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Research News

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HOW IS A SANDPILE LIKE A FRACTAL? LATEST STUDIES SUGGEST THEY BOTH SHOW "SELF-ORGANIZED CRITICALITY"

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An emerging physical principle may help explain many extraordinary or unstable phenomena -- including earthquakes, sandpiles, stock prices, electrical flow, fluctuating river levels, traffic jams, quasar signals -- and even the prevalence of fractal shapes in nature.

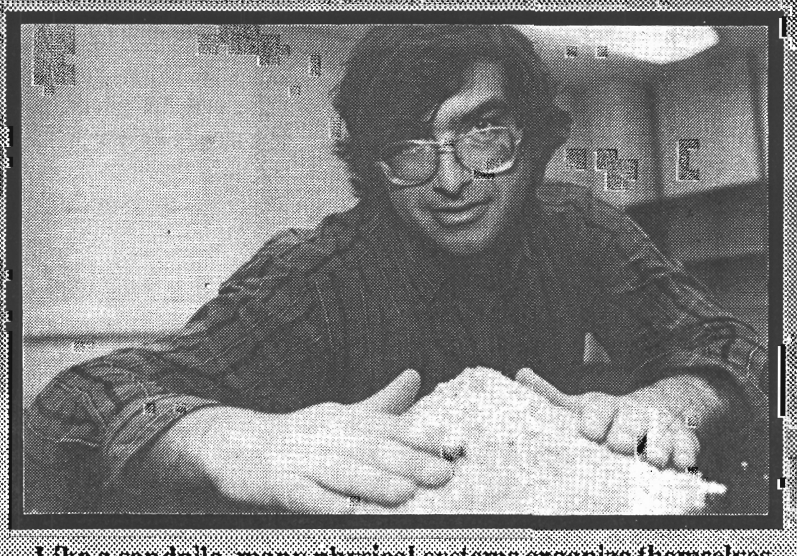
Like a sandpile which constantly erodes but continues to grow as more sand is added, many physical systems seem to exhibit a state of "Self-Organized Criticality," explained Dr. Kurt Wiesenfeld, an assistant professor of physics at the Georgia Institute of Technology.

In a recent issue of Physical Review Letters, Wiesenfeld and his colleagues suggest that unstable systems like sandpiles, which evolve over time, could be fundamentally linked to patterns that exist in space, such as the geometric shapes known as fractals.

For example, Wiesenfeld said, sand falling through an hourglass sets off a series of tiny avalanches, thus remaining in a continuously unstable state. Given a certain degree of freedom, he added, many autonomous individuals in a system -- in this case, the grains of sand -- seem to naturally organize themselves into the least stable state. This notion runs counter to many traditional laws which describe physical systems as instinctively moving toward the most stable state, Wiesenfeld said. Unfortunately, he added, such traditional principles don't explain why sand naturally forms a precarious cone, rather than a flat, stable slab.

In the parlance of Self-Organized Criticality theory, events like these tiny avalanches can be expressed mathematically as "1/f noise" (one over frequency), a quantitative value representing phenomena such as sunspots or earthquakes which seem to occur at arbitrary points in time.

"Anytime you measure something, you make a graph of its value as a function of time," Wiesenfeld noted. "If you chart the temperature in a room, for example, you would ordinarily expect certain areas to be hotter or colder. Then you would probably see fluctuations or 'glitches' in your data because of events like someone turning on a hot plate. But other variations simply can't be explained so easily. '1/f noise' describes these mysterious, quantitative variations which are so pervasive and so ubiquitous that they cry out for some unifying principle."



Like a sandpile, many physical systems organize themselves into a critical state, Dr. Kurt Wiesenfeld says. *(Call for photo.)*

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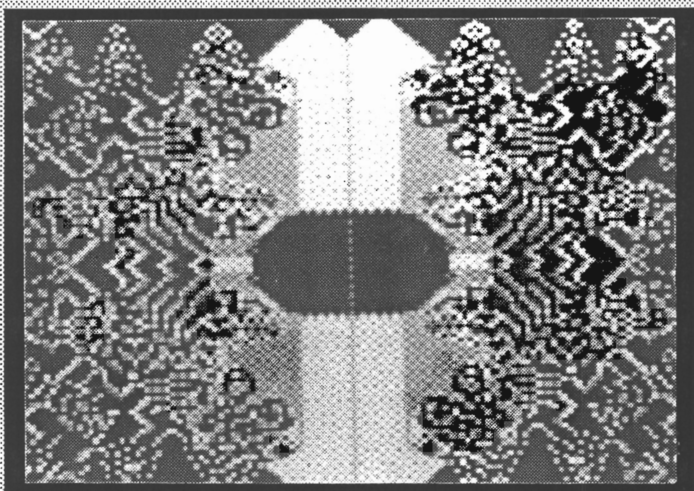
With Dr. James Theiler of the Massachussetts Institute of Technology (MIT) Lincoln Laboratory and Dr. Bruce McNamara of Reed College, Wiesenfeld described the latest Self-Organized Criticality research in Physical Review Letters. (The original work on this theory was prepared by Drs. Per Bak, Chao Tang and Wiesenfeld in 1987, when they worked together at Brookhaven National Laboratory.)

An Answer for Fractals?

Scientists have long been challenged to mathematically describe natural shapes consisting of nonlinear or irregular forms. Since they frequently contain jagged lines, circles, triangles and other nonlinear components, natural forms like snowflakes and leaves can't be easily expressed through traditional mathematics. Recently, however, scientists developed a method for describing even the most complicated natural landscape by breaking it into many fractal units. In this way, each tiny fractal is exactly the same shape as each larger unit, and each larger unit is exactly the same shape as the big picture. Like a big wooden box which contains a smaller box which contains an even smaller box, fractals express the correlation between microscopic and macroscopic environments.



This computer-generated image provides an aerial view of a collapsing sandpile to illustrate the fractal nature of the tiny avalanches that occur constantly.

But it is still unclear why fractal shapes seem to be so prevalent in nature. Wiesenfeld believes that fractals might be a spatial form of the 1/f noise phenomena. In other words, the avalanches occur in a wide range of sizes and irregular shapes. Thus, the sandpile itself ultimately evolves into a fractal profile.

Using computer-simulated images, Wiesenfeld and his colleagues have been able to create color-coded fractal patterns which represent sandpiles, while other scientists have generated aerial images to show the fractal nature of forest fires.

Earthquakes, stock prices, traffic jams, the fluctuating level of the Nile River, the activity of lobster neurons, electrical flow through semiconductors and numerous other events can all be characterized in terms of 1/f noise, according to Wiesenfeld. "We receive light from quasars in space," he said. "We don't know what quasars are. They might be imploding galaxies, or the other end of a black hole; nobody knows. But if you perform a frequency analysis on the light we receive from quasars, it's possible to detect this 1/f noise phenomena."

Still, Wiesenfeld is quick to point out that Self-Organized Criticality probably won't make anyone rich overnight or help predict the next big earthquake -- at least not anytime soon. Such complicated calculations would require vast amounts of information, much of it impossible to obtain, such as when every earthquake has ever occurred or exactly how certain stock market analysts would react to specific economic events. At this point, Wiesenfeld said, Self-Organized Criticality serves merely as a catalyst for new ideas and a promising theory for better understanding the world's unstable phenomena.

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