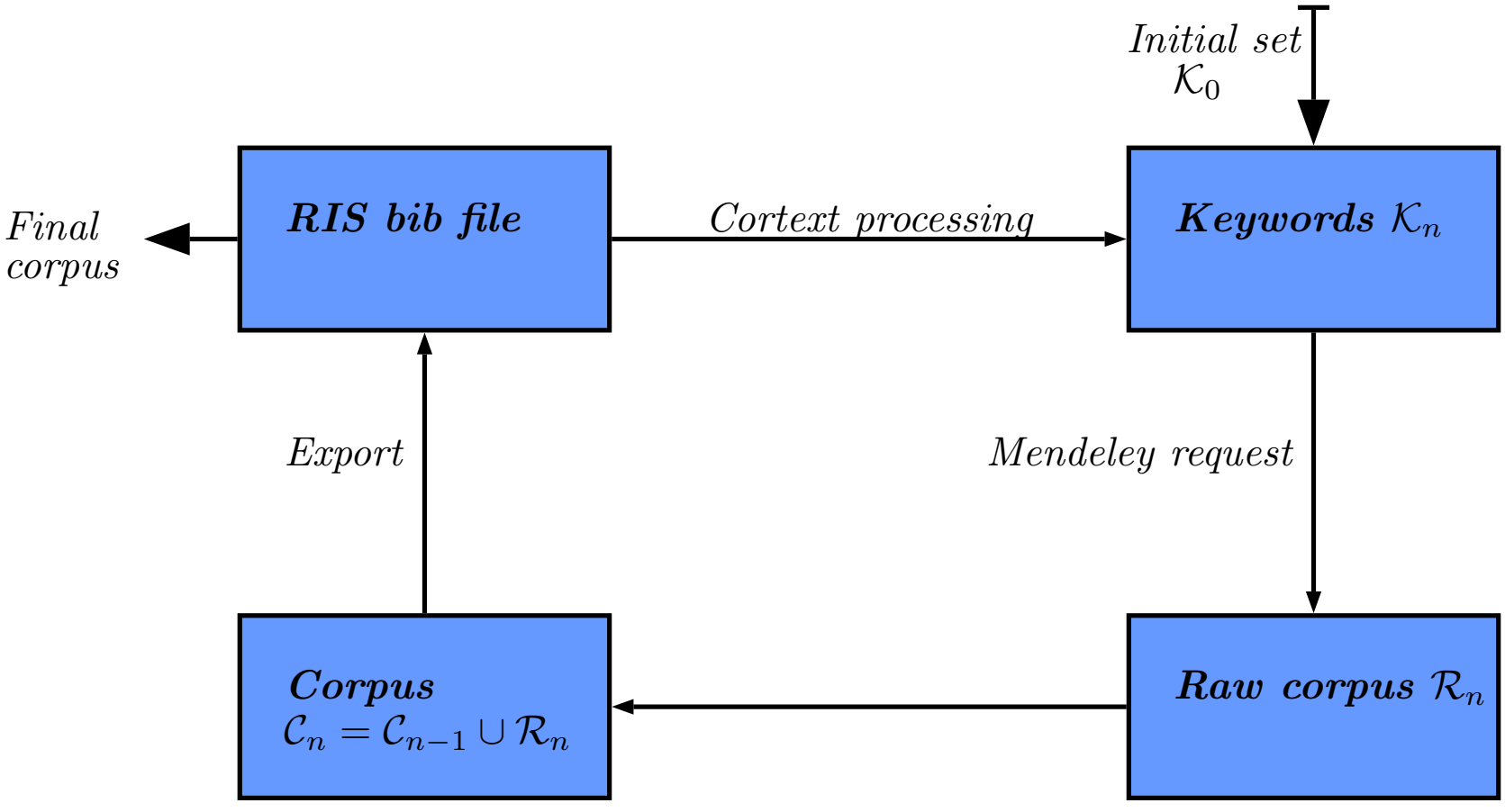
Let M_1, M_2 some models, $c(M_i)$ corresponding Kolmogorov complexity, $\alpha(M_i)$ model parameters, $o(M_i)$ models outputs, $\sim$ an equivalence relation between models.

