New math model could help with systematic predictions like potential coronavirus mutations

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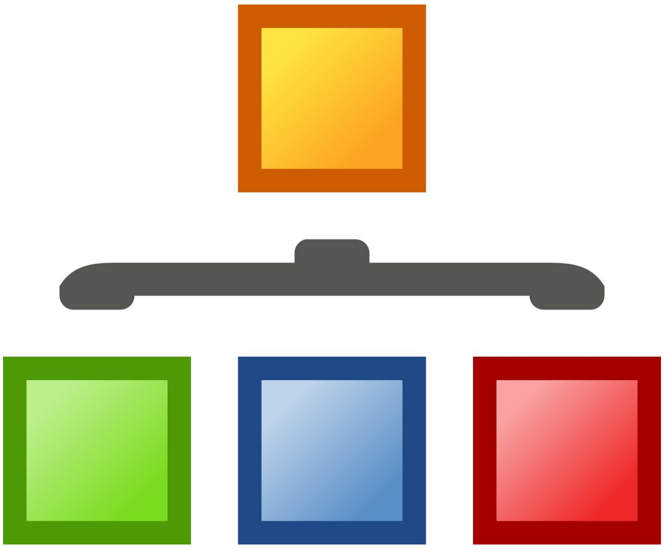

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Could a mathematical model help predict future mutations of the coronavirus and guide scientists' research as they rush to develop an effective vaccine? This is a possibility being considered by researchers at the USC Viterbi School of Engineering—Ph.D. students Ruochen Yang and Xiongye Xiao and Paul Bogdan, an associate professor of electrical and computer engineering.

Over the past year, Yang and Bogdan have worked to develop a model that could be used to investigate the relationship between a network and its parts to find patterns and make predictions. Now, Xiao is applying that successful model to the current pandemic. He is examining the RNA sequence of SARS-CoV-2, also known as coronavirus, to determine whether accurate predictions can be made about how its genetic code might change in the future based on past mutations. This research is still in progress and no conclusions have been reached yet.

Published in *Nature Scientific Reports*, a sister journal of *Nature*, Yang and Bogdan's work is detailed in their paper, "Controlling the Multifractal Generating Measures of Complex Networks."

Their research is widely applicable to the understanding of a variety of real-world networks, from biological systems like the brain and the genome to networks and processes in geoscience social networking and financial markets.

We live in a world made up of a variety of complex systems. From the activity of the human brain to the patterns of traffic flow in a city to the molecular structure of rocks, these intricate networks are all composed of smaller scale interactions and simpler parts. Yang and Bogdan's model is significant because in many real-world experiments we may only be able to observe parts of a system; their model provides a way to find patterns in the network that can help predict how it works on a smaller or larger scale.

"We based our model on the existence of multifractality in many real-world systems," Yang said. A fractal system is one in which the parts are similar to or the same as the whole.

Real-world processes that exhibit multifractal characteristics include human heart rate, blood glucose variability, brain activity, internet traffic, meteorology, and countless more. These multifractal characteristics mean that patterns discovered within the system can be used to make predictions and conclusions about the overall system.

Yang and Bogdan successfully developed a mathematical model for analyzing multifractal networks known as the weighted multifractal graph model, or WMG. The WMG model characterizes the underlying principles of real-world networks, examines the relationship between the smaller parts of a network and the whole, and predicts the future behaviors or changes in the overall system by looking at the parts.

"This mathematical model can be used to analyze a wide range of complex real-world systems, but beyond that, it provides a novel way to control the future behaviors of a system," Bogdan said. "If we understand how the overall system's behavior relates to the activities of the parts that make it up, we can control these smaller scale interactions to achieve the desired overall systemic outcome."

The WMG model could have a wide range of real-world applications, but in their paper, Yang and Bogdan applied it to two: the reproductive process of yeast cells and the brain networks of patients with cognitive impairment leading to Alzheimer's disease.

In the yeast cells' example, the pair found patterns within the reactions and processes of reproduction. They used this knowledge to differentiate the growing states of these cells. The overall system of reproduction of yeast cells is governed by the interactions between chromosomes. Yang and Bogdan's model mapped the relationship between these components and the overall structure and behavior of the genome to describe how all of the smaller interactions that make up reproduction ultimately affect the growing state of a group of yeast cells. The patterns found using their model can be used to regulate the growth of yeast cell cultures by dictating how to control the conditions under which the cells reproduce.

Yang and Bogdan also applied their model to map out the structure and functioning of networks in the human brain to look for small-scale early indicators of Alzheimer's. They examined and compared the brains of patients with early-stage Alzheimer's disease with the brains of cognitively healthy individuals to discover patterns in brain activity associated with cognitive impairments linked to the disease. Yang and Bogdan applied their model to the interactions of the brain matrix in late mild cognitive impairment patients to illustrate how it could be changed to fit the one from cognitively normal people.

This application of their model could be helpful in early detection of the disease. "There's no cure for Alzheimer's disease and terminating the neurodegeneration is impossible," Bogdan said. "However, treatments at an early stage may help to relieve the symptoms and delay the onset of the disease, so early detection is crucial to slow the deterioration process of Alzheimer's disease."

Their model might also allow researchers to control the outcomes of complex networks by controlling the rules by which smaller parts interact within the overall system leading to a more efficient and robust control methodology. If scientists could design therapies to control the differences between healthy brains and cognitively impaired brains as they relate to small-scale structure and function, they could develop new promising treatments for cognitive health and the prevention or treatment of Alzheimer's disease.

The variety of possible applications of this research makes it extremely exciting and promising.

"This research enables us to understand the underlying rules that govern the dynamics of real complex systems and helps us to efficiently control their states and conditions," Bogdan said.

More information: Ruochen Yang et al. Controlling the Multifractal Generating Measures of Complex Networks, *Scientific Reports* (2020). DOI: 10.1038/s41598-020-62380-6

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