Network Science

Ernesto Estrada • Maria Fox • Desmond J. Higham •
Gian-Luca Oppo
Editors

Network Science

Complexity in Nature and Technology

Springer

Editors
Prof. Ernesto Estrada
University of Strathclyde
Department of Mathematics and Statistics
and Department of Physics
G1 1XH Glasgow
UK
ernesto.estrada@strath.ac.uk

Prof. Maria Fox
University of Strathclyde
Department of Computer and
Information Sciences
G1 1XH Glasgow
UK
maria@maths.strath.ac.uk

Prof. Desmond J. Higham
University of Strathclyde
Department of Mathematics and Statistics
G1 1XH Glasgow
UK
djh@maths.strath.ac.uk

Prof. Gian-Luca Oppo
University of Strathclyde
Department of Physics
G4 0NG Glasgow
UK
gianluca@phys.strath.ac.uk

ISBN 978-1-84996-395-4 e-ISBN 978-1-84996-396-1
DOI 10.1007/978-1-84996-396-1
Springer London Dordrecht Heidelberg New York

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Control Number: 2010934727

Cover design: deblik

Printed on acid-free paper

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

Preface

This book of invited, edited chapters arose from the six month programme **Complex Networks across the Natural and Technological Sciences**, held in 2009 at the *Institute for Advanced Studies*, Glasgow.

The motivation for the program was the emergence of a new interdisciplinary activity, sometimes called *Network Science*, that focuses on the patterns of interactions that arise between individual components of natural and engineered systems. The programme had several key objectives:

- To identify commonality across very different areas of application;
- To advance one area by injecting ideas and techniques from another;
- To allow *practitioners* (those who collect and use data) to pose challenges to *theoreticians* (those who develop concepts and derive analytical and computational tools);
- To allow *theoreticians* to bring *practitioners* up to speed on the state of the art.

The programme included three one-week workshops, featuring invited presentations by internationally-renowned researchers.

Workshop 1: Static Networks, organised by Ernesto Estrada and Des Higham, focused on the classic network science of fixed connectivity structures: empirical studies, mathematical models and computational algorithms.

Workshop 2: Dynamic Properties of Complex Networks, organised by Maria Fox, looked at (a) the study of time-dependent processes that take place over networks and modern topics such as *synchronisation*, and *message passing algorithms*, and (b) the study of time-evolving networks such as the World Wide Web and shifts in *topological properties* (connectivity, spectrum, percolation).

Workshop 3: Applications of Complex Networks, organised by Gian-Luca Oppo, emphasised the physical and engineering sciences, and looked ahead to new developments in the field.

In addition to these three international workshops, the six month programme featured tutorials, public lectures and an outreach event for children at the Glasgow Science Centre.

Having organised the programme and witnessed the remarkably wide applicability of the research themes, we feel that the time is ripe for an interdisciplinary, cross-cutting view of the state-of-the-art in network science. We therefore invited a cross-section of the participants to contribute to this book, encouraging them to review recent developments in a specific area of relevance to complex networks, discuss challenging open problems and, where possible, indicate how the field is likely to develop over the next few years. We were delighted with the uniformly enthusiastic response from these authors, and we were equally pleased that the publisher Springer shared our vision. These chapters, which have been brought together with a unified index, appear in an order that reflects the sequence of topics considered in the three workshops.

It is our hope that this resulting book will appeal to a wide range of scientists and stimulate new lines of research.

Acknowledgements This book would never have appeared without the funding and administrative support of the Institute for Advanced Studies, for the programme *Complex Networks across the Natural and Technological Sciences*. We thank the Institute's officers at that time, Nigel Mottram, Jane Morgan and Jason Reese for strategic advice and moral support, and also the Institute's manager, Patricia Krus, for her expert assistance.

Further financial support was provided by the *Institute of Complex Systems at Strathclyde*.

We are extremely grateful to Mary McAuley in the Department of Mathematics and Statistics at the University of Strathclyde for efficiently converting three of the submitted chapters from Microsoft Word format into Springer-style LaTeX.

Finally, we are, of course, hugely indebted to the authors of these chapters for sharing their expertise and insights.

Strathclyde, Glasgow

Ernesto Estrada
Maria Fox
Desmond J. Higham
Gian-Luca Oppo

Contents

Contributors

Gabriella Baranyi Institute of Environmental Studies, Eötvös University, Budapest, Hungary.
Gabriella Baranyi is an environmental scientist with research interests in conservation biology and habitat planning, aided by habitat network analysis.

Stefano Battiston Systemgestaltung, ETH-Zentrum, Zurich, Switzerland, sbattiston@ethz.ch.
Stefano Battiston has a background in physics and neuroscience and has research interests in the modelling and empirical study of economic and social networks.

Guido Caldarelli Centre SMC, and ISC CNR, Dip. Fisica, University "Sapienza", Piazzale Aldo Moro 5, Rome, Italy, Guido.Caldarelli@roma1.infn.it.
Guido Caldarelli has interests in fractal growth, self-organised criticality and the analysis of scale-free networks.

Federica Ciocchetta Centre for Computational and Systems Biology, The Microsoft Research–University of Trento, Povo-Trento, Italy, ciocchetta@cosbi.eu.
Federica Ciocchetta has a background in biomathematics and information/communication technology, and has research interests in modelling and analysis of biological systems, process calculi and state-space reduction techniques.

Ernesto Estrada Department of Mathematics and Statistics, University of Strathclyde, Glasgow, UK; Department of Physics, University of Strathclyde, Glasgow, UK, ernesto.estrada@strath.ac.uk.
Ernesto Estrada has research interests in spectral graph theory, complex networks and their applications in chemistry, biology and many other areas in the physical, social and technological sciences.

