Staying in touch

THE MATHEMATICS OF JOINING DOTS IS HELPING CREATE MORE ROBUST COMMUNICATION NETWORKS, SAYS **S ANANTHANARAYAN**

Having many paths of connections between points in a network makes both for faster communication as well as stability when some of the paths get blocked or crowded. Networks that arise and grow with high interconnectedness, like the biological networks or social networks, are found to provide for ample alternate paths of communication that minimise the chances of the network coming down, even when natural conditions change or people move, and so on. The Internet is one such well-connected and stable network that has come to stay.

But there is now a new entity, wireless networks, where devices set up and dismantle "ad hoc" networks "on the fly". There are instances of emergency responders fanning through a burning building or devices placed on the slopes of a volcano to monitor activity or robots sent out to look for leaks in an oil rig, or for explosives in a minefield. In the case of the Internet, there are fixed routers that channel traffic, and the routers are monitored by service providers to respond to congestion. Similarly, mobile phone users speak not to each other but to cell towers and base stations, which are fixed. But in an ad hoc network, all devices are participants in the working of the network and each one needs to sense the others and collectively ensure that vital information passes intact and in time.

Researchers at the Massachusetts Institute of Technology's Computer Science and Artificial Intelligence Lab, the Israel Institute of Technology at Haifa and the University of Freiburg, Germany, are to present a new approach to the special problems that arise in ad hoc networks at a forthcoming symposium of the industry.

Moshen Ghaffari, Karen Censor-Hillel and Fabian Kuhn.

Special problems

A feature of ad hoc networks is that that the quality of links within the network fluctuates rapidly. Routing strategies of sending more or less information through alternate paths of communication need to be changed often to keep the network going. As responders in the network change position, they could pull further apart, with a drop in the bandwidth of communication channels, or links could be broken or new ones formed. In the adverse conditions where these networks are deployed, some sensors could be destroyed altogether.

The bandwidth and power that the sensors have at their disposal is a relevant factor. If sensors could send data to each other without limit, for instance, the distance between them may not matter. The time for which the sensors can work without a battery recharge is another factor. This may be in hours for robots at oil rigs or in months in the case of sensors placed in a volcano. These are the factors that set apart the problems and solutions in ad hoc networks, as opposed to the Internet or a cell phone network.

Graphs

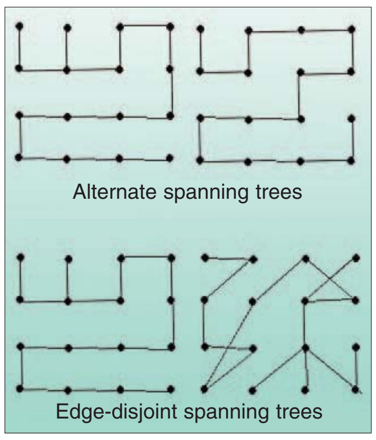
The way the question of connections between places in a network has been abstracted is with a field of mathematics known as *graph theory*. The word *graph* in this context is just a collection of points, which represent objects connected by links that represent the relationship between the objects. Each point may be connected to one or more than one other point. The points are called *nodes* and the connections are called *edges*.

Graph theory looks at the connectivity, or the number of links, in a network so that there are alternative paths, shorter and longer paths, the speed or efficiency of a path that affect the throughput.

Throughput may be measured in quantity of information, in a communication network, or of the number of trains in a railway network, or of microbes in a network that spreads an infectious disease, by the number of citations of research papers, and so on.

Specification of the network, hence, consists of identifying the nodes, and describing the links between adjacent or connected nodes in terms of the time the links take, the quantity they can carry, or the cost or other factors. For instance, in a transport network, there could be a cheaper but slower route and also a faster but expensive route, via an expressway that charges a toll, but where heavy loads are not allowed. Real life networks can have thousands of nodes and proportionate numbers of edges and optimisation becomes a fertile ground for computers.

Computer algorithms have been devised to start from the basic node and edge description and to arrive at a strategy to transfer either from and to any node, or one or more specified nodes, information, people, cargo, etc, in the fastest or cheapest or safest, means possible, with alternatives when a particular node or edge gets congested or defective, etc.



