An Applied Knowledge Framework to Study Complex Systems

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Reflexivity in System Engineering ?

Indirect Knowledge

Reflexivity

RATP

System designer

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.

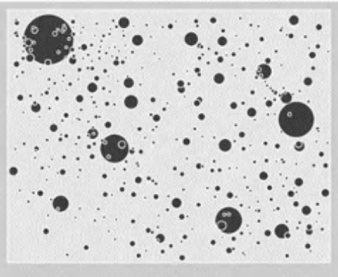
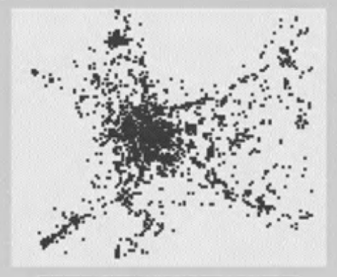
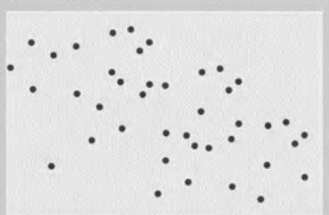
Research objective :
Based on knowledge domains proposed by [Livet et al., 2010], develop a generic Applied Knowledge Framework, capturing some structure of knowledge (epistemological level) with a direct link with concrete applications (discipline level).

Approach and Methodology

Approach : An inductive approach from a case study in Theoretical and Quantitative Geography, developed in the last 20 years (Evolutive 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.

Evolutive Urban Theory

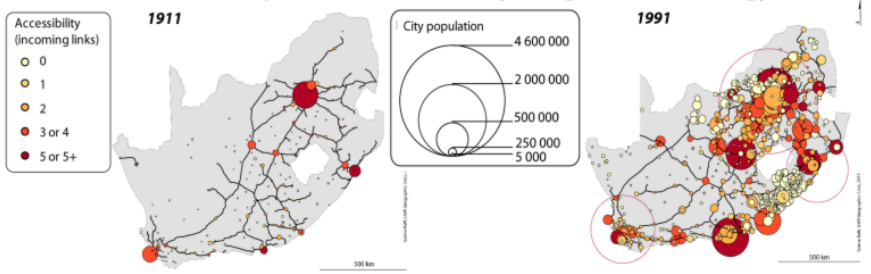
Spatio-temporal scales	Emerging properties	Organization levels
 1day	Hierarchy Functional diversity Spatial pattern	**Macro: System of cities** (urban networks)
 1 hour	Centrality Function Morphology "Ambiance urbaine"	**Meso: City** (urban areas)
Descriptors		
	Life cycle Profession Power	**Micro: Actors** (households, firms, institutions)

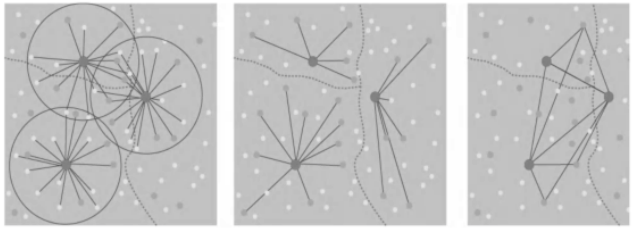
Source :
[Pumain, 2008]

Iterative Construction of Knowledge across Domains

Databases
(ex. [Swerts, 2017])

Empirical studies (ex. [Baffi, 2016])

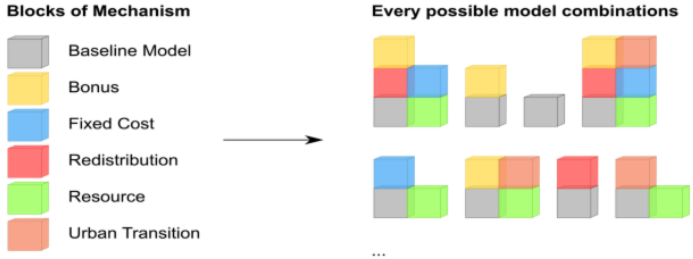




Models (ex. [Pumain, 2008])

