Springer Complexity

Springer Complexity is an interdisciplinary program publishing the best research and academic-level teaching on both fundamental and applied aspects of complex systems – cutting across all traditional disciplines of the natural and life sciences, engineering, economics, medicine, neuroscience, social and computer science.

Complex Systems are systems that comprise many interacting parts with the ability to generate a new quality of macroscopic collective behavior the manifestations of which are the spontaneous formation of distinctive temporal, spatial or functional structures. Models of such systems can be successfully mapped onto quite diverse "real-life" situations like the climate, the coherent emission of light from lasers, chemical reaction-diffusion systems, biological cellular networks, the dynamics of stock markets and of the internet, earthquake statistics and prediction, freeway traffic, the human brain, or the formation of opinions in social systems, to name just some of the popular applications.

Although their scope and methodologies overlap somewhat, one can distinguish the following main concepts and tools: self-organization, nonlinear dynamics, synergetics, turbulence, dynamical systems, catastrophes, instabilities, stochastic processes, chaos, graphs and networks, cellular automata, adaptive systems, genetic algorithms and computational intelligence.

The two major book publication platforms of the Springer Complexity program are the monograph series "Understanding Complex Systems" focusing on the various applications of complexity, and the "Springer Series in Synergetics", which is devoted to the quantitative theoretical and methodological foundations. In addition to the books in these two core series, the program also incorporates individual titles ranging from textbooks to major reference works.

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.

The Springer Series in Understanding Complex Systems series (UCS) promotes new strategies and paradigms for understanding and realizing applications of complex systems research in a wide variety of fields and endeavors. UCS is explicitly transdisciplinary. It has three main goals: First, to elaborate the concepts, methods and tools of complex systems at all levels of description and in all scientific fields, especially newly emerging areas within the life, social, behavioral, economic, neuro- and cognitive sciences (and derivatives thereof); second, to encourage novel applications of these ideas in various fields of engineering and computation such as robotics, nano-technology and informatics; third, to provide a single forum within which commonalities and differences in the workings of complex systems may be discerned, hence leading to deeper insight and understanding. UCS will publish monographs, lecture notes and selected edited contributions aimed at communicating new findings to a large multidisciplinary audience.

NECSI

New England Complex Systems Institute Book Series

Series Editor

Dan Braha

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New England Complex Systems Institute Book Series

The world around is full of the wonderful interplay of relationships and emergent behaviors. The beautiful and mysterious way that atoms form biological and social systems inspires us to new efforts in science. As our society becomes more concerned with how people are connected to each other than how they work independently, so science has become interested in the nature of relationships and relatedness. Through relationships elements act together to become systems, and systems achieve function and purpose. The study of complex systems is remarkable in the closeness of basic ideas and practical implications. Advances in our understanding of complex systems give new opportunities for insight in science and improvement of society. This is manifest in the relevance to engineering, medicine, management and education. We devote this book series to the communication of recent advances and reviews of revolutionary ideas and their application to practical concerns.

Thilo Gross · Hiroki Sayama
Editors

Adaptive Networks

Theory, Models and Applications

Springer

NECSI

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NECSI

For over 10 years, The New England Complex Systems Institute (NECSI) has been instrumental in the development of complex systems science and its applications. NECSI conducts research, education, knowledge dissemination, and community development around the world for the promotion of the study of complex systems and its application for the betterment of society.

NECSI was founded by faculty of New England area academic institutions in 1996 to further international research and understanding of complex systems. Complex systems is a growing field of science that aims to understand how parts of a system give rise to the systems collective behaviors, and how it interacts with its environment. These questions can be studied in general, and they are also relevant to all traditional fields of science.

Social systems formed (in part) out of people, the brain formed out of neurons, molecules formed out of atoms, and the weather formed from air flows are all examples of complex systems. The field of complex systems intersects all traditional disciplines of physical, biological and social sciences, as well as engineering, management, and medicine. Advanced education in complex systems attracts professionals, as complex systems science provides practical approaches to health care, social networks, ethnic violence, marketing, military conflict, education, systems engineering, international development and terrorism.

The study of complex systems is about understanding indirect effects. Problems we find difficult to solve have causes and effects that are not obviously related. Pushing on a complex system here often has effects over there because the parts are interdependent. This has become more and more apparent in our efforts to solve societal problems or avoid ecological disasters caused by our own actions. The field of complex systems provides a number of sophisticated tools, some of them conceptual helping us think about these systems, some of them analytical for studying these systems in greater depth, and some of them computer based for describing, modeling or simulating them.

NECSI research develops basic concepts and formal approaches as well as their applications to real world problems. Contributions of NECSI researchers include studies of networks, agent-based modeling, multiscale analysis and complexity, chaos and predictability, evolution, ecology, biodiversity, altruism, systems biology, cellular response, health care, systems engineering, negotiation, military conflict, ethnic violence, and international development.

