Finding Riddles of Physical Uncertainty

The scientific method hinges on the ability of researchers to perform reproducible experiments: What one scientist has measured, another can replicate under the same conditions.

But what can one do when the slightest error in reproducing an experiment's initial conditions can lead to a vastly different outcome? A new theoretical result suggests that certain simple physical systems — governed by nothing more than Newton's laws of motion — can display just such a pathology. Even qualitatively predicting the system's ultimate behavior proves intrinsically impossible.

"It's an extreme example of how strange simple systems can be," says Edward Ott of the University of Maryland at College Park.

Ott and John C. Sommerer of the Johns Hopkins University Applied Physics Laboratory in Laurel, Md., report their findings in the Sept. 9 NATURE.

A variety of physical systems, from electronic circuits to the simple double pendulum (which consists of two suspended rods, one pivoting from the other), show the sensitive dependence on initial conditions that characterizes chaotic systems. In these cases, measurement errors and other uncertainties severely limit how far into the future one can accurately predict the system's behavior.

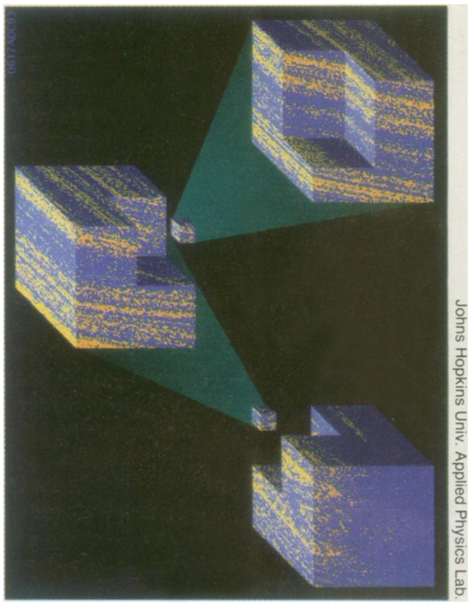
Nonetheless, a chaotic system's behavior generally remains qualitatively predictable. A particular set of initial conditions leads to a certain type of outcome, even though one can't predict the details of that behavior. In mathematical terms, the system tends to evolve toward a particular final state known as an attractor.

There also exist cases in which a system's behavior can evolve to any of several competing attractors. Last year, University of Maryland mathematician James C. Alexander and his co-workers discovered a bizarre variation on this scenario. They found a mathematical example in which the set of initial conditions, or basin, leading to one attractor is riddled with points corresponding to initial conditions leading to another outcome (SN: 11/14/92, p.329). The slightest change in initial conditions could radically alter the system's behavior.

"Because this work was on a rather abstract level, we were interested in knowing whether this type of behavior can occur in some sort of physical situation," Ott remarks.

Ott and Sommerer found their answer in the first example they tried. They considered a differential equation representing the motion resulting from a particle traversing a force field having a particular geometry. The particle, which is periodically jolted as it moves, also experiences a frictional force that depends on its velocity.

In this situation, the particle can either settle into a chaotic type of motion or be forced away toward infinity in certain directions. Which course the particle ultimately takes depends sensitively on its starting position and velocity (see illustration).



Johns Hopkins Univ. Applied Physics Lab.

Each color in these cubes represents the set of initial conditions that eventually leads to one of two possible outcomes. Blowups show that the blue regions are riddled with yellow. Any initial condition destined for one outcome (blue) has an infinite number of neighbors tending toward the other outcome (yellow).

"Sommerer and Ott have discovered a classical physical system with riddled basins of attraction," mathematician Eric J. Kostelich of Arizona State University in Tempe comments in NATURE. "No randomness is built into the model, yet the final state of the system cannot be predicted with certainty if there is any error (no matter how small) in the measurement of the initial condition."

The ease with which Ott and Sommerer found their example and the fact that there is nothing particularly special about the chosen equation of motion suggest that riddled systems may be relatively common — albeit not as ubiquitous as chaotic systems. As a result, "even qualitative reproducibility in simple classical systems cannot be taken for granted," Sommerer and Ott conclude.

No one has yet come up with a real system — perhaps a special kind of pendulum or a mixture of reacting chemicals in which the concentrations of various components oscillate up and down at different rates — that shows this distinctly two-faced behavior. "But there's a chance we can get something like that going," Ott says. — *I. Peterson*

Greenhouse gas ebbs in time

When tropical forests are clear-cut and converted into pasture, the soil increases its release of greenhouse trace gases into the atmosphere. In 1989, researchers warned that pastureland might account for 25 percent of the current imbalance between global production and absorption of nitrous oxide, an important greenhouse gas. That grim estimate may be too high, scientists now report in the Sept. 16 NATURE.

Though grazing land indeed releases large amounts of trace gases after clear-cutting, these emissions dwindle to levels below those of forest soil about 10 years later, says Michael Keller. Keller is a geochemist with the International Institute of Tropical Forestry in Rio Piedras, Puerto Rico, a research unit of the U.S. Department of Agriculture. He and his co-workers measured how much nitrous oxide and methane, both greenhouse gases, and nitric oxide, a greenhouse gas precursor, escaped from forest soil, young pasture soil, and old pasture soil in Costa Rica.

"The implication of this [decline in trace gas emission over time] is that, to draw up a global budget for these gases, you can't take a satellite photo and simply classify the land into forest or pasture. You need to know the land's history, when it became pasture, how it was managed afterwards," Keller says.

While adding more complexity to the already difficult task of tracking the amounts of trace gases cycling through soil, air, and water, Keller says the study makes the gas fluxes more predictable and will help "get a handle on how to interpret emissions over time." After clear-cutting, organic material in the soil decays, supplying inorganic nitrogen to soil bacteria that form nitrogen oxides. After a decade, much of that inorganic nitrogen is exhausted, he says.

Even with shrinking emissions, the greenhouse problem will not go away, Keller cautions, since the inert gas has a lifetime of about 150 years. "It will stay around to bug us, our children, and our grandchildren," he says. □