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EDITORIAL

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Complex networks describe a wide range of systems in fields as disparate as sociology, biology and technology. Examples include networks of acquaintances or collaborations between individuals, neural networks in the brain, or computers in telecommunication networks.

The past ten years have witnessed an increasingly large emphasis in the physics community on the study of complex networks. This interest has certainly been triggered by the optimized rating of computing facilities, and by the grown availability of data on large real world networks (such as the Internet and the World Wide Web, electric power grids, phone call networks, the actors' collaboration network in movie databases, scientific coauthorship and citation networks from the Science Citation Index, but also systems of interest in biology and medicine, as cortical networks or metabolic and protein networks). The massive and comparative analysis of networks from different fields has produced a dramatic advance in the understanding of complex systems.

The first issue handled is on the *structure of complex networks*. In particular, we have learned that, despite the inherent differences, most of the real world networks are characterized by similar topological properties, as for instance, relatively small characteristic path lengths, high clustering coefficients, fat tailed shapes in the degree distributions, degree correlations, and the presence of motifs and community structures. Attempts to explain such similarities have led largely to the understanding of the evolutionary mechanisms that have shaped the topology of a network, and to the design of new models retaining the most significant properties observed empirically. This first stage of the research was motivated by the expectancy that the characterization and the modeling of the structure of a network would lead to a better knowledge of its dynamical and functional behavior.

And, indeed, the second issue concerns the study of *dynamical processes on complex networks*. In this context, we have learned that the coupling architecture has important consequences on the network functional robustness and response to external perturbations, as random failures, or targeted attacks. At the same time, a series of evidences have pointed out the crucial role played by the network topology in determining the emergence of collective dynamical behavior, such as synchronization, or in governing the main features of relevant processes that take place in complex networks, such as the spreading of epidemics, information and rumors.

An increasingly large number of works have been published after the two seminal papers, by Watts and Strogatz on *small-world networks*, that appeared in *Nature* in 1998 [Watts & Strogatz, 1998], and by Barabási and Albert on *scale-free networks* that appeared a year later in *Science* [Barabási & Albert, 1999]. Furthermore, in these last ten years new research lines have sparkled, covering novel topics and problems in network structure and dynamics.

A first example is the increasing interest in the study of *weighted networks*, i.e. graphs in which each link is associated with a real number. Such interest is motivated by the need of suitably modeling a series of relevant situations wherein a complex wiring topology is associated with a large heterogeneity in the capacity and intensity of the connections.

Another relevant example of a novel topic is the study of *spatial networks*, i.e. graphs where the topology is constrained by the geographical embedding (for instance, the long range connections in a spatial network are generally constrained by the Euclidean distance, leading to important consequences on the network's statistical properties).

Other examples, more related to the dynamical aspects, are the issues of *searching* and that of *delivering* within a complex network. How to optimize a searching or a delivering procedure, often in the absence of information on the global structure of the network, are interesting problems with relevant practical technological applications, such as the creation of powerful web search engines or the development of routing strategies in the Internet.

Finally, we wish to mention what we consider one of the most promising among the emerging topics, the modeling of *adaptive networks*. By adaptive networks we indicate all such cases where the wiring topology is allowed to change on time scales comparable to those of the dynamical process taking place over the network, and in which the dynamical process itself shapes the topology of the network.

A number of review articles, books and collection of contributed papers on complex networks, which the reader may find useful, have already appeared in the literature. In particular, Watts' pioneering book on the subject deals with small world networks [Watts, 1999], while Strogatz' review article in *Nature*'s special issue on complex systems contains a discussion on networks of dynamical units [Strogatz, 2001]. Albert and Barabási [2002], and Dorogovtsev and Mendes [2002, 2003] have mainly focused their reviews on models of growing graphs from the point of view of statistical mechanics; while the book by Pastor-Satorras and Vespignani focuses on the analysis and modeling of the Internet [Pastor-Satorras & Vespignani, 2004]. The review by Newman [2003] contains an overview on structural properties, measures and models, and also a final chapter devoted to processes taking place on networks. This attention towards dynamical processes, such as the emergence of collective and synchronized dynamics in large networks of coupled dynamical units, is stressed even more in the review by Boccaletti *et al.* [2006], that also covers novel topics, as for instance, weighted networks and algorithms for finding community structures.

