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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.

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Understanding Complex Systems

Founding Editor: S. 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.

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Editors

Applications of Chaos and Nonlinear Dynamics in Science and Engineering - Vol. 4

 Springer

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ISSN 1860-0832

Understanding Complex Systems

ISBN 978-3-319-17036-7

DOI 10.1007/978-3-319-17037-4

ISSN 1860-0840 (electronic)

ISBN 978-3-319-17037-4 (eBook)

Library of Congress Control Number: 2013938159

Springer Cham Heidelberg New York Dordrecht London

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Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media
(www.springer.com)

Preface

This is the fourth volume of the collection of essays entitled *Applications of Chaos and Nonlinear Dynamics in Science and Engineering*, which has been addressed to Master and Ph.D. Students, as well as to specialists of disciplines other than the hard sciences, in order to help them familiarize with the theory and the applications of nonlinearity, and its use in describing complex phenomena.

As illustrated in the previous volumes, terms such as nonlinear dynamics, chaos and complexity have pervaded the vocabulary of almost all fields of science and technology. As a matter of fact, current mathematical descriptions of evolving phenomena consist of nonlinear ordinary or partial differential equations, of various kinds of stochastic processes and of nonlinear space and time discrete iterative schemes. In the deterministic cases, a typical situation is that in which the propagation of uncertainties is exponential in time, a phenomenon known as sensitive dependence on initial conditions, and concisely and suggestively called deterministic chaos.

To understand the reasons why certain terms have become common in many different fields, it suffices to observe that nonlinearities appear in feedback phenomena, which are ubiquitous in nature, and generically in the evolution equations of systems consisting of interacting parts or interacting with an external environment. Furthermore, any measurement one may perform, like any estimate of the initial state of any material object, is bound to be affected by uncertainties, which propagate in time leading to the conclusion that a degree of unpredictability is intrinsic, in practice as well as in principle, to all time dependent phenomena. For this reason, the study of nonlinear evolutions is commonly associated with statistical concepts, and relies on measures such as the Lyapunov exponents and various kinds of dynamical entropies.

In the previous volumes, we have presented a vast collection of examples, treated explicitly and in moderately technical terms. Indeed, these concepts have in the past decades turned useful in countless practical applications—beyond the mathematical and physical literature in which they have been mostly developed—ranging from engineering to biology, medicine, computer and telecommunication sciences, etc. We have thus followed an approach which we deem suitable to a vast

readership, proposing essays written in the form of tutorials. In this last volume, we complete our survey and introduction to nonlinear, chaotic and complex phenomena, considering some issues of higher theoretical content than in the previous volumes, but preserving the mildly technical style of the previous volumes.

Part I concerns nonlinearities in transport of energy and matter, with one contribution by L. Stricker and L. Rondoni on models of heat transport and their mechanical properties, one contribution on the general theory of diffusion, by G. Boffetta, G. Lacorata and A. Vulpiani, and one contribution by M. Colangeli on the relation between the Boltzmann equation and hydrodynamics.

In Part II, we have three contributions on chaos and synchronization in complex networks: one by J. Stroud, M. Barahona and T. Pereira on modular networks, one by P. Carl on the evolution of climate, and one by A. Tai and S. Jalan on the use of random matrices. The chapters are well illustrated with recent developments on the subject area and possible practical applications.

Part III has two contributions on phase space reconstruction and on biological patterns, respectively, by S. K. Palit, S. Mukherjee, S. Banerjee, M.R.K. Ariffin and D. K. Bhattacharya, and by M. Banerjee. The theories are well illustrated and supported with analytical and numerical results.

Part IV concerns the use of chaos in field programmable gate arrays. This chapter is very useful as an introduction to the subject area.

We hope that this collection of examples, combined with those reported in the previous three volumes have covered a sufficiently wide spectrum of subjects, in terms suitable to a wide audience, interested in importing dynamical concepts in their disciplines, without recourse to sophisticated mathematical tools. The concepts of nonlinear dynamics are indeed proving more and more useful in all fields of research.

Serdang, Malaysia
Torino, Italy
26 January 2015

S. Banerjee
L. Rondoni

Contents

Part I Nonlinearity in Transport, Mechanical Models and Hydrodynamics

- 1 **Microscopic Models for Vibrations in Mechanical Systems Under Equilibrium and Non-equilibrium Conditions** 3
Laura Stricker and Lamberto Rondoni
- 2 **Chaos, Transport and Diffusion** 31
Guido Boffetta, Guglielmo Lacorata, and Angelo Vulpiani
- 3 **Small Scale Hydrodynamics** 65
Matteo Colangeli

Part II Chaos, Synchronization and Complex Networks

- 4 **Dynamics of Cluster Synchronisation in Modular Networks: Implications for Structural and Functional Networks** 107
Jake Stroud, Mauricio Barahona, and Tiago Pereira
- 5 **Synchronous Motions Across the Instrumental Climate Record** 131
Peter Carl
- 6 **Application of Random Matrix Theory to Complex Networks** 195
Aparna Rai and Sarika Jalan

Part III Attractor Reconstructions and Ecology/Biological Patterns

- 7 **Some Time-Delay Finding Measures and Attractor Reconstruction** ... 215
Sanjay Kumar Palit, Sayan Mukherjee, Santo Banerjee, M.R.K. Ariffin, and D.K. Bhattacharya
- 8 **Turing and Non-Turing Patterns in Two-Dimensional Prey-Predator Models** 257
Malay Banerjee

Part IV Chaos and Field Programmable Gate Array

9 Realizing Chaotic Systems on Field Programmable Gate Arrays: An Introduction 283
Bharathwaj Muthuswamy and Santo Banerjee