heads half the time and tails half the time. But this definition of randomness is not entirely satisfactory, Diaconis points out. "We often think of randomness in situations where there is no chance of repeating a process over and over. We talk about the chance of a Mideast war in the next year, for example, although we can't even repeat things once in that case."

The other standard notion of randomness is the subjectivist view. The idea here, says Diaconis, is that "coins don't have probabilities, people have probabilities. A probability is a measure of someone's degree of belief in an outcome—'For me, it's random.'"

A number of statisticians have developed theorems to explain why the frequentists and subjectivists will come to similar conclusions about simple repetitive phenomena. The idea is that as more and more data accumulate—a coin is tossed over and over, for example—two people with different starting assumptions must come to the same conclusions. Or, as statisticians say, the data swamp prior beliefs. Diaconis's theory of randomness multipliers explains why subjectivists and frequentists agree, even when phenomena are not repeated, and captures, he proposes, the essential nature of objective chance devices like spinning wheels, spinning urns, and flipping coins.

It is a theory, Diaconis points out, that is based on the nearly forgotten work of a statistician, Eberhard Hopf, who began such studies in the 1930's. Hopf's work never got much attention, however, and Diaconis believes it was underappreciated in part because Hopf himself and other statisticians soon became focused on the completely unrelated subject of quantum mechanics. "Much of what I'm doing is reinterpreting Hopf's work and bringing it up to date," Diaconis says.

Diaconis's theory has three ingredients. First, there is the space of initial conditions—the velocities and spins of a coin, for example. Then there is a space of outcomes—heads or tails, in the coin-tossing case. Finally, there is the family of probability distributions—all possible opinions on a coin's particular initial velocity and spin.

To get at the notion of a randomness multiplier, Diaconis explains what it means for a family of probability distributions to have a depth. "You and I can have very different ideas of how fast a coin is flipping. I may be sure it is flipping 15 times, and you may guess that it's more like 5 to 20 times," he remarks. The depth of a probability distribution asks, with a family of distributions, what's the most different the guesses can be.

Diaconis's randomness multipliers map the probability distributions that represent guesses about the initial conditions into the space of heads or tails. "The system is a randomness multiplier if it decreases depth," he explains. In the coin-tossing example, two people could differ widely in their opinions on the initial conditions, but would be forced to agree that there is a 50–50 chance that the coin will come up heads. "Very different opinions merge," Diaconis says.

Using this theory of randomness, Diaconis continues, he can identify, quantitatively, just how random the standard examples of chance phenomena are. And he also can quantify chaos.

Randomness is "like the concept of a point in geometry books," Efron says. "What we're trying to do is like taking points apart and seeing what's inside."

In chaos, a little bit of uncertainty in initial conditions is quickly and enormously magnified. The system is unpredictable because the initial conditions can never be specifed so precisely that you can tell where the system will end up. "It is a perfect example of a randomness multiplier," Diaconis observes. Investigators who study chaos have analyzed hundreds of systems. Diaconis says the questions he asks are, How much uncertainty is there in the initial conditions? How many times does the mathematical procedure creating chaos operate? And, finally, after this many iterations, How close is the system to random?

This then provides an objective definition of chaos: To say a system is chaotic to a particular degree means it is a specific distance from random after a specific number of iterations.

Diaconis's theory of randomness is not a simple one, unfortunately. But perhaps that is inevitable. If randomness were simple, it would not have remained undefined for so long in standard probability texts. It may well be that this multistep definition of randomness is the best that can be done. In any event, the new theory will soon be put to use as Diaconis teaches a semester-long course on it at Harvard this semester and instructs other statisticians and mathematicians on how to use it to analyze random events. ■ GINA KOLATA

Briefing:

Stanford Synchrotron X-Ray Beamline Dedicated

After days of drenching rains that caused widespread flooding in California, on the morning of 20 February the sun broke through and a rainbow appeared over the Stanford Synchrotron Radiation Laboratory (SSRL). Laboratory officials hoped it was a sign of good times to come, as that afternoon they dedicated what Stanford's George Brown calls "the brightest source of hard x-rays in the world."

The source is a beamline attached to the PEP electron-positron storage ring, a high-energy physics facility of the Stanford Linear Accelerator Center (SLAC). With the PEP beamline, where the first two experiments are now under way, researchers can tap the intense, highly collimated x-rays emitted by the circulating electrons in PEP when they pass through a special magnet called an undulator. When PEP runs at its normal high-energy physics energy of 14.5 gigaelectron volts, the undulator generates radiation in the wavelength region from about 0.5 to 1 angstrom.

Because of the high brightness or spectral brilliance of their light, undulators are the coming thing in synchrotron radiation, most of which now comes from electrons as they follow a circular trajectory through the bending magnets of a storage ring. The disadvantage of undulators is that the most intense radiation comes at longer wavelengths than it does from bending magnets. Hence, undulators in SPEAR, a smaller storage ring that SSRL shares with SLAC, can make lots of longer wavelength soft x-rays at the normal SPEAR operating energy of 3 gigaelectron volts but not so many hard x-rays. PEP's much higher energy pushes the undulator spectrum to shorter wavelengths.

According to Brown, who oversaw construction of the approximately $3.6-million project (including building, undulator, beamline optics, and an experimental station), the high brightness of the PEP beamline will be immediately useful in the first two experiments. The first is a so-called glancing-angle x-ray diffraction study of the structure of thin films and surfaces. The second is a high-resolution inelastic x-ray scattering study of the momentum dependence of processes in solids with characteristic energies in the range from 0.03 to 2 electron volts. The high brightness both compensates for comparatively weak signals and permits the use of small samples. ■

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