Morphogenesis, evolution and co-evolution of cities

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Abstract

Urban systems have a complexity in their own but still have been described and modelled using analogies and models imported from other disciplines. In particular, biological metaphors have been widely used in urban planning and design. We argue that fruitful transfer of concepts between biology and urban science can be achieved within the Artificial Life interdisciplinary framework. We illustrate this idea by synthesising a recent stream of research focusing on urban morphogenesis, urban evolution and urban co-evolution. In each case, novel definitions specific to the urban case were developed, while keeping the most proximity to the original disciplines. In that context, we suggest that many more interdisciplinary bridges could potentially be constructed through such disciplinary transfers going beyond purely methodological ones.

Introduction

The emergence of cities is tightly linked to the complexification of societies, and can be understood as one further step in cultural evolution (Sjoberg, 1965). To what extent this additional layer of complexity lead to urban systems that themselves evolve with proper rules and processes remains an open question. Properties such as scaling which can be exhibited across successive level of emergence, from biological to social and urban systems (Youn, 2018), suggest at least some analogies between these different scales. In that context, biological metaphors have been used to model, understand, and design cities (Batty and Marshall, 2009). Several disciplines have developed theories and models to understand the dynamics of cities (Pumain and Raimbault, 2020), among which Artificial Life approaches have shown some relevance.

Gershenson (2013) suggests that the application of concepts imported from the study of living systems can bring solutions to urban issues, such as traffic congestion, logistics, or more generally sustainability. Methods such as fractals can be used to quantify urban form (Chen and Jiang, 2010). Urban traffic can also be modelled using ALife methods (Yoshioka et al., 2017). Raimbault (2020a) shows a citation map of the scientific landscape loosely related to ALife in the study of urban systems, ranging from cellular automata models of urban growth to evolutionary computing applied to urban design or optimisation.

Beyond using similar methodologies or techniques, what is a common feature of the study of complex systems, the application of biological metaphors to the study of cities is one crucial feature in which ALife approaches have contributed to urban science, such as urban morphogenesis. The field of urban ecology, and more particularly industrial symbiosis (Chertow, 2007), in which companies are understood as ecosystems, is one other example.

The purpose of this contribution is to illustrate that effective transfer of concepts, which go beyond metaphors with new definitions and an adaptation of concepts, can occur between biology and urban science, and be fruitful to understand the dynamics of urban systems. We furthermore claim that the ALife interdisciplinary framework is a privileged scientific background to operate such transfers. To do so, we propose to synthesise a recent stream of research bridging ALife and urban science, which originated with the study of co-evolutionary processes in urban systems (Raimbault, 2018b). In that context, different concepts were transferred at different scales: urban morphogenesis at the scale of the city itself, and urban evolution and co-evolution at the scale of the system of cities.

Urban morphogenesis

Urban morphogenesis can be in it simplest sense understood as the growth of urban form, at the scale of a city or an urban area. Raimbault et al. (2014) introduce for example a cellular automaton coupled with a dynamical road network, which produces a variety of dynamical regimes of urban growth (Raimbault, 2017). Raimbault and Perret (2019) compare and calibrate generative models at the district scale. Raimbault (2018d) show the complementarity of multiple heuristics to simulate the morphogenesis of transportation networks. The concept of urban morphogenesis can also be made closer to its biological counterpart by showing how reaction-diffusion models can accurately reproduce existing urban forms, as shown by Raimbault (2018a) for urban areas in Europe. Finally, by constructing a definition of urban morphogenesis as *the strong coupling between the growth of urban form and the emergence of urban functions*, Raimbault (2018b) introduces an original viewpoint in which the transfer from biology is crucial. Following this positioning, the morphogenesis model studied by Raimbault (2019) uses transportation network to integrate a functional aspect into the dynamics of urban growth. Processes of urban morphogenesis can be seen as occurring within territorial niches (Holland, 2012), what suggests the relevance of studying urban evolution within and between these niches at larger scales.

