Building a robotic eel that swims through your body

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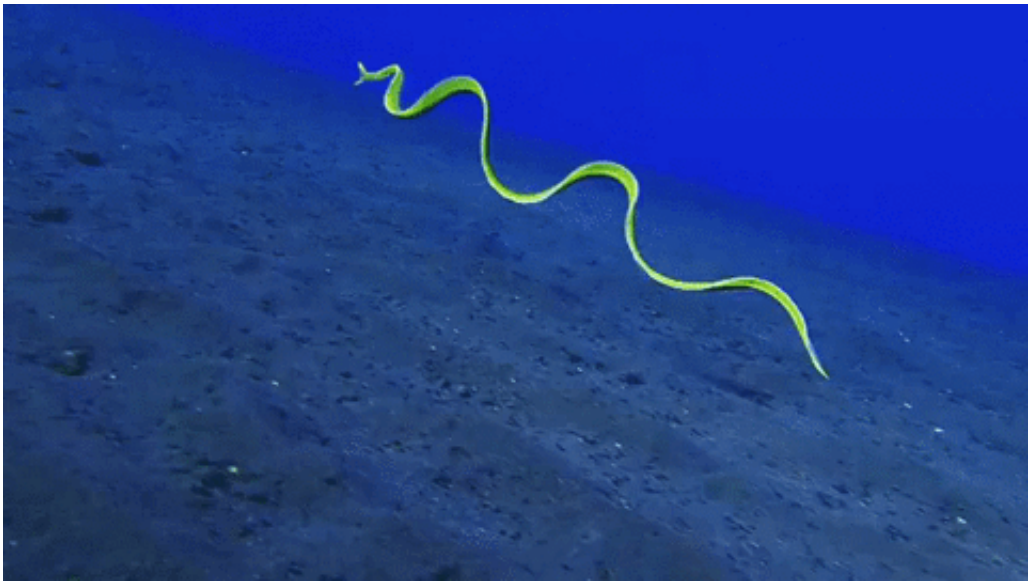

Credit: Brandeis University

As a kid, physicist Seth Fraden loved the movie "Fantastic Voyage," about a microscopic submarine traveling through a human bloodstream. Almost 10 years ago, Fraden began a quest to create a robotic eel he could send on a similar journey, though it wouldn't be for entertainment. The eel would be designed to deliver a drug to cells or genes. And to capture the flexibility of the real sea creature, it would take the form of a gel that could glide through water.

This spring, Fraden announced he'd achieved the first couple of steps

toward realizing his vision. In the journal *Lab on a Chip*, he reported he and his team had created a model using chemicals and microscopic containers of a network of neurons. It's this network that is primarily responsible for the eel's trademark zigzag swimming motion.

Fraden next plans to embed his neural network in a gel. If everything goes as planned, the gel will actually move the same way an eel does while swimming.

Why an eel?

The robotic eel is part of a larger effort by Fraden to build machines made from chemicals and other synthetic materials that behave like living organisms. "Animating inanimate matter" is how he describes it. He's not bringing inorganic matter to life. He's building devices that act a lot like aspects and features of living creatures—clothing that mends itself using the same process our cells use to close a wound, for example, or nanobots that swim like fish through water pipes, carrying materials to repair pipe damage. Fraden's artificial neural network is just the beginning.

Compared with most sea creatures, the eel has a relatively simple system for swimming. Its spine runs the length of its body and is surrounded on either side by a column of neurons. When neurons fire sequentially down one of the columns, they cause a wave of muscular contraction, making the spine curve. When the neurons in the other column fire, the spine curves in the opposite direction. The result is a smooth back-and-forth motion of the spine as the eel swims.

Fraden is following a three-step process to build his drug-delivery eel.

Step 1: Create a neuron.

Neurons oscillate between two states—excitatory and inhibitory. In the excitatory mode, they cause other neurons to fire. When they're inhibitory, they keep other neurons from firing.

As it happens, there is a class of chemical reactions that oscillates between two states, comparable to those of a neuron. First observed in the 1950s and 60s by the Russian scientists Boris Belousov and Anatol Zhabotinsky, the BZ reaction, as it's called, goes back and forth between states of activity and inactivity.

Irv Epstein, the Henry F. Fischbach Professor of Chemistry, is one of the world's foremost experts in the BZ reaction. He worked side-by-side with Zhabotinsky, who came to Brandeis as an adjunct professor of chemistry after the collapse of the Soviet Union. It was Epstein, along with several other researchers, who pointed out that the active/inactive pattern of the BZ reaction was analogous to the exhibitory/inhibitory behavior of nerve cells. This led Fraden to use BZ reactions to create his artificial neurons.

Now that he'd found his "neurons," Fraden and his lab engineered a container to hold them. It looked like an ice cube tray with two columns, each divided into individual ice cube compartments.

Step 2: Build a neural network.

As Fraden envisioned it, every ice cube compartment was an individual neuron. This made the columns comparable to the lines of neurons on either side of the eel's backbone.

Fraden filled each of the ice cube chambers with a liquid solution containing the chemicals necessary for the BZ reaction. The first BZ reaction happened in the container at the top of one of the columns. When it turned active (excitatory), it released a molecule that entered the

ice cube container directly beneath it, activating the

Next, the BZ reaction turned inactive (inhibitory). It then released a molecule that traveled to the ice cube container directly across from it, effectively suppressing, or putting on hold, the BZ reaction in that container.

A pattern emerged. One by one, the BZ reactions in a column were activated, while the BZ reactions in the other column were put into pause mode. When all the BZ reactions in the first column were completed, the reactions in the second column came out of hiatus and started up.

The second column's reactions also proceeded one after the other, downward. And they also now suppressed the reactions in the first column. Thus, the first column started up again only after the second column's reactions were finished.

Remarkably, the BZ reactions were interconnected and communicated with one another in the same order as the eel's spinal neurons, going off one at a time, one column after the other. Fraden knit the BZ reactions together so that they, in effect, acted together as a single entity.

Why did the activating molecules travel only vertically and the deactivating ones only horizontally? This was because of the design of the dividers between the containers. Dividers in the columns allowed only activating molecules to pass through. Dividers between the columns permitted only deactivating ones.

The third step: The neural network goes into a gel.

Fraden has selected a chemical-responsive shape-changing gel into which he will implant his ice cube tray apparatus. "We hope the material will behave in the same way an eel's body does in response to the firings

of its neurons," he says. "It will slither away."

More information: Thomas Litschel et al. Engineering reaction–diffusion networks with properties of neural tissue, *Lab on a Chip* (2017). DOI: 10.1039/C7LC01187C

Provided by Brandeis University