NECSI uses many modes of education to further the investigation of complex systems. Throughout the year, classes, seminars, conferences and other programs assist students and professionals alike in their understanding of complex systems. Courses have been taught all over the world: Australia, Canada, China, Colombia, France, Italy, Japan, Korea, Portugal, Russia and many states of the U.S. NECSI also sponsors postdoctoral fellows, provides research resources, and hosts the International Conference on Complex Systems, discussion groups and web resources.

The New England Complex Systems Institute is comprised of a general staff, a faculty of associated professors, students, postdoctoral fellows, a planning board, affiliates and sponsors. Formed to coordinate research programs that transcend departmental and institutional boundaries, NECSI works closely with faculty of MIT, Harvard and Brandeis Universities. Affiliated external faculty teach and work at many other national and international locations. NECSI promotes the international community of researchers and welcomes broad participation in its activities and programs.

Preface

Adding one and one makes two, usually. But sometimes things add up to more than the sum of their parts. This observation, now frequently expressed in the maxim "more is different", is one of the characteristic features of complex systems and, in particular, complex networks. Along with their ubiquity in real world systems, the ability of networks to exhibit emergent dynamics, once they reach a certain size, has rendered them highly attractive targets for research. The resulting network hype has made the word "network" one of the most influential buzzwords seen in almost every corner of science, from physics and biology to economy and social sciences.

The theme of "more is different" appears in a different way in the present volume, from the viewpoint of what we call "adaptive networks." Adaptive networks uniquely combine dynamics on a network with dynamical adaptive changes of the underlying network topology, and thus they link classes of mechanisms that were previously studied in isolation. Here adding one and one certainly does not make two, but gives rise to a number of new phenomena, including highly robust self-organization of topology and dynamics and other remarkably rich dynamical behaviors.

Adaptive networks have for a long time been implicitly contained in models from a wide range of fields including discrete mathematics, computer science, statistical physics, systems biology, social sciences, engineering and medicine. However, only recently research in the different fields has begun to converge on the functioning of the adaptive networks as such. In the different fields, adaptive networks have appeared as a topic of intense research almost at the same time. Consequently, they are currently attacked from many different angles by the tools different disciplines have established.

It is becoming more and more apparent that adaptive networks could hold the key to many phenomena observed in a wide variety of applications. Major breakthroughs have recently been made and common themes now frequently appear across disciplines. A unified theory of adaptive networks seems within reach.

The book you have at hand, "Adaptive Networks: Theory, Models and Applications", is the first edited volume that illustrates the dawn of a new research field on the coevolution of topologies and states of complex networks. It showcases the recent advances in the theory, models and applications of adaptive networks by cutting-edge scientists. We hope that the book will play a role in setting the scope and directions of this emerging field of research, by raising the researcher's awareness to developments in different fields. It can also act as introductory text for the large group of researchers who presently start working on adaptive networks.

The project about this book started in January 2008 when the first editor (T.G.) invited the second editor (H.S.) as a guest scientist to the Max-Planck Institute for the Physics of Complex Systems in Dresden, Germany. For both of us it was clear that the coevolutionary dynamics of states and topologies in adaptive networks will be *the* next big movement in network research. Fortunately, at that time we had an offer to edit a book in the Springer/NECSI Studies on Complexity Collection; therefore it did not take long to come up with an idea to compile a book that collects the most influential and state-of-the-art in the forefront of adaptive network research. T.G. took the lead of selecting and inviting contributions primarily from statistical physics community, while H.S. invited contributions from empirical network research and computer science communities. All the chapters were included based on invitation only.

The contributors, who collectively represent the cutting edge of the rapidly advancing fields of network research, were enthusiastic about the concept this book aimed to illustrate, and they were extremely cooperative in preparing their chapters on a timely manner following a tight project timeline. We are wholeheartedly thankful for their contribution to and cooperation for this book project, without which it would not have been possible.

We are also very thankful to several people who played key roles in this book project, including: Dan Braha at UMass Dartmouth (Series Editor of the Springer/NECSI Studies on Complexity Collection) and Chris Caron at Springer for inviting us to guest-edit a book; Gabriele Hakuba and Sabine Lehr at Springer for their editorial assistance; Ellen Madison at the Department of Bioengineering at Binghamton University for clerical assistance; and the last but not the least, Cristian Huepe who unconsciously served as a key "hub" in the huge social network that made the two editors get to know each other in the first place and work together for this book. Finally, we thank the Visitor Program of the Max-Planck Institute for the Physics of Complex Systems for financial support.

Dresden, Germany — Thilo Gross
Binghamton, NY — Hiroki Sayama
May 2009

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