Complexity: An epistemological review

Jenny Partanen*

Abstract

Today in the science of complex cities methods are often borrowed from natural sciences to study complex phenomena in cities, in many cases using computer aided methods. However, the universality of such methods has been criticized, claiming that social systems (such as cities) are much more complicated than systems in physics or chemistry. The capability of computer models to represent the reality (if indeed an objective reality exists) has likewise been questioned: Due to the inherent complex inter-linkages in urban systems, models as simplifications may provide only partial (irrelevant) knowledge, or be incapable of producing knowledge about anything else but themselves.

In the first part of the paper, epistemologically fundamental premises behind the correspondences between systems and representations are explored in light of the relevant literature, especially in the case of computer simulations. First of all, complexity thinking provides new insights for a novel relational and dynamic epistemological standpoint combining aspects from relative, social scientific thinking and objective, natural-scientific orientation, enabling a dynamic knowledge formation process in which the computer aided methods play a crucial role. Furthermore, an applied scientific realism perspective is nested with the above dual complexity epistemology, shedding light on how

* Tampere University of Technology, Finland

a model constructed on the basis of the above knowledge formation can represent reality via a concept of universal singularity, enabling 1) correspondence between theories through (and only through) overlapping trajectories in the space of possibilities (behavioral isomorphism), with significantly serious limitations to correspondence, and 2) how simulations can represent the mentioned subjective-objective reality (sufficiency of partial correspondence).

Keywords

Epistemology, Complexity, Philosophy, Emergence, Simulation

Introduction

For decades city planning has been built around a top-down rational paradigm: The communicative turn in planning making the planner into a negotiator can be considered to have sustained the profoundly hierarchical nature of planning. Nevertheless communicative planning accommodates pluralism in the world to the extent (replacing the specialist-planner with a variety of stakeholders), that the essential characteristics of the system or the process have not changed: with an inherently rational basis, the process seeks for (utopist) shared truth and consensus, i.e. equilibrium (Reschner, 1993). Rational-hierarchical planning collides with the complex adaptive nature of urbanity, and more relational and dynamic epistemological views to which the planning can be attached are needed.

Complexity science has been considered to provide an overarching philosophical foundation combining various epistemological views, and providing a common frame for both objective and subjective positions in knowledge production. Typically mixed methods are used in the study of human systems, implying a combination of quantitative (requiring certain objectivity, realism) and qualitative (subjective, semi-relativistic) approaches emerging from different epistemological foundations. In this paper we elaborate a combinatory epistemological foundation capable of merging quantitative and more relational/qualitative methods. We discuss in this paper the issues of system definition in the borderless universe, the concept of "real" in light of relationality and complexity, and the role of emergence and computer simulation in the production of knowledge in these non-linear networks of networks typical of complex systems.

This paper presents a brief review of several key approaches contemplating complexity epistemology, and aims at proposing a coherent epistemological frame, *substantial structural realism*, for complexity studies. We consider that this approach makes it possible to consider both (natural) scientific and relational aspects of the world, and the use of quantitative, qualitative and computational methods in the production of knowledge. At the end of the paper I briefly reflect these ideas against the planning of complex cities.

Epistemological division simplified

In an epistemological sense we live in two worlds: On the one hand, in the world of pure rationalistic (scientific) realism believing in objectivity, and that we can obtain direct knowledge of absolute reality (through scientific method), and on the other, in the world in which there is no absolute reality nor absolute knowledge, but only a possibility of extracting it from a personal or culture-specific perspective, and it can never be universal. Scientific knowledge has been largely considered to be objective, realistic "hard" science, but in the last century (or for even longer) the hegemony of positivist objectivity has been repeatedly challenged in the philosophy of science, with the critique even ranging to physics and mathematics (Rosen, 1996).

One of the perhaps most remarkable steps from within the rational sciences in this process was the Einstein-Bohr debates in the 1920s (Kumar, 2011). These discussions between Alfred Einstein and Niels Bohr contemplated epistemological problems in atomic physics, focusing on the basic nature of very small entities in physics, especially the dual character of light as waves and particles. Bohr eventually pointed out that wave equations described where entities like electrons could be, but that the entities did not actually exist as particles until observed, implying that their mere existence depended on the observer. It was a somewhat revolutionary idea that even the most fundamental building blocks of the universe were not absolute. Although Bohr's view was largely accepted, in natural science the fear for falling into total relativism quite understandably persisted – a world of chemical reactions and biological processes closely resembling objective reality. However, midway post-positivist approaches have gradually gained ground, proposing a constant reflection of conceptions - not abandoning reality but considering that it can only be known imperfectly and probabilistically, thus providing a frame for the elaboration of epistemology with complexity sciences, keeping in mind their origins in natural sciences.

