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Understanding Complex Systems

Founding Editor: J.A. Scott Kelso

Future scientific and technological developments in many fields will necessarily depend upon coming to grips with complex systems. Such systems are complex in both their composition – typically many different kinds of components interacting simultaneously and nonlinearly with each other and their environments on multiple levels – and in the rich diversity of behavior of which they are capable.

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UCS will publish monographs, lecture notes and selected edited contributions aimed at communicating new findings to a large multidisciplinary audience.

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Mathematical Analysis of Urban Spatial Networks

Springer

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To our wives,
Françou and Lyudmila,
and sons,
Nicolas, Olivier, Dimitri, Andreas,
and Wolfgang.

Preface

“We shape our buildings, and afterwards our buildings shape us,” said Sir Winston Churchill in his speech to the meeting in the House of Lords, October 28, 1943, requesting that the House of Commons bombed out in May 1941 be rebuilt exactly as before. Churchill believed that the configuration of space and even its scarcity in the House of Commons played a greater role in effectual parliament activity. In his view, “giving each member a desk to sit at and a lid to bang” would be unreasonable, since “the House would be mostly empty most of the time; whereas, at critical votes and moments, it would fill beyond capacity, with members spilling out into the aisles, giving a suitable sense of crowd and urgency,” [Churchill].

The old Houseof Commons was rebuilt in 1950 in its original form, remaining insufficient to seat all its members.

The way you take this story depends on how you value your dwelling space – our appreciation of space is sensuous rather than intellectual and, therefore, relys on the individual culture and personality. It often remains as a persistent birthmark of the land use practice we learned from the earliest days of childhood.

In contrast to the individual valuation of space, we all share its immediate apprehension, “our embodied experience” (Kellert 1994), in view of Churchill’s intuition that the influence of the built environment on humans deserves much credit.

Indeed, the space we experience depends on our bodies – it is what makes the case for near and a far, a left and a right (Merleau-Ponty 1962). On the small scale of actual human hands-on activity, the world we see is identified as the objective external world from which we can directly grasp properties of the objects of perception. A collection of empirically discovered principles concerning the familiar space in our immediate neighborhood is known as Euclidean geometry formulated in an ideal axiomatic form by Euclid circa 300 BC.

However, it was demonstrated by Hatfield (2003) that on a large scale our visual space differs from physical space and exhibits contractions in all three dimensions with increasing distance from the observer. Furthermore, the experienced features of this contraction (including the apparent convergence of lines in visual experience that are produced from physically parallel stimuli in ordinary viewing conditions) are not the same as would be the experience of a perspective projection onto a plane (Hatfield 2003).

As a matter of fact, the built environment constrains our visual space thus limiting our space perception to the immediate Euclidean vicinities and structuring a field of possible actions in that. By spatial organization of a surrounding place, we can create new rules for how the neighborhoods where people can move and meet other people face-to-face by chance are fit together on a large scale into the city.

In our book, we address these rules and show how the elementary Euclidean vicinities are combined into a global urban area network, and how the structure of the network could determine human behavior.

Cities are the largest and probably among the most complex networks created by human beings. The key purpose of built city elements (such as streets, places, and buildings) is to create the spaces and interconnections that people can use (Hillier 2004). As a rule, these elements originate through a long process of growth and gradual development spread over the different historical epochs. Each generation of city inhabitants extends and rearranges its dwelling environment adapting it according to the immediate needs, before passing it onto the next generation. In its turn, the huge inertia of the existing built environment causes chief social and economic impacts on the lives of its inhabitants. An emergent structure of the city is considered a distributed process evolving with time from innumerable local actions rather than as an object.

Studies of urban networks have a long history. In many aspects, they differ substantially from other complex networks found in the real world and call for an alternative method of analysis.

In our book, we discuss methods which may be useful for spotting the relatively isolated locations and neighborhoods, detecting urban sprawl, and illuminating the hidden community structures in complex fabric of urban area networks.

In particular, we study the compact urban patterns of two medieval German cities (the downtown of Bielefeld in Westphalia and Rothenburg ob der Tauber in Bavaria); an example of the industrial urban planning mingled together with sprawling residential neighborhoods – Neubeckum, the important railway junction in Westphalia; the webs of city canals in Venice and in Amsterdam, and the modern urban development of Manhattan, a borough of New York City planned in grid.

Although we use the methods of spectral graph theory, probability theory, and statistical physics, as should be evident from the contents, it was not our intent to develop these theories as the subject that has already been done in detail and from many points of view in the special literature. We do not give proof for most of the classical theorems referring interested readers to the special surveys. Throughout, we have tried to demonstrate how these methods, while applying in synergy to urban area networks, create a new way of looking at them.

We include as much background material as necessary and popularize it by a large scale, so that the book can be read by physicists, civil engineers, urban planners, and architects with a strong mathematical background – all those actively involved in the management of urban areas, as well as other readers interested in urban studies.

This book is targeted to bring about a more interdisciplinary approach across diverse fields of research including complex network theory, spectral graph theory, probability theory, statistical physics, and random walks on graphs, as well as sociology, wayfinding and cognitive science, urban planning, and traffic analysis.

The subsequent five chapters of this book describe the emergence of complex urban area networks, their structure and possible representations (Chap. 1). Chapters 2 and 3 review the methods of how these representations can be investigated. Chapter 4 extends these methods on the cases of directed networks and multiple interacting networks (say, the case of many transportation modes interacting with each other by means of passengers). Finally, in Chapter 5, we review the evidence of urban sprawl's impact, examine the possible redevelopments of sprawling neighborhoods, and briefly discuss other possible applications of our theory.

Humans live and act in Euclidean space which they percept visually as affine space, and which is present in them as a mental form. In another circumstance we spoke of fishes: they know nothing either of what the sea, or a lake, or a river might really be and only know fluid as if it were air around them. While in a complex environment, humans have no sensation of it, but need time to construct its "affine representation" so they can understand and store it in their spatial memory. Therefore, human behaviors in complex environments result from a long learning process and the planning of movements within them. Random walks help us to find such an "affine representation" of the environment, giving us a leap outside our Euclidean aquatic surface and opening up and granting us the sensation of new space.

Last but not least, let us emphasize that the methods we present can be applied to the analysis of any complex network.

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Bielefeld Philippe Blanchard and Dimitri Volchenkov

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