

An Applied Knowledge Framework to Study Complex Systems

J. Raimbault^{1,2}

`juste.raimbault@parisgeo.cnrs.fr`

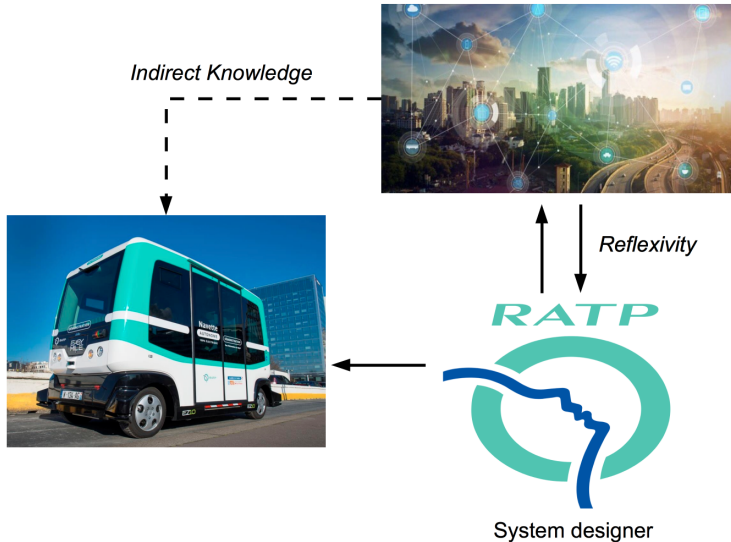
¹UMR CNRS 8504 Géographie-cités

²UMR-T IFSTTAR 9403 LVMT

CSD&M 2017 - Paris

December 12th 2017

Reflexivity in System Engineering ?



Source : www.ratp.fr

Processes of Knowledge Production

The study of processes of knowledge production as an asset to study complex systems ?

→ Philosophical and epistemological approaches to the nature of knowledge : [Kuhn, 2012]'s structure of scientific revolutions, [Feyerabend, 2010]'s advocacy for diverse viewpoints.

→ Quantitative approaches : beyond simple bibliometrics
[Cronin and Sugimoto, 2014]

Following [Morin, 1991], the Knowledge of Knowledge arise from and for the study of Complex Systems : knowledge of the complex is complex knowledge (requisite complexity [Gershenson, 2015])

Knowledge Frameworks

Knowledge Framework : *A systemic framework containing an epistemological component dealing with the nature of knowledge or knowledge production.*

- Knowledge management : [Durantin et al., 2016] coupling engineering with design paradigms ; [Carlile, 2004] knowledge at the boundaries of disciplines.
- Meta-modeling frameworks : [Cottineau et al., 2015] multi-modeling ; [Golden et al., 2012] unified formal description of Complex Systems.
- Applied frameworks : [Moulin-Frier et al., 2017] typology of approaches in Artificial Intelligence.

Research objective

- Existing frameworks specific to a field or discipline, or to a given approach or methodology.
- Can be more or less applied or operational.

Research objective :

Based on knowledge domains proposed by [Livet et al., 2010], develop a generic Applied Knowledge Framework, capturing some structure of knowledge (epistemological level) with a direct link with concrete applications (discipline level).

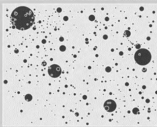
Approach and Methodology

Approach : An inductive approach from a case study in Theoretical and Quantitative Geography, developed in the last 20 years (Evolutionary Urban Theory [Pumain, 1997])

Methodology : Mixed methods. Interview with main contributors of the theory, from different disciplines (D. Pumain, C. Cottineau in Geography, R. Reuillon in Computer Science) ; quantitative analysis of citation network.

