Research team takes neuromorphic computing a step forward

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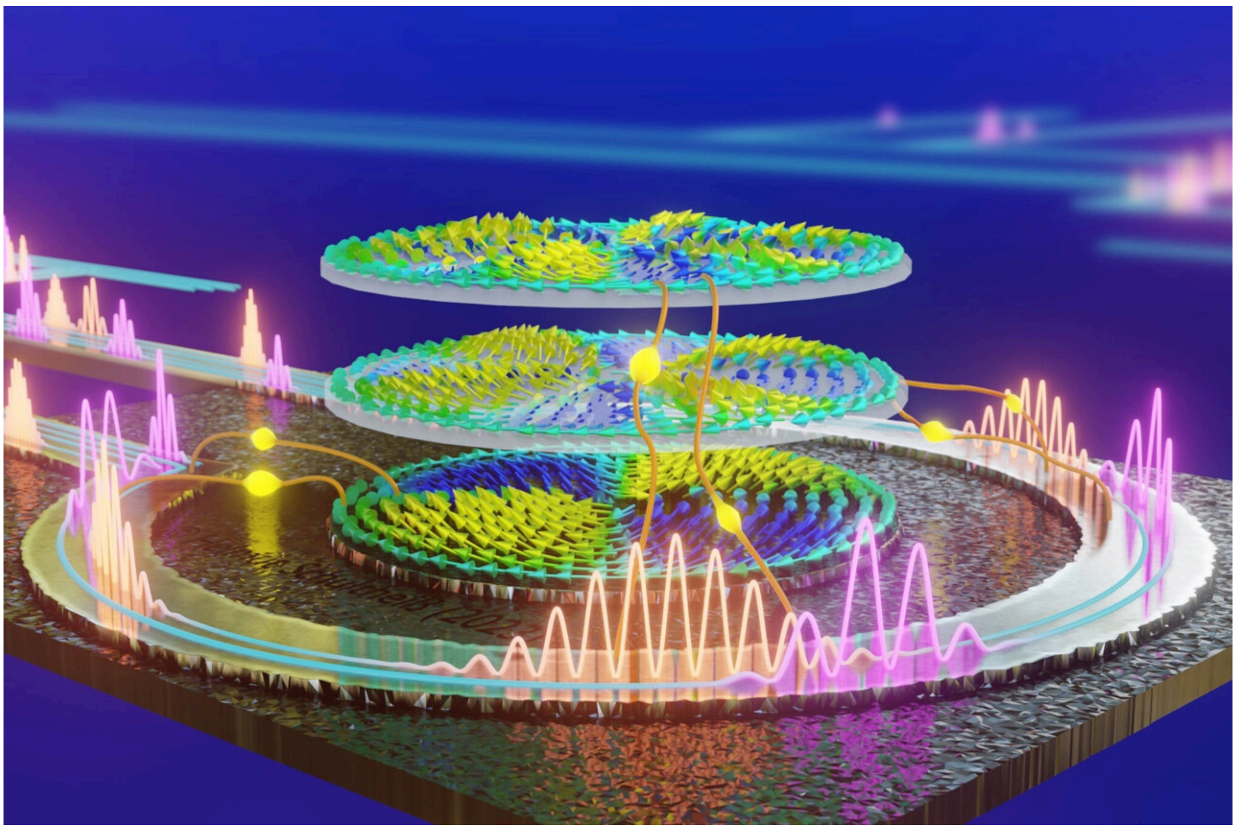

Electromagnetic fields excite oscillations in a magnetic vortex. The nonlinear interaction is similar to the interplay between neurons and synapses in the brain and can be used for pattern recognition. Credit: HZDR / H. Schultheiß

Neuromorphic computers do not calculate using zeros and ones. They instead use physical phenomena to detect patterns in large data streams at blazing fast speed and in an extremely energy-efficient manner.

In their project NIMFEIA, Katrin and Helmut Schultheiß along with their team from the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) have now taken this technology a tremendous step forward. They also demonstrated that their approach can be seamlessly integrated into conventional chip manufacturing. Their findings have now been published in *Nature Communications*.

What the researchers have developed at the HZDR-Institute of Ion Beam Physics and Materials Research is referred to by many names. "Neuromorphic computing," for example, is one term, as the processes resemble those that occur within the brain. "Unconventional computing" is another name, as the technology is so different from the data processing that we are accustomed to today, which uses the Boolean logic of zeros and ones.

