

Making good connections

How groups connect with each other is important in the networked world, says s ananthanayanan

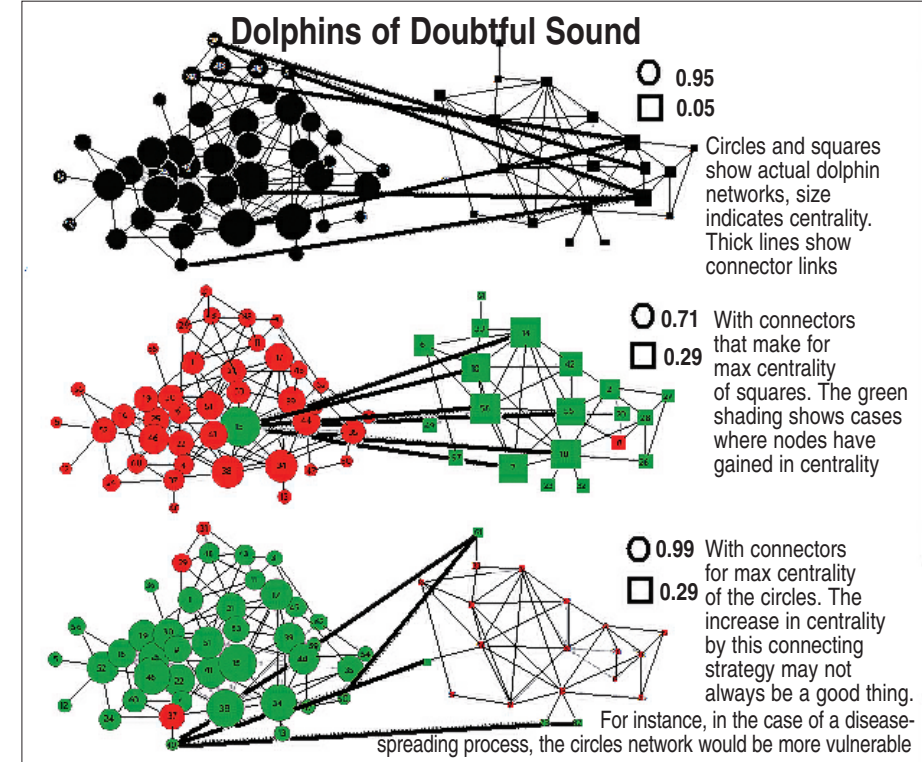
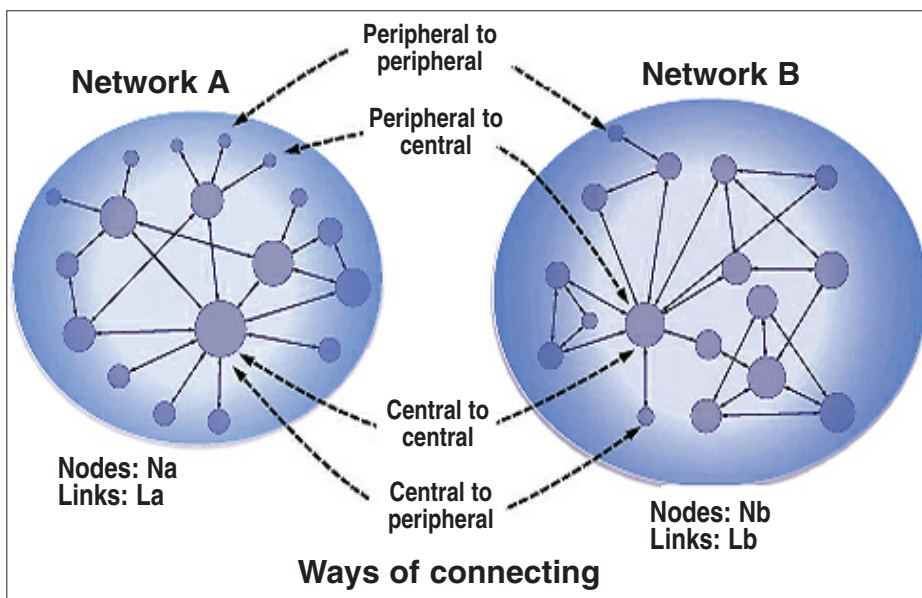
IT is by interdependence or interconnection that things work – within the natural world, in communities, human settlements, the marketplace, roads, airline routes, supply chains, power distribution, epidemics, the Internet... There have been studies of how these networks of related agents grow and stabilise 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 a set of networks.