Def : M couples (or extends) $M_1, M2$ if $\alpha(M_1) \cup \alpha(M_2) \subset \alpha(M)$ and $\exists \vec{\alpha}_1, \vec{\alpha}_2, \forall \vec{X}, i, M[\vec{\alpha}_i, \vec{X}] \sim M_i[\vec{\alpha}_i|_{\alpha(M_i)}, \vec{X}]$

Given constraints on outputs $o(M) = o'$, it should be possible to define minimal coupling $< M_1 \otimes M_2 >$ as an equivalence class of models.

Proposition of definitions of coupling strength :
Computational coupling strength : $\kappa_1 = \frac{c(M_1 \otimes M_2)}{c(M_1)+c(M_2)}$
Functional coupling strength : $\kappa_2 = d(o(M_1 \otimes M_2), o(M_1) \cup o(M_2))$

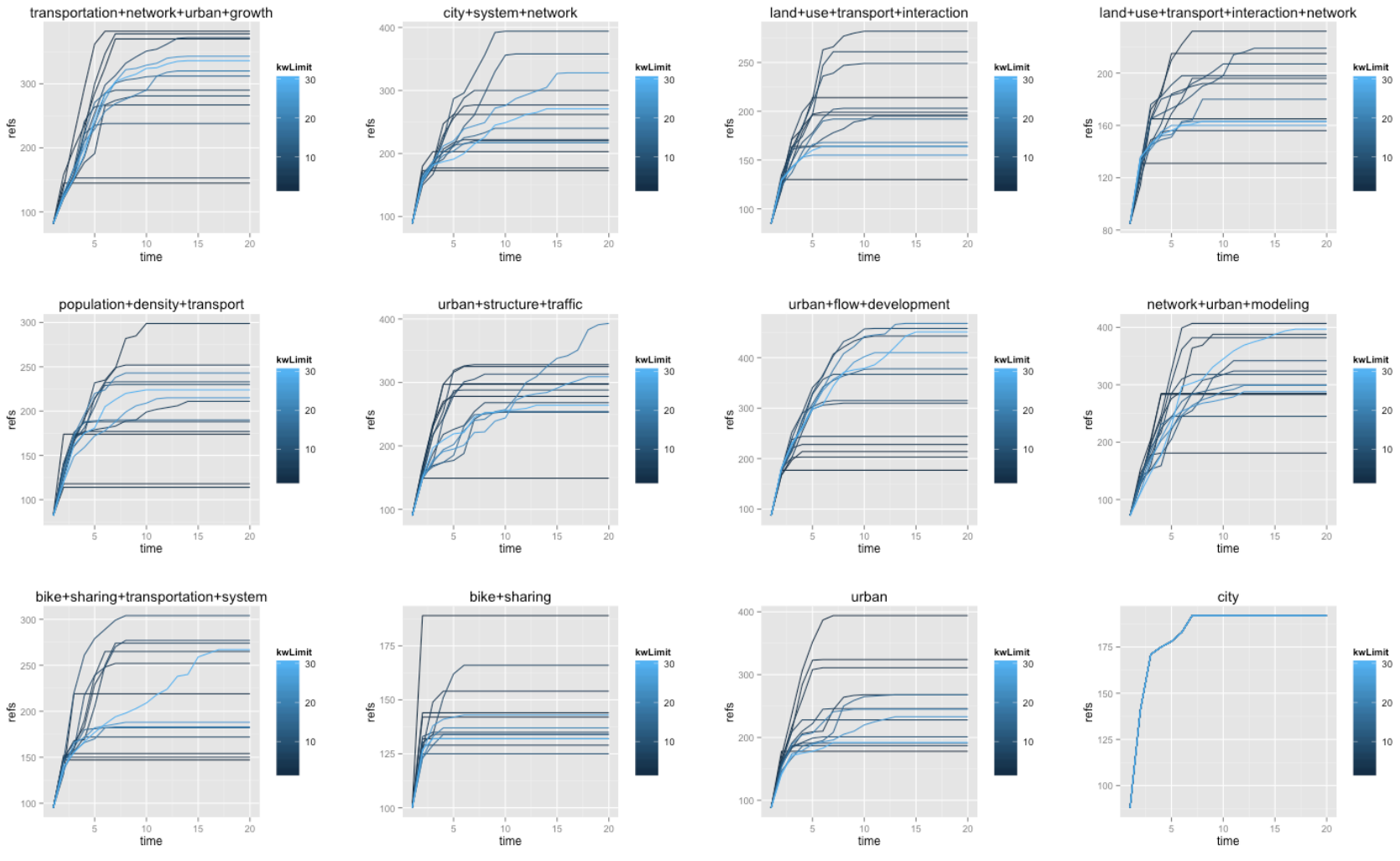
Iterative algorithm, inspired from [Chavalarias and Cointet, 2013]