It is sometimes called "reservoir computing," as it uses non-linear physical phenomena to detect patterns in a data stream. "In many fields of automation—from autonomous driving and the "Internet of Things' to edge computing—the industry is struggling with fast data signals," explains Helmut Schultheiß. He heads the Emmy Noether Group "Magnonics" at the HZDR. "This is because many sensors deliver small data packets at high speed. Recognizing patterns in these packets is very energy-intensive for today's computer architectures."

For this reason, Katrin and Helmut Schultheiß and their team are relying on spin waves; also called magnons. The idea of using them to create a new data processing technology is already a bit old. Through their endeavors, Schultheiß and team, however, have solved a problem that hindered the practical execution.

"All concepts up until this point rely on the fact that spin waves must propagate from A to B in order to work with them," Helmut Schultheiß explains. "But there are really no usable materials in this regard." Schultheiß and team therefore went in another direction. They have pressed the entire process into a magnetic disk only a few micrometers thick and made it vibrate.

Now the entire body vibrates and at different frequencies simultaneously. "Visualize a drum," he explains. "Beautiful patterns are created if you sprinkle sand on a drum and beat it rhythmically. These are the vibration modes." They exist in the entire space. They don't merely go from A to B. They are standing waves that live resonantly on the entire body.

The beating of the drum is the data input that can, for example, come from a sensor. It causes an interplay of different oscillations and resulting non-linear processes. "In our work, we were able to demonstrate that different input patterns always produced unique oscillations patterns," Schultheiß says. "And this process is time sensitive. So, if we change the sequence of the input signals, the patterns will change as well." That is a requirement for evaluating data in real time.

Helmut Schultheiß is certain there is, however, another requirement for the technology to make it from the laboratory to the marketplace. The process must be CMOS compatible—that is, it must be suitable for processing on the chip industry's standard production lines. This is something he learned not least from his experience with industry partners GlobalFoundries and Infineon within the NIMFEIA project.

"Even if we search for new technologies, CMOS technology will continue to ensure our prosperity for decades to come," he says. "This is because it has now permeated our entire lives—from the smallest light switch to telephones and sensors for pacemakers." Enormous investments are required for the chip factories where this prosperity is created. They are not merely plucked from the ground, nor are they simply reconfigured. "The positive aspect about our technology is that nothing needs to be reconfigured," Schultheiß says.

Katrin und Helmut Schultheiß and their team, however, do not wish to replace conventional computers with their new technology. They instead wish to supplement them in a way that makes sense. "Boolean computation is still the leader when it comes to complex mathematical calculations," Helmut Schultheiß says.

"Nothing better will likely arise for arithmetic tasks in the next hundred years. But the current computer architectures have a major problem in recognizing patterns and grasping complexity." He could, for example, imagine an application for traffic optimization. This is because neuromorphic computers could sift through the vast mountain of data—provided by services like Google, combined with smartphones and the cars themselves—for patterns and predict a traffic jam before the first car even comes to a halt.

"That is a highly complex endeavor in which conventional computer architectures, such as our PCs, have immense difficulty. Many calculation steps are required. On the other hand, it is the ideal application area for neuromorphic computing, for reservoir computers and for artificial intelligence."

Because the novel technologies are not only small, but also incredibly energy-efficient, they could work directly on the sensors. This is referred to as "edge computing" and is helpful wherever transmitting large amounts of data is difficult or expensive. In outer space, for example.

Instead of sending all measurement data from an Earth observation satellite to the ground station, it could be processed on site. This saves bandwidth and energy. The application could also be used in medicine. A neuromorphic computer directly integrated into a pacemaker could detect patterns indicating arrhythmia or ventricular fibrillation from the pacemaker's signals.

"Intelligent maintenance could also benefit greatly from edge computing with neuromorphic processes," Schultheiß says. "In terms of wind turbines, for example, they could look for oscillation patterns in the drive shafts that detect bearing damage. This would facilitate maintenance before the bearing even fails. This saves money, energy and resources."

More information: Lukas Körber et al, Pattern recognition in reciprocal space with a magnon-scattering reservoir, *Nature Communications* (2023). DOI: 10.1038/s41467-023-39452-y

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