

Preface

# Dynamics on Complex Networks and Applications

Adilson E. Motter<sup>a,\*</sup>, Manuel A. Matías<sup>b</sup>, Jürgen Kurths<sup>c</sup>, Edward Ott<sup>d</sup>

<sup>a</sup> Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208, USA

<sup>b</sup> Instituto Mediterráneo de Estudios Avanzados, IMEDEA (CSIC-UIB), E-07122 Palma de Mallorca, Spain

<sup>c</sup> Institute of Physics, University of Potsdam PF 601553, 14415 Potsdam, Germany

<sup>d</sup> Department of Physics and Department of Electrical and Computer Engineering, University of Maryland, College Park, MD 20742, USA

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## Abstract

At the eight-year anniversary of Watts and Strogatz's work on the collective dynamics of small-world networks and seven years after Barabási and Albert's discovery of scale-free networks, the area of dynamical processes on complex networks is at the forefront of the current research on nonlinear dynamics and complex systems. This volume brings together a selection of original contributions in complementary topics of statistical physics, nonlinear dynamics and biological sciences, and is expected to provide the reader with a comprehensive up-to-date representation of this rapidly developing area.

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Regarding collective behavior, Philip Anderson already said in 1972 “more is different” [1]. But how different? This question is gaining new momentum with the emergence of fields of research that are treating in great detail the properties of individual components of complex systems, such as genes and proteins in a cell or neurons in the brain. The increasing availability of information about the components of systems calls for a parallel development of a system-level analysis capable of describing the integrated collective behavior.

The theory of complex networks seems to offer an appropriate framework for such a large-scale analysis in a representative class of complex systems, with examples ranging from cell biology and epidemiology to the Internet [2–8]. The research in this area has been fueled by the discovery of universal structural properties in real-world networks and the theoretical understanding of evolutionary laws governing the emergence of these properties [9,10]. However, implicit in the study of the function of such networks is the idea that they sustain dynamical processes. Therefore, along with the study of purely structural and evolutionary properties, there has been

increasing interest in the interplay between the dynamics and the structure of complex networks [4,11–13].

This interest is well motivated since most biological, social and technological complex systems are inherently dynamic. In these contexts, time-dependent phenomena are intimately related to the performance of the system, as exemplified by traffic congestion, cascading failures, and synchronization of biological oscillators.

The idea that dynamical processes could be strongly influenced by the structure of an underlying network was already suggested by Watts and Strogatz in their work on small-world networks [9] using epidemic spreading as an example process. In the context of an epidemic spreading, the importance of the network structure became even more evident after Barabási and Albert's work on scale-free networks [10] and subsequent study by Pastor-Satorras and Vespignani on the absence of an epidemic threshold in such networks [14]. The role of the network structure is further emphasized by the presence of communities [15], correlations [16], patterns of weighted connections [17], and other nontrivial structures in many real-world networks that had not been anticipated from the classical random graph theory of Erdős and Rényi [18]. These alone could serve as a good motivation for the study of dynamics on complex networks. However, there is more to it.

\* Corresponding author.

E-mail address: [motter@northwestern.edu](mailto:motter@northwestern.edu) (A.E. Motter).

A salient property of most dynamical processes in complex systems is their almost unavoidable nonlinearity. Part of the recent interest in the study of dynamics on complex networks comes from the understanding that techniques and expertise developed in the study of nonlinear dynamics and chaos can be useful in the study of such nonlinear systems. A prime example of this is the master stability framework previously introduced by Pecora and Carroll [19] to study synchronization of coupled chaotic oscillators. The same framework has been subsequently applied to separate the contribution of the network structure encapsulated in the eigenvalues of the coupling matrix in the study of network synchronization [20,21]. Similar eigenvalues also govern the influence of the network on a number of other dynamical phenomena, including diffusion [22] and the emergence of coherent behavior in general [23]. These approaches thus help determine not only how the system depends on its parts, but also how it depends on the way the parts are linked together, and this offers a solid glimpse into how different “more can be”.

Because of all this, there is now a fast developing science of dynamics on complex networks that has as an essential underpinning a strong interaction among different disciplines and between theory and applications. To help crystallize this emerging field as a promising area of interdisciplinary research, we have coordinated the four-week International Seminar and Workshop “Dynamics on Complex Networks and Applications” at the Max Planck Institute for the Physics of Complex Systems, Dresden, February 06–March 03, 2006, which was attended by a hundred physicists, mathematicians, and life scientists, among others.

In this Focus Issue, we bring together a selection of original contributions from leading experts in nonlinear dynamics, statistical physics, and biological sciences. This combination of contributions from experts primarily working in different fields is a unique and outstanding aspect of this Focus Issue, which is expected to enhance communication across disciplines, consolidate a common scientific language, and foster the fast growing area of dynamics on complex networks.

The volume is organized as follows. The first section consists of contributions on structural properties of complex networks, and includes new results on clique counting,  $k$ -core percolation, and statistical significance of community detection. The second section comprises a number of contributions on dynamics on complex networks, with emphasis on synchronization and coherent behavior. These works present

new results on the optimization of dynamical performance and structural cost, relations between functional and structural communities, synchronization in networks of oscillators, spatio-temporal dynamics, and network transport. The third section includes contributions on social and human-generated networks where the evolution of the network is coupled to an agent-driven dynamical process. The last section includes contributions on applications to gene regulatory networks, genetic similarity, and neuronal networks.

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