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.

Editorial and Programme Advisory Board

Springer Series in Synergetics

Founding Editor: H. Haken

The Springer Series in Synergetics was founded by Herman Haken in 1977. Since then, the series has evolved into a substantial reference library for the quantitative, theoretical and methodological foundations of the science of complex systems.

Through many enduring classic texts, such as Haken's Synergetics and Information and Self-Organization, Gardiner's Handbook of Stochastic Methods, Risken's The Fokker Planck-Equation or Haake's Quantum Signatures of Chaos, the series has made, and continues to make, important contributions to shaping the foundations of the field.

The series publishes monographs and graduate-level textbooks of broad and general interest, with a pronounced emphasis on the physico-mathematical approach.

Alexander Balanov, Natalia Janson,
Dmitry Postnov, Olga Sosnovtseva

Synchronization

From Simple to Complex

With 150 Figures

Springer

Dr. Alexander Balanov
Loughborough University
Department of Physics
Loughborough
Leicestershire LE11 3TU
United Kindom
a.balanov@lboro.ac.uk

Dr. Natalia Janson
Loughborough University
School of Mathematics
Ashby Road
Loughborough
Leicestershire LE11 3TU
United Kingdom
n.b.janson@lboro.ac.uk

Prof. Dmitry Postnov
Saratov State University
Department of Physics
Astrakhanskaya 83
Saratov, Russia 410026
postnov@chaos.ssu.runnet.ru

Dr. Olga Sosnovtseva
Technical University of Denmark
Department of Physics
Building 309
2800 Lyngby, Denmark
olga@fysik.dtu.dk

ISBN 978-3-540-72127-7 e-ISBN 978-3-540-72128-4

DOI 10.1007/978-3-540-72128-4

Library of Congress Control Number: 2008929606

Typesetting and Production: VTEX, Vilnius
Cover design: WMX Design GmbH, Heidelberg, Germany

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

To our parents

Preface

This book is written by scientists who live in different countries (United Kingdom, Denmark, Russia), but who have graduated from, and were established as researchers at the same place: The Laboratory of Nonlinear Dynamics, Department of Physics, Saratov State University, Russia. Being apart for many years, we have united in one team again to write this book. Why?

We aim to summarize both classical results that are crucial for the understanding of the concept of synchronization, and an up-to-date account of the accompanying fascinating phenomena. The main theme that runs throughout the book is that interaction between complex systems is governed by the same universal principles. We strive to explain the material in a way that the newcomers to the field would hopefully appreciate, namely,

- From simple calculations to advanced theoretical approaches
- From simple dynamics to complex behavior
- From mathematical and physical to general perspectives

Assuming only the basic knowledge of mathematics, our book takes the reader to the frontiers of what is currently known about this research area.

The classical approach to synchronization we have learned by heart during our regular and inevitably hot discussions, and most of the results on the new synchronization phenomena we obtained together. It is therefore difficult to separate scientific contribution and to compare the efforts made by each co-author, so we decided to arrange the list of authors in alphabetic order to emphasize an equal investment of their time, ideas and enthusiasm.

This book would not have been possible without the help of many people. First of all, we are deeply indebted to our teacher Prof. V.S. Anishchenko who has introduced us to Nonlinear World and who patiently taught us to properly speak the language of science. We are grateful to our teachers and colleagues Prof. V.V. Astakhov and T.E. Vadivasova for their active support and many invaluable discussions during the years. We extend our thanks to Prof. E. Mosekilde, Prof. P. McClintock, Prof. S.K. Han, who are our closest collaborators in the field of synchronization, and to Prof. N.-H. Holstein-Rathlou, Prof. D. Marsh, and Prof. H. Braun, with whom we have been enjoying collaborations in the field of modeling of biological systems. Our special thanks are due to Prof. E. Schöll who has encouraged us to write this book. We acknowledge fruitful discussions with our colleagues A. Pikovsky, M. Rosenblum, M. Zaks, J. Kurths, L. Schimansky-Geier, A. Neiman, A. Nikitin, and A. Silchenko on various aspects of synchronization. We gratefully acknowledge the help of S. Malova with references and of P. Sherbakov with experiments. We would also like to warmly thank Victoria Sosnovtseva for making funny illustrations especially for this book. Finally, we would like to express our sincere gratitude to our families for their constant support and inspiration.

Over the years our studies were supported by the Russian Foundation for Basic Research (Russia), the U.S. Civilian Research and Development Foundation (USA), Engineering and Physical Sciences Research Council (UK), Medical Research Council (UK), The Leverhulme Trust (UK), Forskningsrådet for Natur og Univers (Denmark), and the European Union through the Network of Excellence BioSim.

Loughborough,	*Alexander Balanov*
Saratov,	*Natalia Janson*
Lyngby,	*Dmitry Postnov*
May 2008	*Olga Sosnovtseva*

Contents

Part II Case Studies in Synchronization