How to build brain-inspired neural networks based on light

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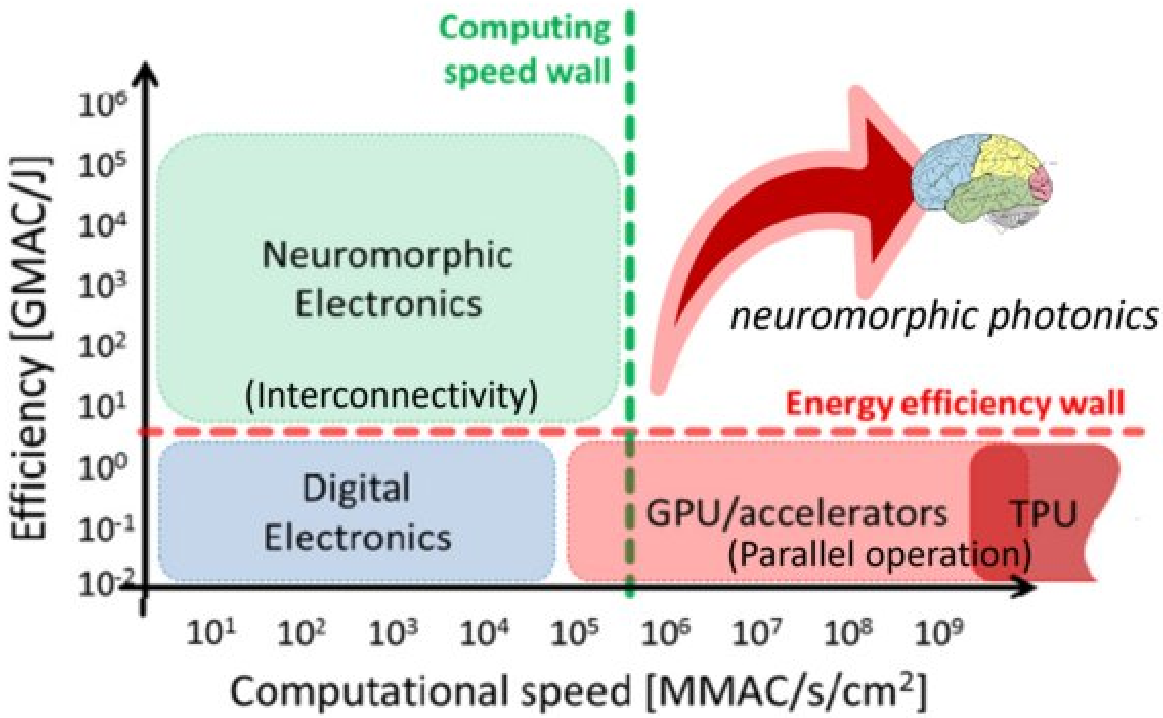


Credit: Eindhoven University of Technology

Supercomputers are extremely fast, but also use a lot of power. Neuromorphic computing, which takes our brain as a model to build fast and energy-efficient computers, can offer a viable and much-needed alternative. The technology has a wealth of opportunities, for example in autonomous driving, interpreting medical images, edge AI or long-haul optical communications. Electrical engineer Patty Stabile is a pioneer when it comes to exploring new brain- and biology-inspired computing paradigms. "TU/e combines all it takes to demonstrate the possibilities of photon-based neuromorphic computing for AI applications."

Patty Stabile, an associate professor in the department of Electrical Engineering, was among the first to enter the emerging field of photonic neuromorphic computing.

"I had been working on a proposal to build photonic digital artificial neurons when in 2017 researchers from MIT published an article describing how they developed a small chip for carrying out the same algebraic operations, but in an analog way. That is when I realized that synapses based on analog technology were the way to go for running artificial intelligence, and I have been hooked on the subject ever since."

Stabile is mainly focusing on realizing neuromorphic computing with integrated photonics technology. "For this exciting multidisciplinary new field, I am reusing a lot of the knowledge I gained while working on optical switching for data center applications."

Unprecedented speeds

In the field of artificial intelligence, vast amounts of data need to be processed and analyzed at unprecedented speeds.

"The algorithms you need to do this cannot run on conventional von Neumann computing architectures, because they are unable to run memory and processing at the same time. What you need are parallel architectures that combine these functions, to ensure smooth and fast data transport. There is a plethora of very promising solutions in electronics, but the dilemma is the limited amount of data that can run through the circuits. In photonics, you can transport almost unlimited amounts of data at the speed of light."

A human brain contains around 100 billion neurons, each of which can communicate with thousands of other neurons via synapses that carry neurotransmitters. "The key concepts here are the nodes and the interconnectivity. And that is quite similar to what we already have in photonic integrated switches."