J Aguirre, D Papo and JM Buldú, of the Centro de Astrobiología, Centre 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 must proceed – which would help intervene where networked systems need to have, or to be kept away from, the power of other 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 gets 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. If the nodes and links in A and B are N_a, L_a and N_b, L_b and the two networks are connected by L



connection links, then the combined network has $N_a + N_b$ nodes and $L_a + L_b + L$ links. The centrality, C_a and C_b , of the two networks, however, would depend on the way the nodes are connected and the centrality, $C_a + C_b$, 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 that 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:

- Connecting the peripheral nodes of both the networks optimises the centrality of the more connected one;
- But connecting the central nodes of the two networks optimises centrality of the weaker network;
- Increasing the number of connector links strengthens the weaker network;
- In general, a network stands to gain if it increases its own number of links and connections;
- 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 these 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 optimise 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 in the study of Aguirre and others, helps understand these situations and also allows prescriptions of successful competition strategies, and an engineering of desirable connectivity patterns. Areas of useful application could be the distribution of populations, spread of epidemics, progress of rumours or patterns of Internet navigation.

An unlikely area where the science has found application is the *Dolphins of Doubtful 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 stretch of water that consists of two distinct layers – one some two 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 blocks 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 a major concern for conservation.

Studying the dolphin community has revealed sub-communities and evidence that a sex- and age-related tendency to associate with like individuals plays 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!

The writer can be contacted at simplescience@gmail.com

Seeking inspiration from locusts

jamie lewis reports on how scientists are working on preventing car crashes

SCIENTISTS hoping to help prevent car crashes have created a computer system that they say was inspired by a swarm of locusts. From the universities of Lincoln and Newcastle, they have discovered that the inspiring insect has a fast and accurate warning system that enables it to detect approaching objects and avoid them while in flight.



Based on these findings, the team behind the findings has created a computer system that they believe could become an early prototype for a technology that could prevent collisions.

Professor Shigang Yue, from the University of Lincoln's School of Computer Science, said, "We were inspired by the way the locusts' visual system works when interacting with the outside world and the potential to simulate such complex systems in software and hardware for various applications."

"We created a system inspired by the locusts' motion sensitive interneuron – the lobula giant movement detector. This system was then used in a robot to enable it to explore paths or interact with objects, effectively using visual input only."

Professor Yue added that building a working system was a major research challenge. She continued, "Vision plays a critical role in the interaction of most animal species and even relatively low-order animals have remarkable visual processing capabilities. For example, insects can respond to approaching predators with remarkable speed."

"This research demonstrates that modelling biological plausible, artificial visual neural systems can provide new solutions for computer vision in dynamic environments. For example, it could be used to enable vehicles to understand what is happening on the road ahead and take swifter action."

The research was carried out as part of a collaborative project with the University of Hamburg in Germany and Tsinghua University and Xi'an Jiaotong University in China.

Dr Claire Rind, from Newcastle University's Institute for Neuroscience, said, "Developing robot neural network programmes, based on the locust brain, has allowed us to create a programme that permits a mobile robot to detect approaching objects and avoid them."

"It's not the conventional approach as it avoids using a radar or infrared detectors, which require very heavy-duty computer processing. Instead, it is modelled on the locust's eyes and neurones as the basis of a collision avoidance system."

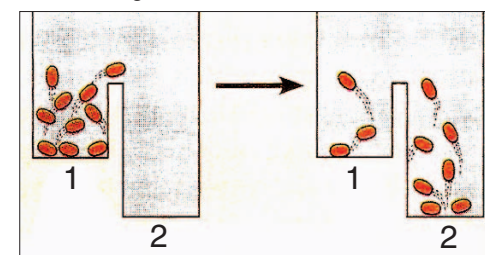
Dr Rind added, "While some collision-avoidance features are pricey options on luxury cars, their performance is not always as good as it could be – and they come at a high cost. This research offers us important insights into how we can develop a system for the car which could improve performance to such a level that we could take out the element of human error."

the independent

Jumping beans and free energy

two chambers are equal at equilibrium, so the equilibrium constant for the jumping reaction under these conditions is 1.0.

