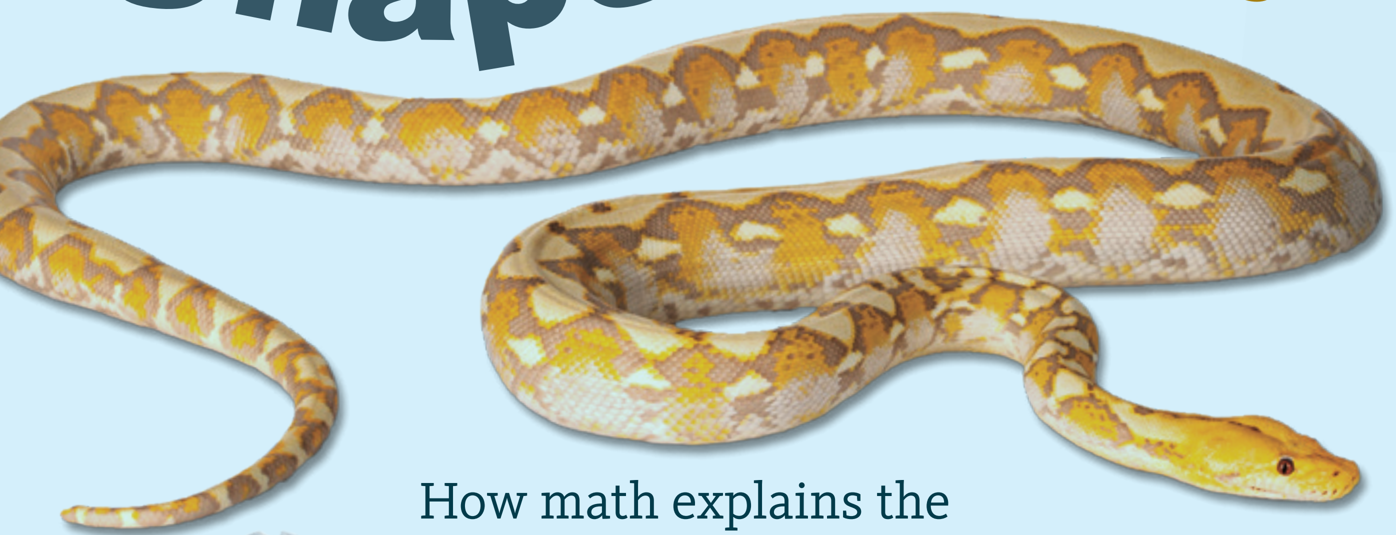
Shape Shifters



How math explains the movement of snakes, jellyfish, cats, and … astronauts?

By Emily Velasco

Across the animal kingdom, creatures move through their environments not by walking, running, or climbing but rather by changing the shape of their bodies. This kind of locomotion is found in snakes as they slither, in jellyfish as they swim, and even in cats as they twist themselves to land on their feet.

The contortions of a falling cat and a sidewinding snake have more in common than you might think. A team of researchers led by Caltech's Peter Schröder say they have discovered a single algorithm that describes how this process works in many types of animals.

"One classic example is a single-celled organism," says Schröder, the Shaler Arthur Hanisch Professor of Computer Science and Applied and Computational Mathematics. "How does it move? It doesn't have legs. It doesn't have wings to fly with. The only thing it can really do is change its shape. Once you understand that basic observation, you see there are all kinds of creatures who move by changing their shape. Astronauts can even turn in zero gravity by doing a dance-like motion that manages to turn them without the need to push off a surface."

Schröder says this phenomenon can be explained by the principle of least dissipation of energy, which states natural systems will always try to be as efficient as possible. As an example, he cites an ice skate, which can easily slide forward or backward but has great difficulty sliding side to side. If a person wants to skate forward, they push their skates away from the center line of their body. The skates (and the person wearing them) will move forward because forward motion is easier and more efficient than sideways motion. The system consisting of the skater, the skates, and the ice favors forward motion because it wastes the least energy.

The same principle is at work when a snake undulates across a sandy desert. A snake, being long and skinny, can slide forward and backward much more easily than it can slide sideways. The snake moves forward while undulating back and forth because forward motion reduces the energy lost to friction during its side-to-side undulations. Motion along the length of the snake encounters less friction, so the system favors it, and the snake slithers along its scaly way.

Schröder's team modeled these examples of locomotion on computers with the animals rendered as sets of flexible nodes connected by rigid bars. This allowed the researchers to examine how the creatures move in a simulated space and compare it to real-life data. Guided by the principle of least dissipation (and other math), these animal models showed movement remarkably like that seen in their real-world counterparts.

"It's not 100 percent accurate, but it shows remarkable agreement with motion observed in real life, suggesting that it captures a major part of what happens in nature," Schröder says. "There's a certain mathematical beauty when you have a very simple principle that can explain a whole bunch of things at once. That's what gets me up in the morning."

A paper describing the research titled "Motion from Shape Change" appears in the August 2023 issue of *ACM Transactions on Graphics*.