One idea that is used is of the *spanning tree*, or a path through the network that touches all the nodes. It is easy to see that there may be many spanning trees in a given network. The next concept is of the minimum spanning tree, or the tree that has the least length, or cost, etc. For a cable company laying the cable to cover all houses in an area, for instance, the interest could be to use the least length of cable, but this may not be the cheapest solution if the shortest path involved a portion where the cable had to be buried deeper or specially shielded, etc. The ideal layout may even depend on the bandwidth required at different nodes.

Another concept is of the *edge-disjoint spanning trees*, or alternate trees that do not share any edges. Such trees are true alternate paths and can become simultaneous or parallel channels so that the total throughput is multiplied and the network is safe, even if there are failures of links.

Ad hoc networks

The networks of interest so far have been of the kind that have a good number of nodes that are very rich in connection to other nodes. These nodes are called hubs and this structure makes for lesser numbers of nodes that have more connections. The result is a network with more nodes with less connections, and hence the greater chance that a failure will occur at such nodes. The stability of the graph in any case depends on both the number of nodes, or vertices, and the number of edges, or links, which need to be removed before stability is affected. And there has been much work on the subject, with the emphasis on the edge connectivity, rather than the vertex connectivity.

Later this month, MIT graduate student Moshen Ghaffari is to present the work of his team, which includes Keren Censor-Hillel of Israel and Fabian Kuhn of Germany. The new work addresses the properties of vertex connectivity in a manner similar to the work on edge connectivity. The team broke up the network into groups of vertices that have the property that each vertex is connected to all the others in the group and at least one of them is adjacent to a node outside the group. This property allows information to flow within the group and also connection outside the group, which is called a *connected dominating set*.

Just like a graph is known to contain almost as many edge-disjoint spanning trees as edge connectivity, "each graph contains almost as many vertex-disjoint connected dominating sets as its vertex connectivity", says Ghaffari. "So if you think of an application like broadcasting information through a network, we can now decompose the network into many groups, each being one connected dominating set," he says. "Each of these groups is then going to be responsible for broadcasting some set of the messages, and all groups work in parallel to broadcast all the messages fast — almost as fast as possible."

As connections and spanning trees are variable in ad hoc networks, breaking the network into groups of nodes is the way to optimise performance in these applications. It would also help analyse the effects of node failures, as against edge failures.

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ABOUT GENE EXPRESSION

TAPAN KUMAR MAITRA EXPLAINS THE NEGATIVE AND POSITIVE CONTROL OF TRANSCRIPTION

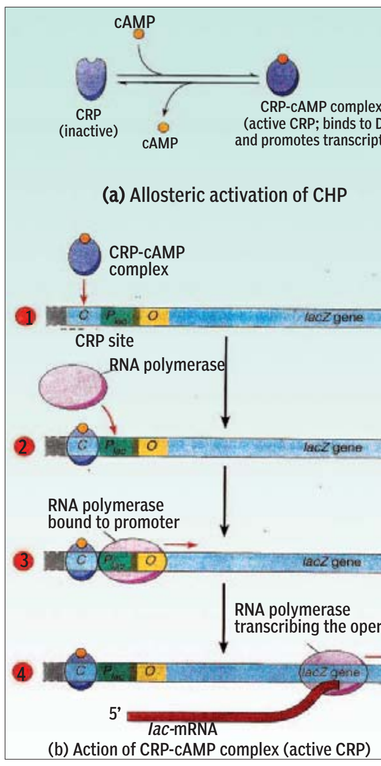
Repressor proteins can control the transcription of genes involved in either catabolic or anabolic pathways. For catabolic pathways, the active (DNA-binding) form of the repressor is the effector-free repressor protein, whereas for anabolic pathways, the active form is the effector-bound repressor protein. But regardless of which is the active form of the repressor, the effect of repressor action is always the same: the active repressor prevents transcription of the operon by blocking the proper movement of RNA polymerase along the DNA. Repressors, in other words, never turn anything on; their effect is always to turn off the expression of specific genes (or keep it turned off). This is, therefore, a system of negative control in that the active form of the repressor works by inhibiting gene transcription.