Complexity can be considered to provide a unifying mode of thinking on two levels: first, on the level of methodology (quantitative and qualitative approaches), and secondly, on the level of epistemology, i.e. how to produce knowledge of the world. On the methodology level, as Portugali (1999) points out echoing C.P. Snow (1962), complexity thinking may have potential to bridge the gap between the two scientific cultures with decidedly distinct epistemological grounds. Although complexity originates in "hard", quantitative sciences, for example in an urban context, complexity has much in common with approaches in social sciences. First, both of these share a systemic view abandoning analytical reduction; secondly, in social sciences and complexity thinking the inherent dynamic progress is irreducible and not smooth; the system progresses via ruptures or revolutions to a qualitatively novel state. Finally, many social scientists, for example Giddens and Castells, consider space as a social production, which, however, operates as an order parameter controlling or "enslaving" the parts producing it (Portugali, 1999, 2006; Haken, 1980; Castells, 2000).

Furthermore, complexity thinking has potential for a new epistemological post-positivist approach. Cilliers (2005) considers that the properties enabling this are inherent characteristics of complex systems, reaching beyond the subjective/objective dichotomy and implying that the relation between knowledge and the network producing it is dialectic. It is impossible to define first the system (or context) and then the knowledge it produces – these two emerge within a recursive, interconnected process. Both the nature of knowledge and the system that produces it is in constant flux; in other words, the system cannot be uncoupled from its context due to its history. The identity is produced by their unique history, making them likewise unique and singular entities. Therefore no "botanical" generalization is possible (Cilliers, 2005).

Complex system is by definition constituted through a large number of non-linear interactions and cannot be separated from its environment, thereby rendering a complete analytical description impossible. The 'incompressibility' of the complex system implies that it cannot be simplified – the representation of a complex system is as complex as the system itself. The non-linearity of the system may become an issue regarding this compression - the impact of eliminated factors is impossible to predict. However, in practice a certain reduction (temporary "closing" of the system) is often needed to enable any research maneuvers. The system must be defined, or framed for description ("separated" temporarily from the environment of which it is inherently a part). Since an absolute separation is impossible, a pure objective view of an observer is impossible. The limits we draw cannot be objective; they are intuitive or strategic decisions of the observer influenced by her worldview. In the complex system knowledge is relational in the way it is constituted in the network within which it emerges, not atomized objective facts. However, knowledge is not subjective either - the knowing subject does not exist prior to the network of knowledge, but is constituted within the network: the observer exists in relation to the observed system, which emerges as it is delineated from the unlimited dynamic web (Cilliers, 2005; Cabrera, 2006).

This post-positivist, relational-rational mid-way position is not easy to maintain once we start computerizing. For computing, knowledge needs to be objective and the subject may not intervene in data gathering, storing, and manipulating, leading easily back to brutal positivism (Cilliers, 2005). This illusion can be questioned though – even in the process of dynamic modeling the model and the modeler can be considered to be in interaction through the strategies, aims, and decisions of the modeler and her reactions to the model's behavior (Crooks *et al.*, 2007).

Emergence: deciphering the mystery

One of the most essential characteristics for complex systems is the trans-scalar pattern formation process resulting from interactive parts (reflecting back to the parts from the "enslaving" whole). This process is often referred to as emergence, a concept which implies that the whole is qualitatively different from the sum of its parts, and irreducible (Holland, 2000). Since the 1920s (see e.g. O'Connor and Wong, 2015), the term has been criticized for implying a "mystical" moment at which qualitatively new, previously unobservable features appear in the system as observed on the higher level (deLanda, 2011; O'Connor and Wong, 2015)[1]. The aim of the early emergentists wanted was actually quite the opposite - to argument against the mystical "élan vital"[2]-theory, proposing that the emergent novelty was actually a natural consequence of the system's dynamic interactions (causal emergence) (Bergson, 1949; deLanda, 2011). As Meehl and Sellars, (1956), for example, state, the question is not metaphysical - the basic causal nature of emergent structures shows as our understanding of them increases. The more we study the interactions and patterns in these processes, the more causal they appear. Many emergent processes - for example in the case of convection the appearing of the emergent whole or a qualitatively new pattern (e.g. the rather complex process behind a thunderstorm) - are today understood in detail and thus largely demystified. Emergence may imply surprising elements (until they are better understood), not mystical ones (deLanda, 2011).

