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PREFACE

Complex Networks: from Biology to Information Technology

The field of complex networks is one of the most active areas in contemporary statistical physics. Ten years after the first papers initiated the modern study of networks, interest in the field is in fact still growing, as indicated by the ever increasing number of publications in network science. The reason for such a resounding success is most likely the simplicity and broad significance of the approach that, through graph theory, allows researchers to address a variety of different complex systems within a common framework.

This special issue comprises a selection of contributions presented at the workshop 'Complex Networks: from Biology to Information Technology' held in July 2007 in Pula (Cagliari), Italy as a satellite of the general conference STATPHYS23. The contributions cover a wide range of problems that are currently among the most important questions in the area of complex networks and that are likely to stimulate future research. The issue is organised into four sections. The first two sections describe 'methods' to study the structure and the dynamics of complex networks, respectively. After this methodological part, the issue proceeds with a section on applications to biological systems. The issue closes with a section concentrating on applications to the study of social and technological networks.

The first section, entitled *Methods: The Structure*, consists of six contributions focused on the characterisation and analysis of structural properties of complex networks:

- The paper *Motif-based communities in complex networks* by Arenas *et al* is a study of the occurrence of characteristic small subgraphs in complex networks. These subgraphs, known as *motifs*, are used to define general classes of nodes and their communities by extending the mathematical expression of the Newman–Girvan modularity.
- The same line of research, aimed at characterising network structure through the analysis of particular subgraphs, is explored by Bianconi and Gulbahce in *Algorithm for counting large directed loops*. This work proposes a belief-propagation algorithm for counting long loops in directed networks, which is then applied to networks of different sizes and loop structure.
- In *The anatomy of a large query graph*, Baeza-Yates and Tiberi show that scale invariance is present also in the structure of a graph derived from query logs. This graph is determined not only by the queries but also by the subsequent actions of the users. The graph analysed in this study is generated by more than twenty million queries and is less sparse than suggested by previous studies.
- A different class of networks is considered by Travençolo and da F Costa in *Hierarchical spatial organisation of geographical networks*. This work proposes a hierarchical extension of the polygonality index as a means to characterise geographical planar networks and, in particular, to obtain more complete information about the spatial order of the network at progressive spatial scales.
- The paper *Border trees of complex networks* by Villas Boas *et al* focuses instead on the statistical properties of the boundary of graphs, constituted by the vertices of degree one

(the leaves of border trees). The authors study the local properties, the depth, and the number of leaves of these border trees, finding that in some real networks more than half of the nodes belong to the border trees.

- The last contribution to the first section is *The generation of random directed networks with prescribed 1-node and 2-node degree correlations* by Zamora-López *et al*. This study deals with the generation of random directed networks and shows that often a large number of links cannot be 'randomised' without altering the degree correlations. This permits fast generation of ensembles of maximally random networks.

In the section *Methods: The Dynamics*, significant attention is given to the study of synchronisation processes on networks:

- Díaz-Guilera's contribution *Dynamics towards synchronisation in hierarchical networks* consists of an overview of recent studies on hierarchical networks of phase oscillators. By analysing the evolution of the synchronous dynamics, one can infer details about the underlying network topology. Thus a connection between the dynamical and topological properties of the system is established.
- The paper *Network synchronisation: optimal and pessimal scale-free topologies* by Donetti *et al* explores an optimisation algorithm to study the properties of optimally synchronisable unweighted networks with scale-free degree distribution. It is shown that optimisation leads to a tendency towards disassortativity while networks that are optimally 'un-synchronisable' have a highly assortative string-like structure.
- The paper *Critical line in undirected Kauffman Boolean networks—the role of percolation* by Fronczak and Fronczak demonstrates that the percolation underlying the process of damage spreading impacts the position of the critical line in random boolean networks. The critical line results from the fact that the ordered behaviour of small clusters shields the chaotic behaviour of the giant component.
- In *Impact of the updating scheme on stationary states of networks*, Radicchi *et al* explore an interpolation between synchronous and asynchronous updating in a one-dimensional chain of Ising spins to locate a phase transition between phases with an absorbing and a fluctuating stationary state. The properties of attractors in the yeast cell-cycle network are also shown to depend sensitively on the updating mode.

