The Nature of Complex Networks

Sergey N. Dorogovtsev
University of Aveiro

José F. F. Mendes
University of Aveiro

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For those whom we love

Gentlemen! As is custom among our kind, we do not
plunge headlong into folly on the orders of a single madman,
but act according to our own collective madness!
Assassin's Creed IV: Black Flag

Preface

The authors of this book are scientific workers in the field of complex networks. This is an explosively developing multidisciplinary area, which involves practically everything, natural and artificial, in the world, and we, theoretical physicists, explore it, armed with the standard tools of statistical physics. What we are doing is uncovering the actual simplicity and beauty of complex systems including the random complex networks. The book is about the key ideas and concepts of this field which is already called the science of networks. The highly heterogeneous networked systems, which we explore, typically have no governing authority, no command centre taking decisions and issuing orders. Nonetheless, even without orchestration, these remarkably widespread systems function very effectively and reliably. Moreover, the absence of centralization in favour of distributed self-organization is vital for their existence and robustness.

Thanks to numerous tips one can appreciate the pace and scale of efforts to surveil, control, protect, and manipulate society, in essence, large social and information networks. The sweeping reset of our 'highly interconnected and interdependent world', induced and concerted by the Covid-19 pandemic (Schwab and Malleret, 2020), is forcefully amplifying these exertions. The big problem now is how to control large complex systems that is impossible to govern. A related fundamental problem is how to structure and efficiently process the collected big data. Similarly impressive and costly efforts are under way to engineer and manage large cellular, technological, deep-learning, and many other networks. These extensive works demonstrate how important it is to understand in detail the principles of organization and function of highly heterogeneous and highly structured random networked systems, that is the nature of complex networks.

In 2003 we published the first reference book in this research area, the 'Evolution of Networks: From Biological Nets to the Internet and the WWW,' which essentially focused on evolving networks. Our new, more dense and advanced, book touches upon a much wider range of networks and networked systems paying particular attention to the directions that emerged after 2002–2003. Writing a book is about asking good questions. So, keeping the book compact, we consider only the issues and key results that, we believe, will not lose their value in the future. To avoid drowning in serious mathematics we have to present a number of basic theorems from graph theory without even sketching the ideas of their proofs. Furthermore, for the sake of brevity we do not include in the book chapters devoted to numerous applications and empirical material. The reader will find detailed discussions of these matters in a number of comprehensive books and reviews, which we cite.

The researchers studying complex networks will acquire from this concise modern book a number of new issues and ideas, not yet touched upon in other reference volumes. We propose a statistical mechanics view of random networks based on the concept of statistical ensembles, but approaches and methods of modern graph theory, concerning random graphs, overlap strongly with statistical physics. Hence mathematicians have a good chance to discover interesting things in our book, even though it does not contain mathematical proofs and trades off rigour for comprehension, brevity, and relevance. We expect that this book will be useful for undergraduate, master, and PhD students and young researchers from multidisciplinary studies, physics, computer science, and applied mathematics wishing to gain a serious insight into the principles of complex networks. The book can be used as a text in university courses on complex networks. We propose to determined students not only a brief trip to the land of complex networks but an option to stay there forever. For a more elementary and concise introduction to the science of networks, we refer most impatient readers to the text of one of us, S. N. Dorogovtsev, 'Lectures on Complex Networks.'

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