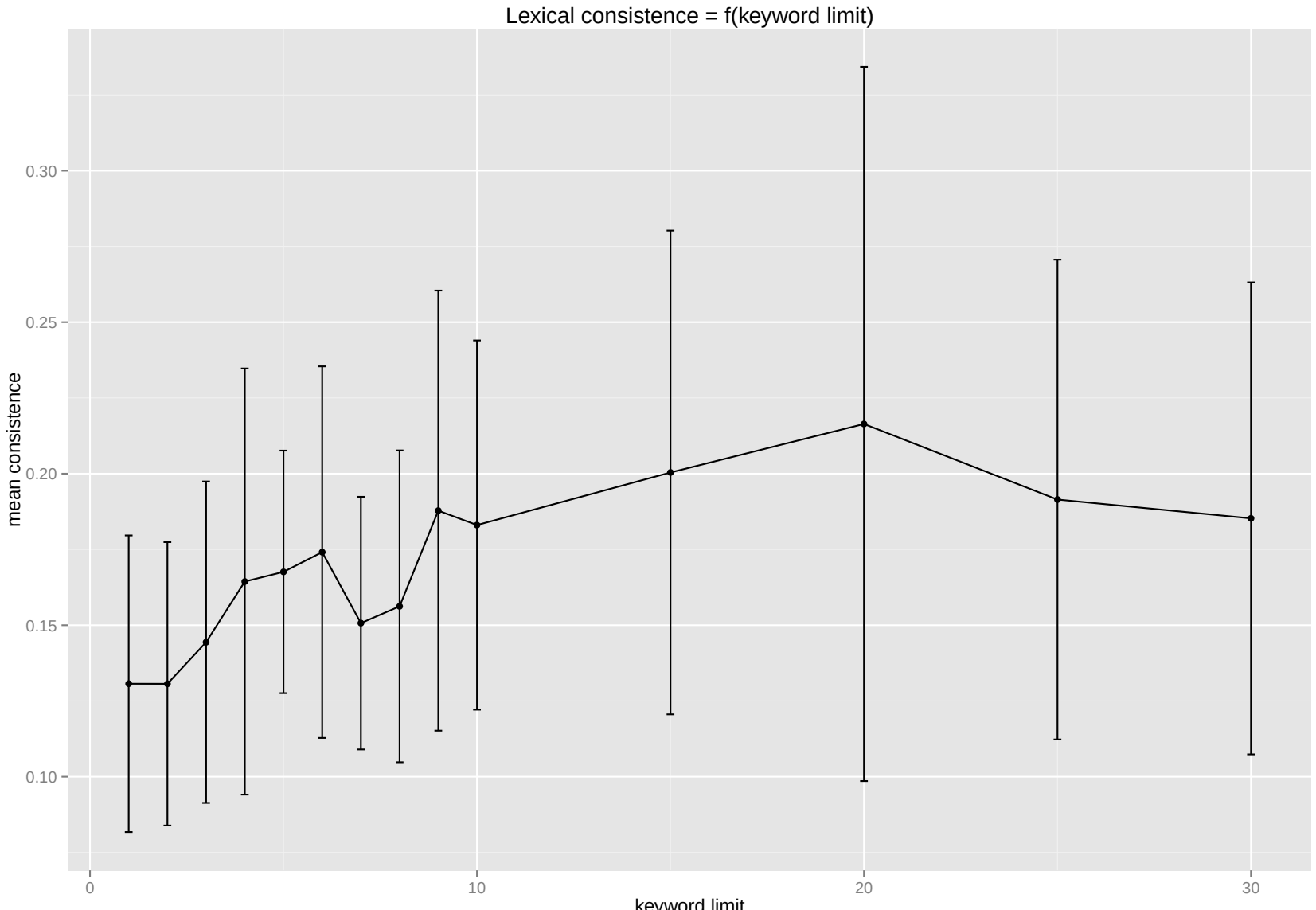
Algorithm Implementation

Catalog Requests : Mendeley API, easy to use and relatively open.
Ongoing work : Implement a Google scholar API to compare relative exhaustivities of catalogs.
Natural Language Processing : Procedure given in supplementary material of [Chavalarias and Cointet, 2013] ; difficultly reproducible (!), so implemented web API to Cortext project website that provides the service online.
