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Beating the Competition: Scientists Discover How the Size of Networks Can Skyrocket

A single new connection can dramatically enhance the size of a network -- no matter whether this connection represents an additional link in the Internet, a new acquaintance within a circle of friends or a connection between two nerve cells in the brain.

The results, which are published in *Nature Physics*, were part of a theoretical study carried out by researchers from the Max Planck Institute for Dynamics and Self-Organization (MPIDS), the Bernstein Center for Computational Neuroscience Göttingen and the University Göttingen. This study mathematically describes for the first time the influence of single additional links in a network.

Imagine the following scenario: In your sports team you get to know a new player and arrange to go out and see a movie on the next weekend. The new team member brings along three friends -- and suddenly by adding one new contact, your own circle of friends has grown by four people. Growth processes of this sort occur in many networks: Neurons in the brain constantly establish new connections, websites link to each other and a person travelling infected with influenza creates a network of infected places with each intermediate stop. From a scientist's point of view, such growth processes are still poorly understood: How does a network change when single links are added? How quickly does a network grow in this way?

To answer these questions, the scientists from Göttingen tracked the growth of networks link by link. A new connection, however, can not only add one new element. It can also merge two networks (as in the example in the sports team above). The researchers focused on a special form of network growth that introduces a form of competition between possible links: If several new connections are possible, only the one connection is created: the one that results in the smallest new network.

"There is evidence, that growing networks of neurons at first prefer forming small groups and thus roughly follow the growth process we discuss," says Jan Nagler, staff researcher at the University of Göttingen and the MPIDS.

The situation can be compared to the social contacts established in a summer camp for children, whose

participants all don't know each other at the beginning of their vacation. Most likely, the children will at first team up in small groups and pairs. If such a pair wants to expand its social circle, it typically proceeds cautiously, approaching another pair or a small group rather than a large clique. At the beginning of the vacation, the social networks within the camp therefore grow slowly. At the end, all children will have become acquainted: The network has then reached its largest possible size and connects all elements of the system.

"In our study we zoomed in on an intermediate growth phase. This phase arises after the elements have begun to sporadically connect into small groups, but before the entire system is linked," explains Marc Timme, head of the Network Dynamics Group at MPIDS. How do the many small networks link to form a whole? Are several large networks created at the same time or does one dominant network develop that towers above the others? In addition to performing computer simulations, the Göttingen researchers were for the first time able to derive mathematical expressions that describe this growth phase link by link.

The scientists found that after a certain number of new links, a sudden growth spurt occurs: The size of the largest network within the system is enhanced dramatically. "With respect to the size of the system, this jump is more dramatic in small systems than in large ones," says Nagler. However even in systems that consist of a huge number of elements -- comparable for example to the number of neurons in the brain -- the size of the largest network can double. "At first, many networks of moderate size develop in this way," says Timme. Thus, a dominant spanning network emerges only at a late stage in the growth process.

In a next step, the researchers now want to identify which forms of competition in natural systems from biology and physics imply this rapid growth and study the consequences of these growth spurts.