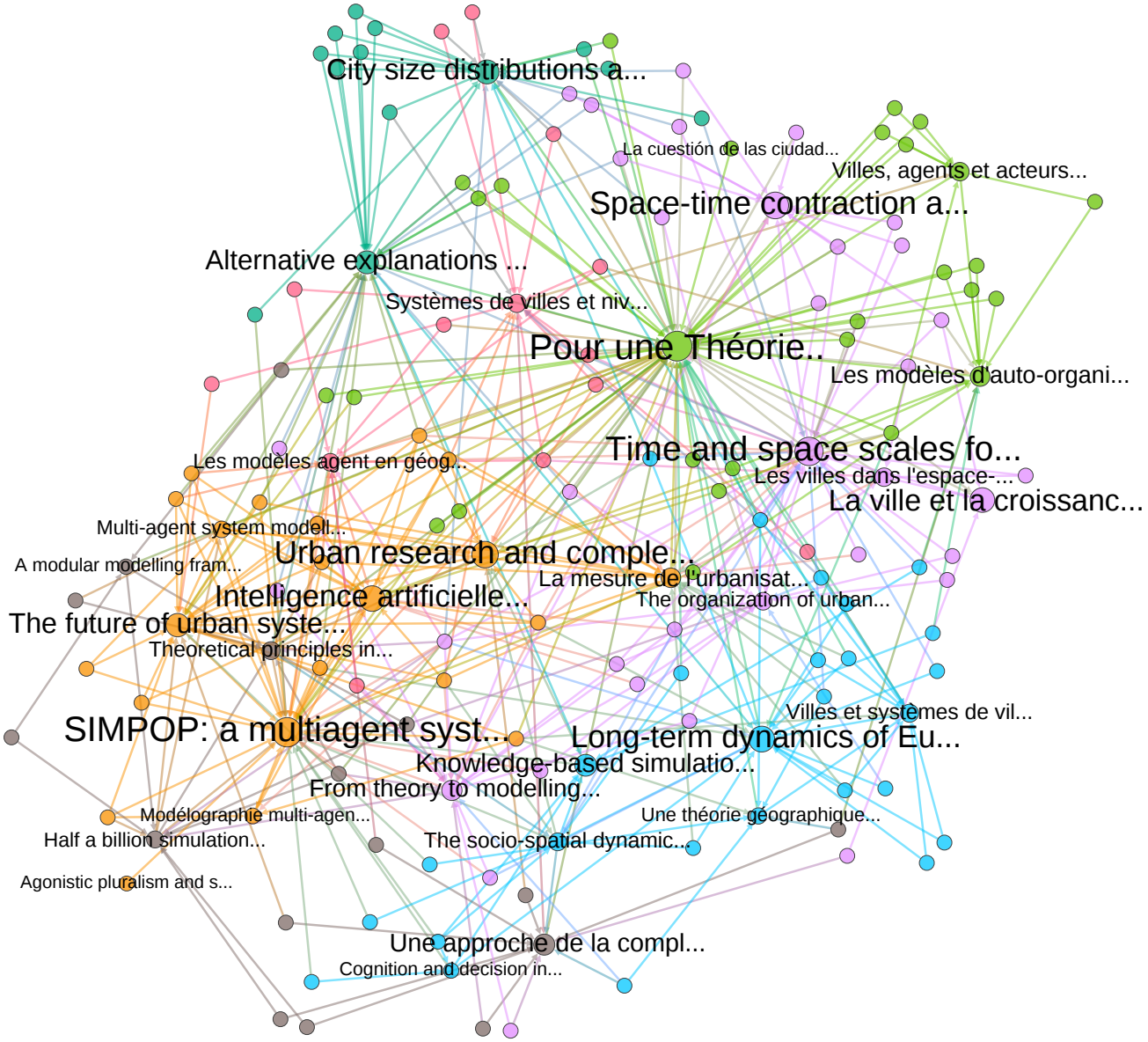
Tools (ex. [Reuillon et al., 2013])

Theory
[Pumain, 1997]
[Pumain, 2010]



Methods (ex. [Cottineau et al., 2015])

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 Fundations

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 :

