Chapter **1**

Hierarchy and co-evolution processes

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Pumain (2019)

1.1. Introduction

1.1.1. *Complexity and hierarchy*

sci pol Crumley (1987)

Physique Mones *et al*. (2012), SystÃ¨mes complexes Pumain (2006*c*)

Jiang (2009) transportation flows

Fanelli and Glänzel (2013) empirical evidence of "hierarchy of sciences", in the sense of possibility to reach theoretical and methodological consensus

Lane (2006) classifies four frequent uses of the term hierarchy, namely (i) order hierarchy corresponding to the existence of an order relation for a set of elements, (ii) inclusion hierarchy which is a recursive inclusion of elements within each other, (iii) control hierarchy which is the "common sense" use of the term as ranked entities controlling other entities with lower rank, and (iv) level hierarchy which captures the multi-scale nature of complex systems as ontologically distinct levels (or scales). For the particular study of social systems, he concludes that hierarchical levels may be entangled, that upward and downward causations are both essential, and that at least three levels (micro, meso, macro) are generally needed to capture the complexity of such systems.

1.1.2. *Territorial systems and hierarchy*

Batty (2006) shows that hierarchies are inherent to urban systems, as fat tail distribution of settlement size are already produced by simple models of urban growth, and suggests also that urban design processes imply underlying overlapping hierarchies.

Pumain (2006*a*) links hierarchical selection and hierarchical diffusion of innovation across cities to the long-term dynamics of urban systems.

1.1.3. *Co-evolution and hierarchy*

Hierarchy in complex systems is furthermore intrinsically linked to the concept of co-evolution. Following Lane (2006), the approach to complex adaptive systems proposed by Holland (2012) integrates levels and nested hierarchies, since it considers complex systems as ensembles of boundaries that filter signals.

Pumain (2006*b*) methodological questions: how are hierarchies produced? How do hierarchies evolve?

Our contribution brings new elements of answer to these two questions, in the particular case of co-evolution of transportation networks and territories. More precisely, we systematically explore a macroscopic co-evolution model and study its properties regarding both hierarchies of cities and networks, in terms of final hierarchy produced but also in terms of dynamics of hierarchies.

1.2. Co-evolution model

1.2.1. *Context and rationale*

The issue of interactions between transportation networks and territories remains an open question for which different approaches have been proposed Offner (1993), Offner *et al*. (2014). Raimbault (2018*a*) has explored a co-evolution approach, in the sense that both dynamics have circular causal relationships. More precisely, Raimbault (2019*a*) introduces a definition of co-evolution in that particular context, based on co-evolution niches Holland (2012)

Raimbault (2019*b*)

1.2.2. *Model description*

The co-evolution model for cities and transportation networks at the macroscopic scale extends the spatial interaction model introduced by Raimbault (2018*b*) by adding dynamical speeds to network links. More precisely, (i)

1.2.3. *Quantifying hierarchy in systems of cities*

1.2.3.0.1. Static quantification of hierarchy

A simple way to quantify hierarchy is to use Zipf rank-size law, or more generally scaling laws. Let Y_i the dimension considered

1.2.4. *Dynamical indicators*

The rank correlation between initial and final distribution of a variable will measure how much an ordering hierarchy was modified, which is different from the variation of hierarchy given the variations of previous indicators such as the rank-size slope.

Dynamical hierarchy regimes are defined the following way:

1.2.5. *Spatialized indicators*

A spatial non-stationary version of a scaling law would write

1.3. Results

1.4. Discussion

1.5. Bibliography

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