Substantially real

Since there are no absolute boundaries in the universe (except for perhaps some fundamental strings), the question is how to derive knowledge of a system if no actual "system" exists. Despite the non-existence of boundaries we can assume that certain relatively resilient and stable temporary structures or patterns emerge. These can be treated as if they had a "limited existence", as if they almost existed (Richardson, 2005). The level of their limited existence depends on their relational position on the *distribution of boundary (entity) stabilities*, a conceptual spectrum describing the stability of patterns in various types of systems (Figure1).

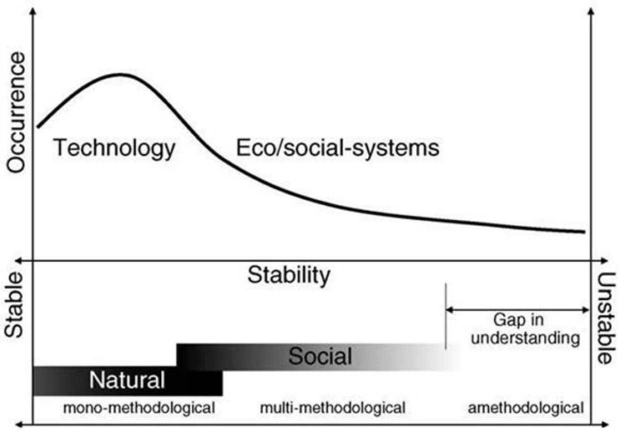

Figure 1 - Distribution of boundary (entity) stabilities (source: Richardson, 2005).

On the left hand side of the stability spectrum the structures or boundaries are relatively stable and it is safe to say that they are real, providing a foundation e.g. for science-based technology. As we move towards the other end there is increasing noise, and the borders are more and more a result of the interpretation of the observer, and patterns emerge

and decay much faster (Richardson, 2005). Urban/social systems range between the two extremes, occupied by patterns relatively stable for observation and research. The boundary definition is in an essential role here: borders, temporarily closing the system, are necessary for the meaning without which the knowledge does not exist; borders are strategic considerations, but they have subjective/intersubjective components; because of the conditional and historical nature of complex structures, constant revision and interpretation of the system (of both boundaries and strategies) is required. Consequently, although there is no absolute reality, due to the resilient patterns the world as we see it can be considered *substantially real* for purposes of scientific treatment, particularly in the natural/monomethodological area of the spectrum. As the borders are (re)defined, it is important to realize that borders are not necessarily inclusive but sometimes enabling such as the eardrum, or *ecotones*[3] in nature. The border is not necessarily spatially continuous; it may be fragmented or even virtual, and dynamic. In some cases the actors of such a complex web are never far from the edge – the system may be folded, or consist only of boundaries (Cilliers, 2005).
But as the turbulence of the system increases, how can we produce knowledge with any general use, and not only about a particular, unique system?

Singularities and generalization through pattern isomorphism

The emergent patterns are dynamically stable only temporarily (using scientific analogy, until the gradient is cancelled[4] and the pattern decays). They have most probably a tendency to behave in a certain way, to gravitate towards an attractor in a space of all possible actions. Once on these attractors, the systems are surprisingly resilient to perturbation – if disturbed they soon revert to their prior trajectory. Many of the emergent systems are independent of the mechanism: materially completely different systems may settle on a same attractor, i.e. share similar dynamics (deLanda, 2011). These *singularities* are here considered in a more general manner, as islands of probabilities reflecting the typical behavior of the system, not as mathematical attractors. This form of structural (scientific) realism[5] implying the mechanism independence has consequences: first, we can reflect our observations of reality (referring here to "substantially real") against certain formalizations – mathematical formulae, models, statistics etc. The reality can be reflected through these structures/singularities. Secondly, we can compare systems to each other ignoring their material qualities and making observations based on potential (partial) overlapping singularities (in the space of possibilities). This enables the extraction of more generalized knowledge of real world systems, the dynamics of which is structurally similar. In an urban context scaling laws, fractality or dynamic states (stable, periodic, chaotic, complex) for example form structurally coherent representations of dynamic systems, and they have often been used to estimate the success of urban dynamics, evolution, and transformation (e.g. Bettencourt, 2007, Pumain, 2012): We can assume that a certain "law" (scaling law, fractal dimension) reflects the maximal capacity of self-organization of the system, and if the system in reality follows the same law (gravitates to the same attractor) they share generative features. Since human systems are extremely complex trans-scalar interlinked networks of networks, in these the (interpretations) of both systems and temporary patterns must be pliable. Due to the inherent turbulence in the system certain robust "general laws" may not apply or apply only in certain cases or conditions

