EDITORIAL

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A wide variety of real-world systems as diverse as molecules linked by chemical reactions, to single cells, the brain, the Internet, routers and computers connected by physical links can suitably be described as complex networks. A relatively recent statistical physics understanding of graph theory, a centuries-old branch of applied mathematics, affords an intuitive and versatile set of tools that allows the description of important properties of these systems at various scales [Albert & Barabási, 2002; Newman, 2003; Boccaletti *et al.*, 2006]. This has allowed the reformulation of some fundamental problems not only in statistical mechanics, but also in various fields in which networks theory have been applied, from descriptive or phenomenological modeling, to engineering problems ranging from optimization to control, and to an understanding of complex structure-dynamics-function particularly in biological systems.

Physicists first studied the structural properties of complex networks, which were initially modeled as random graphs. Soon though, it was realized that the topology and evolution of real networks are typically governed by nontrivial and reproducible organizing principles. In fact, much of the attraction of network theory initially stemmed from the fact that many networks seem to exhibit some sort of universality, as most of them belong to one of three classes: random, scale-free and small-world networks. Structural properties have been shown to translate into different important properties of a given system, including efficiency, speed of information processing, vulnerability to various forms of stress, and robustness. For example, scale-free and random topologies were shown to be characterized by drastically different vulnerabilities to random and targeted attacks. Somehow reciprocally, it can be shown that network topologies differ in the extent to which they can be controlled around given values and, perhaps even more interestingly, the conditions under which target dynamical states can be reached independently of the natural dynamics of the system.

Soon, it was also realized that elucidating the mechanisms leading to the emergence of these global network topologies may help give a better understanding of the design principles of biological networks, and therefore provide some clues into the dynamical evolutionary processes that generated these networks. Various lines of research have developed around this issue. Early efforts investigated the emergence of global topological classes of the network regarded as a dynamical system and subject to certain evolution rules. Candidate mechanisms have been proposed, for instance, for the formation of small world [Watts & Strogatz, 1998] and scale-free networks [Barabási & Albert, 1999]. In addition, the values of important topological properties of a network that is evolving in time were studied; more recently, it was revealed that the complex organization of networks results in a wide spectrum of critical phenomena and singularities [Dorogovtsev *et al.*, 2008]. Further efforts have been devoted to understanding the role of micro and mesoscale properties of networks, e.g. motifs, community structure, modules in the emergence of these complex global behaviors [Fortunato, 2010].

A complementary line of research focused on the dynamics on networks. In this line of research, the nodes are dynamical systems coupled according to the network topology, which remains static while the states of the nodes change dynamically. In most real-world networks, topological aspects of networks and the dynamical processes taking place on them are mutually intertwined. On the one hand, the topology of structural networks influences the dynamical processes (namely synchronization) taking place on them [Boccaletti *et al.*, 2006]. On the other hand, the synchronization process unveils hierarchical neural communities at different time scales [Arenas *et al.*, 2006]. Mesoscale properties are associated with rich nonlinear dynamical behavior. For instance, modular networks tend to produce time-scale separation, between fast intra-modular processes and slow inter-modular processes [Pan & Sinha, 2009], coexistence of both segregated and integrated activity [Shanahan, 2008; Pan *et al.*, 2010], or transient chimera states [Shanahan, 2010] where synchronization and desynchronization coexist across the network. The need to protect or optimize natural networks and to create robust and efficient technical networks prompted studies of processes taking place on networks. Examples of processes include contact processes such as opinion formation and epidemic spreading [Kuperman & Abramson, 2001; Pastor-Satorras, 2004; Newman, 2002]. These studies convincingly showed that certain topological properties have a strong impact on the dynamics.

At the beginning of complex network theory, most of the attention was devoted to the topology of real world systems; nevertheless, instead of remaining an isolated topic, it was soon realized that topology is the substrate upon which the dynamics of the system evolves. And this substrate is not passive: different network structures can favor (or inhibit) certain dynamics. Therefore, understanding **the role of the topology**, and of single nodes, is an important preliminary step toward the understanding of dynamics and processes on complex networks. This problem is firstly tackled by Buldú *et al.*, by analyzing the function of single nodes in a network composed of different communities. Each node is characterized by its relevance at a global level, measured as its ability to reduce the length of paths between the different communities of the network. Furthermore, links are defined by the number of shortest paths crossing them. The combination of both metrics allows a detailed characterization of the role of nodes in the global connectivity of the network.

In many situations, the role of nodes is not a static property, but evolves with the evolution of the network itself. *Gomez-Gardeñes et al.* develop this concept in adaptive networks: here, the process (spreading of a disease) is driven by the topology, while at the same time the network evolves as a consequence of the process. The most important results is the emergence of nontrivial structures, for instance, clustering patterns. Traffic, understood as the efficient transmission of information through a network, is another important process occurring in complex networks, clearly relevant for its real-world implications. Two contributions deal with this. *Wang-Kit Thong and Chen* study the problem of deflection routing, that is, routing mechanisms that take into account the dynamical state of the system to avoid moving information through saturated nodes. Here, the topology of the network can lead to complex dynamics, for instance, to traffic with self-similarity property. *Meloni et al.* tackle another aspect of the flow of information in the Internet infrastructure: the relationship between the mean traffic crossing a node, and its fluctuation. The key characteristic governing this variability is found to be the degree of heterogeneity of nodes, with important implications for the saturation of the system. Going back to the characterization of the topology of a network, *Granell et al.* propose a novel algorithm for the analysis of its modular structure. It is well known that classical approaches are not able to detect communities when there is a high heterogeneity in their size, and therefore in the topological scales of the network. Their proposal is based on a multiresolution hierarchical decomposition, which can efficiently solve challenging problems used as benchmarks.