Four other references are worthwhile to mention in this Editorial. These are three collections of contributed papers, such as those edited by Bornholdt and Schuster [2003], by Pastor-Satorras *et al.* [2003] and by Ben-Naim *et al.* [2004]. And, finally, a very recent collections of published papers, edited by Newman *et al.* [2006], also containing a significant number of historical papers, mainly mathematical graph theory and from social network analysis.

Considerable research that has characterized activities in the last two–three years has motivated our effort to edit a new series of contributions into this theme issue. Of course, the purpose of this issue is not to provide a fully comprehensive coverage of the field of complex networks. Instead, the issue offers a collection of contributed works that:

- complements the collections of contributed papers already available in the market;
- covers what we believe are, today, the most important and modern aspects in the study of complex networks, and possibly also the best candidates to attract further attention in the next future.

The works are divided into *tutorials*, *papers* and *letters*, and are organized by following the natural order: first on measures, methods and models to study the structure of a network, and then those studying different kinds of dynamical processes over a network.

The issue opens with three tutorials. The first two tutorials deal with structural issues. The first, by *Christensen and Albert*, describes how **network measures and models** have contributed to the understanding of the organization of complex systems. The second one, by *Braunstein, Wu, Chen, Buldyrev, Kalisky, Sreenivasan, Cohen, López, Havlin and Stanley*, is about **weighted networks**. The authors deal with random networks with weighted links or nodes and review results on optimal paths (i.e. paths with minimum sum of the weights) and minimal spanning trees. The third tutorial, by *Stoop and Wagner*, is on the **dynamics of neural systems**. In particular, the authors show how the neocortical neurons are arranged and coupled into a network that optimizes information propagation and synchronizability at a minimal total connection length.

The issue follows with thirteen papers. The first by *Park, Celma, Koppenberger, Cano and Buldú*, analyzes the structure of two **networks of contemporary musicians**: the collaboration network in which two musicians are connected if they have performed together, and the similarity network in which two musicians are connected if they are musically similar according to music experts. The second paper, by *Criado, Hernández-Bermejo and Romance*, deals with the mathematical definition of the structural measures of **efficiency, vulnerability and cost** of a (either nondirected or directed) network, and with an application of these measures to compare the performance of a sample of subway networks worldwide. Centrality measures are an essential concept in network analysis, although the exact computation of centrality measures based on shortest paths is often infeasible for many large networks of interest today. The paper by *Brandes and Pich* deals with **approximate methods to estimate closeness and betweeness** in large networks based on the computation of single-source shortest-paths from a limited number of nodes (pivots). The authors investigate numerically different numbers of pivots and different selection criteria in either real networks and models. The fourth paper, by *Tumminello, Coronnello, Lillo, Miccichè and Mantegna*, introduces a method to associate a new kind of tree, named the **average linkage minimum spanning tree**, to empirical data of correlation based systems. The method is then applied to the network of the 300 most capitalized stocks traded at New York Stock Exchange during the time period 2001–2003. The paper by *De Los Rios and Petermann* deals with **spatial small-world networks**. Since the small-world behavior relies on the presence of long-range connections that are likely to have a cost which is a growing function of the length, the two authors explore whether it is possible to choose suitable probability distributions for the shortcut lengths in order to preserve the small-world feature and, at the same time, to minimize the network cost. The sixth and the seventh papers deal with search engines. *Fortunato and Flammini* provide some **exact results on the distribution of PageRank**, the prestige measure for Web pages used by Google. PageRank is the stationary probability of a peculiar random walk on directed graphs, which interpolates, through a damping factor q, between a pure random walk and a process where all nodes have the same probability of being visited. The two authors study the two limiting cases $q = 0$ and $q = 1$. In his paper, *Marchiori* considers how society and technological progress somehow have changed the rules of the game, introducing good but also bad components, and argues how social flows can be used to make up for a new generation of **social search engines**. The paper by *Tadić, Rodgers and Thurner*, shows how transport processes over a computer network depend crucially on the underlying topology. The authors present numerical simulations of dynamical models for the **transport of information packets** that include driving, searching and queuing, and consider the transition to the jammed phase on different network topologies. Papers nine and ten deal with models of spins on complex topologies. *Da Fontoura Costa and Sporns* simulate the **dynamics of neural thalamocortical systems** by the anti-ferromagnetic Ising model with Metropolis update rules, while *Schnegg and Stauffer* consider **models of opinion dynamics** on a model topology that reproduces the structures observed in real social systems. In the eleventh paper, *Buscarino, Fortuna, Frasca and Rizzo* show how the inclusion of long-range links in a network model describing the interactions in a **system of mobile robots** (moving in a $2D$ space) increases the tendency to form a coordinated group of robots which travel in the same direction. The last two papers deal with synchronization in networks of coupled dynamical units. *Di Bernardo, Garofalo and Sorrentino* consider the **synchronization dynamics** of a networks of nonlinear oscillators, and investigate how the synchronizability is influenced by topological properties such as the degree distribution and degree-degree correlations. *Dercole, Loiacono and Rinaldi* focus on **synchronization in ecological networks**, finding results supporting the conjecture that evolution drives ecological networks toward weak forms of synchronization.

