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

# Complex Networks

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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 vul-

nerabilities 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

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## Part I Network Structure

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### Tomography and Stability of Complex Networks

<i>Tomer Kalisky, Reuven Cohen, Daniel ben-Avraham, Shlomo Havlin</i> . . . . .	3
1 Introduction . . . . .	3
2 General Results . . . . .	4
3 Scale-Free Networks . . . . .	8
4 Tomography of Scale Free Networks . . . . .	11
5 Random Breakdown . . . . .	18
6 Intentional Attack . . . . .	19
7 Critical Exponents . . . . .	23
8 Conclusions . . . . .	31

### Spectral Analysis of Random Networks

<i>Sergei N. Dorogotsev, Alexander V. Goltsev, José F.F. Mendes, Alexander N. Samukhin</i> . . . . .	35
1 Introduction . . . . .	35
2 Random Walk on a Tree . . . . .	36
3 General Theory . . . . .	37
4 Spectra of Uncorrelated Graphs . . . . .	39
5 Effective Medium Approximation . . . . .	40
6 Tail Behavior and Finite-Size Effects . . . . .	40
7 Spectrum of a Transition Matrix . . . . .	42
8 Spectra of Different Topological Graphs . . . . .	43
9 Conclusions . . . . .	48

### A Tractable Complex Network Model

#### Based on the Stochastic Mean-Field Model of Distance

<i>David J. Aldous</i> . . . . .	51
1 Introduction . . . . .	51
2 Formulas . . . . .	53
3 The Model . . . . .	59
4 Calculations . . . . .	67
5 Further Calculations . . . . .	77
6 Comparison with Other Models . . . . .	84



**The Small World Phenomenon in Hybrid Power Law Graphs**

<i>Fan Chung, Linyuan Lu</i> .....	89
1 Introduction .....	89
2 Preliminaries .....	91
3 Local Graphs .....	93
4 The Hybrid Power Law Model .....	95
5 Several Facts Concerning Random Power Law Graphs .....	97
6 The Diameter of the Hybrid Model .....	99
7 Concluding Remarks .....	101

**Classes of the Shortest Pathway Structures  
in Scale Free Networks**

<i>Kwang-Il Goh, Eulsik Oh, Chul-Min Ghim, Byunghnam Kahng, Doochul Kim</i> .....	105
1 Introduction .....	105
2 Load or Betweenness Centrality .....	107
3 Load-Load Correlation .....	115
4 Diameter Change Distribution .....	118
5 Conclusions and Discussion .....	123

**The Optimal Path in an Erdős-Rényi Random Graph**

<i>Lidia A. Braunstein, Sergey V. Buldyrev, Sameet Sreenivasan, Reuven Cohen, Shlomo Havlin, H. Eugene Stanley</i> .....	127
1 Introduction .....	127
2 Theoretical Arguments .....	128
3 Numerical Analysis .....	129
4 Probability Distribution of the Maximal Weight on the Optimal Path .....	132

**Clustering in Complex Networks**

<i>Gábor Szabó, Mikko Alava, János Kertész</i> .....	139
1 Introduction .....	139
2 Examples of Clustering .....	141
3 Models That Create Clustering .....	143
4 Rate-Equation Approach .....	151
5 Conclusions .....	159

**Equilibrium Statistical Mechanics of Network Structures**

<i>Illés Farkas, Imre Derényi, Gergely Palla, Tamás Vicsek</i> .....	163
1 Introduction .....	163
2 Preliminaries .....	165
3 Graph Ensembles .....	166
4 Main Features of Equilibrium Graphs: Local and Global Properties ...	176
5 Topological Phase Transitions in Equilibrium Network Ensembles ...	178
6 Summary .....	184

## Information Theory of Complex Networks: On Evolution and Architectural Constraints

<i>Ricard V. Solé, Sergi Valverde</i> .....	189
1 Introduction .....	189
2 Measuring Correlations .....	191
3 Entropy and Information .....	194
4 Model Networks .....	196
5 Real Networks .....	198
6 Simulated Annealing Search .....	202
7 Discussion .....	204

---

## Part II Network Dynamics

---

### Extremal Properties of Random Structures

<i>Eli Ben-Naim, Paul L. Krapivsky, Sidney Redner</i> .....	211
1 Introduction .....	211
2 Random Trees .....	213
3 Random Graphs .....	223
4 Random Networks .....	225
5 Summary and Discussion .....	231

### On the Analysis of Backtrack Procedures for the Colouring of Random Graphs

<i>Rémi Monasson</i> .....	235
1 Introduction .....	235
2 Colouring in the Absence of Backtracking .....	239
3 Colouring in the Presence of Massive Backtracking .....	244
4 Conclusions: What Is Missing? .....	251

