

The resilience and robustness of dynamical complex networks to disruption

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The topology of naturally occurring networks is now recognised to have a much richer taxonomy than was thought to be the case at the turn of the century. The connectivity of nodes in a network is described by the distribution of links connecting them, and these can describe connections that are not necessarily between nearest neighbours. When this 'substrate' has a dynamical process acting upon it, emergent behaviours can result between the interplay between the network's form and behaviours or functioning of nodes comprising it. For example, clusters of similar behaving nodes may aggregate, leading to a structure similar to a macroscopic phase resulting from the microscopic dynamical processes. The robustness of these emergent structures has been partially explored using ideas of equilibrium thermodynamics whereby additive (Gaussian) noise characterized by a temperature (variance) acts on a system, but such an approach is local in nature and does not provide an adequate model to study the effect of shocks of finite duration to a system.

Recently [1] a model for non-Gaussian noise has been developed to model what are colloquially termed 'black-swan' events. This provides the opportunity to treat non-perturbative random shocks to a system that cannot be treated by a traditional thermodynamic approach, in particular addressing large and intermittent fluctuations that can have flicker noise ($1/f$) characteristics, among others. The innovation here is the facility to model fluctuations that have a characteristic timescale of duration associated with them. In this way network architectures that are robust to such events can be identified, together with assessing their ability to regain functionality either during or after the event. The dynamics that will be considered is the Potts model, whereby the orientation of a state vector (in its simplest form 'up-down') is affected by those of its neighbouring nodes, and these need not be nearest neighbours by virtue to the network structure.

Identifying and monitoring events of an intermittent nature provides its own challenges, and this project requires the performance of a state variable associated with the nodes to be measured and related to similar behaving nodes. The time behaviour of these nodes prior to and post a disruptive event will provide information about precursors, and whether after-shocks are exacerbated by dynamics upon and wiring of the network. A recently developed technique [2] has been used to successfully reveal latent periodicities embedded in synthetic and real-world data of intermittent character, and to group emergent features in the data to distinct causal sources. We propose using this method to reveal latent structure in the spatio-temporal signatures of the dynamical processes at the nodes. Thus the microscopic behaviours can be related to the macroscopic performance.

The interdisciplinarity of the project arises because the models provide a methodology for assessing the robustness and efficacy of diverse network types of which exist in reality. These include both natural (e.g. gene regulatory networks) and man-made systems such energy distribution networks that have proved susceptible to massive failures caused by cascades, a situation that may worsen as energy generation becomes localised.

[1] K.I. Hopcraft, E. Jakeman, 'On the joint statistics of stable random processes', *J.Phys. A*, 44,435101,(2011).

[2] D.S. Barrack, K.I. Hopcraft, 'Aggregation, mode decomposition and projection: a time-frequency feature extraction method for intermittent time-series data', *Data Mining & Knowledge Discovery* – in the press.