(Arcaute *et al.*, 2014; Pumain *et al.*, 2004), or novel patterns and regularities may emerge (Batty, 2006). Formally speaking, due to the independence of the mechanism, only the "degree of freedom" counts – that is, how many variables affect the dynamics (deLanda, 2011). Simple systems (degree of two - e.g. mass/velocity; or temperature/pressure) produce four probable dynamics, considering very complex systems such as cities we can easily see that the ratio increases exponentially (ad infinitum), bringing the issue back to the relationality, interpretation, and system definition and eventually singularities are discussed rather metaphorically.

Computers and the production of knowledge

Computers and increased computing capacity have played a crucial role in the development of theories of complex systems, for example in the study of self-organizing systems, fractals and chaos. Mathematically these systems or their mathematical formalizations are not necessarily beyond human capacity, but possibility for visualization and simulation have been the key elements of computing, helping to discover the universality and revealing the non-intuitive features of complex phenomena, and to formulate hypotheses decisively affecting progress in science and the resulting worldview (de Rosnay, 2011). Good computer models are not only rooted in relevant theories, but increasingly also assist in theory formulation (Crooks *et al.,* 2007). Computers, for example, have enabled the groundbreaking work of Lorenz, Mandelbrot, Kauffman, Holland and others (de Rosnay, 2011). It is thus relevant to ask what the role of the computer is in knowledge production (e.g. in simulations, genetic algorithms). The computer, however, is a black box, which Cilliers (2005) considers similar to an abstract or divine source of which we can never have knowledge – Cilliers even claims that we can gain knowledge only from a situated position. This is not necessarily a problem since we only need to concede the limits of our understanding (Cilliers, 2005). On the other hand, and despite that, the computer is comparable to certain other tools for observing phenomena which are far beyond human cognition: while a microscope acts as a tool for observing the infinitely small and a telescope for the infinitely large, a computer can be considered to be a "*macroscope*" which helps us to study "infinitely complex" entities. The macroscope does not produce knowledge as such since (at least if we abandon strict positivism) for data to become knowledge, meaning given by a human is required, but its role is very similar to a laboratory experiment. A laboratory test is not reality, but real world phenomena can be tested in a (virtual) laboratory – "in silica" - to gain new insights into their perhaps otherwise imperceptible aspects on the basis of which we can produce knowledge. This raises another question about the relationship between simulation and reality which will be contemplated next.

Simulation and knowledge

Computer aided micro-simulation has been a core method in the study of self-organizing systems enabling the observation of dynamic trans-scalar patterns emerging from multiple lower level interactions. What was revolutionary was that for the first time it was possible to construct systems from bottom up from smaller parts instead of analytically breaking the systems apart. Computer simulations of complex systems serve as exploratory, educational or theory constructing tools: at their best, they may reveal general principles of organized complexity, similarities of structures, optimal zones of evolution, and rules of construction for networks (de Rosnay, 2011). There are, however, several key challenges in using computer models which are related, first, to the (abovementioned) issues in system definition and agents, and aggregation of data for building blocks/variables for higher level processes, and secondly, to the representation of reality as nonlinear, unpredictable, and incompressible complex systems.

The first challenge is related to the way model dynamics are represented in terms of agents and agent interactions. These definitions of an agent and the process(es) it is involved in are intertwined with the interpretation of the system (borders) and patterns – artificially closing a certain part of the webs of the webs of the webs. If agents are (theoretically invariably) aggregations of lower level entities, our decisions may inadvertently change the processes they enable. It also becomes more difficult to define relevant processes - these are aggregations of lower level behavior as well. Furthermore, the vast number of agents, attributes, and processes causes problems for our ability to deal with the resulting exponentiation; sampling is a poor alternative since it is simplifying, and probably skews the model behavior. However, as stated, once on, the attractor emergent patterns can be considered resilient enough to form essentially stable entities - this feature enables science in the first place, since we do not need to construct the universe every time from the quarks. In addition, model construction is possible based on these entities (constructed of other entities) (deLanda, 2011). Here we return to the question of interpretation and the coupled subjective/objective –nature of the system - it is again all about interpretation and the two-way relationship between model and modeler.