Enthalpy change (ΔH)
Now suppose the level of Chamber 1 is somewhat higher than that of Chamber 2, as shown in the next diagram. Jumping beans placed in Chamber 1 will again tend to distribute themselves between Chambers 1 and 2, but this time a higher jump is required to get from 2 to 1 than from 1 to 2, so the latter will occur more frequently. As a result, there will be more beans in Chamber 2 than in Chamber 1 at equilibrium, and the equilibrium constant will therefore be greater than 1.

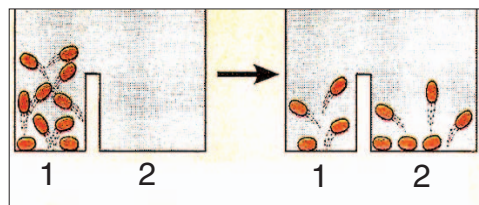


The relative heights of the two chambers can be thought of as measures of the enthalpy, or heat content (H), of the chambers, such that Chamber 1 has a higher H value than Chamber 2, and the difference between them is represented by ΔH . Since it is a "downhill" jump from Chamber 1 to Chamber 2, it makes sense that ΔH has a negative value for the jumping reaction from Chamber 1 to Chamber 2. Similarly, it seems reasonable that ΔS for the reverse reaction should have a positive value because that jump is "uphill".

Entropy Change (ΔS)
So far, it might seem as if the only thing that can affect the equilibrium distribution of beans between the two chambers is the difference in enthalpy, ΔH . But that is only because we have kept the floor area of the two chambers constant. Imagine, instead, the situation shown below, where the two chambers are again at the same height, but Chamber 2 now has a greater floor area than Chamber 1. The probability of a bean finding itself in Chamber 2 is, therefore, correspondingly greater, so there will be more beans in Chamber 2 than in Chamber 1 at equilibrium, and

tapan kumar maitra presents a simple analogy to explain the concept

the equilibrium constant will be greater than 1 in this case also. This means that the equilibrium position of the jumping reaction has been shifted to the right, even though there is no change in enthalpy.



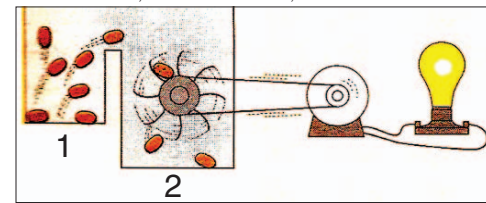
The floor area of the chambers can be thought of as a measure of the entropy, or randomness, of the system and the difference between the two chambers can be represented by ΔS . Since Chamber 2 has a greater floor area than Chamber 1, the entropy change is positive for the jumping reaction as it proceeds from left to right under these conditions. Note that for ΔH , negative values are associated with favourable reactions, while for ΔS , favourable reactions are indicated by positive values.

Free energy change (ΔG)
So far, we have encountered two different factors that affect the distribution of beans: the difference in levels of the two chambers (ΔH) and the difference in floor area (ΔS). Moreover, it should be clear that neither of these factors by itself is an adequate indicator of how the beans will be distributed at equilibrium because a favourable (negative) ΔH could be more than offset by an unfavourable (negative) ΔS , and a favourable (positive) ΔS could be more than offset by an unfavourable (positive) ΔH . You should, in fact, be able to design chamber conditions that illustrate both of these situations, as well as situations in which ΔH and ΔS tend to reinforce rather than counteract each other.

