# New design advances optical neural networks that compute at the speed of light using engineered matter

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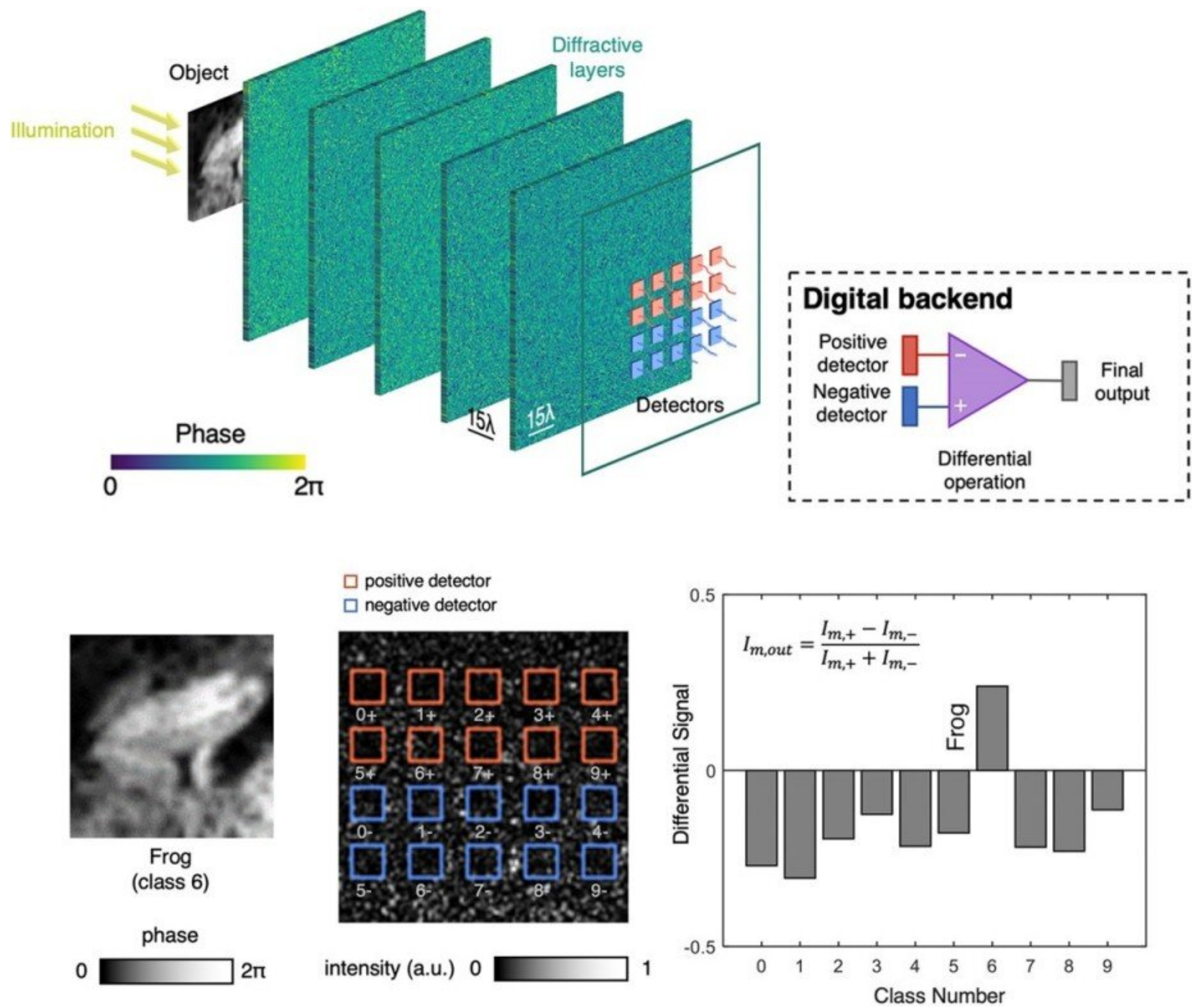


Engineered optical neural network applied to a conventional machine learning task. Credit: UCLA Engineering Institute for Technology Advancement