The second issue in particular refers to the extent to which the model can be verified (e.g. with another model type) and replicated, which in social sciences is questionable due to difficulties in controlling for all the variables in a particular situation, but most importantly, the ways the model can be calibrated and validated (Crooks *et al.*, 2007). This raises an important question of how the model relates to the system it represents (reality). This is a salient point since the (dissipated) model structures are often too rich and the data needed for complete validation is likely to be too poor (Crooks *et al.*, 2007, Batty *et al.*, 2006). It is possible to validate the model qualitatively– to estimate if the visualized output "looks right" (Mandelbrot, 1983, Crooks *et al.*, 2007). In a more quantitative manner, the validity of the model can be evaluated by running it exhaustively: observing the complete range of possible outcomes with a particular specification - exploring the space of possibilities (Couclelis, 1997; Torrens, 2011). With this in mind, and echoing deLanda, we can say that if the space of possibilities is structurally similar (i.e. enables the existence of similar singularities) to the real world system, it can probably produce dynamics whose singularities are (partly) overlapping with singularities in reality, and it can represent the reality (regarding the quality of the dynamics but not necessarily regarding the material details). For example, dynamic states of cellular automata can be referred (generally) to the types of real complex system dynamics – the complex, generative state (class IV) can be considered analogical to the most preferable, self-organizing state able to create new qualities and renew itself in a resilient manner (this is the iconic "edge of chaos" behavior (Langton 1990)). This high level of conceptualization causes the simulation to remain on a rather abstract level as a tool for visualizing and exploring the (level of isomorphism of) spaces of possibilities of the model and the world. In city planning, this could mean learning about the triggers which may affect the shifts in the dynamics (make the system change the attractor), to facilitate the most preferable (self-generating) dynamics and leave the rest of the system intact to operate autonomously.

Conclusions

Complexity thinking provides guidelines for an epistemological frame capable of accommodating objective-realistic aspects, and more relativist, interpretational, and constantly changing worldviews. The s*ubstantial structural realism* suggested in this paper implies that so far no objective, absolute reality exists, but to certain extent the world is considered *substantially real* to study emergent, temporary patterns as if they existed. However, these need constant revision due to their turbulent characteristics, and the ambivalent nature of border definition (increasingly as moved towards the right end of the stability spectrum of the Figure 1). In complex cities rich in turbulence this implies that we need to increase our understanding of the structures, processes, and dynamics of the self-organizing[6], emergent processes and patterns in cities. In urban systems it is likely that these patterns are rather unstable yet resilient, emerging and decaying according to their own logics and therefore general stable knowledge of them is not possible, but constant revision is needed.

Many of these emergent patterns are mechanism independent and surprisingly resilient, and they can form a relatively stable basis for scientific procedures and computer simulations: their behavior may be reflected against general singularities, and compared to each other, or with the results of simulation with regard to their potential gravitation to the same attractor.

In addition to actual patterns, the "space of possibilities" needs constant revision. Similar to the system definition, singularities can be considered to emerge from interpretations of phenomena, against which these phenomena are again reflected. Singularities represent a generalized reading of the world, providing reflections of how systems might behave in certain conditions. This implies that the nature of knowledge of cities is considered to be "good enough" and pluralistic, instead of objective (rational) or idealized (consensus). Consequently in city planning it would be absurd to seek for total control and optimization of the city based on "objective" truth. Instead we need to aim at dynamic (re)building of adequately loose frames and rules in a self-organizing manner, based on an appropriate (constantly renewing) understanding of the urban system dynamics.

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[1] This is a crude simplification – there is a wide philosophical discourse contemplating the issue of ontological/causal emergence not discussed here, see e.g. http://plato.stanford.edu/entries/properties-emergent/

[2] The–"vital force" –concept, which was a hypothetical explanation for the evolution and development of organisms

[3] A border between two ecosystems with often remarkable diversity of species, or unique species ecosystems

[4] Gradient – a difference between energy/concentration etc. levels in the different parts of the system that acts as an energy storage device

[5] A form of scientific realism which relies solely on the structure of the scientific theories instead of their empirical content (avoiding both meta-induction and no-miraculous –arguments, for and against "pure" scientific realism) Stanford Encyclopedia of Philosophy.

[6] Self-organization and emergence are not synonymous: self-organization emphasizes the dynamic increase in order, while emergence focuses on the novelty of macro-level behavior from micro-level interaction. (De Wolf and Holvoet, 2005, pp.12-13) The system can self-organize without emergence, or vice versa, or emergence and self-organization may occur simultaneously (De Wolf and Holvoet, 2005), which is often the most interesting case in cities.

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