EDITORIAL

R. CRIADO, M. ROMANCE
Departamento de Matemática Aplicada,
Universidad Rey Juan Carlos, C/Tulipán s/n,
28933 Móstoles (Madrid), Spain.

H. MANCINI and W. GONZALEZ-VIÑAS
Departamento de Física y Matemática Aplicada,
Universidad de Navarra, C/ Irunlarrea s/n
31008 Pamplona (Navarra), Spain.

The study of networks has become one of the paradigms of the science of complexity as well as a fascinating branch of research in applied mathematics, science (metabolic and protein networks, neural networks, genetic regulatory networks, protein folding), sociology (social networks, acquaintances or collaborations between individuals) and engineering (phone call networks, computers in telecommunication networks) ([Albert & Barabási, 2002], [Bar-Yam, 1997], [Boccaletti, Latora, Moreno, Chavez & Hwang, 2006], [Newman, 2003], [Newman, Barabási & Watts, 2006], [Strogatz, 2001], [Cohen, Erez, ben-Avraham & Havril, 2000, 2001]).

The wide range of systems in the real world which can be modeled by complex networks are held to have behavioral and structural features in common, and they can be studied by using non-linear mathematical models and computer modeling approaches. The interest for complex networks has certainly been promoted by the optimized rating of computing facilities, and by the availability of data on large real networks (World Wide Web, cortical networks, citation networks from Scientific Citation Index). This issue is characterized to emphasize the latest applications of complex networks rather than the theoretical aspects, but covering several aspects as topological properties, algorithms and computation tools, models of interactions between complex systems, synchronization and control and some other related topics.

Since the publication of the two seminal papers, by Watts and Strogatz on *small world networks*, [Watts & Strogatz, 1998], and by Barabási and Albert on *scale-free networks*, [Barabási & Albert, 1999], there is growing interest for complex networks reflected in the large number of papers that have been published about this topic, and the new problems and research lines which have been tackled.

According to the tradition of *International Journal of Bifurcation and Chaos*, this is a special issue about the structure and dynamics of complex networks and its goal is to give a selection of contributed papers that covers a wide range of relevant and modern aspects in the analysis of complex networks, giving a state of the art picture of the field of complex networks. The contributed papers presented in this special issue where selected among the works presented at the International Conference Net-Works 2008. This conference, which took place in the University of Navarra, Pamplona (Spain) on June 9-11th, 2008, was held in

cooperation with the Society for Industrial and Applied Mathematics (SIAM) and the American Institute for Mathematical Sciences (AIMS).

The works contained in this special issue are divided into *tutorials*, *papers* and *letters* and it cover a wide range of topics not only related to the topological properties of complex network but also to their dynamics and the relationship between them. The issue opens with three tutorials. The first one, by *Almendral, Leyva- Sendiña-Nadal & Boccaletti*, reviews some of the main results on the setting of **collective (synchronized) behaviors in globally and locally identical coupled oscillators** and the main formalism that gives the necessary condition for the stability of a synchronous motion is discussed in detail. In addition to this, the case of a growing network of non identical oscillators is also briefly described, where the growth process is entirely guided by dynamical rules and the final synchronized state is accompanied with the emergence of a specific statistical feature (the scale-free property) in the network's degree distribution. The second tutorial, by *Buscarino, Di Stefano, Fortuna, Frasca & Latora*, is about **the effect of motion on the spreading of diseases in dynamical social networks of mobile agents**, which has recently attracted considerable attention in the scientific community. The existing relations between dynamical networks of random walkers with jumps and static small-world networks are discussed and also those between systems of Lévy walkers and scale-free networks. The last tutorial, by *Rosso, De Micco, Larrondo Martin & Plastino*, deals with a generalized **statistical complexity measure** wich is a functional that characterizes the probability distribution P associated to the time series generated by a given dynamical system. Several fundamental issues are reviewed such as the selection of the information measure, the choice of the probability metric space and associated distance D, the definition of the so-called *generalized disequilibrium* Q or the adequate way of picking up the probability distribution P associated to a dynamical system or time series under study, but it is also showed that sensible improvements in the final results can be expected if the underlying probability distribution is *extracted* via appropriate consideration regarding causal effects in the systems dynamics.

