Getty Images

Recognizing faces in photos, monitoring credit-card transactions for fraud, recommending music based on personal taste and identifying tumors in medical

Optical technology allows ANNs to be implemented directly in hardware, with data encoded in light pulses and neurons made from beam splitters, waveguides and other components.

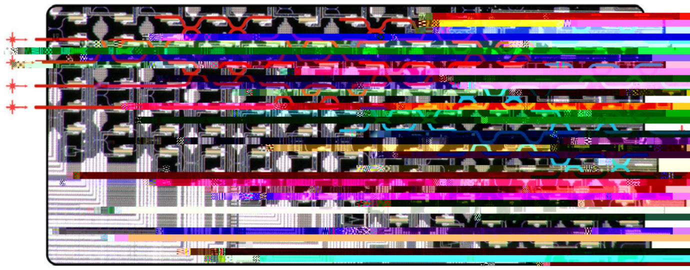
Coheren ol ion

[illegible] started to dream of building an optical computer. The emphasis initially was on a digital device, which would use the optical equivalent of a tran- [illegible] machine, claimed its proponents, might operate much faster than an electronic computer, thanks both to the far higher raw speed of light through a circuit and to the possibilities for parallel processing, since photons don't interact with one another.

However, this very non-interaction of photons itself created a problem, as it means that they couldn't be used directly to control the behavior of other photons. Instead, switching had to be done indirectly, by modifying some kind of intermediate material. But the power needed to achieve such nonlinearity was so high that many proposed optical schemes were impractical for more than a handful of logic gates. Unable to build an optical transistor that could come close to outperforming its electronic equivalent, many researchers left the [illegible]

Yet these problems didn't spell the end of optical computing. As Alexander Tait at NIST in Boulder explains, optical ANNs have less need for switching than digital computers. In an ANN, each neuron receives multiple weighted (linear) inputs, but generates just one (nonlinear) output (see "The power of learn- [illegible] large numbers of nonlinear elements (an AND gate, for example, consists of two transistors in series), the nonlinearity in an ANN is restricted to neurons' out- [illegible] how many connections there are to a given neuron.

Physicists have devised numerous ways of realizing ANNs optically, one of which uses Mach-Zehnder interferometers (MZIs) to calculate matrix products. By interfering a coherent pair of incoming light pulses [illegible] these devices multiply a two-element vector, encoded in the amplitude of the pulses, by a 2×2 matrix. An array of the interferometers can then perform arbitrary matrix operations.



Researchers at MIT have used a photonic processor containing Mach-Zehnder interferometers to carry out matrix

[illegible] length bulk optics, but advances in integrated photonics [illegible] Institute of Technology (MIT), USA, announced independently that they had made "nanophotonic processors" capable of carrying out general matrix operations that could potentially be applied to a variety of problems in classical and quantum physics.

The MIT groups, led by Dirk Englund and Marin [illegible] nanophotonic processor to implement two layers of [illegible] using half the data for training, they found that the [illegible] digital computer.

Despite these positive results, the scheme faces major challenges. For one thing, says Tait, scaling [illegible] because the phase shifters require lots of power. Then there is the question of the nonlinear operation needed to link one set of MZIs with another, which the MIT researchers simply simulated using a normal computer. According to Tait, this nonlinearity would corrupt the light's phase, ruining the calculations. Adherents of this technology, he says, "have yet to propose how the MZIs will cascade from one to another."

Problems with all-optical ANNs have led some groups to investigate optoelectronic schemes in which neurons convert signals from light into electricity and then back to light.

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With Moore's law under threat as electronic circuits reach the limits of miniaturization, optical technologies have attracted significant interest and some investment.

[illegible] a venture arm of Google's parent company Alphabet.

The research at Princeton has also led to the creation of a new company, Luminous Computing, which has [illegible] who did his Ph.D. with the Princeton group, thinks [illegible] founded is important because there are now big teams of engineers working on these problems," he says.

But not all groups are thinking about commercial products. Tait is working on a NIST project headed by Shainline that is developing hardware designed, says Shainline, to "be scalable up to the human brain or beyond." That entails potentially building networks with tens of billions of neurons, which, Shainline says, [illegible] limit energy consumption (the human brain requiring a [illegible] a strict design criterion: communication between neurons must occur at the level of single photons.

The scheme on the drawing board relies on superconductors to detect photons and to update weights and sum inputs; semiconductors to generate the photons; and photonic components to distribute them—all at just a few degrees above absolute zero. Shainline acknowl- [illegible]