appeared on 6th Mar 2013

Making good connections

How groups connect with each other is important in the networked world, says S.Ananthanrayanan.

It is by interdependence or interconnect that things work – within the natural world, in communities, human settlements, the marketplace, roads, airline routes, supply chains, power distribution, epidemics, the Internet … There have been studies of how these networks of related agents grow and stabilize and the features that make them efficient, responsive or robust. But there has been less work on how one network may benefit or lose in the way it connects to another network, or set of networks.

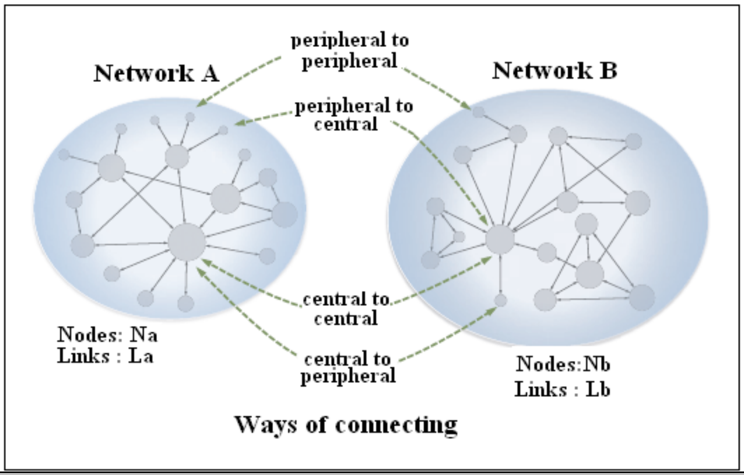
J. Aguirre, D. Papo and J. M. Buldú, of the ***Centro de Astrobiología, Center for Biomedical Technology***, Madrid and the ***Complex Systems Group*** at Móstoles, in Spain report in the journal, ***Nature***, their study of the interaction of networks, to derive rules, based on the internal features of networks, of how the interaction between networks must proceed – which would help intervene where networked systems need to have, or to be kept away from, the power of other networks.

Competing networks

Competition, which promotes efficiency, is usually between individuals. But the outcome may be affected not only by the competitors but also the network of connections of the different agents involved. Networks usually evolve to make for the best returns to all participants and also the stability of the network. But things change when the networks need to, or have to, contend with other networks, often in competition for limited resources. This raises a question of how one network can best use or save itself against the advantage that the other network could gain from the interaction. An example may be of an airline that shares one of its service or stopover facilities with another airline. How should the two airlines modify their flight schedules so that each takes optimum advantage of the arrangement?

To answer this question, we note that each network consists of nodes, with links to other nodes. The importance of a node arises from the number of links it has and how well connected other nodes, are and a measure of the value of the network could be the total importance of its nodes. When networks interact, they create common links and the question of competition reduces to one of how the value of each network get affected by the links created. Quantification of the importance of nodes is done through a concept of ***centrality*** – which is to assign relative scores to all nodes in the network, based on the principle that connections to high-scoring nodes contribute more to the score of the node in question than equal connections to low-scoring nodes. And in a group of networks, the importance of a network is the total of the centralities of all its nodes.

A simple case of networks A and B is shown in the picture. If the nodes and links in A and B are **Na, La** and **Nb,Lb** and the two networks are connected by L connection links, then, the combined network has **Na +Nb** nodes and **La+Lb+L** liknks. The centrality, **Ca** and **Cb**, of the two networks, however, would depend on the way the nodes are connected and the centrality, **Ca+Cb**, of the combined network, would depend on the manner of linking the networks.



The nodes of a network could be classified according to how important they are – the well connected ones would be ***'central'*** and the poorly connected ones would be '***peripheral***'. There could then be four kinds of connector links between the networks, and these are shown in the picture.