Maria Fox Department of Computer and Information Sciences, University of Strathclyde, Glasgow, UK, maria.fox@cis.strath.ac.uk.
Maria Fox has research interests in automated planning, scheduling and constraint satisfaction and their application in solving combinatorial search and optimisation problems.

Diego Garlaschelli Said Business School, University of Oxford, Oxford, UK.
Diego Garlaschelli has research interests in complex networks and statistical mechanics, with applications to biological and socio-economic systems.

James B. Glattfelder Systemgestaltung, ETH-Zentrum, Zurich, Switzerland, jglattfelder@ethz.ch.
James Glattfelder develops ideas from complexity science and agent-based modelling to study large databases of international companies and ownership networks.

Naomichi Hatano Institute of Industrial Science, University of Tokyo, Tokyo 153-8505, Japan, hatano@iis.u-tokyo.ac.jp.
Naomichi Hatano develops and analyses models from the perspective of statistical and mathematical physics, to capture the essence of complicated physical phenomena.

Desmond J. Higham Department of Mathematics and Statistics, University of Strathclyde, Glasgow, UK, d.j.higham@strath.ac.uk.
Des Higham is an applied/computational mathematician with interests in matrix computations, stochastic modelling and simulation, and applications in biology and neuroscience.

Ferenc Jordán Centre for Computational and Systems Biology, The Microsoft Research-University of Trento, Povo-Trento, Italy, jordan@cosbi.eu.
Ferenc Jordán is a researcher at CoSBi with MSc in biology and PhD in genetics who has research interests that span across all organisational levels of biological networks, ranging from molecular to landscape graphs.

Holger Kantz Max Planck Institute for the Physics of Complex Systems, Dresden, Germany, kantz@pks.mpg.de.
Holger Kantz has research interests that are centred around understanding, modelling, and predicting the complex temporal evolution of real world systems.

Rowland R. Kao Faculty of Veterinary Medicine, University of Glasgow, Glasgow, UK, r.kao@vet.gla.ac.uk.
Rowland Kao has research interests that include modelling and parameter estimation for the transmission of livestock diseases using network analysis, differential equations, statistics and computer simulations, principally funded through a Wellcome Trust Senior Research Fellowship.

Vito Latora Dipartimento di Fisica ed Astronomia, Universitá di Catania and INFN Sezione di Catania, Catania, Italy, latora@ct.infn.it.
Vito Latora uses his background in theoretical physics and nonlinear dynamics to look into biological problems, to model social systems, and to find new solutions for the design of technological networks.

Fabrizio Lillo Dipartimento di Fisica e Tecnologie Relative, Università di Palermo, Palermo, Italy, lillo@unipa.it; Santa Fe Institute, Santa Fe, USA.
Fabrizio Lillo has research interests that focus on the application of methods and tools of statistical physics to economic, financial, and biological systems.

Stefano Luccioli Consiglio Nazionale delle Ricerche, Istituto dei Sistemi Complessi, 50019 Sesto Fiorentino, Italy; Centro Studi Dinamiche Complesse, Sesto Fiorentino, Italy.

Stefano Luccioli has a background in nonlinear dynamics and statistical mechanics with interests in modelling and simulating biological systems (proteins and neural networks).

Gian-Luca Oppo Department of Physics, University of Strathclyde, Glasgow, UK, gianluca@phys.strath.ac.uk.
Gian-Luca Oppo, who is director of the Institute of Complex Systems at Strathclyde, has research interests that include complexity and spatial structures in nonlinear optics, and nonlinear dynamics of laser devices

Antonio Politi Consiglio Nazionale delle Ricerche, Istituto dei Sistemi Complessi, 50019 Sesto Fiorentino, Italy; Centro Studi Dinamiche Complesse, Sesto Fiorentino, Italy, antonio.politi@isc.cnr.it.
Antonio Politi is a physicist who works on the dynamics of neural networks, heat conductivity in low-dimensional systems and chaotic behaviour in systems with many degrees of freedom.

Sergio Porta Urban Design Studies Unit, Department of Architecture, University of Strathclyde, Glasgow, UK, sergio.porta@strath.ac.uk.
Sergio Porta has research interests that span from urban morphology, adaptive space and spatial analysis to public space design, urban design and traffic management.

Nataša Pržulj Department of Computing, Imperial College London, London, UK, natasha@imperial.ac.uk.
Nataša Pržulj is a computer scientist with research interests in applications of graph theory, mathematical modelling, and computational techniques to solving large-scale problems in computational and systems biology, especially planar cell polarity, proteomics, cancer informatics, and chemo-informatics.

V. Anne Smith School of Biology, University of St Andrews, St Andrews, Fife KY16 9TH, UK, anne.smith@st-andrews.ac.uk.
V. Anne Smith uses computational methods to analyse complex biological networks, and evaluates the computational methods with both computer simulation and biological intervention.

Emanuele Strano Urban Design Studies Unit, Department of Architecture, University of Strathclyde, Glasgow, UK, emanuele.strano@gmail.com.
Emanuele Strano has research interests that include urban studies, informal settlements, land titling, urban morphology, complex system theory applied to urban studies, urban sociology.

Alan Taylor Department of Mathematics and Statistics, University of Strathclyde, Glasgow, UK, a.taylor@strath.ac.uk.
Alan Taylor has a background in mathematics and computer science, and his research interests lie in computational algorithms for network science.