The special issue follows with eleven papers, dealing with different aspects of the topological and dynamical properties of complex networks. The first, by *Cárdenas, Mouronte, Santiago, Feliu & Benito*, analyzes the **topological properties of optical transport networks** and show that the *Synchronous Digital Hierarchy* (SDH) network operated by Telefónica in Spain presents a power-law scaling in the degree distribution and it displays small world properties with a high clustering and short path length similar to the Internet routers network. An ad-hoc computational model of such networks is proposed, that considers the network design policies, user demand, geographical location and types of equipment present in the SDH network operated by Telefónica. The second paper, by *da Fontoura Costa, Aparecido Rodrigues & Ribeiro Villas Boas*, deals with the **evolution of complex networks** thorough path-star transformations and optimal multivariate methods. It is also shown, by using canonical projections and maximum likelihood classification, that while the US highways network adheres closely to a geographical network model, its path-star transformation yields a network whose topological properties closely resembles those of the respective airport transportation network. A paper by *Hernández-García, Tuğrul, Herrada, Eguíluz & Klemm* is included that presents, from a numerical point of view, two **branching models for scaling in phylogenetic**

trees and the power-law scaling are displayed in both models (in one case by analytical methods, while in the other is obtained by numerical methods).

The fourth paper, by *Hövel, Dahlem & Schöll*, studies the **synchronization of coupled neurons** which are modelled as **FitzHugh-Nagumo systems**. The cooperative dynamics between coupled neurons are modified by a local external stimulus in form of an extended **time-delayed feedback** loop that involves multiple delays weighted by a memory parameter and investigate if local control applied to a subsystem can allow one to steer the global cooperative dynamics and several measures are considered to quantify the influence on synchronization, including the ratio of interspike intervals, the power spectrum, the interspike interval distribution, and the phase synchronization intervals. It is shown that the control method is more robust for increasing memory parameter. The next paper, by *Leyva, Sendiña-Nadal, Almendral, Buldú, Li, Havlin & Boccaletti*, considers the response of a random and modular networks to the simultaneous presence of two frequencies and it shows that the **competition for controlling the dynamics** of the network results in different behaviors, such as frequency changes or permanent synchronization frustration, which can be directly related to the network structure. As a consequence of these facts a new method for detecting overlapping communities in structured networks is presented. A paper by *Miranda & Burguete* is included, studying the **spatiotemporal phase synchronization** in an array of oscillators, extracting the time-varying topology from the dynamics, which help to understand the phenomenon of interacting oscillators in a 1D convective system and it contributes to clarify also other complex systems exhibiting similar phase chaotic dynamics.

The seventh paper, by *Poncela, Gómez-Gardeñes, Moreno & Floría*, deals with the **cooperative behavior** of agents playing the **Prisoner's Dilemma game in scale-free networks**. It is shown that the survival of cooperation is enhanced respect to random homogeneous networks while it decreases when compared to that found in Barabási-Albert scale-free networks. In addition to this, it is presented a mean field approximation, which is is similar to the one used in disease spreading models in complex networks, for studying evolutionary dynamics in networks with no degree-degree correlations and with arbitrary degree distribution. The next paper, by *Schmidt, Zamora-López & Kurths*, analyzes how to reproduce the dynamical behavior of the multilevel model of the **resting-state dynamics of the cortico-cortical connectivity of the mammalian brain** by a strongly simplified model that replaces each cortical area by a single Rulkov map or a neuron model by Izhikevich. It is stated that while the network of interconnected Rulkov maps recreates the patterns of dynamical correlations of the multilevel model, the simulations performed using the Izhikevich model shows that the dynamics does not depend on the underlying topology. A paper by *Torres, de Franciscis, Johnson & Marro* is presented, that reports how dynamics depend on connectivity in a **model of excitable media** (Amari-Hopfield network with a Hebbian learning rule) and it is shown that there is a strong correlation between wiring topology and network functionality. In addition to this, it is described the nature of both the irregular wandering of the activity among the stored patterns and the system critical behavior at the onset of this irregular behavior in the resulting non-equilibrium steady states.

The tenth paper, by *Criado, Romance & Vela-Pérez*, introduces the concept of **hyper-structure** as a new tool for modelling real problems, such as

communication networks. This new approach extends the concept of network and hyper-networks and some analytical estimates are presented relating an hyper-structure with the underlying network and hyper-network. The last paper, by *Vidal & Mancini*, analyzes the **synchronization** between identical pairs of **hyperchaotic mathematical systems symmetrically coupled** and the effects of coupling two identical hyperchaotic oscillators of three different origins is studied.

