Using machine learning to predict the unpredictable

ASU researchers develop new method to forecast complex ecosystem behavior

By TJ Triolo, ASU News
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As the natural world rapidly changes, humanity relies on having reliable, accurate predictions of its behavior to minimize harmful impacts on society and the ecosystems that sustain it.

Ecosystems of all scales are becoming more and more vulnerable to collapse. For example, coral reefs are being affected by warming waters, pollution and overfishing; around the world, 84% of reefs suffer from coral bleaching, a stress response to such impacts. These events displace or kill the marine life that call reefs home, reducing biodiversity and harming humanity by kneecapping economies reliant on tourism and eliminating food supplies.

Anticipating harm is critical for developing effective control and mitigation strategies — an area where modern artificial intelligence, or AI, and machine learning could play a transformative role.

However, the scarcity and incompleteness of ecological data make it difficult to train machine learning models effectively. Addressing this challenge is the focus of Arizona State University electrical engineering doctoral student Zheng-Meng Zhai, who is exploring how to harness the power of AI to better predict and prevent ecosystem failures.

Zhai, a student in the Ira A. Fulton Schools of Engineering, led a project focused on developing a new way to teach AI algorithms to make accurate predictions about ecological systems, for which accurate data is often sparse.

His work, conducted under his doctoral thesis advisor, ASU Regents Professor Ying-Cheng Lai, was selected for publication in the prestigious research journal Proceedings of the National Academy of Sciences of the United States of America, or PNAS, due to its impact.

An eye on the future

“Machine learning normally requires a lot of data to work well,” Zhai says. “The mismatch with the sparse data typically available from ecological systems motivated us to search for a method that can still make good predictions when data is scarce."

His research determined how to double the accuracy of machine learning algorithms with five to seven times less data available than would typically be needed. This increased accuracy has applications wherever time series data is used to record measurements of the same variable over time. Zhai points to climate research, such as modeling ocean currents, as one example.

"The Atlantic Meridional Overturning Circulation, or AMOC, is a major ocean current system that helps keep northern Europe and eastern North America relatively warm and livable, yet scientists have only short and incomplete records of how it behaves," Zhai says. "If AMOC weakens or collapses, it could have major global impacts. Our method could help improve behavior prediction in cases like this."

Beyond climate science, his work could also be applied to modeling the spread of disease epidemics, helping public health authorities take necessary precautions to keep populations safe, and predicting traffic patterns to help transportation planners keep roads flowing smoothly.

Sending AI to school

To tackle these challenges, Zhai and Lai developed the meta-learning method, which trains machine learning algorithms to learn in new ways. Traditionally, machine learning algorithms complete one specific task using a single robust dataset — but this presents a problem when the unpredictability of nature is involved.

Meta-learning functions more similarly to how a human would learn, teaching algorithms to integrate experience from numerous related tasks. Zhai trained the system using a variety of chaotic synthetic datasets, which are generated by a computer and designed to simulate realistic, unpredictable conditions.

After being exposed to these synthetic datasets, a machine learning algorithm trained on meta-learning can "understand" how to interpret and make inferences from ecological systems that have minimal available data. The algorithms' learning is enabled by a specialized type of computer system designed to function like a human brain, known as a time-delay feed-forward neural network.

A bright future in machine learning

As he prepares to defend his doctoral thesis, Zhai's work developing the meta-learning method is the latest in a highly productive academic career. He has had more than 10 papers published in journals that include Nature Communications and PRX Energy. He aims to continue his research in the field, expanding his work to predict more types of system behavior, including additional types of instabilities in climate systems, ecosystem collapse and infrastructure networks.

"Zheng-Meng has become a leading expert in the application of machine learning to complex and nonlinear dynamical systems," Lai says. "He is recognized as a rising star in this interdisciplinary field."

Zhai says he is honored to have his work published by such a prestigious journal as PNAS.

“Seeing our work recognized by PNAS is deeply rewarding and represents an important milestone in my academic journey,” he says. “I hope that publication in such a highly visible journal will introduce our approach to a broader scientific audience, encourage collaboration and inspire future research on data-limited systems.”