Wrapped as an executable program. Allows distribution and tests by others (under acceptation of Cortext API) ; but also behavior exploration from external application (R in our case).

Results : convergence

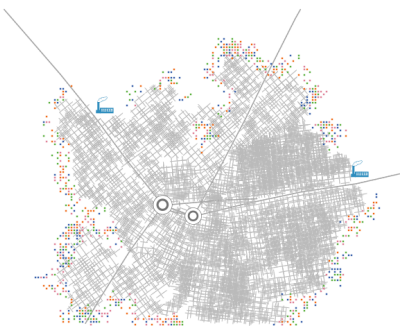


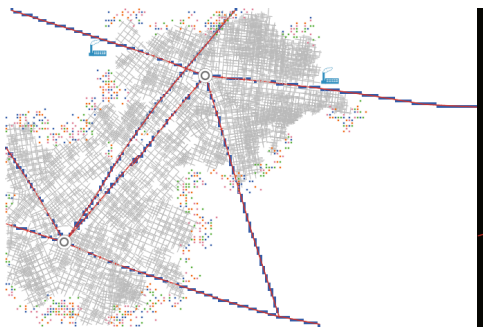
Results : lexical consistence

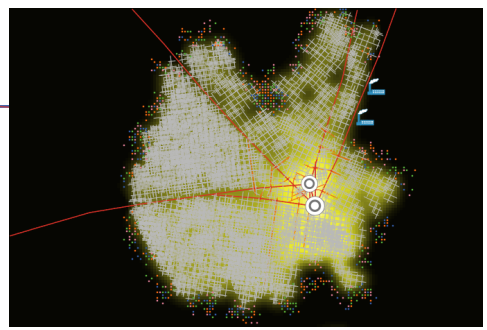


On the need of model formalization for reproducibility

Model for Tijuana bordertown, integrated in NL Urban Suite [De Leon et al., 2007
Unvolontary falsification of results.