It is not possible to fully understand the **dynamics of nonlinear systems** by treating them as isolated systems. Once a certain structure of connections is created between a group of dynamical systems, not only the local activity but also global emerging dynamical features rely both on the nature of the systems and the topology of the network of connections. Within this framework, *Frasca et al.*, study a star structure of Stuart–Landau oscillators, for which they derive the bifurcation diagram and discuss the different forms of synchronization arising in such a system. Their approach allows to calculate the separatrices between the regions with distinct dynamical behavior and to determine the nature of the different transitions to synchronization appearing in the system. With regard to collective emerging phenomena, *Sotelo-Herrera et al.* study how traveling waves appear in coupled map lattices of oscillators with both global and neighbor coupling. Interestingly, they show how the waves are triggered by the individual dynamics of the oscillators belonging to the lattice. Nevertheless, collective phenomena may emerge at different scales, with a trade-off between local and global interactions.

Comin et al. study how integrate-and-fire systems show correlations maps of global and local properties in order to probe the macro and microscopic behavior of the dynamics. They observe global maps with large fluctuations on regions related to lattice-like structures, indicating that in this regime the topology of the source is unimportant when trying to characterize the appearance of avalanches in the network. Interestingly, the time for the avalanches onset showed significant correlations with structural features for a large number of network configurations. They also observe that before the avalanche, the local topology of the source plays an essential role on the dynamics of the majority of the nodes, but after the avalanche, a sharp transition unfolds and the collective behavior of the network then overshadows any influence of the source.

Synchronization is probably the most studied emerging phenomenon arising due to interaction between dynamical systems. The control and targeting of the synchronous state of a set of chaotic oscillators is studied by *Padmadan et al.*, showing that it is possible to control the transition from synchronization to antisynchronization by a smooth adjustment of the coupling between oscillators. Results are confirmed by the experimental implementation of the model in electronic circuits. Nevertheless, the structure of the network may also play an important role on the route to synchronization. *Lakshmanan et al.* study how global and partial-phase synchronizations arise in linear arrays of unidirectionally coupled time-delay systems with open and closed-loop configurations. They show that in a linear array with open end boundary conditions, global phase synchronization is achieved by the sequential appearance of functional clusters, as the coupling strength increases. In the case of closed-loop boundary conditions, partial phase synchronization is achieved by forming different groups of phase synchronized clusters above some threshold value of the coupling strength (a first-order transition) where they continue to be in a stable partial phase synchronization state.

In other cases, it could be of interest to drive the dynamics of a system to a desired dynamical state, i.e. to control the dynamics of the whole network. In the work of *Lu et al.*, the introduction of impulsive pinning is used as a way of driving a system with time delay in the coupling by only acting on a small sample of nodes. The proposed strategy is closely related to the proportion of the controlled nodes, the impulsive strength, the impulsive interval and the time-delay. The time-varying delay is only required to be bounded without assuming its smoothness. Nevertheless, other collective (or coordinated) phenomena may only affect a portion of the nodes of the network. That is so for the case of neuronal networks, where a synchronized spiking activity emerges inside groups of neurons that are functionally related. *Grau et al.* show that that up/down dynamics may appear spontaneously in scale-free neuronal networks, provided an optimal amount of noise acts upon all network nodes. They study the structure of the up/down regime both in time and in terms of the node degree and also examine whether localized random perturbations applied to specific network nodes are able to generate up/down dynamics. Finally, the possibility that oscillators move over the Euclidean space, changing their interactions with other dynamical agents is studied by *Prignano et al.* They present a model of integrate-and-fire oscillators that move on a plane where the phase of the oscillators evolves linearly in time. When the phase reaches a threshold value, oscillators fire choosing their neighbors according to a certain interaction range. With this model, authors show that depending on the velocity of the motion and the average number of neighbors each oscillator fires to, different synchronization regimes can be distinguished in a phase diagram.

The last part of this Theme Section is devoted to **applications**, that is, to the use of all the theoretical knowledge and techniques to better understand real-world problems and systems. *Balenzuela et al.* study the field of recommendation networks, that is, the structures created by users sharing their preferences about different items, in this case, movies. Specifically, they propose models for understanding the evolution of the system, represented by a bipartite network composed of users and items, and scores assigned to the latter by the former. Several ingredients are essential to the understanding of this problem: a bursty activity of users, as well as preferential attachment mechanisms and random selection processes. *Kenett et al.* focus on financial markets, and specifically on the dynamics of the stocks composing the Dow Jones Industrial Average index. By expanding the concept of correlation between the evolution of prices, it is possible to construct networks representing the causal activity relations between the network nodes. This, in turn, provides new knowledge about the system under analysis; specifically, authors focus on past financial crises, unveiling the trail.

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