As this last contribution shows, a large part of the theoretical activity in the field can be applied to the study of biological systems. The section *Biological Applications* brings together the following contributions:

- In *Applying weighted network measures to microarray distance matrices*, Ahnert *et al* present a new approach to the analysis of weighted networks, which provides a generalisation to any network measure defined on unweighted networks. The clustering coefficient constructed using this approach is used to identify a number of biologically significant genes in data sets from microarray experiments.
- The paper *Quantifying the universal taxonomic diversity in real species assemblage* by Caretta Cartozo *et al* reports on universal statistical properties in taxonomic trees. The results, which are obtained by sampling a large pool of species from all over the world, suggest that it is possible to quantitatively distinguish real species assemblage from random collections.
- In the contribution *Insights into biological information processing: structural and dynamical analysis of a human protein signalling network*, de la Fuente *et al* investigate the dynamical properties of a human protein signalling network while accounting for edge directionality and topological properties both at the local and global scale. The

relationship between the node degrees and the distribution of signals through the network is characterised using degree correlation profiles.

- A study of a brain network is presented by de Vico Fallani *et al* in *Persistent patterns of interconnection in time-varying cortical networks estimated from high-resolution EEG recordings in humans during a simple motor act*. The authors introduce an approach based on the estimate of time-varying graph indexes that allows the capture of schemes of communication within the network. The method is applied to a set of high resolution EEG data recorded from a group of subjects performing a simple foot movement.

The last section, devoted to *Social and Technological Applications*, includes eight contributions in the broad area of infrastructure, economic, and social systems:

- The paper *Uncovering individual and collective human dynamics from mobile phone records* by Cándia *et al* explores extensive phone records resolved in both time and space to study collective behaviour and the occurrence of anomalous events. At the individual level, it is shown that the distribution of time intervals between consecutive calls is heavy tailed, which agrees with results previously reported on other human activities.
- In *Mining the inner structure of the Web graph*, Donato *et al* present a series of measurements of the Web, which offer a better understanding of the individual components of its bow-tie structure. The scale-free properties permeate all bow-tie components although they do not exhibit self-similarity and their inner structure is quite distinct.
- *Effects of network topology on wealth distributions*, by Garlaschelli and Loffredo, shows that a networked economic system self-organises towards a stationary state whose associated wealth distribution depends crucially on the underlying interaction network. In particular, this study implies that first-order topological properties alone (such as the scale-free property) are not enough to explain the emergence of the empirically observed mixed form of the wealth distribution.
- In the paper *Resource allocation pattern in infrastructure networks*, Kim and Motter show that real communication and transportation networks tend to exhibit larger load-to-capacity ratio in nodes and links with *larger* capacities. This surprising pattern, which is a consequence of decentralised evolution and network traffic fluctuations, suggests that infrastructure networks have evolved to minimise local failures but not necessarily large-scale failures that can be caused by cascading processes.
- The paper *Consensus formation on coevolving networks: groups' formation and structure* by Kozma and Barrat addresses the effect of adaptivity on a social model of opinion dynamics and consensus formation. The authors find that on adaptive networks the rewiring process fosters group formation by enhancing communication between agents of similar opinion, though it also makes possible the division of clusters. This result is significantly different from the percolation phenomena observed to govern the process in static networks.
- Capocci and Caldarelli, in the paper *Folksonomies and clustering in the collaborative system CiteULike*, analyse an online collaborative tagging system where users bookmark and annotate scientific papers. Such a system can be naturally represented as a tripartite graph whose nodes represent papers, users and tags connected by individual tag assignments. The semantics of tags is studied here, in order to uncover the hidden relationships between tags. Authors find that the clustering coefficient reflects the semantical patterns among tags.
- Lambiotte's contribution, *Majority rule on heterogeneous networks*, focuses on the majority rule model for opinion formation when the agents interact through a complex network. It is shown that on networks with modular structures the system may exhibit

an asymmetric regime, where nodes in different communities reach opposite average opinions. In addition, the node degree heterogeneity is shown to play an important role in the emergence of collective behaviour.

- In *Structural analysis of behavioural networks from the Internet*, Meiss *et al* analyse the structure of the Internet. The authors present a characterisation of the properties of the behavioural networks generated by several million users of the Abilene (Internet2) network. Structural features of these networks offer new insights into scaling properties of network activity and ways of distinguishing particular patterns of traffic.
- The final contribution, *Collaboration networks and innovation: the problem of clustering* by Uzzi, is an analysis of the collaboration network of artists that made Broadway musicals in the post World War II period. It is shown that when the clustering coefficient ratio in this network is low or high, the financial and artistic success of the industry is low while an intermediate level of clustering is associated with successful shows.

We hope that this special issue will serve as a reference of the state of the knowledge in this exciting area of interdisciplinary research and that it will appeal to both experts and newcomers to the field.

Finally, we would like to thank all participants of the workshop for their very significant contributions and the IOP Publishing team, particularly Rebecca Gillan, for the careful production of this special issue.

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