Diffractive deep neural network is an optical machine learning framework that uses diffractive surfaces and engineered matter to all optically perform computation. After its design and training in a computer using modern deep learning methods, each network is physically fabricated, using for example 3-D printing or lithography, to engineer the trained network model into matter. This 3-D structure of engineered matter is composed of transmissive and/or reflective surfaces that altogether perform machine learning tasks through light-matter interaction and optical diffraction, at the speed of light, and without the need for any power, except for the light that illuminates the input object. This is especially significant for recognizing target objects much faster and with significantly less power compared to standard computer based machine learning systems, and might provide major advantages for autonomous vehicles and various defense related applications, among others. Introduced by UCLA researchers [1], this framework was experimentally validated for object classification and imaging, providing a scalable and energy efficient optical computation framework. In following research, UCLA engineers further improved the inference performance of diffractive optical neural networks by integrating them with standard digital deep neural networks, forming hybrid machine learning models that perform computation partially using light diffraction through matter and partially using a computer [2].

In their latest work, [3] published in *Advanced Photonics*, an open access journal of SPIE, the international society for optics and photonics, the UCLA group has taken full advantage of the inherent parallelization capability of optics, and significantly improved the inference and generalization performance of diffractive optical neural networks (see the Figure), helping to close the gap between all-optical and the standard electronic neural networks. One of the key improvements incorporated a differential detection scheme, where each class score at the optical network's output plane is calculated using two different detectors, one representing positive numbers and the other representing negative numbers. The correct object class (for example cars, airplanes, ships etc.) is inferred by the detector pair that has the largest normalized difference between the positive and the negative detectors. This differential detection scheme is also combined with parallel-running diffractive optical networks, where each one is specialized to specifically recognize a sub-group of object classes. This class-specific diffractive network design significantly benefits from the parallelism and the scalability of optical systems, forming parallel light paths within 3-D engineered matter to separately compute the class scores of different types of objects.

These new design strategies achieved unprecedented levels of inference accuracy for all-optical neural network based machine learning. For example, in one implementation UCLA researchers numerically demonstrated blind testing accuracies of 98.59%, 91.06% and 51.44% for the recognition of the images of hand-written digits, fashion products, and CIFAR-10 grayscale image dataset (composed of airplanes, cars, birds, cats, deer, dogs, frogs, horses, ships, and trucks), respectively [3]. For comparison, these inference results come close to the performance of some of the earlier generations of all-electronic deep neural networks, for example, LeNet, which achieves classification accuracies of 98.77%, 90.27%, and 55.21% corresponding to the same datasets, respectively. More recent electronic neural network designs, such as ResNet, achieve much better performance, still leaving a gap between the performances of all-optical and electronic neural networks. This gap, however, is balanced by important advantages provided by all-optical neural networks, such as the inference speed, scalability, parallelism and the low-power requirement of passive optical networks that utilize engineered matter to compute through diffraction of light.

This research was led by Dr. Aydogan Ozcan who is a Chancellor's

Professor of electrical and computer engineering at UCLA, and an associate director of the California NanoSystems Institute (CNSI). The other authors of this work are graduate students Jingxi Li, Deniz Mengu and Yi Luo, as well as Dr. Yair Rivenson, an adjunct Professor of Electrical and Computer Engineering at UCLA.

"Our results provide a major advancement to bring optical neural network-based low power and low-latency solutions for various machine learning applications," said Prof. Ozcan. Moreover, these systematic advances in diffractive optical network designs might bring us a step closer to the development of next generation, task-specific and intelligent computational camera systems.

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**More information:**

1. All-Optical Machine Learning Using Diffractive Deep Neural Networks, *Science*, DOI: 10.1126/science.aat8084 (2018).

2. Analysis of Diffractive Optical Neural Networks and Their Integration with Electronic Neural Networks, ***IEEE Journal of Selected Topics in Quantum Electronics*** DOI: 10.1109/JSTQE.2019.2921376 (2019).

3. Class-specific Differential Detection in Diffractive Optical Neural Networks Improves Inference Accuracy, ***Advanced Photonics*** (2019) DOI: 10.1117/1.AP.1.4.046001

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