Catabolite repression illustrates the positive control of transcription. The transcription of some operons is under positive control, meaning that the active form of a key regulatory protein turns on an expression of the operon. An important example of positive transcriptional control is found in catabolite repression, which refers to the ability of glucose to inhibit the synthesis of catabolic enzymes produced by inducible bacterial operons. To understand this phenomenon, we need to recognise that glucose is the preferred energy source for almost all prokaryotic cells (and for most eukaryotic cells, too). This is because the enzymes of the glycolytic and tricarboxylic acid (TCA) pathways are produced constitutively in most cells, so glucose can be catabolised at any time without the synthesis of additional enzymes.

Although molecules other than glucose can also be metabolised as energy sources, catabolite repression guarantees that other carbon sources are used only when glucose is not available. For example, E. coli cells grown in the presence of both glucose and lactose use the glucose preferentially and have very low levels of the enzymes encoded by the lac operon, despite the presence of the inducer for that operon.

Like the other regulatory mechanisms we have encountered, this preferential use of glucose is made possible by a genetic control mechanism that involves an allosteric regulatory protein and a small effector molecule. The actual effector molecule that controls gene expression is not glucose but a secondary signal that reflects the level of glucose in the cell. This secondary signal is a form of AMP called cyclic AMP or cAMP. Glucose acts by indirectly inhibiting adenylyl cyclase, the enzyme that catalyses the synthesis of cAMP from ATP. So the more glucose present, the less cAMP is made.

How does cAMP influence gene expression? Like other effectors, it acts by binding to an allosteric regulatory protein. In this case the regulatory protein, called the cAMP receptor protein (CRP), is an activator protein that turns on transcription. By itself, CRP is nonfunctional, but when complexed with cAMP, CRP changes to an active shape that enables it to bind to a particular base sequence within operons that produce catabolic enzymes. This sequence, the CRP recognition site, is located upstream of the promoter. Like the location of the CRP recognition site (labelled C) in the lac operon; similar sites are found in a variety of inducible operons. When CRP, in its active form (that is, the CRP-cAMP complex), attaches to its recognition site in DNA, the binding of RNA polymerase to the promoter is greatly enhanced, thereby stimulating the initiation of transcription. Thus, CRP has a positive effect on gene expression.



The cAMP Receptor Protein and Its Function. CRP mediates catabolite repression by activating the transcription of various inducible operons in the presence of cyclic AMP (cAMP), whose concentration is in turn controlled by glucose. (a) CRP is an allosteric protein that is inactive in the free form but is converted to the active form by binding to cAMP. (b) The resulting CRP-cAMP complex binds at or near the promoter of a variety of inducible operons, including the lac operon, increasing the affinity of the promoter for RNA polymerase and thereby stimulating transcription. (1) In the lac operon, the CRP-cAMP complex binds to the CRP recognition site (C) near the promoter region, thereby (2) making the promoter more readily bound by RNA polymerase. (3) RNA polymerase binds to the promoter and (4) transcribes the operon.

This phenomenon explains how glucose exerts its influence on the transcription of genes coding for catabolic enzymes. When the glucose concentration inside the cell is high, the cAMP concentration falls and hence CRP is largely in its inactive form. Therefore, CRP cannot stimulate the transcription of operons that produce catabolic enzymes. In this way, cells turn off the synthesis of catabolic enzymes that are not needed when glucose is abundantly available as an energy source.

Conversely, when the glucose level falls, the cAMP level rises, activating CRP by binding to it. The CRP-cAMP complex greatly enhances transcription of inducible operons, leading to the production of catabolic enzymes that allow cells to obtain energy from the breakdown of nutrients other than glucose. For example, transcription of the lac operon can be increased 50-fold in this way — provided, of course, that the repressor for that operon has been inactivated by the presence of its effector (that is, allolactose).

