A Flight of Fancy Mathematics

Chaos brings harmony to a birder's puzzle

By RICK WEISS

Almost everyone has witnessed a flock of birds erupting from the ground in astounding unison, or a cloud of starlings swooping through the sky in a coordinated display of aeronautical acumen.

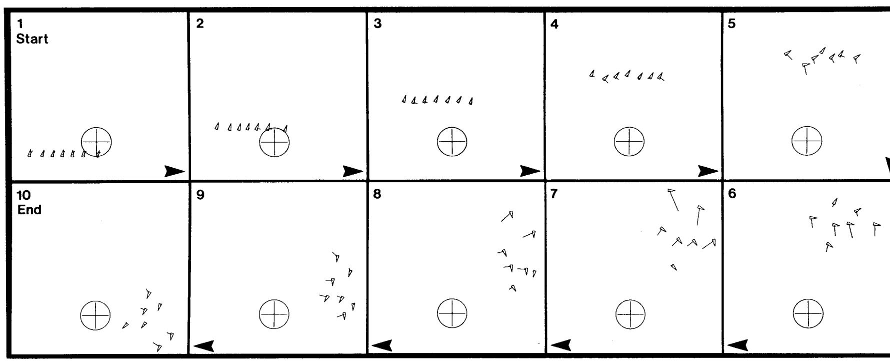
Frank H. Heppner, a zoologist at the University of Rhode Island in Kingston, wasn't satisfied with gawking. He wanted to know how birds maintain such high levels of in-flight cohesion while minimizing the chance of serious collisions. Using a combination of simple photography and some computer programming, he's come to his answer: Birds of a feather are chaotic together.

"I'd been looking at these flocks for 20 years and I was just about to stop because I couldn't find a model that would explain it," Heppner says. Then a colleague introduced him to the concept of mathematical chaos, which provides a logical means of generating complex spatial imagery from relatively simple mathematical equations. In collaboration with Daniel Potter, an undergraduate computer whiz at Brown University in Providence, R.I., and Ulf Grenander, chairman of Brown's division of applied mathematics, Heppner has devised a way of using chaos theory to explain many of the behaviors seen in bird flocks and perhaps in schools of fish.

Moreover, the approach may prove useful in designing spaces that must accommodate mass movements of large numbers of people, Heppner said in New Orleans last month at the annual meeting of the American Association for the Advancement of Science.

First, Heppner wanted to confirm his suspicion that bird flocks do not rely upon any one leader as they swoop and reel through the sky *en masse.* Using a pair of movie cameras mounted at 90-degree angles, he filmed flocks of birds at three frames per second, then analyzed the movies one frame at a time to see if a fearless feathered leader emerged. None did. Instead, the flock maintained a state of dynamic equilibrium, with different birds briefly finding themselves at the flock's leading edge at different times. "We found that the leadership changed completely," he says.

Then he and his colleagues designed a set of rules that together might account for the seemingly coordinated interactions they had recorded on film. They found that by programming their computer with four simple rules, they could make a "flock" of little triangles on a screen behave very much like a flock of birds.



A series of computer images depicts the evolution of coordinated flight among seven leaderless "birds" taking off from a telephone wire. Birds are attracted to a cross-haired "roost," and to each other unless they get too close. Lines emanating from birds show the net attractive forces operating on each at any given time.

Heppner

The rules went like this: 1. Birds are attracted to a focal point, or roost; the closer they get to it, the stronger the attraction. (So that the birds don't all "land" immediately at the roost, Heppner also programmed a neutrally attractive airspace directly above the roost, such that birds flying over that spot keep gliding, then begin to feel the tug of its attractiveness again after they've flown by.) 2. Birds are attracted to each other, but become repelled if they get too close. 3. Birds want to maintain a fixed velocity. 4. Flight paths can be altered by random inputs such as wind gusts.

Given those rules, Heppner lined up a bunch of triangles on a line on his computer screen – representing birds on a telephone wire – and "released" them near a preprogrammed roost, letting the mathematical rules determine the birds' behaviors thereafter. To his delight, the resulting patterns closely mimicked bird flock behavior, with the initial scattering of triangles coalescing into apparently coordinated masses, or flocks. By varying the "strength" of each rule, he generated a host of classical avian maneuvers.

"That's neat stuff," said Charles Walcott, executive director of the Cornell Ornithology Laboratory at Cornell University in Ithaca, N.Y., after watching a video film of the computer program in action. "You watch flocks of pigeons feeding and they look just like that."

Since developing the program, Heppner has become absorbed in the work. "I never was a big computer person," he says. "But after we came up with this I started getting bags under my eyes, changing a few parameters and staying up at night to see what would happen."

Heppner calls the program "probably the first application of chaos to a problem of animal behavior," and speculates the work may someday prove useful to engineers and architects designing such spaces as auditoriums and aircraft interiors. With some insight into the rules people use when interacting in large groups, he suggests, architects may one day use computer models to design these structures in ways that will facilitate coordinated behaviors when there is a risk of panic and confusion.

For now, he concedes, such applications remain highly theoretical. Indeed, he says, even chaos' usefulness as an explanation for flock formation remains unresolved. "We're not saying this is the way birds do it," he says. "All we're saying is this is the way birds *could* do it."

Heppner plans to add a computer-game "joy stick" to the apparatus to see how group behavioral patterns may change when he makes an individual "bird" perform particular moves.

Meanwhile, regarding his ongoing observations of living animals, he's considering changing his focus from birds in the sky to fish in tanks. "Birds are not cooperative because they can fly out of the field of camera range," he says, watching a few computer specks drift off the screen. "Fish are easier." □