### Small-World Synchronized Computing Networks for Scalable Parallel Discrete-Event Simulations

<i>Hasan Guclu, György Korniss, Zoltán Toroczkai, Mark A. Novotny</i> .....	255
1 Introduction .....	255
2 The Basic Conservative Scheme .....	256
3 The Small-World Synchronized Conservative PDES Scheme .....	261
4 Summary .....	272

### Critical Phenomena in a Small World

<i>Matthew B. Hastings, Balázs Kozma</i> .....	277
1 Introduction .....	277
2 Long-Range Versus Small-World .....	280
3 Edwards-Wilkinson Equation: An Example .....	288
4 Discussion .....	296

**Attacks and Cascades in Complex Networks**

*Ying-Cheng Lai, Adilson E. Motter, Takashi Nishikawa* . . . . . 299

1 Introduction . . . . . 299

2 Conceptual Network of Language . . . . . 301

3 Attack-Induced Cascades in Complex Networks . . . . . 302

4 Range-Based Attacks on Links in Complex Networks . . . . . 305

5 Discussion . . . . . 308

**Part III Information Networks & Social Networks**

**Scholarly Information Network**

*Paul Ginsparg* . . . . . 313

1 arXiv Background and Lessons . . . . . 313

2 New Scholarly Publication Models . . . . . 318

3 Novel Corpus Navigation Tools . . . . . 322

4 Text Classification and Support Vector Machines . . . . . 326

5 arXiv q-bio Extraction . . . . . 329

6 Conclusion . . . . . 334

**Who Is the Best Connected Scientist?**

**A Study of Scientific Coauthorship Networks**

*Mark E.J. Newman* . . . . . 337

1 Introduction . . . . . 337

2 Coauthorship Networks . . . . . 339

3 Basic Results . . . . . 341

4 Distances and Centrality . . . . . 352

5 Weighted Collaboration Networks . . . . . 361

6 Conclusions . . . . . 366

**Information Dynamics in the Networked World**

*Bernardo A. Huberman, Lada A. Adamic* . . . . . 371

1 Introduction . . . . . 371

2 Email as Spectroscopy . . . . . 372

3 Information Flow in Social Groups . . . . . 379

4 Small World Search . . . . . 386

5 Conclusion . . . . . 395

**Emergence of Complexity in Financial Networks**

*Guido Caldarelli, Stefano Battiston, Diego Garlaschelli, Michele Catanzaro* . . . . . 399

1 Introduction . . . . . 399

2 The Board and Director Networks . . . . . 400

3 Network of Price Correlations . . . . . 406

4 The Stock Investment Network . . . . . 412

**Topology, Hierarchy, and Correlations in Internet Graphs**  
*Romualdo Pastor-Satorras, Alexei Vázquez, Alessandro Vespignani* . . . . . 425

1 Introduction . . . . . 425

2 Internet Maps . . . . . 427

3 Average Properties . . . . . 428

4 Scale-Free Properties . . . . . 430

5 Hierarchy and Correlations . . . . . 434

6 Conclusions . . . . . 438

**Part IV Biological Networks**

**Characteristics of Biological Networks**  
*Albert-László Barabási, Zoltán N. Oltvai, Stefan Wuchty* . . . . . 443

1 Introduction . . . . . 443

2 Basic Network Features . . . . . 444

3 Network Models . . . . . 445

4 Conclusions . . . . . 453

**Boolean Modeling of Genetic Regulatory Networks**  
*Réka Albert* . . . . . 459

1 Introduction . . . . . 459

2 The Segment Polarity Gene Network . . . . . 463

3 Description of the Model . . . . . 465

4 Modeling the Wild Type Segment Polarity Genes . . . . . 467

5 The Functional Topology of the Segment Polarity Network . . . . . 469

6 Gene Mutations . . . . . 472

7 Determination of the Steady States  
 and Their Domains of Attraction . . . . . 473

8 Possible Changes in the Assumptions . . . . . 476

9 Conclusions . . . . . 479

**Theoretical Neuroanatomy: Analyzing the Structure, Dynamics,  
 and Function of Neuronal Networks**  
*Anil K. Seth, Gerald M. Edelman* . . . . . 483

1 Introduction . . . . . 483

2 Structure . . . . . 484

3 Dynamics . . . . . 488

4 Function . . . . . 493

5 General Discussion . . . . . 504

Appendix A: Implementation Details . . . . . 506

**Index** . . . . . 513

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