Finally, the special issue also contains six letters. The first one, by *Arévalo, Zuriguel, Ardanza-Trevijano & Maza*, studies the statistics of **third-order loops in force networks of granular materials** and their relationship with force distributions, by showing that almost all the third order loops allocate a force that is below the average and as a consequence, the experimental methods need to determine univocally the topology of the small forces between particles in order to understand completely the jamming transition. A letter by *De Vico Fallani, Astolfi, Cincotti, Mattia, Maksuti, Patidar, Salinari, Marciani, Zouridakis & Babiloni* is included that analyzes the influence of human learning on **functional brain organization** from a network-theoretical perspective, using efficiency measures to characterize the topological changes induced by the learning of a complex visuomotor task with strategic components. The third letter, by *Goñi, Martincorena, Corominas-Murtra, Arrondo, Ardanza-Trevijano & Villoslada*, deals with the use of **random walks** to explore the nodes of a networked system inspired in the information retrieval in **semantic networks**. In particular, the typical next-nearest neighbor movement of walkers is coupled with the possibility that the walkers make a hop to a distant neighbor with some probability and several network topologies (random, Small-World, modular and scale-free) are analyzed by using the mean first passage time of the walks to characterize the efficiency of information search in the different topologies.

The fourth letter, by *Santiago & Benito*, presents some results concerning the connectivity metrics in a natural extension of the class of **heterogeneous preferential attachment models** that shows that the introduction of heterogeneity induces a richer scaling behavior in the degree densities of the models with regards to their homogeneous counterparts. It is also shown that the power-law scaling in the degree distribution of the models is robust in presence of the offset in the attachment kernel, so that higher offset terms only yield a right shift in the higher bound of the spectrum of scaling exponents in the extended class. The letter by *Tuğrul & Kabakçioğlu* investigates the dynamical properties of the **transcriptional regulation of gene expression** in the yeast *Saccharomyces Cerevisiae* within the framework of a synchronously and deterministically updated Boolean network model and reports the robustness of gene expression against a binary parameter related with the genes regulatory rules. The last letter, by *Zanin, Buldú and Boccaletti*, deals with the **propagation of perturbations** through spatially distributed **networks of springs** and it is shown that the topological properties of the network are related with the dissipation of the energy within the system. The obtained results are connected with the transmission of information through a complex structure and they could be of potential application to the design of more efficient damping systems.

We are extremely grateful to the *International Journal of Bifurcation and Chaos*, and specially to Editor in Chief and Publishers for having hosted this theme issue. We would like to express our most sincere thanks and great ap-

preciation to all the members of Scientific Committee for their help and their important support, specially to S.Boccaletti, J.Kurths, E.Schöell, V.Latora, and Y.Moreno. It was a great honour for us to count on the above leaders on Complex Networks as members of Scientific Committee of Net-Works 2008. We want also to thank the many anonymous referees who helped us to greatly improve the manuscripts for the support that they gave us and for the many attempts to finish their work on time. We would like to thank also to all those colleagues who have helped us in the realization of this special issue, specially to the contributors of the different manuscripts. Finally, we want to thank specially the University Rey Juan Carlos, the University of Navarra, and all the sponsors of this project for the financial support.

References

Albert, R. & Barabási, A.L. [2002], "Statistical mechanics of complex networks", *Rev. Mod. Phys.* **74** , 47–97.

Barabási, A.L. & Albert, R. [1999], "Emergence of scaling in random networks", *Science* **286**, 509–512.

Bar-Yam, Y. [1997], Dynamics of Complex Systems, Addison-Wesley,1997.

Boccaletti, S., Latora, V., Moreno, Y., Chavez, M. & Hwang, D.-U. [2006] "Complex networks: Structure and dynamics", *Physics Reports* **424**, 175–303.

Cohen, R.,Erez, K.,ben-Avraham, D. and Havril, S. [2000], "Resilience of the Internet to random breakdowns", *Physical Review Letters* **85** (21) (2000), 4626–4628.

Cohen, R.,Erez, K.,ben-Avraham, D. and Havril, S. [2001], "Breakdown of the Internet under intentional attacks", *Physical Review Letters* **86** (16) (2001), 3682–3685.

Newman, M. E. J. [2003], "The structure and function of complex networks", *SIAM Review* **45**, 167–256.

Newman, M.E.J., Barabási, A.L. & Watts, D.J. [2006], "The structure and dynamics of networks", *Princeton University Press, Princeton, NJ.*, 167–256.

Strogatz, S.H. [2001] "Exploring complex networks", *Nature* **410**, 268–276.

Watts, D.J. & Strogatz, S.H. [1998], "Collective dynamics of small-world networks", *Nature* **393**, 440–442.