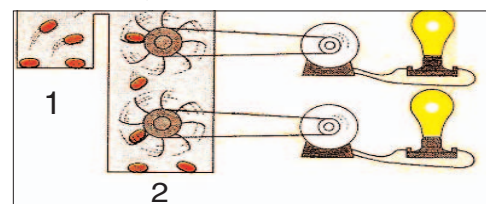
Clearly, what we need is a way of summing up these two effects algebraically to see what the net tendency will be. The new measure we come up with is called the free energy change, ΔG , which ought to

be the most important thermodynamic parameter for our purposes. ΔG is defined so that negative values correspond to favourable (ie, thermodynamically spontaneous) reaction and positive values represent unfavourable reactions. Thus, ΔG should have the same sign as ΔH (since a negative ΔH is favorable), but the opposite sign from ΔS (since for ΔS , a positive value is favourable). In terms of real-life thermodynamics, the expression for ΔG in terms of ΔH and ΔS is: $\Delta G = \Delta H - T\Delta S$. (Notice that the temperature dependence of ΔS is the only feature of this relationship that cannot be readily explained by our model, unless we assume that the effect of changes in room size is somehow greater at higher temperatures.)

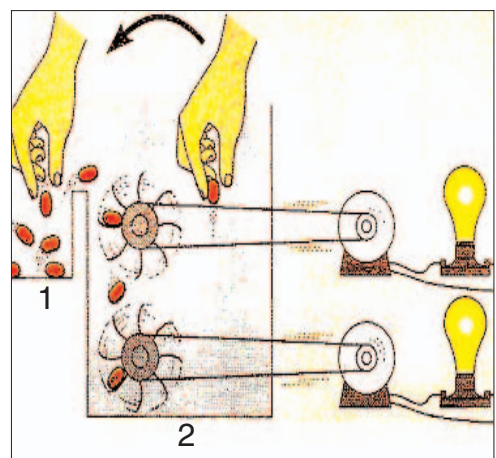
DG and the capacity to do work
You should be able to appreciate the difficulty of suggesting a physical equivalent for ΔG because it represents an algebraic sum of entropy and energy changes, which may either reinforce or partially offset each other. But as long as ΔG is negative, beans will continue to jump from Chamber 1 to Chamber 2, whether driven primarily by changes in entropy, internal energy, or both. This means that if some sort of bean-powered "bean wheel" is placed between the two chambers, as shown below,



the movement of beans from one chamber to the other can be harnessed to do work until equilibrium is reached, at which point no further work is possible. Furthermore, the greater the difference in free energy between the two chambers (that is, the more highly negative ΔG is), the more work the system can do.



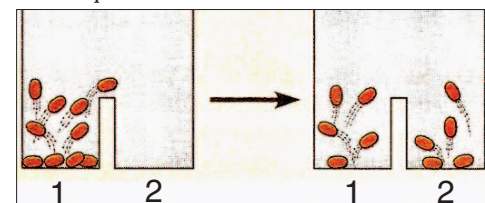
Thus, ΔG is first and foremost a measure of the capacity of a system to do work under specified conditions. You might, in fact, want to think of ΔG as free energy in the sense of energy that is free or available to do useful work. Moreover, if we contrive to keep ΔG negative by continuously adding beans to Chamber 1 and removing them from Chamber 2, we have a dynamic steady state, a condition that effectively harnesses the inexorable drive to achieve equilibrium. Work can then be performed continuously by beans that are forever jumping toward equilibrium but never actually reach it.



Looking ahead
To anticipate the transition from the thermodynamics of this chapter to the kinetics of the next, begin thinking about the rate at which beans actually proceed from Chamber 1 to Chamber 2. Clearly, ΔG measures how much energy will be released if beans do jump, but it says nothing at all about the rate. That would appear to depend critically on how high the barrier between the two chambers is. Label this the activation energy barrier and then contemplate the means by which you might get the beans to move over the barrier more rapidly.

One approach might be to heat the chambers; this would be effective because the larvae inside the seeds wiggle more vigorously if they are warmed. Cells, on the other hand, have a far more effective and specific means of speeding up reactions: they lower the activation barrier by using catalysts called enzymes.

The writer is associate professor and head, Department of Botany, Ananda Mohan College, Kolkata



The equilibrium constant
Once our system is at equilibrium, we can count the number of beans in each chamber and express the results as the ratio of the number of beans in Chamber 2 to the number in Chamber 1. This is simply the equilibrium constant K_{eq} for the jumping reaction:

$$K_{eq} = \frac{\text{number of beans in chamber 2 at equilibrium}}{\text{number of beans in chamber 1 at equilibrium}}$$

For the specific case, the numbers of beans in the