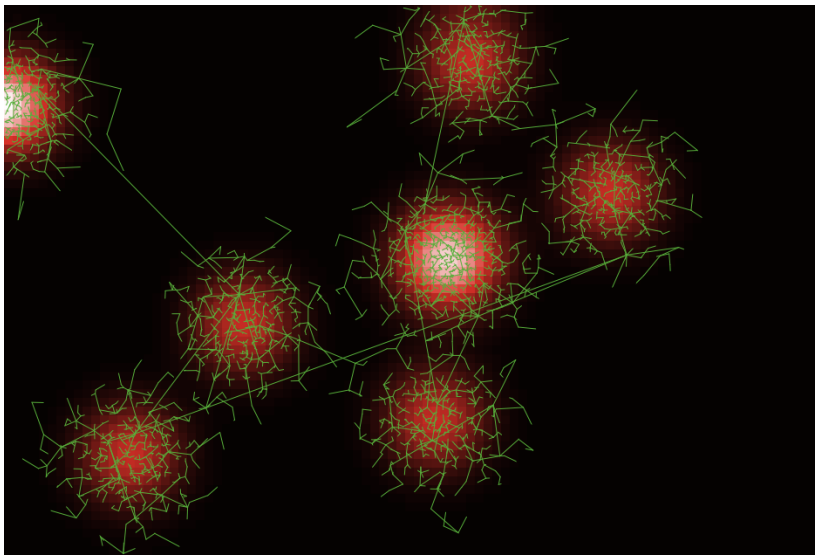


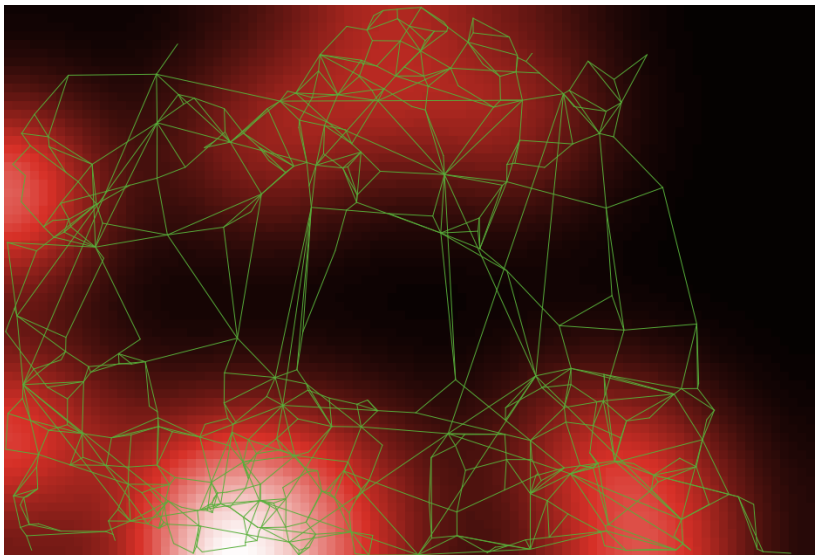




On the need of rigorous implementation

Geometrical street network growth model [Barthélemy and Flammini, 2008]
Non-reproducible results.





Long Term Planning, 6 months

State of the Art, Literature Review, Quantitative modelography, refined research question.

Short Term Planning, 1 month

Finish systematic review (corpus synthesis, "hand" systematic review), implement and compare various models (ex. quantitative comparison of network growth models), test various paths (e.g. Florent's model on endogeneisation of transportation infrastructure evolution)

References I


Achibet, M., Balev, S., Dutot, A., and Olivier, D. (2014).
A model of road network and buildings extension co-evolution.
Procedia Computer Science, 32:828–833.


Adamatzky, A. and Jones, J. (2010).
Road planning with slime mould: if physarum built motorways it would route m6/m74 through newcastle.
International Journal of Bifurcation and Chaos, 20(10):3065–3084.


Barthélemy, M. and Flammini, A. (2008).
Modeling urban street patterns.
Physical review letters, 100(13):138702.


Barthélemy, M. and Flammini, A. (2009).
Co-evolution of density and topology in a simple model of city formation.
Networks and spatial economics, 9(3):401–425.

