Classification of Complex Networks in Spatial, Topological and Information-Theoretic Domains

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Abstract

Complex network theory has in the past been proven as a powerful tool to quantify the structure of many real-world complex systems and its associated characteristics allow to discriminate such systems into different classes. In addition, so-called functional networks where links indicate functional or statistical interdependencies between dynamics at individual nodes have been utilized extensively to study, among other systems, the global climate system. The thesis first demonstrates the discriminative power of complex network theory to classify Eastern and Central Pacific phases of El Niño which were in the past not always consistently distinguished from each other using methods from classical statistical climatology. Therefore, an index based on evolving climate networks is proposed that objectively discriminates between both types. It confirms recent unanimously defined classifications of El Niño phases and also assigns types to the formerly ambiguous cases. In contrast to classical tools, the proposed index provides a meaningful discrimination into two types for La Niña episodes as well. After a thorough investigation of the climatic impacts of the thus discriminated flavors of El Niño and La Niña, the work moves from the classification of sets of single-layer networks to the more general study of interacting networks. Here, subnetworks represent oceanic and atmospheric variability and links between them indicate interactions between the two climatic subsystems. It is revealed that the ocean-to-atmosphere interaction in the Northern hemisphere follows a hierarchical structure and macroscopic network characteristics discriminate well different parts of the atmosphere with respect to their interaction with the ocean. Acknowledging that climate networks and a variety of real-world networks are in fact spatial networks, the second part of the thesis assesses the effect of the nodes' spatial embedding on the networks' topological characteristics, an effect that has so far been rarely taken into account. A hierarchy of null models is proposed which generate random surrogates from a given network such that global and local statistics associated with the spatial embedding are preserved. The proposed models capture macroscopic properties of the studied spatial networks much better than standard random network models and depending on the models' actual performance networks can ultimately be categorized into different classes. The thesis closes with extending the zoo of network classifiers by a two-fold metric to discriminate different classes of networks based on assessing their complexity. The basis of this metric is formed by a statistical complexity measure composed of a network's averaged per-node entropic measure and the associated Jensen-Shannon divergence. Within this framework networks of the same category tend to cluster in distinct areas of the resulting complexity-entropy plane. In particular, connectome networks exhibit among the highest complexity while, e.g., transportation and infrastructure networks display significantly lower values. The proposed framework further allows to objectively construct climate networks such that the statistical network complexity is maximized. In summary, the present work enhances the understanding of functional climate networks and provides valuable complements to existing methods from classical statistics. Secondly, the proposed classification schemes are generally applicable to study complex networks in many fields, ranging from social systems over infrastructures to neurophysiology.