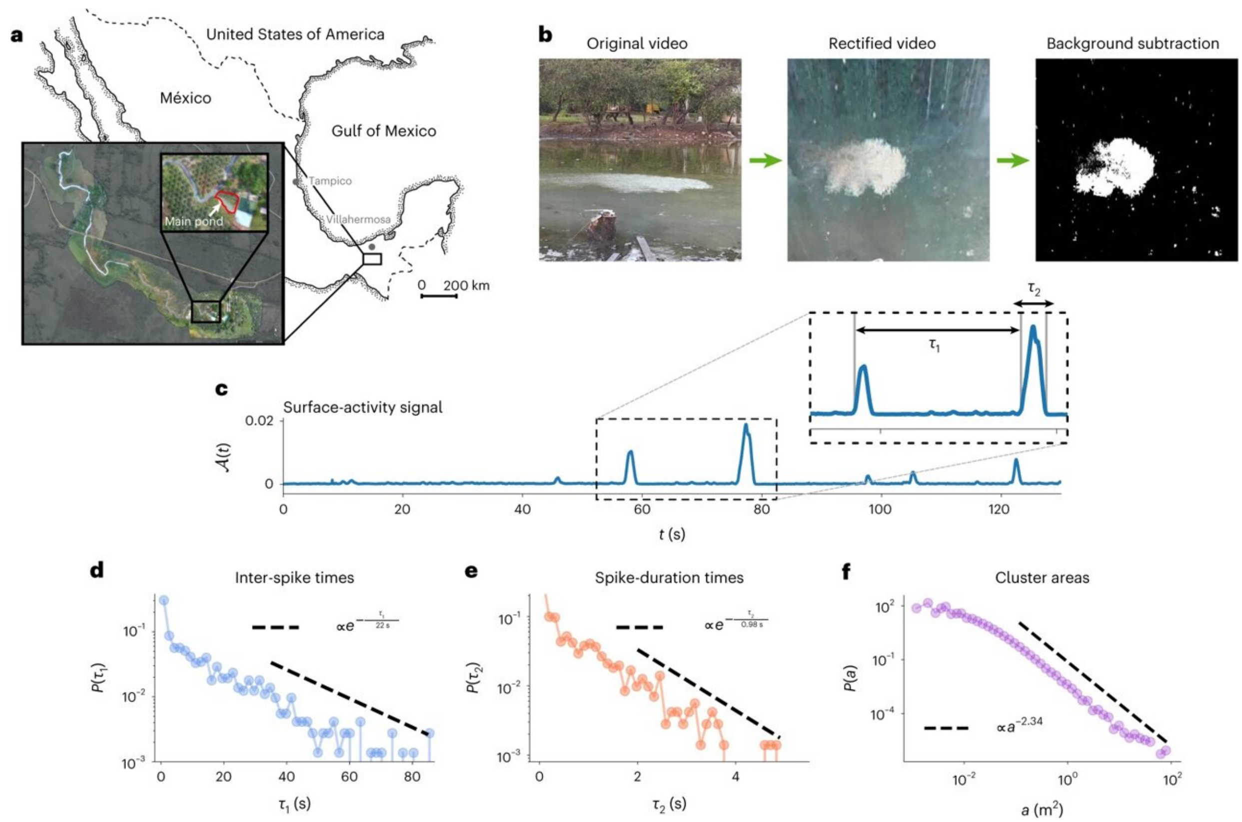
How fish schools work in a similar manner to the brain

February 7 2023, by Nadja Neumann



Analysis of empirical data of the surface-wave activity. Credit: *Nature Physics* (2023). DOI: 10.1038/s41567-022-01916-1

What do the brain and a school of fish have in common? They are both capable of efficient collective information processing, although each unit within them only has access to local information.

In the brain, it is the stimuli from 86 billion neurons that form the basis for information processing; in the shoal, it is the decisions of each individual on how to move and interact with neighbors. However, little is known about how biological systems like the brain or a swarm of fish manage to optimally bring together a multitude of individual pieces of information from different locations.

There is a hypothesis according to which the best performance of the brain lies at the border between order and chaos, in the state of so-called criticality. Researchers of the Cluster of Excellence "Science of Intelligence" from Humboldt-Universität(HU), the Technical University of Berlin (TU), and the Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB) have now been able to demonstrate this hypothesis on a large school of fish. The study was published in *Nature Physics*.

