

Coupling multi-agent system and game theory to model the emergence and the allometric growth of systems of cities

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Systems of cities are complex systems because cities are not isolated. They interact with others through material or virtual exchanges, and their growth partly depend of these interactions. City systems have been widely studied by Complex Theory and Geography (Batty, 2013, Pumain, Reuillon, 2017) because understanding these systems appears to be crucial when the majority of the world's population lives in cities.

Work on city systems has mainly allowed:

- to discover regularities in the distribution of the size of cities: the rank size law (Batty, 2006, Arcaute et al., 2015,), which is a power law relating the rank and the size of cities that can be observed in many countries
- to point out the role of innovation and its diffusion in the urban hierarchy to explain the differential growth of cities (Pumain, 2017)

However, the question “ where do cities emerge and how new cities contribute to the hierarchy of the city system” remains partially open. Most of the time, simulation of the allometric growth of cities start indeed from an existing hierarchy, and current models which try to understand emergence of cities are very complex and based on a lot of assumptions, regarding in particular the economic interaction (Pumain, Sanders, 2013, Pumain, Reuillon, 2017).

Trying to understand the emergence and the growth of city systems and following a principle of parsimony, we propose a model coupling Multi-Agent System (MAS) simulations and game theory (Leyton-Brown, Shoham, 2008).

The model is based on the simulation of interactions between cities at an individual level.

The aim is to show how, starting from a scatter of cities of the same size, it is possible to obtain a hierarchical system, including emerging cities, by acting only on the rules governing the exchange of people between cities.

Our model is composed of three main objects:

- i. The city modeled by a node on a graph. It have a starting population, a rate of demographic growth and an attractiveness (i.e. a capacity to attract people from other cities), which is a function of the number of exchanges it has been had till the start of the simulation.
- ii. The transport network, which is modeled by the arcs of the graph connecting cities. Arcs are characterized by a length and a speed. The graph changes during the simulation when new cities emerge and are connected to an attractive city. This connection is not mandatory. The connection occurs in 50% of the cases.
- iii. The individuals (inhabitants of the cities): some of them (same rate of the population for all the cities) go outside their city i to reach another city j . The destination j is chosen regarding the respective attractiveness of the cities and their network distance from i . The attractiveness of a city i at a step t of the simulation is a function of its contribution to the exchange till the start of the simulation :

Attractiveness $i = [(nb. \text{ individuals which have left } i \text{ to exchange before } t + nb. \text{ individuals who have chosen } i \text{ as a destination}) / \text{total of the exchange between all the city before } t]$

Other types of attractiveness function (not linear with exchange) can be tested.

When individuals met along the network, they “exchange” at this exchange location and get profit of these exchange. In order to maximize their gains, individuals have to meet a lot of individuals the closer as possible from their city of origin. Based on their “experience” agents calibrate the minimum and maximum distances they accept to travel in order to exchange. After a period of time, when a threshold of number of exchanges is reached at an exchange place k , individuals which have previously exchange in k in the most profitable way move to k and a new city will emerge.

To explore the model, we test different starting population, rate of moving people, attractiveness function, network configurations and threshold of emergence.

At last we seek to validate the model by using empirical data.

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KEYWORDS

System of cities / Multi-agent system / Game Theory / Emergence and growth of cities / Interactions