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.

Santo Banerjee • Mala Mitra • Lamberto Rondoni
Editors

Applications of Chaos and Nonlinear Dynamics in Engineering – Vol. 1

Springer

Editors
Santo Banerjee
Department of Mathematics
Politechnico di Torino
Corso Duca degli Abruzzi 24
10129 Torino
Italy
santoban@gmail.com
santo.banerjee@polito.it

Mala Mitra
Department of Physics
Camellia School of Engineering
and Technology
Nadibag PO Kajipara Barasat
700124 Kolkata
India
malamitra0@gamil.com

Lamberto Rondoni
Dipartimento di Matematica
Politecnico di Torino
Corso Duca degli Abruzzi 24
10129 Torino
Italy
lamberto.rondoni@polito.it

INFN, Sezione di Torino
Via P. Giuria 1
10125 Torino
Italy

ISSN 1860-0832 e-ISSN 1860-0840
ISBN 978-3-642-21921-4 e-ISBN 978-3-642-21922-1
DOI 10.1007/978-3-642-21922-1
Springer Heidelberg Dordrecht London New York

Library of Congress Control Number: 2011936888

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

In the past 60 years, the terms nonlinear dynamics and chaos have become familiar in the technical vocabulary of most sciences and technology. Indeed, the mathematical formulation of the vast majority of phenomena evolving in time, which has been given so far, consists of nonlinear ordinary or partial differential equations, or of nonlinear space and time discrete iterative processes. The typical situation, then, presents a kind of propagation of uncertainties which is exponential in time, is known as sensitive dependence on initial conditions, and is concisely and suggestively called chaos. Nonlinearities appear in feedback phenomena and generically in the evolution equations of most systems consisting of interacting parts or interacting with an external environment, which is itself affected by the interaction. Because of the mutual interactions, a given perturbation or action performed on the system of interest is shared by its elementary constituents in different ways, and the resulting effect is hardly predictable, especially in the long term, when the concatenation of causes and effects amounts to a long list. This concatenation may have constructive or destructive outcomes, with respect to the initial perturbations, and, typically, the consequent response of the object under investigation to the external actions will not be merely proportional to the size of the imposed perturbations. This is what nonlinearities mean, in general terms, and it is evident that observable natural phenomena and human artifacts commonly behave in nonlinear fashions.

Long-term predictions of the response of nonlinear dynamics to perturbations are usually problematic, but unpredictability is not an exclusive feature of nonlinear dynamics; even the simplest idealization of motion in space, the uniform motion of a single body subjected to no forces, enhances in time the initial uncertainty on its initial condition. Therefore, it is impossible to even predict whether an ideal arrow, which moves strictly along a straight line, will hit its target, if the direction of the motion is affected by some uncertainty and the target is sufficiently far. In this case, uncertainties grow linearly in time: to double the accuracy of predictions, it suffices to halve the uncertainty on the initial conditions. Beyond a certain limit, however, that may be practically impossible to achieve. Then, given the fact that any measurement one may perform, like any estimate of the initial state of any material object, is bound to be affected by uncertainties, one concludes that some degree of unpredictability is intrinsic, in practice as well as in principle, to our descriptions of all time dependent phenomena.

Nonlinearities commonly result in more serious difficulties as far as predictions, and hence control of the phenomena of interest is concerned. The limiting situation, known as chaos, is obtained when uncertainties are enhanced at an exponential rate. This situation is qualitatively, not simply quantitatively, different from those that enjoy linear or polynomial growths of perturbations. The striking fact is that even simple devices, such as the double pendulum, and not only very complex phenomena, like the climate, follow this kind of dynamics, in which there are no chances of reliable predictions beyond quite short times. This has then pushed researchers to develop the statistical approach to nonlinear dynamics, an approach that performs surprisingly well, in many circumstances, particularly when the degree of chaos, measured, e.g., by Lyapunov exponents, is quite high, or when the number of interacting elementary constituents of the system of interest is very large.

In the past decades, the growing understanding of these concepts has turned in practical applications, of particular interest in the development of present day technology. Time is therefore ripe for a review of the applications of chaos and nonlinear dynamics in engineering. As a matter of fact, numerous books are devoted to this purpose, but they are typically quite theoretical in nature. Therefore, the present collection of articles takes a more practical stand by addressing the various issues in the form of self-contained tutorials, which will guide step by step even the inexperienced reader to an informed use of the existing mathematical tools and softwares.

The first contribution, by S. Lynch, introduces the very popular and powerful Matlab software, by considering examples drawn from mechanical and electrical engineering applications, like Leon Chua's circuit, relevant for the problem of synchronization. M.F. Alves and Z.M. Assis Peixoto then tackle the important phenomenon of voltage flicker in electrical networks, which may be produced by an arc furnace operation. A case study concerning a 30 MVA arc furnace plant is considered in detail. Chapter 3, by S. Lynch and A. Steel, concerns the nonlinear dynamics and the stability properties of optical resonators, which are, for instance, one fundamental component of lasers. Chapter 4 is devoted to the problem of turbulence, and to the control of some of its aspects which are of primary technological importance, like turbulent mixing, which concerns the emissions of carbon dioxide and the spreading of pollutants, among its very many manifestations. This chapter is coauthored by B.S.V. Patnaik and S. Muddada. Vibration-based damage detection methods are widely used to identify hidden damages in beam and structural components. This application of nonlinear dynamics is considered by C.D. Dubey and V. Kapila in Chap. 5. The authors of Chap. 6, B. Kaygisiz, M. Karahan, A.M. Erkmen, and I. Erkmen, address another aspect of modern technology, that of the design of robots. This technology faces strong challenges, including those posed by vibrations, noisy sensing, and robot/irregular-environment interactions. The last four chapters are devoted to the evergrowing field of telecommunications and communications protocols, a number of which are based on chaos techniques. Chapter 7, by Jose M.V. Grzybowski, M. Eisencraft, and E.E.N. Macau, addresses, among other issues, the possibility of chaos-based ultra-fast communication. Chapter 8, by R. Martínez-Guerra, J.L. Mata-Machuca, A. Rodríguez-Bollain, and R. Aguilar-López, concerns secure transmission of information. In Chap. 9, Yu. Andreyev, A. Dmitriev, A.N. Miliou, and A.N. Anagnostopoulos describe an efficient method for storing, retrieving and processing information. Chapter 10, by S. Banerjee and S. Mukhopadhyay, concludes this book with another presentation of chaos-based secure communication methods.

This volume is the first of two, devoted to applications of chaos and nonlinear dynamics in engineering. The ten chapters present are organized in five parts, each concerning one of the most active fields of present-day engineering:

I. Nonlinearity and Computer simulations
II. Chaos and Nonlinear Dynamics in Electrical Engineering
III. Chaos and Nonlinear Dynamics in Building Mechanism and Fluid Dynamics
IV. Chaos in Robotics
V. Chaos and Nonlinear Dynamics in Communication.

We wish that this collection of essays, with their tutorial character, provide valuable help to those who intend to familiarize with both the theoretical and mathematical aspects of engineering applications of the fascinating modern theory of dynamical systems. As proved by the applications discussed in the following ten chapters, and those of the second volume which will follow, many applications of this theory, which are of high technological interest, have already been realized. But given the pace at which new ideas and new techniques are being developed, we anticipate that many more applications will be developed in the coming years, which makes of tantamount importance for scientists as well as engineers to familiarize with issues such as those addresses in this book.

Torino

Santo Banerjee
Mala Mitra
Lamberto Rondoni

Contents

Part V Chaos and Nonlinear Dynamics in Communication