References II


Bonin, O., Hubert, J.-P., et al. (2012).
Modèle de morphogénèse urbaine: simulation d'espaces qualitativement différenciés dans le cadre du modèle de l'économie urbaine.
In *49è colloque de l'ASRDLF*.


Bretagnolle, A. (2009).
Villes et réseaux de transport : des interactions dans la longue durée, France, Europe, États-Unis.
Hdr, Université Panthéon-Sorbonne - Paris I.


Chang, J. S. (2006).
Models of the relationship between transport and land-use: A review.
Transport Reviews, 26(3):325–350.

References III


Chavalarias, D. and Cointet, J.-P. (2013).
Phylomemetic patterns in science evolution—the rise and fall of scientific fields.
Plos One, 8(2):e54847.


Cottineau, C., Chapron, P., and Reuillon, R. (2015).
An incremental method for building and evaluating agent-based models of systems of cities.


De Leon, F., Felsen, M., and Wilensky, U. (2007).
Netlogo urban suite-tijuana bordertowns model.
Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.


Dori, D. (2002).
Object-Process Methodology: A Holistic Systems Paradigm, volume 1.
Springer Science & Business Media.

References IV


Duranton, G. and Turner, M. A. (2012).
Urban growth and transportation.
The Review of Economic Studies, 79(4):1407–1440.


Golden, B., Aiguier, M., and Krob, D. (2012).
Modeling of complex systems ii: A minimalist and unified semantics for heterogeneous integrated systems.
Applied Mathematics and Computation, 218(16):8039–8055.


Goldspink, C. (2000).
Modelling social systems as complex: Towards a social simulation meta-model.
Journal of Artificial Societies and Social Simulation, 3(2):1–23.


Iacono, M., Levinson, D., and El-Geneidy, A. (2008).
Models of transportation and land use change: a guide to the territory.
Journal of Planning Literature, 22(4):323–340.

References V


Levinson, D. (2008).
Density and dispersion: the co-development of land use and rail in london.
Journal of Economic Geography, 8(1):55–77.


Levinson, D. M., Xie, F., and Zhu, S. (2007).
The co-evolution of land use and road networks.
Transportation and traffic theory, pages 839–859.


L'Hostis, A., Soulas, C., Wulfhorst, G., et al. (2012).
La ville orientée vers le rail.
Ville et mobilité.


Offner, J.-M. (1993).
Les "effets structurants" du transport: mythe politique, mystification scientifique.
Espace géographique, 22(3):233–242.

References VI


Raimbault, J., Banos, A., and Doursat, R. (2014).
A hybrid network/grid model of urban morphogenesis and optimization.
In *Proceedings of the 4th International Conference on Complex Systems and Applications (ICCSA 2014), June 23-26, 2014, Université de Normandie, Le Havre, France; M. A. Aziz-Alaoui, C. Bertelle, X. Z. Liu, D. Olivier, eds.: pp. 51-60.*


Reuillon, R., Leclaire, M., and Rey-Coyrehourcq, S. (2013).
Openmole, a workflow engine specifically tailored for the distributed exploration of simulation models.
Future Generation Computer Systems, 29(8):1981–1990.


Schmitt, C., Rey-Coyrehourcq, S., Reuillon, R., and Pumain, D. (2014).
Half a billion simulations: Evolutionary algorithms and distributed computing for calibrating the simpoplocal geographical model.

References VII


Tero, A., Takagi, S., Saigusa, T., Ito, K., Bebber, D. P., Fricker, M. D., Yumiki, K., Kobayashi, R., and Nakagaki, T. (2010).
Rules for biologically inspired adaptive network design.
Science, 327(5964):439–442.


Xie, F. and Levinson, D. (2009).
Modeling the growth of transportation networks: A comprehensive review.
Networks and Spatial Economics, 9(3):291–307.


Zeigler, B. P. (1989).
Devs representation of dynamical systems: Event-based intelligent control.
Proceedings of the IEEE, 77(1):72–80.