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Unravelling Charles Darwin's entangled bank

How can studying the internet and the way we interact with our friends help us understand Darwin and ecosystem fragility? **Jose Montoya** has some answers.

> It is interesting to contemplate an entangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent on each other in so complex a manner, have all been produced by laws acting around us.

Charles Darwin

The concluding paragraph of The Origin of Species *(1859) Published by John Murray.*

Imagine you are snorkelling on an Indonesian coral reef, birdwatching in Scotland or climbing up Monte Verde in Costa Rica. You will be amazed by the variety of life forms you encounter. If you are curious enough, you will soon realise how tightly interconnected all these life forms are: butterflies visiting flowers, spiders feasting on insects, or birds eating fruits. If you are even more curious, you will start thinking whether this bewildering richness of species and their connections can be understood and simplified to some basic laws or principles. If you are that curious, congratulations, you could have been Darwin, and you could have proposed the most famous biological metaphor of all time, the so-called 'entangled bank'. The question is: can we untangle it?

Let's stop here for a moment and look at the internet because part of the answer lies in the way this network is organised. Each web page is a node. Two nodes are connected if from the first you can reach the second. You can see that a small number of web pages have a huge number of connections – the hubs – for example, Google or Yahoo. But there are a large number of pages with very few connections. This pattern gives a lot of robustness to the entire network. If some of the pages disappear, or a virus infects pages randomly, this will affect pages loosely connected to these pages, but won't harm others. However, the internet has an Achilles' heel: if the hubs disappear or a virus infects them, this will have serious consequences for many other web pages. Simply imagine the internet without Google or without my personal page. Unfortunately for me, the effect will not be the same.

Are ecological networks like the internet? Superficially, it seems so. Ecosystems containing a large number of species are dominated by specialists: hummingbirds with long or strangely curved bills, for example, pollinate flowers with corresponding specialised structures. Some generalists, which interact with numerous species, also exist such as butterflies pollinating many plant species, or one species of predator attacking many different preys, for example jaguars.

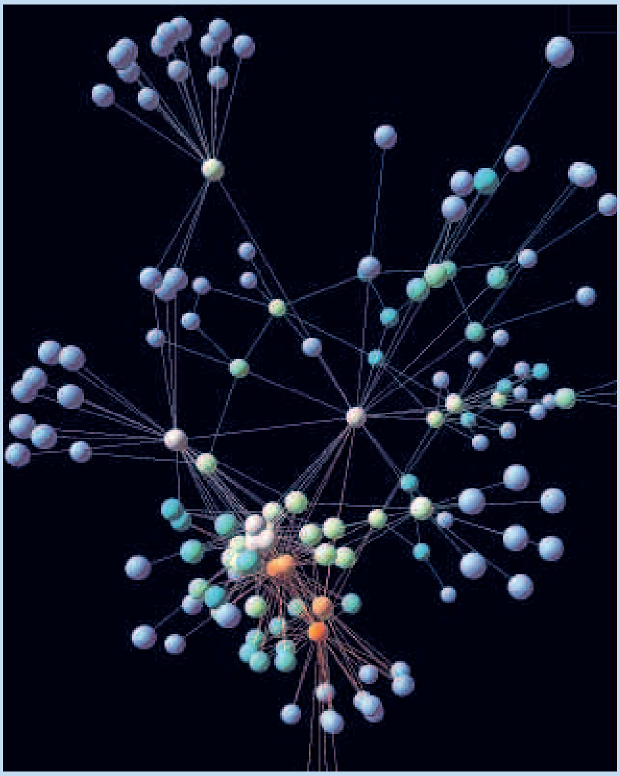
If some of these species disappear, this may trigger a cascade of extinctions of the species dependent upon them. When predators are lost, jaguars in our example, a dominant herbivore species can outcompete other herbivores that used to coexist with it in the presence of the predator. Computer simulations using data of ecological networks from temperate forests show that the extinction of just seven percent of the most highly-connected insect prey, for example some omnivorous insects, results in the coextinction of approximately half of the remaining species.

We can call these species the 'keystones' of the ecological network: like in architecture, they support the building, and without them, the whole structure may collapse. You may think ecosystems are much more flexible than cathedrals, and that species may easily adapt. And they are, but such plasticity requires time, and current extinctions are incredibly fast. It is a daring bet to count on species adaptation.

You may think this is self-evident. But not really. Many of these 'keystones' are not emblematic species, usually there is no conservation effort to protect them, and sometimes we have no idea of the state of their populations and even less about their extinction risk. Studying these interaction networks is essential if we are to identify these keystones. The simple mathematical laws describing how interactions are distributed within the ecosystem are a powerful way of doing this.

Another exciting finding is that species interactions exhibit 'small-world' properties. We all intuitively use this term to refer to chance and unexpected meetings. The formal concept originated indeed in the study of social realtionships between humans. Human societies have so-called six-degrees of separation: you are probably six handshakes away from Einstein, and from anybody in the world you may think of. The idea is that you always have a friend who was once in a place, where he met someone, who knew... and so on. Ecological networks have between two and three degrees of separation. In a compilation of a dozen food webs – describing who eats whom – 80 percent and 97 percent of the species are, respectively, within two or three links of each other. Everything is more connected than expected, so any perturbation on a particular species that reduces its population size, or a contaminant, for example, will buffet every other species. So, metaphorically, when a tree falls in a rainforest, every species in that species-rich system would quickly 'hear' the fall.

At the same time, we can identify species clusters, that is groups of species more connected to each other than with the rest of the ecosystem. For example, some fish species feed exclusively on plankton, while others feed on species living in the sediment. These compartments are usually connected by some generalist species. Like in your network of social interactions, you have your cluster of close friends, and either you or your very 'popular' friend connects your cluster of friends with other clusters. It is 'popular', highly connected nodes which allow the coexistence of local compartments and small worlds in ecosystems.



The food web associated with a member of the pea family, the Scotch Broom (the white node in the centre). Each node represents the relationship of a species of insect to the plant, and to other insects. The colours represent the number of connections of each species (red: highly connected; blue: loosely connected). It is clear that if one of the red or green species were to disappear this would affect many other species (in blue).

It is very hard to compile data of the entire ecological network of any ecosystem. It requires a lot of observation, and in the case of food webs, the nasty task of analysing gut contents. But if we aim to untangle Darwin's entangled bank, we need to do so. Patterns as the ones described here are crucial to understanding the fragility and persistence of species and their interactions in a constantly changing world. Estimations of impending extinction rates, for example, should include the possible 'domino' effects of the extinction of some species on the remaining species within the network.

And it is always nice to discover how similar our social and technological networks are to the ecological networks that sustain us. Maybe a powerful reason to preserve them?

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