iorists" long argued that individual behavior is shaped by its consequences, particularly by rewards. Although Nowak and Sigmund take an analogous approach to the evolution of cooperation, they call their successful strategy "Pavlov" because it responds reflexively to rewards.

Nowak and Sigmund applied Pavlov and other tactics to the "prisoner's dilemma," in which two players can either cooperate or act selfishly. A player receives the most points for acting selfishly when the other cooperates, slightly fewer points if both cooperate, fewer still in cases of dual selfishness, and no points for cooperating when the other acts selfishly.

In this game, a Pavlov player cooperates only if both participants chose the same alternative – either cooperating or not – in their prior encounter.

The researchers had previously found that a tit-for-tat strategy which forgives a few selfish acts by others helps boost cooperation (SN: 1/18/92, p.39).

Pavlov, however, outperformed all other tactics in a series of computerized encounters intended to simulate biological evolution, Nowak and Sigmund contend. Strategies that yielded higher payoffs gained more influence in the overall simulation, whereas less successful tactics either lost favor or were eliminated.

Pavlov wielded little influence in the early stages of the trials but attained dominance by the end of the simulations, the investigators note. Pavlov's success stems from its tolerance of occasional random deceptions in the trials and its willingness to exploit consistently cooperative programs, they say.

Strategies rooted in the Pavlov approach may indeed evolve naturally, writes zoologist Manfred Milinski of the University of Bern in Switzerland in an accompanying comment. Milinski and his co-workers find that stickleback fish that cooperatively check for predators in pairs and then encounter partners who flee during several consecutive predator checks react in Pavlovian fashion – they alternately cooperate and flee on successive predator searches with defectors.

– B. Bower

Drill nears bottom of Greenland ice cap

After four years of sometimes frustrating drilling, a U.S. team has bored almost to the bottom of Greenland's thick glacial cap, reaching ice that contains information about the climate from 250,000 years ago. While it has not yet hit bedrock, the team late last week set a record for the longest ice core ever collected, surpassing a nearby European operation that finished its hole last year.

Monastersky

A member of the drilling crew examines a segment of the Greenland ice core.

The work will continue over the next week or more until the drill grinds into the rock below the ice sheet. Currently at a depth of 3,054 meters, the drill is advancing slowly through silty, rock-studded ice, a sign that it has neared the bottom, according to the National Science Foundation (NSF), which funds the project.

The U.S. effort, called the Greenland Ice Sheet Project 2 (GISP 2), involves a team of 50 researchers, drillers, and support staff who have spent their summers near the broad, featureless summit of the island's ice cap (SN: 9/14/91, p.168). The Europeans drilled 30 kilometers away, at the summit. Progressing faster than the GISP 2 team, the Europeans stopped at a depth of 3,028 meters after reaching the silty ice and deciding not to continue (SN: 9/26/92, p.199).

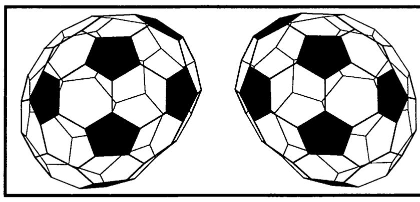
Formed over millennia by the accumulation of snowfall each year, Greenland's ice cap contains trapped gases, chemicals, and dust that can reveal how the climate behaved at the time the snow fell. In studies of ice collected last year, GISP 2 scientists discovered that the climate of the North Atlantic took only a year or two to jump between ice age conditions and a much balmier state (SN: 12/12/92, p.404).

While the European effort used a drill proven in previous projects, the GISP 2 team broke in a new U.S.-built drill. In 1991, motor problems slowed the drilling, and last year a worn cable put an early stop to the summer work. "In the first couple of years, we had some bugs to work out, but this year the drilling has been very successful," says Julie Palais, the glaciology program manager at the NSF in Washington, D.C.

The U.S. drill bores a 5.2-inch-wide core of ice, providing almost twice as much ice for study as the European version. After GISP 2 finishes, the U.S. machine will head to Antarctica, where it will drill a 600-meter-long core near McMurdo Station. Researchers eventually hope to drill two long cores in West Antarctica to compare with the Greenland records. *– R. Monastersky*

Sorting fullerenes by their handedness

Many organic molecules can exist as right- and left-handed versions, or enantiomers (SN: 5/29/93, p.348), but chemicals consisting purely of one element generally come in only one form. For example, diamond and graphite – both pure carbon – don't form enantiomers because their architectures are symmetrical, making handedness impossible.



Hawkins, Meyer/UC Berkeley

A lopsided 76-carbon fullerene can now be chemically separated into its two mirror-image forms.

However, some of the all-carbon molecular cages known as buckminsterfullerenes do exist as enantiomers. When researchers synthesize these 60-atom buckyballs, the soot they produce also contains a 76-carbon molecule shaped like a squashed sphere. This fullerene occurs as a 50-50 mixture of its right- and left-handed forms.

Now, two University of California, Berkeley, chemists have found a way to separate the two subtly different fullerene forms – a significant accomplishment considering that the two enantiomers of the 76-carbon "rugbyball" vary by an almost imperceptible twist. "Only when you look at the molecule from a particular orientation does it even appear lopsided," notes Joel M. Hawkins, who with co-worker Axel Meyer reported the results of their experiment in the June 25 SCIENCE.

The researchers employed a chemical reaction called osmylation that selectively uses up one enantiomer faster than the other. They reacted a 50-50 mixture of carbon-76 molecules with an osmium compound and a plant alkaloid that preferentially grabs one version of the molecule (SN: 1/2/93, p.6). The alkaloid appears to tell one enantiomer from the other by how well it fits with the puckered surface at two of the molecule's 30 types of bonds, Hawkins says. He and Meyer stopped the reaction just before completion and found that the remaining unreacted fullerene contained 98 percent of one enantiomer. They then treated the osmylated product to recover the other enantiomer.

The researchers found that the pure right- and left-handed versions of the rugbyball dramatically rotated the direction of plane-polarized light rays. Such molecules may one day prove useful as optical materials (SN: 8/24/91, p.127).

– K.F. Schmidt