Urban evolution

The idea of evolving entities within urban systems directly evokes theories of cultural evolution (Mesoudi, 2016), as social and cultural processes are occurring within cities, which are furthermore highlighted as incubators of social change (Pumain, 2019). The concept of urban evolution however goes beyond this, as cities themselves can be seen as evolving entities. Pumain (1997) proposed an *evolutionary theory of cities* to understand the dynamics of urban systems, in the sense of adaptive complex systems. Pumain and Reuillon (2017) synthesise the empirical and modeling results which were obtained in the direct heritage of this positioning.

Approaches of urban evolution with a definition closer to its biological and social counterparts however remains to be constructed. A partial proposition for a model of urban evolution is done by Raimbault (2020c). Extending the model of Favaro and Pumain (2011), the main ingredients are innovations which propagate between cities. Therein, transmission processes are captured through diffusion, while transformation processes occur as mutations when new innovations are created. A one-dimensional urban genome is thus the adoption of each innovation in each city. While this model remains stylised and limited, first in the fact that other urban dimensions are not accounted for, secondly as innovations all compete on the same dimension, it however provides a definition and operationalisation of urban evolution which includes the formal processes required for evolution (transmission, transformation, isolation of sub-systems for differentiation) (Durham, 1991).

Co-evolution in urban systems

Finally, one concept for which a relevant transfer can be achieved between biology and urban science is the concept of co-evolution. Raimbault (2018b) introduces a multi-level definition, with at the intermediate level the possibility of *statistically co-evolving population of urban entities within territorial niches*. More concretely, it is applied to the co-evolution between transportation networks of cities, and hypothesises that a circular relation between some properties of cities and some of transportation networks can be observed within some geographical regions. A method to characterise it on spatio-temporal data was introduced by Raimbault (2017). At the mesoscopic scale of urban areas, the morphogenesis model of Raimbault and Perret (2019) effectively captures such a co-evolution between indicators of urban morphology and the topology of road networks. Le Néchet and Raimbault (2015) propose a model strongly coupling land-use dynamics with transportation infrastructure dynamics, integrating network governance agents. At the macroscopic scale of the system of cities, Raimbault (2018c) study a co-evolution model between cities and intercity networks, and show that diverse regimes of co-evolution can be produced. Raimbault (2020b) extends this model with a more precise representation of transportation networks. These different applications show how this transfer of concept is fruitful to the understanding of urban dynamics.

Discussion

Several further transfers and developments can be suggested following this synthesis. A main research direction also strongly inspired by ALife and complexity is the construction of multi-scale models of urban evolution and urban dynamics. Previous efforts have remained limited as they did not used distinct ontologies and strong coupling between scales. For example, Batty (2005) introduces a common formalisation using cellular automata to simulate urban dynamics from the neighbourhood scale to the system of cities scale. Murcio et al. (2015) study a model simulating urban migrations migrations at different spatial ranges. A first step towards such models has been recently proposed by Raimbault (2021).

Such multi-scale models of urban dynamics would be essential tools for a sustainable territorial planning (Rozenblat and Pumain, 2018). Similarly, the benchmarking and comparison of multiple models for urban dynamics, as illustrated by Raimbault et al. (2020) for multiple urban systems worldwide, is a crucial step to ensure the robustness of policies.

Finally, many concepts originating from biology and studied across disciplines in the field of Artificial Life, remain relevant candidates for a strong transfer of concept and an operationalisation within urban science. For example, biomimicry has been put forward as an effective tool for urban design and architecture (Taylor Buck, 2017). The concept of autopoiesis (Bourgine and Stewart, 2004), which is tightly linked with morphogenesis but also cognition, remains to be investigated in the case of urban systems. Urban computing and collective intelligence, as research fields such as smart cities and digital twins are booming (Batty, 2018), may be linked to evolutionary computation, and more generally to studies of collective computation in biological systems. Altogether, we suggest that the integration of ALife into urban science and underlying transfer of concepts between disciplines, are relevant research directions for both.

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