Physical Science

Ivars Peterson reports from Arlington, Va., at the Experimental Chaos Conference

Adding chaos to achieve synchrony

Most scientists and engineers view the erratic, unpredictable behavior of a chaotic system, and its sensitive dependence on initial conditions, as something to avoid. A new finding, however, suggests that a dash of chaos may be just the ingredient needed to bring a set of separate but identical oscillators into synchrony.

This startling conclusion stems from the work of two scientists at the Naval Research Laboratory (NRL) in Washington, D.C. – Louis M. Pecora, whose theoretical work and numerical simulations unveiled the effect, and Thomas L. Carroll, who designed and constructed an electrical circuit to demonstrate the phenomenon. The circuit shows how the addition of a small chaotic component to a smoothly varying, regularly repeating input signal used to drive two separate oscillators helps the signals emanating from the oscillators fall into step. Without this chaotic component, the two oscillators would generate signals that are either fully in step or exactly out of step.

"This is a new area," Pecora says. "There has been very little work on using chaotic signals to drive nonlinear systems." In a sense, he adds, "we're using chaos to make things behave better."

In Carroll's electrical analog, a signal generator feeds a smoothly varying wave to a pair of separate but identical oscillator circuits. In response, each circuit generates a fluctuating signal that repeats itself at intervals twice as long as those in the input signal. Nonetheless, although both oscillators are driven by the same input signal, they themselves generate signals that aren't necessarily matched, or in phase. Indeed, repeated experiments show that the output signals end up in phase only about half the time. However, when a chaotic component is added to the input signal, two oscillators that start out of sync rapidly match their signals and remain in phase from then on. Theoretical work indicates that synchronization should occur for any number of oscillators.

While these findings suggest a novel method for synchronizing signals coming from arrays of generators, they may have biological implications as well. "Our results now give a very concrete reason for having chaotic driving signals in the body," Pecora says. "Things don't get out of sync this way, yet they still behave smoothly and very similarly to periodically driven systems," such as heartbeats.

From heart to mind

The kinds of mathematical techniques now being applied to the study of chaos in physical systems may also prove useful in the study of complex biological systems. Dana J. Redington and Steven P. Reidbord of the University of California, San Francisco, are exploring the possibility of applying these methods to the interaction between brain and heart in patients undergoing psychotherapy. Such data-analysis techniques can pick up subtle heart-rate changes that conventional forms of electrocardiogram analysis miss.

Preliminary results show that a detailed analysis of a patient's heart rate during therapy reveals a number of specific, readily identifiable patterns that appear associated with such postures as defensiveness and therapeutic engagement. By correlating shifts from one pattern to another with certain types of behavior and with the therapist's own responses to the patient, Redington and Reidbord hope eventually to provide a model of normal and abnormal shifts that may occur between psychological states, and to develop new tools for increasing the effectiveness of psychiatric treatment.

"We're in the very early stages of this," Redington says. "We've evaluated our methodology on a couple of patients, and we're in the process of taking a look at the therapists."

Space Science

Radio jolts indicate Venusian bolts

Lightning often flashes across the sky on Earth, and spacecraft have photographed "superbolts" on Jupiter. Uranus, Saturn and Neptune also appear to harbor the telltale crackle of electrical storms, but for years researchers have debated whether Venus experiences such jolts. Data from the orbiting U.S. Pioneer-Venus spacecraft and a series of Soviet craft that landed on the planet remain suggestive but inconclusive. Now, a series of radio bursts detected by the Galileo craft as it swung around Venus last year appear to confirm the existence of lightning on the planet.

A special antenna, designed to detect radio signals from Jupiter when Galileo reaches the giant planet in 1995, took center stage in the Venusian discovery. The antenna's ability to detect higher frequency radio signals than previous craft enabled Galileo scientists to search for characteristic radio bursts associated with lightning.

Lightning also produces lower frequency radio waves. But such signals – like those from a radio station – would bounce back from Venus' ionosphere rather than pass through it. Thus, most of the waves would remain trapped inside Venus' lower atmosphere and could not reach Galileo, notes Donald A. Gurnett of the University of Iowa in Iowa City. He and his colleagues, who built the antenna, detail their findings in the Oct. 4 SCIENCE.

During a survey that lasted just under an hour on Feb. 10, 1990, the antenna detected nine bursts as it pointed toward the night side of Venus. Although the intensity of the bursts – transmitted to Earth last December – only slightly exceeded noise levels in the instrument, Gurnett's team says lightning seems the most likely cause of the signals. The antenna found no such bursts during hour-long control studies conducted in flight before and after the Venus flyby, they note.

"The findings do indeed indicate that there is lightning on Venus," says William J. Borucki of NASA's Ames Research Center in Mountain View, Calif. "But that doesn't answer the fundamental question: What causes it?"

Some researchers speculate that if Venus still experiences volcanic activity, dust particles produced by the flow of molten rock would rub against each other, taking on electric charge and providing the raw material for lightning. But Borucki asserts that this explanation would require an unrealistically high level of volcanism, since the Venusian lightning may occur as frequently as 100 times a second. Instead, he favors the idea that sunlight on the planet's day side creates updrafts of dust or other particles, which form the basis for lightning. That scenario, he says, could explain why most attempts to photograph lightning flashes on Venus' night side have failed.

A flare for pondering Halley's outburst

Two astronomers speculate that shock waves from solar flares may have triggered Comet Halley's brief and unexpected outburst, first observed last February (SN: 3/2/91, p.133). The comet, normally a quiescent body of ice and dust as it exits the solar spotlight, suddenly appeared 300 times as bright as predicted some 2 million kilometers from the sun.

The researchers suggest that heightened solar activity just before and during the outburst may account for Halley's brightening. A shock wave generated by a solar flare may have damaged the comet's fluffy ice crust, and the kick from a second may have cracked open part of the crust, releasing a pocket of gas from within the comet. The expelled gas could have dragged out enough dust – which reflects sunlight well – to account for the brightening. Devrie S. Intriligator of the Carmel Research Center in Santa Monica, Calif., and Murray Dryer of the National Oceanic and Atmospheric Administration in Boulder, Colo., present their proposal in the Oct. 3 NATURE.