Evolutionary Urban Theory

Spatio-temporal scales



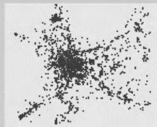
1 day

Emerging properties

Hierarchy
Functional
diversity
Spatial pattern

Organization levels

**Macro: System
of cities**
(urban networks)

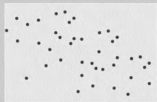


1 hour

Centrality
Function
Morphology
"Ambiance urbaine"

Meso: City
(urban areas)

Descriptors

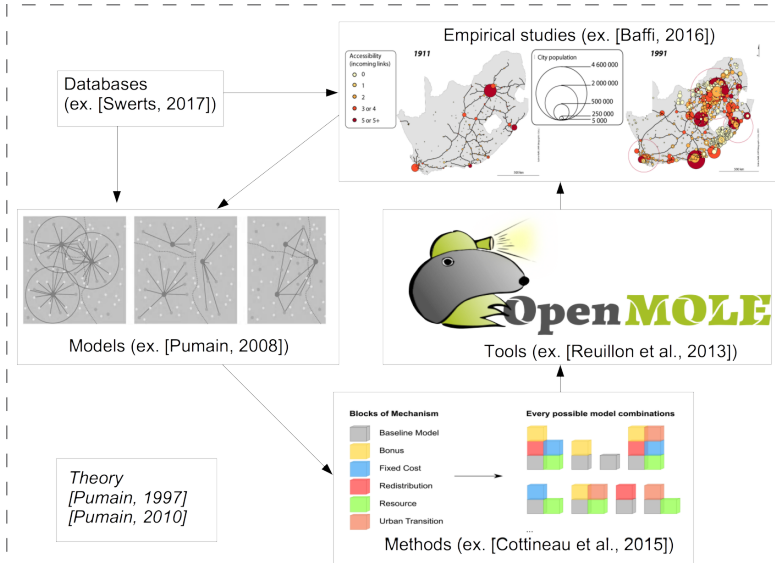


Life cycle
Profession
Power

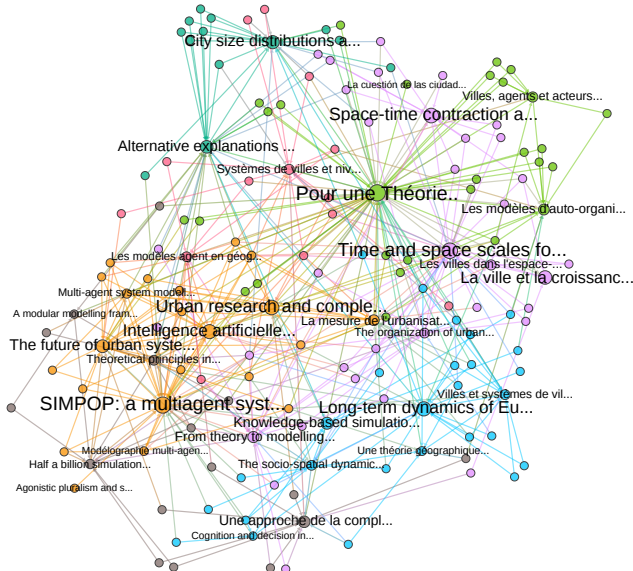
Micro: Actors
(households, firms,
institutions)

Source :
[Pumain, 2008]

Iterative Construction of Knowledge across Domains



Citation Network Analysis



Core citation network of Evolutive Urban Theory

$$|V| = 155$$

$$|E| = 449$$

7 communities,
modularity 0.39

Constraints on the Framework

We postulate the following integration constraints for the framework :

- Integration of disciplines, as Complex Systems are mostly interdisciplinary.
- Integration of knowledge domains : no particular type of knowledge must be privileged in the production process.
- Integration of types of methodologies : for example different modeling approaches can be taken into account.

Epistemological Foundations

Giere's cognitive approach to science [Giere, 1990] : cognitive agents have *perspectives* on aspects of the real world.

Scientific perspectivism [Giere, 2010] : *cognitive agents* use *media*, the models, to represent something with a certain purpose.

[Varenne, 2017]'s classification of main model functions : perception and observation, understanding, theory building, communication, decision making.

