New algorithm cuts through 'noisy' data to better predict tipping points

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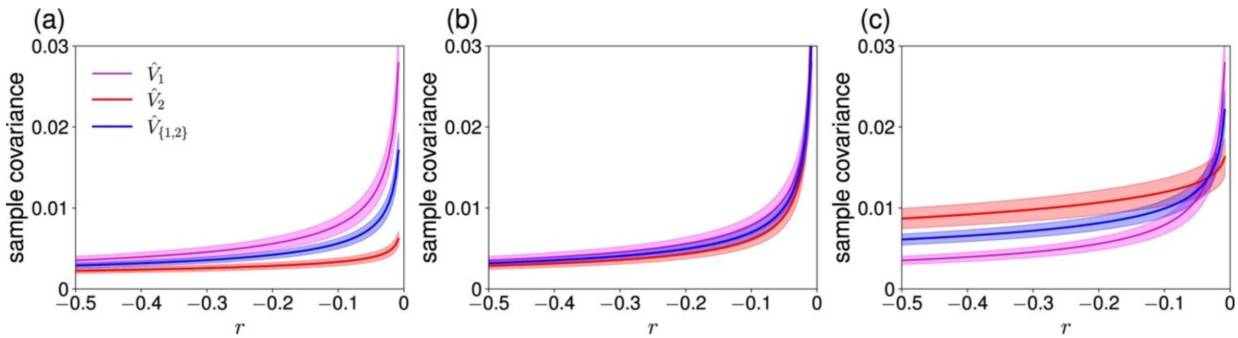

Early warning signals with different node sets in a network with N = 2 nodes connected by a directed edge. Credit: *Nature Communications* (2024). DOI: 10.1038/s41467-024-45476-9

Whether you're trying to predict a climate catastrophe or mental health crisis, mathematics tells us to look for fluctuations.

Changes in data, from wildlife population to anxiety levels, can be an early warning signal that a system is reaching a critical threshold, known as a tipping point, in which those changes may accelerate or even become irreversible.

But which data points matter most? And which are simply just noise?

A new algorithm developed by University at Buffalo researchers can identify the most predictive data points that a tipping point is near. Detailed in *Nature Communications*, this theoretical framework uses the power of stochastic differential equations to observe the fluctuation of data points, or nodes, and then determine which should be used to calculate an early warning signal.

Simulations confirmed this method was more accurate at predicting theoretical tipping points than randomly selecting nodes.

"Every node is somewhat noisy—in other words, it changes over time—but some may change earlier and more drastically than others when a tipping point is near. Selecting the right set of nodes may improve the quality of the early warning signal, as well as help us avoid wasting resources observing uninformative nodes," says the study's lead author, Naoki Masuda, Ph.D., professor and director of graduate studies in the UB Department of Mathematics, within the College of Arts and Sciences.

The study was co-authored by Neil Maclaren, a postdoctoral research associate in the Department of Mathematics, and Kazuyuki Aihara, executive director of the International Research Center for Neurointelligence at the University of Tokyo.

Warning signals connected via networks

The algorithm is unique in that it fully incorporates network science into the process. While early warning signals have been applied to ecology and psychology for the last two decades, little research has focused on how those signals are connected within a network, Masuda says.

Consider depression. Recent research has considered it and other mental disorders as a network of symptoms influencing each other by creating feedback loops. A loss of appetite could mean the onset of five other symptoms in the near future, depending on how close those symptoms are on the network.

"As a network scientist, I felt network science could offer a unique or perhaps even improved approach to early warning signals," Masuda says.

By thoroughly considering systems as networks, researchers found that simply selecting the nodes with highest fluctuations was not the best strategy. That's because some selected nodes may be too closely related to other selected nodes.

"Even if we combine two nodes with nice early warning signals, we don't necessarily get a more accurate signal. Sometimes combining a node with a good signal and another node with a mid-quality signal actually gives us a better signal," Masuda says.

While the team validated the algorithm with numerical simulations, they say it can readily be applied to actual data because it does not require information about the network structure itself; it only requires two different states of the networked system to determine an optimal set of nodes.

"The next steps will be to collaborate with domain experts such as ecologists, climate scientists and medical doctors to further develop and test the algorithm with their empirical data and get insights into their problems," Masuda says.

More information: Naoki Masuda et al, Anticipating regime shifts by mixing early warning signals from different nodes, *Nature Communications* (2024). DOI: 10.1038/s41467-024-45476-9

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