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Explaining Bolt's success

STEVE CONNOR REPORTS ON RESEARCH THAT SAYS JAMAICAN CHILDREN HAVE PARTICULARLY SYMMETRIC LEGS IN COMPARISON TO OTHERS AROUND THE WORLD

Symmetrical knees could help to explain why Jamaicans are so good at sprinting, according to a study into why such a small nation dominates international sprint events for both men and women. Jamaican runners, epitomised by the 100-metres world record holder Usain Bolt, lead the world in sprinting and now scientists believe they can explain why with the help of long-term research findings into the body symmetry of Jamaican children.

The researchers found that the most symmetrical children with the most symmetrical knees in the study were also the most likely in the group to become the best sprinters when they became adults, said Professor John Manning of Northumbria University in Newcastle. "We found that Jamaican children have particularly symmetric legs, in comparison to Europeans.

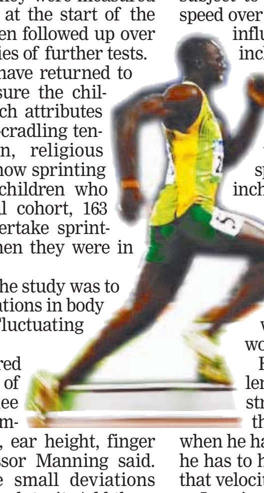
Fur thermore, in children symmetry in the legs, particularly in the knees, predicted their willingness to sprint and their sprinting times when they were adults."

The childhood symmetry project began in 1996 and involves about 300 primary school children from rural Jamaica, with an average age of eight when the study started. They were measured for body symmetry at the start of the project and have been followed up over the years with a series of further tests.

The researchers have returned to Jamaica to re-measure the children and to test such attributes as handedness, doll-cradling tendencies, aggression, religious convictions — and now sprinting speed. Of the 288 children who formed the original cohort, 163 volunteered to undertake sprinting tests in 2010 when they were in their early 20s.

"The purpose of the study was to consider small deviations in body symmetry called Fluctuating Asymmetry.

These are measured from about 10 pairs of traits such as knee width, ankle circumference, foot length, ear height, finger length, etc," Professor Manning said. "Most people have small deviations from symmetry in each trait. Add these across many traits and you have the composite FA per individual."



Body symmetry is thought to be a sign of overall genetic fitness and good physical development. It has also been correlated with a wide range of attributes, from running speed and physical attractiveness in both sexes to sperm production in men, Professor Manning explained.

"With regard to sprinting, we found that participants with symmetric legs in 1996, particularly knees, tended to volunteer for the sprints and they tended to run the fastest when tested in 2010. Also, there was some evidence that these Jamaican children had substantially more symmetry in their legs than UK children," he said. "So we think our results inform the debate as to why Jamaicans tend to win gold medals in sprinting. I think this may, in part, explain Jamaican success in sprinting disciplines.

However, to be sure we need to follow it up by looking at international level sprinters and adding some genetic tests. Also, more comparative data on Caucasians will help to further clarify the issue. We intend to look at some of the best Jamaican male and female athletes early in 2014," he added.

The researchers, who included evolutionary biologist Robert Trivers of Rutgers University in New Brunswick, suggested in their research paper published in the online journal *PlosOne* that the strong West African ancestry of Jamaicans could help to explain their sprinting prowess. "It does seem likely… that peoples of West African origin have been subject to strong natural selection for speed over short distances, and this has influenced a number of traits, including developmental stability of the knees and of associated traits in the legs," they said.

Usain Bolt does not have the physique of a typical sprinter. At six feet and five inches, he is taller and leaner than many previous world record holders, such as American sprinter Carl Lewis, who was three inches shorter and a stone heavier than Bolt when he held the 100 metres world record in the 1980s.

However, Bolt's height and leg length means he has a very long stride, which is an advantage in the middle stages of the race when he has reached his top speed – but he has to have the stamina to maintain that velocity until the finish line.

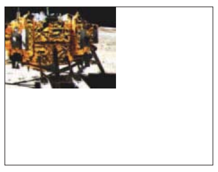
Jamaican athletes with West African ancestry also have significantly more "fast-twitch" muscle fibres than runners from other parts of the world. Fast-twitch fibres tire easily but are good for rapid muscle contraction over short distances — a critical attribute for sprinting.