Knowledge Domains

Definition of Knowledge Domains :

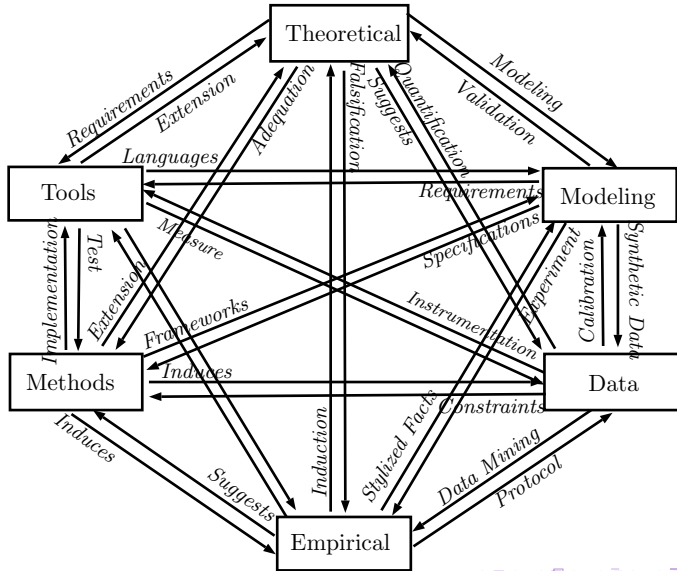
- **Empirical.** Empirical knowledge of real world objects.
- **Theoretical.** Conceptual knowledge, implying cognitive constructions.
- **Modeling.** The model as the formalized *medium* of the perspective.
- **Data.** Raw information that has been collected.
- **Methods.** Generic structures of knowledge production.
- **Tools.** Implementation of methods and supports of others domains.

Co-evolution of Knowledge within domains

Description of the Knowledge Framework :

- 1 Any scientific knowledge construction on a complex system can be understood as a perspective, decomposed into knowledge domains.
- 2 Contents within domains *coevolve* [Holland, 2012] between themselves and with other elements of the perspective (including cognitive agents and the purpose).
- 3 It implies weak emergence [Bedau, 2002] what is consistent with the existence of bodies of knowledge.

Illustration of interactions between domains



Application : Engineering the Metropolitan

Table: Illustration of Knowledge Framework Application

Engineering Issue	Knowledge Domains	Transferability	References
Autonomous Transportation	Empirical, Modeling	Integrated Modeling	[Belmonte et al., 2008]
Innovative Modeling	Modeling, Methods	Method development	[Balbo et al., 2016]
Functional Requirements	Empirical, Tools	Ergonomic tools	[Foot, 2005]
Societal Adaptation	Theoretical, Empirical	Stakeholders involvement	[Foot, 1994], [Hatchuel et al., 1988]
Technical Requirements	Empirical, Modeling	Integrated Modeling	[Moreno Regan, 2016]

Discussion : Application

Application

→ Sounds like a generic framework, but as it arises from the structure of complex knowledge itself, is anchored within reflexivity and therefore aimed at a direct application.

→ Different levels of integration make it particularly suited to study Complex Systems. Specifications or targeted application guidelines would decrease integration ?

Discussion : Developments

Developments

- Towards a formalisation : perspectives as dataflow machines [Golden et al., 2012] with an ontology [Livet et al., 2010] ; canonic decomposition of ontologies with emergence structure, condition with correspondance with the canonic decomposition of the machine to be investigated.
- Towards a quantification : applying coupled semantic and citation networks analysis [Raimbault, 2017], empirical investigation of knowledge domains co-evolutionnary dynamics within a targeted corpus.

Conclusion

→ We constructed an applied knowledge framework by induction from the study of the genesis of a scientific theory.

→ Operational application to diverse cases and engineering issues still to be tested.

- Code, data and results available at <https://github.com/JusteRaimbault/CityNetwork/Models/QuantEpistemo/EvolutiveUrbanTheory>
- Transcripts of interviews at <https://github.com/JusteRaimbault/Entretiens>
- Paper on arXiv at <https://arxiv.org/abs/1706.09244>
- Acknowledgments : I thank D. Pumain, R. Reuillon and C. Cottineau for giving of their time for the interviews.

Reserve slides

Reserve Slides

References I



Baffi, S. (2016).

Railways and city in territorialization processes in South Africa : from separation to integration ?

Theses, Université Paris 1 - Panthéon Sorbonne.



