Sana Krichen thinks often like a bat and a shark, and a sea turtle, and several types of birds. For Krichen, who is a doctoral candidate in mechanical engineering, understanding how certain animals can detect magnetic fields is a key part in determining how those species navigate their way as they fly through the world (or swim, crawl, run, or hop).

Some animal navigators can rely the Earth’s magnetic field to sense whether they’re traveling north or south. A subset of these animals can do even more. Using a kind of sixth sense called magnetoreception, some species are able to implement an internal geophysical positioning system to understand where they are and where they’re heading next.

But how precisely these animals detect the Earth’s very weak magnetic field is the topic of much scientific debate. Many mechanisms have been proposed to explain the phenomenon, though none are able to explain how magnetoreception converts magnetic fields into electricity inside the cells of some animals.

Krichen provides a detailed model to explain the mechanisms underpinning animal magnetoreception in an article published in October in the journal *Physical Review E*. Her conclusions may spark challenges from other scientists, but she remains open to all comments.

“Our work provides perhaps the first and arguably a very simple explanation for this,” Krichen said. She performed the research under the supervision of Pradeep Sharma, professor and chair of the mechanical engineering department, and Professor Liping Liu from Rutgers University.

The sixth sense
The animal kingdom’s expert navigators vary widely in shapes and sizes. They include migrating species, such as giant sharks that cross the great oceans and several species of birds, like the small European robin. But while not all types of birds possess natural ability to be excellent navigators, several non-migrating animals do, including lobsters.

“We have five senses. These animals have those plus an additional sense,” Krichen said.

How do these species, large and small, steadily maintain their course and speed while other species easily get disoriented? How can loggerhead sea turtles leave the coast of Japan and cross the Pacific all the way to Baja California without distraction while humans well, who hasn’t wandered a parking garage, fumbling for a sense of where they left the car?

Krichen says the answer lies in magnetoreception, which is the potential to sense the Earth’s north-south magnetic fields. As described in a 1970s article in the Proceedings of the National Academy of Sciences, scientists demonstrated the theory by fastening small magnets onto the heads of birds known to be good navigators. As expected, the birds became disoriented and waivered off their paths.

Magnetoreception provided lots of answers, but it still left big questions. In particular, how do these animal species sense magnetism, which is undetectable by humans and other animals (as far as studies have shown)? Do these particular species possess an extra sensory gift?

“Each of our five senses depends on an organ,” Krichen explained. “The sense of sight requires eyes, for example. Taste needs a mouth and smell needs a nose. Hearing requires ears and touch uses skin. Magnetoreception is a sense, too, but it involves no organ that we now know about.”

While some scientists consider a missing organ does exist but is so small that it eludes searchers, others turn to alternate possibilities, such as chemical changes in the bodies of these animals. While these theories provide important insights, none is able to explain how the weak magnetic signals are converted to electricity inside of the animals’ cells.

Controversial internal GPS

After combing through the literature on this topic Krichen proposed a new model that puts to rest some of the open questions pertaining to animal magnetoreception.

A class of materials called magnetoelactics can convert magnetic fields into electrical signals and vice versa. However the only magnetoelectric materials discovered so far are hard and exotic crystals, which certainly are not components of a biological cell.

So Krichen and her collaborators pursued a very different path. Through detailed mathematical modeling they found that although magnetoelectric materials don’t exist inside of the animals, certain qualities of their cells allow them to behave like magnetoelectric materials.

Krichen found three conditions that must exist in order for a biological cell to behave as a magnetolectric material. First, there must be a pre-existing electric field in and around the cell. Second, the cells must have magnetic permeability that is higher than that of a vacuum. (The insides of magnetosensitive species’ cells contain iron oxide, which is magnetic.) Finally, the cells must contain a soft material. These squishy cells, as they are called, change shape when exposed to magnetic fields.
A weak pre-existing electrical current exists across all biological cells due to an imbalance of charges inside and outside each cell that act as a permanently attached battery pack. When a squishy cell deforms due to exposure to a magnetic field, it alters the operation of its "battery," causing a change in the flow of electricity across the cell.

The altered current flow alerts neurons in magnetosensitive animals, giving the animal a feeling that it's time to shift a wing or a fin or a hoof, just a bit, to get back on target.

In other words, these particular animals are expert at finding their way not because of any mysterious ability to sense magnetism; they keep from straying because changes in their perceptions of electrical signals alert them any time they falter off course. You might say these species have an inborn GPS that is not much different than your car's onboard GPS.

With so many theories competing for attention on the subject, Krichen and her advisors expect their article's conclusions to meet controversy.

"We're waiting on other scientists to test our ideas. People may disagree, and we're okay with that," she said. The team expects about six months to a year to pass before other scientists publish comments, maybe longer before practical applications might be considered.

**Great things take time**

Her newly-published article was submitted to *Physical Review E* about the same time Krichen and her husband, Ali Khadimallah, a mechanical engineering postdoctoral fellow at UH, learned she was pregnant with their first child. While both projects involved a lot of waiting, the baby arrived first.

Youssef Khadimallah is now 10 months old — happy, healthy, very busy. And his mother's breakthrough article, at last, has debuted after prolonged exchanges between reviewers and the investigators.

"You can gauge the controversial nature of the work and the rather long back and forth between reviewers and us simply by the fact that the paper finally got accepted as I am celebrating the 10th month of my first-born," she said. "I almost feel I have given birth to two babies!"

Krichen expects to have her Ph.D. in about a year and then plans to pursue postdoctoral research. Ultimately she will seek a faculty position in mechanical engineering — her "dream job," she said.

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