THE INDEPENDENT

PLUS POINTS

Life on Mars?

It was the year China went to the moon, America continued to explore the surface of Mars and Britain won a place on Europe's manned space programme with a candidate astronaut who instantly became known as "Major Tim".If space is the final frontier, then China wants to show it can reach out and touch it. Last month, the world's most populous nation successfully landed a space probe on the lunar surface in the first "soft touchdown" on the moon since 1976. Using retro-rockets to soften its descent, the *Chang'e-3* spacecraft landed its own lunar probe in the Mare Imbrium plain in preparation for an exploratory trek by a small solar-powered rover.



Chinese lunar lander *Chang'e-3*

China has come a long way since its first manned space mission 10 years ago and shows every sign of completing its ambition of sending astronauts to the moon. As one commentator remarked, "It's very possible the next person to walk on the moon could be Chinese in 15 years' time."

Tantalising evidence that Mars was once a water-filled, habitable world continued to emerge in 2013. The National Aeronautics and Space Administration's *Curiosity* rover discovered smoothly eroded pebbles in rock formations known as conglomerates, which were almost certainly the result of water erosion in fast-flowing streams. "This is the first time we've seen water-transported gravel on Mars," said William Dietrich of the University of California, Berkeley, who worked on the project.

Later on in the year, *Curiosity* topped this discovery by finding mudstone, which is formed by the silt of a still body of water. It had found the bed of an ancient lake where life could have emerged some 3.8 billion years ago, Nasa said. This was the strongest evidence yet that Mars was once a habitable planet — not that it had life, but that it had the conditions necessary for simple, microbial life. As Sanjeev Gupta of Imperial College London, one of the researchers on the *Curiosity* mission, said, "This is dramatic. We have effectively found what was once a standing body of water and although we don't know how long it was there for, liquid must have been stable on the Martian surface for at least thousands or even millions of years."

THE INDEPENDENT

Forests feel the heat

In a dramatic response to global warming, forests in high-elevation areas across the world have been "browning" since the 1990s. A study has shown that forests have been steadily losing foliage and showing lesser photosynthetic activity.

When satellites measure sunlight that has bounced off the surface of the earth, different surfaces have different reflection patterns. Areas with lush foliage (where photosynthetic rates are high) appear green and areas with less foliage (where photosynthetic rates are low) look brown. The "greenness" or "brownness" of an area can be expressed through a formula called Normalised Difference Vegetation Index. The study used this formula to determine changes in tropical mountain vegetation from 1982 to 2006 and researchers concentrated on protected areas in regions 1,000-6,000 metres above sea level, selecting 47 such areas across five continents and covering more than 50,000 square km, all located in the world's biodiversity hotspots.

Mount Kinabalu in Sabah, Borneo, was one of the sites selected for studying the effects of change in rain and temperature on photosynthetic rates of forests.

Until the mid-1990s, the NDVI increased, indicating a greening across all the areas under study. Then came an abrupt shift, synchronous in all 47 areas, and the "greening" became "browning".

Says lead author of the paper, Jagdish Krishnaswamy, from the Ashoka Trust for Research in Ecology and the Environment, Bengaluru, "The 'browning' was with respect to the maximum greenness attained in each year — so it was a decline in the maximum photosynthetically active leaf biomass attained in the entire year. Something was affecting the ability of tropical mountain vegetation to sustain the same canopy biomass in the early 1990s."

While there was an increase in temperature in these areas, there were no clear trends in rainfall. The authors state that this causes what is called "moisture stress" — an increase in temperature not accompanied by a concomitant increase in moisture. This usually causes a drop in photosynthetic rate, or browning.

Interestingly, a shift from greening to browning in the 1990s has been reported from large areas in the northern hemisphere. The study was published in *Global Change Biology* on 17 November.

SANDHYA SEKAR/CSE-DOWN TO EARTH FEATURE SERVICE