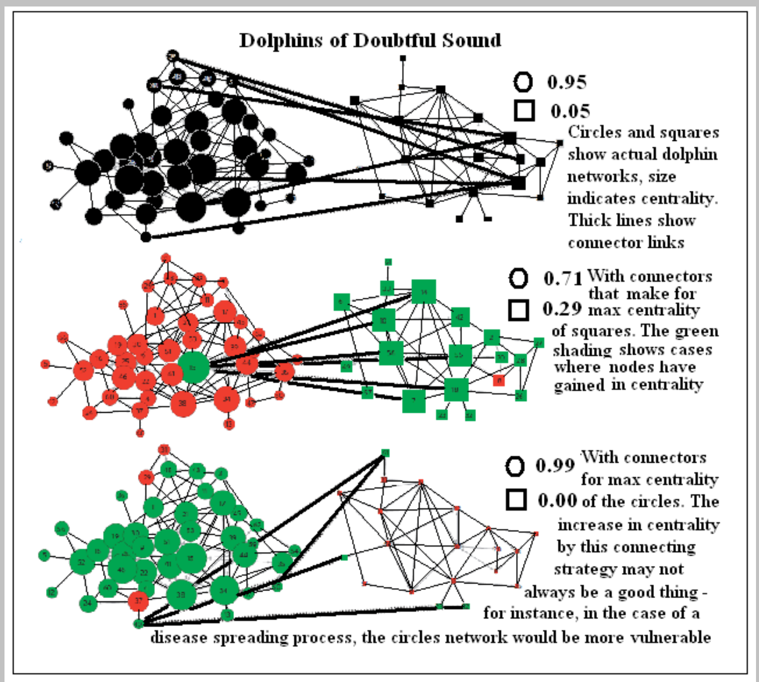
Working out the way centrality of networks depends on the parameters of network before they are interconnected, and on the possible connector links, provides mathematical expressions which include the values of centralities of the networks and the factors that arise from the connections made. In the case of one of the two networks being clearly more connected than the other, it turns out that:

i. Connecting the peripheral nodes of both the networks optimizes the centrality of the more connected one
ii. But connecting the central nodes of the two networks optimizes centrality of the weaker network
iii. Increasing the number of connector links strengthens the weaker network
iv. In general, a network stands to gain if it increases its own number of links and connections
v. While the stronger network generally retains its advantage, in the case of large and comparable networks, the strategy in choosing connector nodes determines the benefit that comes out of the interaction

Any one or more of theses strategies may not be available for a network, either because of physical constraints or even behavioral or cultural impediments. The airline company, in the example, for instance, cannot add airport hubs at will and may even be constrained in the routes that it flies because of political reasons. In such cases, the recourse would be to strengthen, or even weaken, its internal connectivity, to reverse the effects of the nature of inter-network connects that circumstances have imposed.

Uses of network strategies

Understanding the way networks change when connections are modified helps remedy and optimize real-life situations. In the case of a mix of species living together, changes in the environment may be to the advantage of some. There would then be evolutionary changes among the less advantaged species, to bring about changes in the relationships of networks, so that the balance could be restored. In the case of the evolution of populations of RNA molecules, for instance, there is work in progress to quantify the competition for the way different genetic strains express themselves, to better understand their evolvability and adaptability. The analysis of the way networks behave, as carried out it the study of ***Aguirre*** and others, helps understand these situations and also allow prescriptions of successful competition strategies, and engineering of desirable connectivity patterns. Areas of useful application could be the distribution of popluations, spread of epidemics, progress of rumours or patterns of Internet navigation.



An unlikely area where the science has found application is in with the ***dolphins of Doubful Sound***, a fiord in the far south west of New Zealand. ***Doubtful Sound***, first called Doubtful Harbour by Captain Cook who discovered it in 1770, is a piece of water that consists of two distinct layers – one, some 2 to 10 metres deep, of fresh water from surrounding mountains, and stained red-brown due to tannin, and below this a warmer and denser, salt water body.

The tannin stain in the upper layer bocks sunlight and the lower layer has become home to many deep sea species, despite being quite shallow. These include the bottlenose dolphin and the fiord houses an insular community of these animals, which are locked away from the open sea, both by the cooler habitat in the fiord and also the fresh water separator. But the community is only some 70 strong and presents major concern for conservation.

Studying the dolphin community has revealed sub-communities and evidence that sex- and age-related tendency to associate with like individuals play a role in the formation of clusters of preferred companionship. Also identified are brokers who act as links between sub-communities and who appear to be crucial to the social cohesion of the population as a whole. Network analysis will hopefully result in finding ways to raise populations and save the species!