Finally, the issue contains nine letters. The first letter, by *Boccaletti, Hwang and Latora*, introduces a **growing network model** that is capable of generating, without an explicit preferential attachment rule, networks with a scale-free degree distribution, a slightly disassortative degree-degree correlation, a high average clustering and a scaling of the clustering coefficient with the node degree. The second letter, by *Ferrer i Cancho, Capocci and Caldarelli*, is an application of **spectral methods for detecting community structures in linguistic networks** where vertices represent four classes of words (verbs, nouns, adverbs and adjectives) and edges stand for syntactic relationships between words. The third letter, by *Rosas-Casals, Valverde and Solé*, is an analysis of the topology and, in particular, of the **structural vulnerability of the European electric power grid** under errors and attacks. The fourth letter, by *Remondini, Neretti, Sedivy, Franceschi, Milanesi, Tieri and Castellani*, is a study of the topology of **gene-gene networks** derived from the correlation properties of gene expression time series. In particular, the authors consider data of mRNA concentration values measured from genetically engineered rat fibroblasts cell lines responding to conditional cMyc proto-oncogene activation. The letter by *Lee, Goh, Kahng and Kim*, deals with the **structure and dynamics of the Internet** at the autonomous system level. The authors construct a toy model for the Internet topology based on the ingredients of multiplicative stochastic evolution of nodes and edges, and adaptive rewiring of edges. Then, they study data packet traffic at the microscopic scale, and derive analytically queue length distributions and average delay times. In the sixth letter, *Colizza, Barrat, Barthélemy and Vespignani* address the problem of **predictability of epidemic forecasts in a large scale disease propagation model**. In the model considered, the local epidemic evolution inside an urban area is described by a set of Langevin equations for the evolution of the numbers of susceptible, latent, infected and recovered individuals inside the urban area. The equations for different urban areas are then coupled by taking into account that individuals are allowed to travel from one area to another. This spatial movements is simulated by using a weighted network based on information extracted from an airline transportation database. The seventh letter, by *Gómez-Gardeñes and Moreno* deals with **synchronization in scale-free networks of Kuramoto oscillators**. The authors investigate how the critical properties of the dynamics and the appearance of complete synchronization depend on the clustering coefficient and on the average shortest path length. The letter by *Rosvall and Sneppen* brings up a beautiful example of an adaptive social network. The authors propose a way to model the **interplay between communication and topology in social networks**. In the model, the individuals communicate to build up a perception of the network that they can use to create strategic links to improve their standing in the network. The final letter, by *Popovych, Krachkovskyi and Tass*, addresses the bifurcation analysis of **desynchronization transitions in coupled phase oscillators with delay**.

We are extremely grateful to the *International Journal of Bifurcation and Chaos* for having hosted this theme issue. We finally would like to express our most sincere thanks and great appreciation to all those colleagues who have helped us in the realization of this special issue, to the contributors of the different manuscripts, and to all our colleagues who assisted us in the reviewing process of the papers.

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