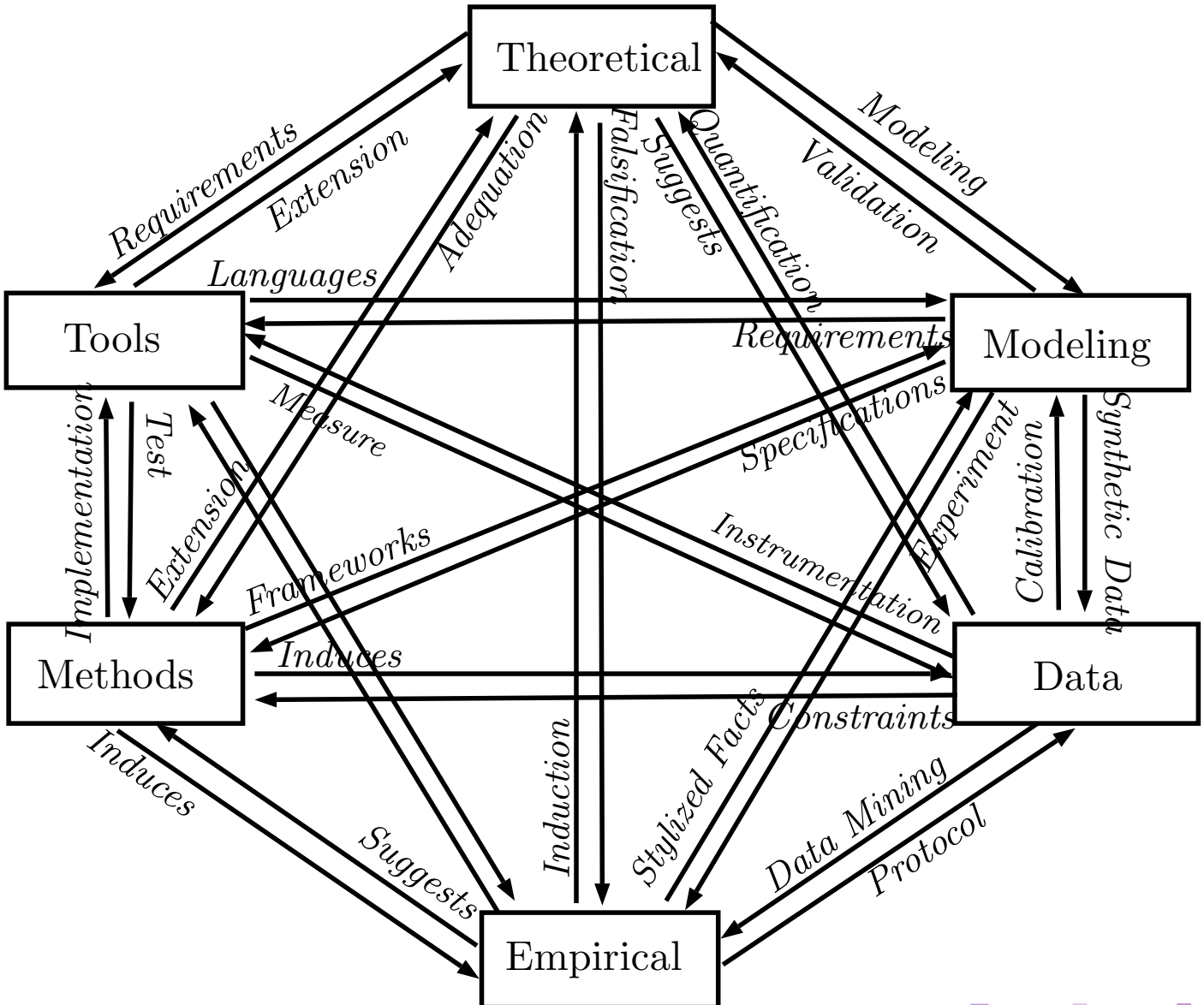
- **Empirical.** Empirical knowledge of real world objects.
- **Theoretical.** Conceptual knowledge, implying cognitive constructions.
- **Modeling.** The model as the formalized *medium* of the perspective.
- **Data.** Raw information that has been collected.
- **Methods.** Generic structures of knowledge 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 involvment	[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

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