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How bee brains are shaping next-generation computer chips

Bees navigate their surroundings with astonishing precision. Their brains are now inspiring the design of tiny, low-power chips that could one day guide miniature robots and sensors.

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When a bee leaves the nest, it already has its own version of a GPS in its head. By analysing patterns in the sky and its flying speed, a bee can keep track of its location and safely return home. Researchers are now taking their cue from this in the hope of transforming how computers find their way around.

“A bee finds its way back without a smartphone or satellite navigation,” said Anders Mikkelsen, professor at Lund University in Sweden. “They do this by looking at the polarisation of the sky, and their speed. Based on that, they don’t get lost.”

Mikkelsen is part of a group of scientists in an EU-funded initiative named InsectNeuroNano who want to replicate the bee’s internal navigation system on a computer chip. Today’s chips can already emulate how bees find their way home, but bees do it much more efficiently than computers.

“If you take a lightweight chip, it will easily weigh more than 80 grams and use more than 7 watts of power,” said Mikkelsen, who coordinates the initiative. “A bee weighs under one gram and uses less than one hundredth of a watt to power its brain. Imagine if you could make a chip that efficient.”

That is exactly what Mikkelsen’s team – researchers from universities and labs in five European countries – is setting out to do. They are building an insect-inspired chip that can determine its own position. This chip will be smaller and more efficient than anything currently available for this kind of navigation task.

It could be used in anything from low-cost environmental sensors to insect-like robots that clean up the environment.

“We could make small, insect-sized robots with this,” said Mikkelsen. “It would be like having a bee colony, but you get to tell it what to do. You could, for example, use these little bots to clean up pollution, build a

structure, or artificially pollinate a field.”

Hard-wired navigation

But why is the bee’s brain more efficient than a chip? Today’s standard chips are versatile and made to perform different tasks. For example, the central processing unit – a computer’s “brain” – allows us to send emails, load webpages and edit text documents.

More specialised chips such as graphics cards handle everything from photos of cats to complex video game worlds.

The chip that the InsectNeuroNano team is designing is built to do just one thing. It uses signals from a light sensor attached to the chip, plus speed, to determine its own position.

The chip is highly specialised, much like the bee’s brain, which has evolved for efficient navigation rather than versatility. That may seem like a limitation, but it allows the chip to be small and energy-efficient.

“Our chip can only do one task,” said Mikkelsen. “But it can do it extremely energy efficiently and in a tiny size. It’s a completely different strategy from other computer chips.”

From insect brain to chip

The research team’s biologists and engineers are working to bring insights from the world of insects into that of computer design. Professor Elisabetta Chicca from the University of Groningen in the Netherlands, who specialises in bio-inspired circuits and systems, is one of them.

“For some problems, nature has already found a solution that is compact, low-power and efficient,” said Chicca. “Insect brains offer one such solution. We don’t know everything about them, but we know enough to start building a system.”

Drawing on insights from biologists, Chicca built virtual models of the chips, a task made harder by the fact that insect brains are still not fully understood. “You need to make hypotheses about how they work so you can translate it to the chips,” she said.

This kind of research is helpful for biologists as well. By having scientists from other fields fill in the blanks, they learn how insect brains might be working. For example, chip models could suggest how certain circuits in the insect brain might be wired.

“We are learning from biologists,” said Chicca. “But the biologists are also learning from us. It’s great to see that.”

First steps for robot bees

The research is helping to rethink how chips work. Usually, a chip sends electrical signals between its components through wires. That has been the dominant model of computing for decades.

Instead, InsectNeuroNano uses nanophotonic circuits, which guide light through tiny structures on the chip, only billionths of a metre across, in a process called photonic computing.

“You can send more data with light in a more energy-efficient way,” said Mikkelsen. “Also, our sensor detects light, so we’re using light to sense and to think, which simplifies things. Both of those are quite important if we want a chip the size of an insect brain.”

So far, the researchers – whose project runs until September 2026 – have managed to create a first prototype chip in lab conditions that mimic insect brain function.

Still, according to Mikkelsen, it will take around 10 years before this technology finds its way into the real world.

Making chips this small, while using new design principles such as nanophotonic computing, is complicated. Still, the team's work has already helped to move the technology forward, and the researchers have learned a lot in the process.

"There are many steps we still have to take before we'll have a robot bee flying around," said Mikkelsen.

"But we have made a huge leap in this project. We went from a theoretical concept to something on a lab table that mimics insect brains."

Their work, although still requiring years of research, has paved the way for insect-sized robots that could one day navigate by reading the sky, just like real bees.

"Now we have to put together a whole system," said Mikkelsen. "We need to scale up everything we learned in the lab. The first steps have been made – now the real progress can begin."

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- InsectNeuroNano (CORDIS)
- InsectNeuroNano project website
- A Europe fit for the digital age
- European Chips Act
- The EU and photonics