"Swarm behavior is often about information spreading like an avalanche. In this state, the individuals react maximally quickly to external stimuli with maximally effective information transfer. We wanted to investigate whether the regularity of criticality, which has already been demonstrated for neuronal networks, describes this state," explained study leader Pawel Romanczuk, Professor in the Department of Biology at HU and a member of the Cluster of Excellence.

Criticality: The brain works most effectively at the threshold between order and chaos

Information processing in the brain is based on a network of around 86 billion neurons. They pass on information in the form of voltage impulses. According to a thesis in neurobiology called "the critical brain hypothesis," the reason why our brain is so efficient at processing information is that the brain is permanently at a critical point between two dynamic states, namely order and chaos, where order means neurons are active in a highly synchronized manner, and chaos means that the cells emit impulses independently of each other.

According to the critical brain hypothesis, transmission of information within the brain works best when neural connections are neither too weak nor too strong, i.e. at an intermediate state between order and chaos, known as criticality. In this state, the brain is maximally excitable and even small stimuli suddenly cause a multitude of neurons to fire and information spreads like an avalanche and can easily be transmitted, even to areas of the brain that are far away from the starting point.

Mexican wave for maximum alertness

Sulfur mollies, which are small fish living in sulfidic springs in Mexico, swim in shoals by the hundreds of thousands and show a typical and unusual behavior: They dive up and down in waves; from a bird's eye view, it looks like a huge Mexican wave that is repeated manifold. At first, as the team has already shown in a previous study, the small fish use the waving behavior to successfully confuse attacking birds.

But this behavior could also have a different function: it could be putting the swarm in a state of optimal alert—in a way that closely resembles a brain's state of criticality described above. This last-second alertness is needed because the animals are exposed to high predator pressure.

However, the fish also perform their wave motions when there are no birds attacking. "For this reason, we wanted to find out whether this wave motion in the resting stage could be an analogy to the neuronal lockstep of the brain, as in, few surface waves when no birds attack, stronger and more waves when birds attack. If so, the observed collective diving of the swarm would indeed happen at criticality, with the highest possible alertness," explained first author Luis Gómez-Nava, a researcher at the Cluster of Excellence.

The researchers combined empirical data from behavioral studies in the field with mathematical models, and were thus able to show that the spatio-temporal collective dynamics of large swarms of sulfur mollies actually do mimic an excitable system at criticality—in a way that is similar to the brain.

Maximum discrimination of environmental stimuli and maximum communication range

Being at a critical point allows the sulfur molly swarms to constantly watch out for disturbances in the environment, and to pass on information about the intensity of the cue, even over long distances. This was demonstrated in collaboration with other members of the Cluster of Excellence working in the field of artificial intelligence, Robert Lange and Professor Henning Sprekeler.

They used state-of-the-art machine learning algorithms to test the response of the system to different intensities of disturbances in the environment and concluded that, indeed, the swarm is able to efficiently process the information of external stimuli—like attacking birds—to their advantage.

"In the case of sulfur mollies, stimulus intensity correlates with danger, as hunting birds often enter the water with their bodies resulting in high-intensity visual, acoustic and hydrodynamic disturbances, whereas birds in overflight provide little visual cues. Therefore, information about the intensity of the stimulus is very important for fish to coordinate appropriate responses, which might even include repeated diving for several minutes. Moreover, this information can be transmitted over long distances so that fish can act even when they are not in the danger zone—as a prevention mechanism," explained first author Luis Gómez-Nava, a researcher at the Cluster of Excellence.

"And this is similar to the way the brain works," he concluded.

Nevertheless, there are also important differences between the fish swarm and neuronal systems. In neuronal systems, the structure of the interaction network between individual elements (neurons) changes at a much slower time scale than the dynamic behavior in the school of fish.

"The dynamical group structure and individual behavioral parameters such as individual speed or attention to conspecifics have strong effects on collective behavior, and can lead to alternative mechanisms of self-organization towards criticality by modulating individual behavior. Here, many questions remain open, and we continue to investigate," said co-author Jens Krause, Professor at HU, IGB and in the Cluster of Excellence.

The resemblance between the diving behavior of fish and the neuronal activity in the brain could provide insights into a better understanding of collective systems in nature, also giving clues as to how far the complex patterns displayed by groups of animals could be interpreted as a sort of "collective mind."

More information: Luis Gómez-Nava et al, Fish shoals resemble a stochastic excitable system driven by environmental perturbations, *Nature Physics* (2023). DOI: 10.1038/s41567-022-01916-1

Provided by Forschungsverbund Berlin e.V. (FVB)

April 2024 from https://phys.org/news/2023-02-fish-schools-similar-manner-brain.html