STATISTICAL MECHANICS OF COMPLEX NETWORKS

Abstract

by

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The emergence of order in natural systems is a constant source of inspiration for both physical and biological sciences. While the spatial order characterizing for example the crystals has been the basis of many advances in contemporary physics, most complex systems in nature do not offer such high degree of order. Many of these systems form complex networks whose nodes are the elements of the system and edges represent the interactions between them.

Traditionally complex networks have been described by the random graph theory founded in 1959 by Paul Erdős and Alfréd Rényi. One of the defining features of random graphs is that they are statistically homogeneous, and their degree distribution (characterizing the spread in the number of edges starting from a node) is a Poisson distribution. In contrast, recent empirical studies, including the work of our group, indicate that the topology of real networks is much richer than that of random graphs. In particular, the degree distribution of real networks is a power-law, indicating a heterogeneous topology in which the majority of the nodes have a small degree, but there is a significant fraction of highly connected nodes that play an important role in the connectivity of the network.

The scale-free topology of real networks has very important consequences on their functioning. For example, we have discovered that scale-free networks are extremely resilient to the random disruption of their nodes. On the other hand, the

selective removal of the nodes with highest degree induces a rapid breakdown of the network to isolated subparts that cannot communicate with each other.

The non-trivial scaling of the degree distribution of real networks is also an indication of their assembly and evolution. Indeed, our modeling studies have shown us that there are general principles governing the evolution of networks. Most networks start from a small seed and grow by the addition of new nodes which attach to the nodes already in the system. This process obeys preferential attachment: the new nodes are more likely to connect to nodes with already high degree. We have proposed a simple model based on these two principles wich was able to reproduce the power-law degree distribution of real networks. Perhaps even more importantly, this model paved the way to a new paradigm of network modeling, trying to capture the evolution of networks, not just their static topology.