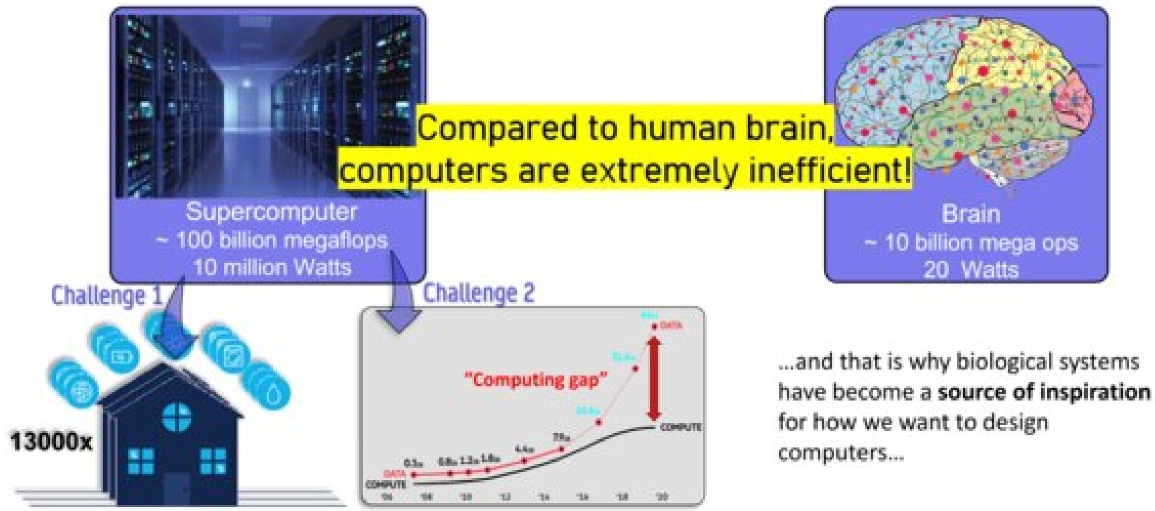
That is why Stabile sees promising possibilities of using integrated photonics to build neuromorphic networks. She also believes this entirely new field of neuromorphic photonics will bring further advances in optical switch architectures.

Challenges

However, building a neuromorphic photonic network is far from trivial. "The big challenge is to scale up to large numbers of neurons. This means that new research questions arise: How can you stack neurons in two to three layers only and still end up with reliable computing results? Is it possible to redesign algorithms in such a way that we can simplify the required network architecture?"

To answer these and other questions, Stabile collaborates with many other colleagues from complementary disciplines, ranging from material science and embedded systems to mathematics and computer science.

"That is the most fun part of my work, the fact that I can cover the entire chain, from the materials and technology side all the way up to the actual application through the full computing layer stack," the electrical engineer says.



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Applications

Stabile sees a wealth of opportunities for this technology. "For example, in autonomous driving, where you need to process and analyze a myriad of data from a vast number of sensors to enable real-time decision making. Or in ultra-fast image classification, where you could use convolutional optical neural networks to support radiologists in interpreting medical images or to allow extreme signal processing for astronomical imaging.

But also in long-distance optical communications, to relieve the power consumption of digital signal processing at the receiving side. Or in aerospace, where you could use ultra-low-power photonic neural networks to pre-process the acquired data before you send them down to earth."

Optimize and simplify

But those are all dreams for the long run. At the moment, Stabile focuses on optimizing the on-chip network architecture. Instead of building as complex networks as possible, Stabile first goes back to the basics.

"I am trying to determine to what extent we can simplify the required networks and still obtain reliable predictions. What would be the killer application for these types of networks, and what requirements do they have to meet? The next step is to integrate the required physical layers, control systems, algorithms, and readouts into a working system that is able to accelerate computation in an efficient manner."

Scaling up the technology will be the next phase. "We can explore ample possibilities to achieve the desired performance, ranging from nano-photonics to spintronics and plasmonics."

A 3D neuron

In the near future, Stabile hopes to demonstrate a 3-dimensional neuron based on the integration of electronics and multi-functional photonics.

"That could consist of an indium phosphide layer for nonlinear processes, covered with a routing layer made out of silicon nitride for ultra-low loss synaptic operations. This is then loaded by a memory layer, based on phase-changing materials. An in-depth analysis of the metricsour calculations has shown that this can allow petascale computation at tens of femtojoules per operation.

Here in Eindhoven, we have the right ecosystem, the right expertise, and the right equipment to produce such a neuron and study its properties. Also, the recently launched Eindhoven Hendrik Casimir Institute will further stimulate our research."

Testbed

Besides optimizing the on-chip network architecture, Stabile is currently focusing on developing an experimental platform for accelerating the technology. The testbed can attract the interest of companies to explore how this technology could help solve their problems.

And, of course, she wants to attract new scientists and students to this emerging field of research. "Neuromorphic photonics is a very exciting multidisciplinary field that holds great promises for the future. At TU/e, we are at the forefront of the topic, working on technology, networks, architecture, and computer science. What's not to like?"

The research is published in *IEEE Journal of Selected Topics in Quantum Electronics*.

More information: Bin Shi et al, Deep Neural Network Through an InP SOA-Based Photonic Integrated Cross-Connect, *IEEE Journal of Selected Topics in Quantum Electronics* (2019). DOI: 10.1109/JSTQE.2019.2945548

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