Press Release

Brain Networks under Attack

What pruning network links can tell us about the dynamics of neuronal networks

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What would happen if we cut 90 percent of the links in a neuronal network? “Not much, as long as its most critical links remain intact” says **Simachew Abebe Mengiste**. In his current research, the mathematician and PhD student at the Bernstein Center Freiburg (BCF) studies what happens if a complex network is under attack by systematically pruning its links. His paper entitled “Effect of edge pruning on structural controllability and observability of complex networks”, which was published in *Scientific Reports*, the online open-access journal by the publishers of *Nature,* offers new perspectives for understanding the mechanisms underlying neurodegenerative diseases and the dynamics of complex networks.

Our universe is full of interacting systems. Networks such as power grids, the Internet or social networks determine our daily routine. Biological neuronal networks (BNNs) are the most complex example of such systems. In our brain, both the states of the nodes, the neurons, and the pattern of their interaction, their synaptic connections, progressively change throughout our lives. Mengiste investigated how such systems can be controlled and observed – particularly when they are under attack. The goal of his research is to understand the conditions required for achieving structural controllability of networks. “In dynamical systems, controllability means to be able to direct the network state from where it currently is to where you want it to be”, Mengiste says. “In this respect, structural controllability provides the tools to identify the minimum number of nodes in a network required to design a controllable structure for the entire system.”

Because networks are often not static in their structure, their optimal control configuration is likely to change: “Consider the street network in a city. When there is a construction site, some roads need to be blocked. This resembles the removal of some links in a network. In such a situation, the authorities need to ensure that all locations in the city remain accessible. For this, it is crucial to identify the most frequented roads and to adapt traffic guidance accordingly to prevent the traffic from collapsing”, Mengiste explains. “Using the idea of structural controllability we can not only identify the critical links between any two destinations, but also calculate how many roads could be blocked, while the main network remains intact.”

Biological neuronal networks, like most real world networks, are relatively resilient to random removal of their edges. When the full structure of the network is not known, a progressive attack on its edges, systematically killing links of individual nodes, one by one, is very efficient in altering the control configuration of many types of networks. When the full network structure is known, Mengiste can devise even more powerful edge attack strategies which either do not affect the controllability or, alternatively, quickly cripple the network. “Our insights can not only help to structurally protect complex networks, such as neuronal networks, airport networks, street grids, or some social networks, which are highly sensitive to intentional attacks on their critical edges. They can also help us define more efficient strategies for attacking potentially harmful network dynamics, such as the distribution of pandemic diseases, and they may help us understand the dynamics of such structures”, Mengiste explains.

A similar situation arises in a brain suffering from a neurodegenerative disease such as Alzheimer’s or Huntington’s disease, which typically result in the death of neurons and the failure of synapses. “In these diseases, network structures gradually deteriorate until they reach a stage in which natural compensation mechanisms can no longer make up for the loss of neurons and synapses,” says Mengiste. “As a result, inputs may no longer reach their targets efficiently and effectively.” Therefore, it is useful to reanalyze the control structure of such networks under attack and to identify where additional inputs are necessary.

Original Publication:

Mengiste SA, Aertsen A, Kumar A (2015) Effect of edge pruning on structural controllability and observability of complex networks. Scientific Reports, www.nature.com/articles/srep18145.

Image caption

As in a road network, up to 90 percent of the links in a neuronal network can be cut while still maintaining reasonable network function, as long as the critical links remain intact.

Image: Kiyoshi Takahase Segundo / ktsimage / www.stockami.com

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