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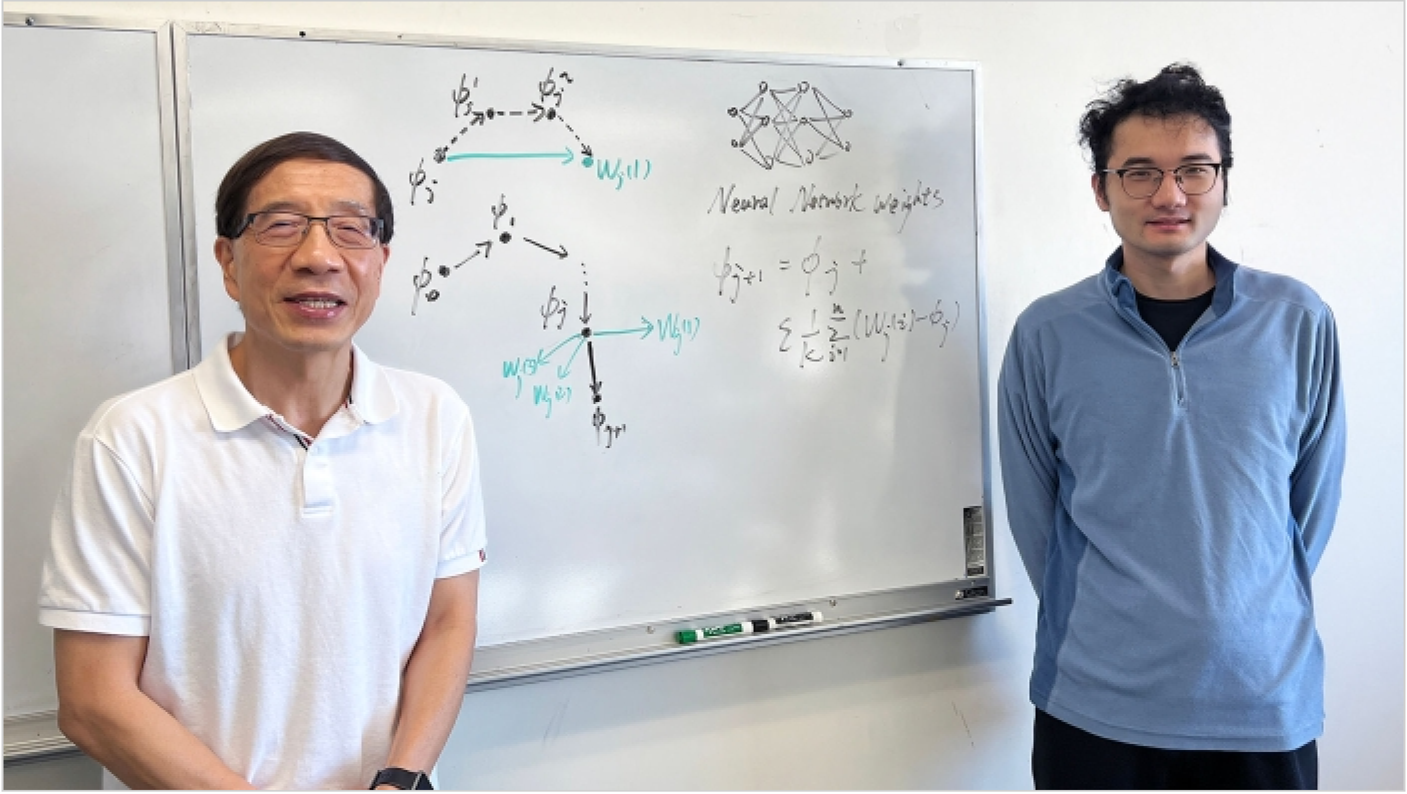
Main image

Ecosystems of all scales are becoming more and more vulnerable to collapse — like the 84% of reefs that suffer from coral bleaching. But a new method that trains machine learning algorithms to predict ecosystem behavior could help minimize harmful impacts on society. Photo credit: XL Catlin Seaview Survey

Text image(s)



ASU Regents Professor Ying-Cheng Lai (left), who teaches in the electrical engineering program in the Ira A. Fulton Schools of Engineering at Arizona State University, and his doctoral student Zheng-Meng Zhai pose for a photo in front of a whiteboard showing diagrams of machine learning technology. Zhai led development of a new training method for machine learning algorithms to increase the accuracy of predictions about systems using limited ecological data. Photo courtesy of Zheng-Meng Zhai/ASU