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E. Ben-Naim H. Frauenfelder Z. Toroczkai (Eds.)

Complex Networks

Springer

Editors

Eli Ben-Naim
Hans Frauenfelder
Zoltan Toroczkai
Los Alamos National Laboratory
Complex Systems Group
Theoretical Division
87545 Los Alamos, NM
USA

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Preface

The study of interacting particle systems has traditionally focused on cases where the underlying topology can be described by simple structures such as regular crystalline lattices or by a continuum medium. The emerging science of complex networks addresses complementary situations where the underlying topology is a graph whose structure is complex, irregular, and dynamically evolving. Complex networks are ubiquitous in nature. Natural networks include biological networks (metabolic networks, gene regulatory networks, protein interaction networks, signaling networks, epidemic networks), and ecological networks (food webs). Man-made networks include communications networks (WWW, Internet, phone, wireless), transportation infrastructures (power grid, waterways, natural gas, roadways, airlines), and social interactions (acquaintance networks, scientific collaboration networks, terrorist networks).

Network science dates back to Leonhard Euler who initiated graph theory by his solution in 1736 to the famous Königsberg bridges problem. For the next 200 years graph theory dealt with regular or small structures. Network science was reborn with the introduction of random graph theory, through the seminal works of Ray Solomonoff and A. Rapoport in 1951, and separately, by the works of Pál Erdős and Alfréd Rényi in 1959-1960 who introduced probabilistic methods to graph theory.

Currently, a third revolution is underway. It has been motivated by the emergence of communication networks and the need to characterize biological networks and facilitated by the availability of large data sets and the explosive growth in computing power. Based on characteristics of real-world networks, the small-world network model by Duncan Watts and Steven Strogatz and the preferential attachment model of scale-free networks by Albert-László Barabási and Réka Albert have reshaped the way we think of networks.

These contributions showed that the structure of many real-world large-scale complex networks are far from those of the traditional random graphs, and they opened up many avenues for future research. They demonstrated that complex networks is an intellectually deep and ripe area, relevant to many scientific disciplines including physics, biology, engineering, and social science, far beyond the traditional fields of mathematics and computer science.

Now, the research front turns to networks dynamics. Most networks have the role and function to transport or transfer entities (information, energy, etc.) along the links. Optimizing transport efficiency and quantifying network vulnerabilities and robustness constitute the next open questions. Predicting the dynamical evolution of the network structure and its coupling with the transport processes are the ultimate challenge for complex networks science.

This volume of the Lecture Notes in Physics series focuses on the application of techniques from statistical physics to characterization and modeling of complex networks. There is a deep connection between statistical physics and statistical graph theory as both aim to characterize macroscopic observables based on a probabilistic treatment of all microstates of the system. As a concrete example, the polymerization process proposed by Paul Flory and used by chemical physicists to model gelation is equivalent to the growth of a random graph. This natural connection between statistical mechanics and statistical graph theory is currently being exploited by many physicists and the present volume presents the state-of-the-art in the application of statistical physics methods to complex networks research.

This volume consists of four parts. The first two parts concern theory and modeling of networks while the last two parts involve applications to real-world networks. Part I deals with theoretical characterization of structural properties of networks including spectral and extremal properties and structural robustness. Part II addresses dynamical aspects of networks including evolving networks, dynamical processes and transport on networks, and synchronization of networks. Part III focuses on information and social networks including publication networks, collaboration networks, email communication, and board membership networks. Part IV starts with an overview of networks in biological systems, followed by applications to genetic and neural networks.

The articles in this volume were written by speakers at the conference "Complex Networks: Structure, Dynamics, and Function", the 23rd annual conference of the Center for Nonlinear Studies at Los Alamos National Laboratory, held from May 12–16, 2003 in Santa Fe, New Mexico, USA. The papers in this volume are review articles by experts in network science, many of whom made seminal contributions to the foundations of this novel field. As a collection, this volume covers a large fraction of the state-of-the art of complex network research. The articles are aimed at students, newcomers to the field, as well as experts. All articles have been carefully peer-reviewed not only for scientific content but also for self-consistency and readability.

The editors thank the authors for their contributions and the referees, whose comments improved the articles in a significant way. The editors also wish to thank the conference organizers Benjamin McMahon, Paul Fenimore, and Pieter Swart, as well as the conference coordinator Roderick Garcia.