Balbo, F., Adam, E., and Mandiau, R. (2016).

Positionnement des systèmes multi-agents pour les systèmes de transport intelligents.

Revue des Sciences et Technologies de l'Information-Série RIA: Revue d'Intelligence Artificielle, 30(3):299–327.



Bedau, M. (2002).

Downward causation and the autonomy of weak emergence.

Principia: an international journal of epistemology, 6(1):5–50.

References II



Belmonte, M., Churchill, G., Schon, W., and Boulanger, J.-L. (2008).

Automatisation intégrale de la ligne 1: étude et modélisation du trafic mixte.

In *Lambda-Mu*, pages Session–5B.



Carlile, P. R. (2004).

Transferring, translating, and transforming: An integrative framework for managing knowledge across boundaries.

Organization science, 15(5):555–568.



Cottineau, C., Reuillon, R., Chapron, P., Rey-Coyrehourcq, S., and Pumain, D. (2015).

A modular modelling framework for hypotheses testing in the simulation of urbanisation.

Systems, 3(4):348–377.

References III



Cronin, B. and Sugimoto, C. R. (2014).

Beyond bibliometrics: Harnessing multidimensional indicators of scholarly impact.

MIT Press, Cambridge, ISBN: 9780262026796.



Durantín, A., Fanmuy, G., Miet, S., and Pegon, V. (2016).

Disruptive innovation in complex systems.

In *Complex Systems Design & Management*, pages 41–56. Springer.



Feyerabend, P. (2010).

Against method.

Verso, ISBN: 9781844674428.



Foot, R. (1994).

Ratp, un corporatisme à l'épreuve des voyageurs.

Travail, 31:63–100.

References IV



Foot, R. (2005).

Faut-il protéger le métro des voyageurs? ou l'appréhension du voyageur par les ingénieurs et les conducteurs.

Travailler, (2):169–206.



Gershenson, C. (2015).

Requisite variety, autopoiesis, and self-organization.

Kybernetes, 44(6/7):866–873.



Giere, R. N. (1990).

Explaining science: A cognitive approach.

University of Chicago Press, Chicago, ISBN: 9780226292069.



Giere, R. N. (2010).

Scientific perspectivism.

University of Chicago Press, Chicago, ISBN: 9780226292137.

References V



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.



Hatchuel, A., Pallez, F., and Pény, A. (1988).

Des stations de métro en mouvement: Station 2000, un scénario prospectif.

In *Les Annales de la recherche urbaine*, volume 39, pages 35–42.

Persée-Portail des revues scientifiques en SHS.



Holland, J. H. (2012).

Signals and boundaries: Building blocks for complex adaptive systems.

Mit Press, Cambridge, ISBN: 9780262525930.

References VI



Kuhn, T. S. (2012).

The structure of scientific revolutions.

The University of Chicago Press, Chicago, ISBN: 9780226458120.



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.



Moreno Regan, O. (2016).

Etude du comportement des tunnels en maçonnerie du métro parisien.

PhD thesis, Paris Est.



Morin, E. (1991).

La méthode tome 4: les idées.

Paris, Seuil.

References VII



Moulin-Frier, C., Puigbò, J.-Y., Arsiwalla, X. D., Sanchez-Fibla, M., and Verschure, P. F. M. J. (2017).

Embodied artificial intelligence through distributed adaptive control: An integrated framework.

ArXiv e-prints.



Pumain, D. (1997).

Pour une théorie évolutive des villes.

Espace géographique, 26(2):119–134.



Pumain, D. (2008).

The socio-spatial dynamics of systems of cities and innovation processes: a multi-level model.

The Dynamics of Complex Urban Systems, pages 373–389.

References VIII



Pumain, D. (2010).

Une théorie géographique des villes.

Bulletin de la Société géographique de Liège, (55):5–15.



Raimbault, J. (2017).

Exploration of an Interdisciplinary Scientific Landscape.

ArXiv e-prints.



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.



Swerts, E. (2017).

A data base on chinese urbanization: Chinacities.

Cybergeog: European Journal of Geography.

References IX



Varenne, F. (2017).

Editions Matériologiques, Paris.