Los Alamos machine learning discovers patterns that reveal earthquake fault behavior

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Artificial intelligence finds precise link between laboratory fault state and signal strength, leads to accurate quake prediction

Scientists can predict where an earthquake might occur, but predicting when it will occur and how strong it will be has been an intractable challenge. A new artificial intelligence-based method identifies sounds that indicate when a fault is about to rupture.

An earthquake occurs when massive blocks of Earth, often near the interface between tectonic plates, suddenly slip along fractures in the earth, or faults. The same stress that holds the rock in place under pressure—friction—builds up to a point that the rocks slip past one another rapidly and forcefully, releasing energy via seismic waves.

Los Alamos National Laboratory researchers and colleagues discovered a way to successfully predict earthquakes in a laboratory experiment that simulates natural conditions. Late last year, this team discovered a way to train a computer to pinpoint and analyze seismic and acoustic signals emitted during the movements along the fault to predict an earthquake. The team published a paper revealing how their machine learning algorithm and technique processed massive amounts of data and identified a particular sound pattern previously thought to be noise that precedes an earthquake. The team was able to characterize the time remaining before a laboratory earthquake at all times.

In the lab, the team imitated a real earthquake using steel blocks interacting with rocky material (fault gouge) to induce slipping that emitted seismic sounds. An accelerometer recorded the acoustic emission emanating from the sheared layers.

For the first time, researchers discovered a pattern that accurately predicted when a quake would occur. The team acknowledges that the physical traits of the lab experiment (such as shear stresses and thermal properties) differ from the real world but the application of the analysis to real earthquakes to validate their results is ongoing. This method can also be applied outside of seismology to support materials' failure research in many fields such as aerospace and energy.

The team's lab results reveal that the fault does not fail randomly but in a highly predictable manner. The observations also demonstrate that the fault's critical stress state, which indicates when it might slip, can be determined using exclusively an equation of state.

The goal of the team's recent research was to determine if the experimental fault's continuous seismic signal contained information about the frictional state, which controls fault rupture and contains key clues to how a quake will occur, its magnitude and when the next event might occur under particular stress.

This month, the team published a new paper in *Geophysical Research Letters* that outlines how they continued to use machine learning to further study the seismic data. Their breakthrough surprised them: there was a precise quantitative link between the fault's frictional state and the strength of the signal. Their discovery of this equation showed how these new signals are directly connected to the state of the fault and when a quake will occur. This new information could help researchers characterize a fault's state remotely and identify new signals in the Earth.

So far seismologists and Earth scientists have relied exclusively on catalogues of historical data to try to characterize the state of faults. These catalogues contain a minute fraction of seismic data, and remaining seismic data is discarded during analysis as useless noise. The authors discovered that hidden in this noise-like data there are signals emitted by the fault that inform them of the state of the fault much more precisely than catalogues.

"Our work shows that machine learning can be used to extract new meaningful physics from a very well studied system," said Bertrand Rouet-Leduc, Los Alamos Earth and Environmental Sciences Division scientist and the paper's lead author. "It also shows that seismogenic faults are continuously broadcasting a signal that precisely informs us of their physical state and how close they are to rupture, at least in the laboratory."

The team comprised researchers from Los Alamos, Pennsylvania State University, the University of Cambridge and Grenoble Alpes University. Funding provided by Los Alamos National Laboratory Directed Research and Development (LDRD).

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