Los Alamos, New Mexico, USA
February 2004

Eli Ben-Naim
Hans Frauenfelder
Zoltan Toroczkai

Contents

Part I Network Structure

List of Contributors

Lada A. Adamic
HP Labs
1501 Page Mill Road
Palo Alto, CA 94304
USA
ladamic@exch.hpl.hp.com

Mikko Alava
Laboratory of Physics
Helsinki University of Technology
P. O. Box 1100, FIN-02015 HUT
Finland
mja@fyslab.hut.fi

Réka Albert
Department of Physics
Pennsylvania State University
University Park, PA 16802
USA
ralbert@phys.psu.edu

David J. Aldous
Department of Statistics
367 Evans Hall
University of California
Berkeley, CA 94720
USA
aldous@stat.berkeley.edu

Albert-László Barabási
Department of Physics
University of Notre Dame
Notre Dame, IN 46556
USA
alb@nd.edu

Stefano Battiston
Laboratoire de Physique Statistique
ENS, 24 rue Lhomond
75005 Paris
France
battiston@ens.fr

Daniel ben-Avraham
Department of Physics
Clarkson University
Potsdam, NY 13699
USA
qd00@clarkson.edu

Eli Ben-Naim
Theoretical Division
Los Alamos National Laboratory
Los Alamos, NM 87545
USA
ebn@lanl.gov

Lidia A. Braunstein
Department of Physics
Boston University
Boston, MA 02215
USA
lidia@meta.bu.edu

Sergey V. Buldyrev
Department of Physics
Boston University
Boston, MA 02215
USA
sergey@meta.bu.edu

Guido Caldarelli
Dipartimento di Fisica
Università La Sapienza
P.le Moro 5
00185 Roma
Italy.
gcalda@pil.phys.uniroma1.it

Michele Catanzaro
Dipartimento di Fisica
Università La Sapienza
P.le Moro 5
00185 Roma
Italy
michele@pil.phys.uniroma1.it

Fan Chung
Department of Mathematics
University of California, San Diego
La Jolla, CA 92093
USA
fan@math.ucsd.edu

Reuven Cohen
Department of Computer Science &
Applied Mathematics
Weizmann Institute of Science
Rehovot
Israel
cohenr@shoshi.ph.biu.ac.il

Imre Derényi
Department of Biological Physics
Eötvös University
Pázmány P. stny. 1A,
1117 Budapest
Hungary
derenyi@angel.elte.hu

Sergei N. Dorogovtsev
Departamento de Física
Universidade de Aveiro
Campus Universitário de Santiago
3810-193 Aveiro
Portugal
sdorogov@fis.ua.pt

Gerald M. Edelman
The Neurosciences Institute
10640 John Jay Hopkins Drive
San Diego, CA 92121
USA
edelman@nsi.edu

Illés Farkas
Biological Physics Research Group
Eötvös University
Pázmány P. stny. 1A,
1117 Budapest
Hungary
fij@angel.elte.hu

Diego Garlaschelli
Dipartimento di Fisica
Università di Siena
Via Roma 56
53100 Siena
Italy
diego@pil.phys.uniroma1.it

Chul-Min Ghim
School of Physics
Seoul National University
Seoul 151-747
Korea
cmghim@phya.snu.ac.kr

Paul Ginsparg
Departments of Physics
Cornell University
Ithaca, NY 14853
USA
ginsparg@cornell.edu

Kwang-Il Goe
School of Physics
Seoul National University
Seoul 151-747
Korea
vrooom@soeh.snu.ac.kr

Alexander V. Goltsev
Departamento de Física
Universidade de Aveiro
Campus Universitário de Santiago
3810-193 Aveiro
Portugal
goltsev@fis.ua.pt

Hasan Guclu
Department of Physics
Rensselaer Polytechnic Institute
110 8^{th} Street
Troy, NY 12180
USA
gucluh@rpi.edu

Matthew B. Hastings
Theoretical Division
Los Alamos National Laboratory
Los Alamos, NM 87545
USA
hastings@lanl.gov

Shlomo Havlin
Department of Physics
Bar-Ilan University
Ramat-Gan
Israel
havlin@ophir.ph.biu.ac.il

Bernardo A. Huberman
HP Labs
1501 Page Mill Road
Palo Alto, CA 94304
USA
huberman@hpl.hp.com

Byungnam Kahng
School of Physics
Seoul National University
Seoul 151-747
Korea
kahng@phya.snu.ac.kr

Tomer Kalisky
Department of Physics
Bar-Ilan University
Ramat-Gan
Israel
kaliskt@mail.biu.ac.il

