Transportation and the city : renewing the research agenda

Working Paper

Juste Raimbault

Friday October 9th

Abstract

TBW

1 Introduction

1.1 Context

2 Theoretical positioning

2.1 Introduction

In order to tacke well-defined questions, it is a prequisite to set up a consistent theoretical background, implying precise definitions of concepts and objects studied. Indeed, as mentioned above, we would like to clarify interrelations between “transportation” and “cities” (or “land-use”), but these notions are as vague as what we could really want to understand. The general theoretical framework we propose is positioned into the heritage of *Complexity Theories of Cities* in the sense of Portugali [Portugali, 2012], and more precisely Pumain’s *evolutive theory of cities*.

Within this evolutive urban theory [Pumain et al., 2006], a considerable body of knowledge on urban systems self-organisation has recently been built through the construction, the exploration and the calibration of thematic-based models of simulation, of which the serie of Simpop models is emblematic [Pumain, 2012a]. The elaboration of an integrated platform for the construction and the evaluation of geographical models, including the development of the user-friendly, yet powerful by the transparent access to grid computation ressources, Model Experiment software OpenMole [Reuillon et al., 2013], but also an epistemological framework and associated meta-heuristics for model validation [Rey-Coyrehourcq, 2015], was central for the establishment of evidence-based thematic conclusions, which differentiation with the consequent previous amount of geographical research lead by similar methods of agent-based modeling and simulation was indeed the introduction of novel methods and tools going a step further for the validation stage. A illustrative example is the application of the Calibration Profile algorithm (which reveals a single parameter influence on model performance within the whole parameter space) to the sufficient and necessary parameters to reproduce existing urban systems patterns on a long time scale by the SimpopLocal model [Schmitt et al., 2014], and other methods such as PSE algorithm aimed to detect rare outputs of a model, were successively applied, to the Marius model in that case [Chérel et al., 2015].

At first sight this methodological and scientific context seems rather disconnected from our geographical objects of study which are the processes of coevolution between transportation network and urban growth, in a generic form (i.e. at any scale temporal and spatial scales, and in any geographical context) in a first approach and of course geographically contextualized once the entreprise of this paper will have been completed. These works are indeed the giants on which shoulder we intend to stand on. We rely on Bretagnolle concluding considerations in [Bretagnolle, 2009], insisting on the need to pursue the various empirical findings on long-time network and cities interactions, by modeling approaches which should shed light on underlying coevolution processes. We propose to explore that paradigm which has been poorly tackled and has many obstacles associated with. Theoretically, Bretagnolle's work is positioning precisely within the evolutionnary urban framework, which assets include the compliance with complexity approaches which allow to take into account the particularities of urban systems such as their non-ergodicity [Pumain, 2012b]. Methodologically, it seems intuitively suitable to our purpose, what will be confirmed further. Indeed, many of the issues we will identify, espacially related to modeling, should be efficiently tackled building on it.

2.2 Theoretical framework

We can now propose a precise construction of our theoretical framework. Along disciplines dealing with complex systems, the epistemological approach of *perspectivism* proposed recently by Giere [Giere, 2010], suits well the kind of problematics tackled within these. To sum up, it interprets any scientific approach as a perspective, in which someone pursues some objective and uses what is called *a model* to reach it. The model is nothing more than a medium. Varenne developped [Varenne, 2010] model typologies that can be interpreted as a refinment of this theory. Let for now relax this possible precision and use perspectives as proxies of the undefined objects and concepts.

Definition 1 We define a perspective on a geographical system a dataflow machine in the sense of [**?**], which has at least partially an ontology

2.3 Modeling the coevolution : overview of the scientific landscape

Many disciplines have found interest in studying city growth, transportation network growth, or both including some of their interactions. Each has its own problematics, corresponding models and time scales. We propose an overview of the scientific landscape on the subject, to better understand typical issues that can arise.