János Kertész
Department of Theoretical Physics
Budapest University of Technology
8 Budafoki út, 1111
Hungary
kertesz@phy.bme.hu

Doochul Kim
School of Physics
Seoul National University
Seoul 151-747
Korea
dkim@snu.ac.kr

György Korniss
Department of Physics
Rensselaer Polytechnic Institute
110 8^{th} Street
Troy, NY 12180
USA
korniss@rpi.edu

Balázs Kozma
Department of Physics
Rensselaer Polytechnic Institute
110 8^{th} Street
Troy, NY 12180
USA
kozmab@rpi.edu

Paul L. Krapivsky
Department of Physics
Boston University
Boston, MA 02215
USA
paulk@bu.edu

Ying-C. Lai
Department of Mathematics
Arizona State University
Tempe, AZ 85287
USA
yclai@chaos1.la.asu.edu

Linyuan Lu
Department of Mathematics
University of California, San Diego
La Jolla, CA 92093
USA
llu@math.ucsd.edu

José F. F. Mendes
Departamento de Física
Universidade de Aveiro
Campus Universitário de Santiago
3810-193 Aveiro
Portugal
jfmendes@fis.ua.pt

Rémi Monasson
Laboratoire de Physique Théorique
ENS, 24 rue Lhomond
75005 Paris
France
monasson@lpt.ens.fr

Adilson E. Motter
Max Planck Institute for
the Physics of Complex Systems
Nöthnitzer Strasse 38
01187 Dresden
Germany
motter@mpipks-dresden.mpg.de

Mark E. J. Newman
Department of Physics
University of Michigan
Ann Arbor, MI 48109
USA
mejn@umich.edu

Takashi Nishikawa
Department of Mathematics
Southern Methodist University
Dallas, TX 75275
USA
tnishi@chaos6.la.asu.edu

Mark A. Novotny
Department of Physics
Mississippi State University
Mississippi State, MS 39762
USA
man40@ra.msstate.edu

Eulsik Oh
School of Physics
Seoul National University
Seoul 151-747
Korea
oes@phya.snu.ac.kr

Zoltán N. Oltvai
Department of Pathology
Northwestern University
Chicago, IL 60611
USA
zno008@northwestern.edu

Gergely Palla
Department of Biological Physics
Eötvös University
Pázmány P. stny. 1A
1117 Budapest
Hungary
pallag@angel.elte.hu

Romualdo Pastor-Satorras
Department de Física
Universitat Politècnica de Catalunya
Campus Nord
08034 Barcelona
Spain
romu@sinera.upc.es

Sidney Redner
Department of Physics
Boston University
Boston, MA 02215
USA
redner@bu.edu

Alexander N. Samukhin
Departamento de Física
Universidade de Aveiro
Campus Universitário de Santiago
3810-193 Aveiro
Portugal
samukhin@fis.ua.pt

Anil K. Seth
The Neurosciences Institute
10640 John Jay Hopkins Drive
San Diego, CA 92121
USA
seth@nsi.edu

Ricard V. Solé
Complex Systems Lab-ICREA
Universitat Pompeu Fabra (GRIB)
Dr Aiguader 80
08003 Barcelona
Spain
ricard.sole@upf.edu

Sameet Sreenivasan
Department of Physics
Boston University
Boston, MA 02215
USA
sameet@buphy.bu.edu

H. Eugene Stanley
Department of Physics
Boston University
Boston, MA 02215
USA
hes@bu.edu

Gábor Szabó
Department of Theoretical Physics
Budapest University of Technology
8 Budafoki út, 1111
Hungary
szabo@phy.bme.hu

Zoltán Toroczkai
Theoretical Division
Los Alamos National Laboratory
Los Alamos, NM 87545
USA
toro@lanl.gov

Sergi Valverde
Complex Systems Lab-ICREA
Universitat Pompeu Fabra (GRIB)
Dr Aiguader 80
08003 Barcelona
Spain

Alexei Vázquez
Department of Physics
University of Notre Dame
NotreDame, IN 46556
USA
avazque1@nd.edu

Alessandro Vespignani
Laboratoire de Physique Théorique
Bâtiment 210
Université de Paris-Sud
91405 ORSAY Cedex
France
Alessandro.Vespignani
@th.u-psud.fr

Tamás Vicsek
Department of Biological Physics
Eötvös University
Pázmány P. stny. 1A
1117 Budapest
Hungary
vicsek@angel.elte.hu

Stefan Wuchty
Department of Physics
University of Notre Dame
Notre Dame, IN 46556
USA
swuchty@nd.edu