Land-Use Transportation Interaction Models A wide range of models that have been developed mainly in an aim of transportation planning are the so-called Land-Use Transportation Interaction Models (LUTI). Transportation planners (historically beginning in the US for road infrastructure planning) mainly propose that kind of model to evaluate the impact of a new infrastructure on the evolution of the urban system through the impact on land-use. Recent reviews give an broad idea of existing approaches and capabilities of such models [Chang, 2006, Iacono et al., 2008, Wegener and Fürst, 2004]. Different scales can be considered (e.g. from the scale of the metropolitan area to the regional scale in the frame of regional planning). Contrary to most common ideas, these models do not necessarily rely on equilibrium assumptions [Kryvobokov et al., 2013]. Furthermore, operationnal models are still developped today and state-of-the-art models do provide accurate forecasts on an intermediate time-scale. Various features can be included, such as in [Delons et al., 2008] where a detailed structure of the metropolitan housing market for Paris region gives targeted high-resolution forecasts. The main feature of interest for our question is the fact that these models consider transportation network as static, and simulates the evolution of a dynamic land-use. It means that the characteristic time-scale is smaller than the time scale of infrastructure evolution.

Network Growth Modeling

Coevolution Approaches

2.4 Proposing a research agenda

The purpose of this paper is therefore to identify crucial obstacles to a dynamic modeling of coevolution, notions and methods associated, and to propose a research agenda making a synthesis of key problems that in our perspective need to be tackled to be able to construct such models.

The rest of the paper is organised as follows : we analyse first separately each axis proposed before, developing for each a specific problematic and proposing associated research projects. We make then a synthesis of these various aspects, establishing the research agenda.

3 Analysis

3.1 Giere's Deamon, or when disciplinary compartimentation narrows perspectives

As Laplace had its Deamon that was the embodiement of a determinist and reductivist approach to science , we could imagine Giere's Deamon, the embodiement of perspectivism. Whatever its initially attributed tasks, the poor Deamon would surely desesperately try to reconcile conflicting disciplines and viewpoints.

3.2 Empirical analysis : "Lost in the Smog"

3.3 Methodological Foundations, need for concrete

The modeling of coevolution of instrisically a problem of coupling in a complex way (in the sense of Varenne [Varenne, 2010]) complementary geographical processes. The question of coupling models is shady and subtle, and no generalized approach have been proposed up to date. Indeed, this would partially consist in a meta-modeling entreprise, what could be the reason of its absence.

Difficulty of the coupling problem

Modular model construction A recent methodological progress within the context of agent-based modeling has been the proposition of a modular framework for model construction [Cottineau et al., 2015]. A 3 dimensionnal space in which a model is embedded, allows to modularly construct a model, at different levels of complexity for each dimension. Some works in other types of modeling approaches do also propose modularity as a key point to capture the complexity of systems

Note that the concrete application of this framework in [Cottineau, 2014] underlies that the next spatial complexity levels to build are indeed the modeling of the coevolution (our problem) and the inclusion of governance structures at a next level (in transition with the next explored axis).

Let formulate a generalisation of the incremental framework, that would be compatible with other modeling approaches (e.g. dynamical systems, statistical modeling), would allow a formal definition of model coupling and would also be compatible with the ontological vision of agent-based modeling of Livet et al. [Livet et al., 2010].

We propose to try to tackle the following points

- ontological dimensions can be of any number
- complexity level within an ontological dimension can be represented as an order relation

Let $(M_i)_{1\leq i\leq N}$ the models to be compared. We define the ontological model space by

$$\mathcal{O} = \bigcup_{i=1}^{N} O[M_i]$$

where O is the definition of model ontology. Models extension and coupling will be defined by equivalence and order relations in a partially ordered space. We say that M_0 extends M_1 *within the same ontological dimension* if and only if $O[M_1] \subset O[M_0]$ and we write $M_1 \leq M_0$. We define an equivalence class within the ontological space by

$$M_1 \sim M_2 \iff M_1 \leq M_2 \& M_2 \leq M_1$$

The coupling of M_1 and M_2 can not be a unique model as many thematic and technical choice are made when concretely coupling models. In our framework, a generic model coupling will be an equivalence class of models, denoted $M_1 \times M_2$, such that The degree of coupling can be defined through Kolmogorov complexity of models implementation. The degree of complexity is given by

$$\kappa = \frac{c[M_1 \times M_2]}{c[M_1] + c[M_2]}$$

where Kolmogorov complexity is computed on the shortest implementation possible.

We can also add a "meta-dimension" to our framework, i.e. an other aspect needed to be able to compare models, is the performance on data. To compare two models on that aspect, at least two points have to be verified :

- Models can be run on the same dataset for the same purpose (i.e have necessarily a common sub-ontology)
- Models have a non-empty intersection of similar outputs

Statistical control on model meta-parameters Let consider a model which initial conditions (that can be viewed as meta-parameters) can be generated by another *upstream* model. Contretely they can be spatial distribution of variables, configurations of agents, etc., the essential feature shared being the existence of a generator of such "synthetic" configurations. The overall process is in fact a simple coupling (or serial coupling) of models.

To begin, we simply assume determinism, and propose to look at a way to conduct sensitivity analysis of the downstream model at any order. We have the composite derivation formula along the parameter α at the first order

$$\partial_\alpha[D \circ U] = [\partial_\alpha D \circ U] \cdot \partial_\alpha U$$

yielding that sensitivity of downstream model to an implicit parameter α (parameter of the upstream model) can be obtained through the systematic study of the behavior of their coupling. Therethrough, we achieve statistical control when regressing outputs of D against its parameters, by adding the meta-parameters as explicative variables.

This can be viewed in an other way,

3.4 Modeling the Governance : the Grand Pari(s)

4 Synthesis

4.1 Proposition of a research agenda

4.2 Towards calibrated dynamic models of coevolution

5 Conclusion

References

[Bretagnolle, 2009] 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, 2006] Chang, J. S. (2006). Models of the relationship between transport and land-use: A review. *Transport Reviews*, 26(3):325–350.

[Chérel et al., 2015] Chérel, G., Cottineau, C., and Reuillon, R. (2015). Beyond corroboration: Strengthening model validation by looking for unexpected patterns. *PLoS ONE*, 10(9):e0138212.

[Cottineau, 2014] Cottineau, C. (2014). *L'évolution des villes dans l'espace post-soviétique. Observation et modélisations.* PhD thesis, Université Paris 1 Panthéon-Sorbonne.

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

[Delons et al., 2008] Delons, J., Coulombel, N., and Leurent, F. (2008). PIRANDELLO an integrated transport and land-use model for the Paris area.

[Giere, 2010] Giere, R. N. (2010). *Scientific perspectivism.* University of Chicago Press.

[Iacono et al., 2008] 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.

[Kryvobokov et al., 2013] Kryvobokov, M., Chesneau, J.-B., Bonnafous, A., Delons, J., and Piron, V. (2013). Comparison of static and dynamic land use-transport interaction models. *Transportation Research Record: Journal of the Transportation Research Board*, 2344(1):49–58.

[Livet et al., 2010] Livet, P., Muller, J.-P., Phan, D., and Sanders, L. (2010). Ontology, a mediator for agent-based modeling in social science. *Journal of Artificial Societies and Social Simulation*, 13(1):3.

[Portugali, 2012] Portugali, J. (2012). Complexity theories of cities: Achievements, criticism and potentials. In *Complexity Theories of Cities Have Come of Age*, pages 47–62. Springer.

[Pumain, 2012a] Pumain, D. (2012a). Multi-agent system modelling for urban systems: The series of simpop models. In *Agent-based models of geographical systems*, pages 721–738. Springer.

[Pumain, 2012b] Pumain, D. (2012b). Urban systems dynamics, urban growth and scaling laws: The question of ergodicity. In *Complexity Theories of Cities Have Come of Age*, pages 91–103. Springer.

[Pumain et al., 2006] Pumain, D., Paulus, F., Vacchiani-Marcuzzo, C., and Lobo, J. (2006). An evolutionary theory for interpreting urban scaling laws. *Cybergeo: European Journal of Geography.*

[Reuillon et al., 2013] 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.

[Rey-Coyrehourcq, 2015] Rey-Coyrehourcq, S. (2015). *Une plateforme intégrée pour la construction et Une plateforme intégrée pour la construction et l'évaluation de modèles de simulation en géographie.* PhD thesis, Université Paris 1 Panthéon-Sorbonne.

[Schmitt et al., 2014] 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.

[Varenne, 2010] Varenne, F. (2010). Framework for m&s with agents in regard to agent simulations in social sciences. *Activity-Based Modeling and Simulation*, pages 53–84.

[Wegener and Fürst, 2004] Wegener, M. and Fürst, F. (2004). Land-use transport interaction: state of the art. *Available at SSRN 1434678.*