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Photonics Chips for Machine Learning

With the development of technology, many electronic products have appeared and become an indispensable part of our life. Originally, people used the electronic chip as a symbol of the human brain, making it the most important component in electronic equipment.

In recent years, a new type of chip, photonic chip, has become a research hotspot because of its superior performance in signal transmission and processing. Compared with electronic chips, photonic chips have advantages in energy consumption and efficiency. Optical-based integrated circuits that use photons instead of electrons are better at reducing power consumption, largely due to the properties of light. As electrons pass through transistors and other traditional integrated circuit components, they encounter resistance and generate heat. As designers continue to add various components to the chip, the heat generated by the chip naturally rises. This characteristic of electronics has even become an obstacle to improving the performance of microchips, and it is also the main reason why computers consume so much energy.

In contrast, photonic chips do not have resistance problems, because photons generated by a laser can quickly pass through an array of components such as waveguides, modulators, and reflectors. As a result, photonic chips generate less heat, consume less power, and compute faster. Photonic chips will bring breakthrough development in AI. In light-based devices, data moves at the speed of light, which is 10 times faster than electrons in ordinary circuits, and photonic chips have higher computing speeds than electronic chips. Photonic chips can also easily perform matrix-vector multiplication while supporting deep learning. Moreover, photonic chips can perform linear algebra calculations that traditional integrated circuits cannot. So, to make machine learning more efficient, we need photonic chips.

There are still many applications based on photonic chips. The most important applications of photonic chips in machine learning are in optical computing, such as optical computers and self-driving cars. Optical computers are computers that use beams of photons instead of electrical currents. When people need to transmit data or signals over long distances, optical computers let people know how powerful they are. In addition to being faster, optical computers can hold more data on a smaller size than electronic computers because beams and light don't interact as they pass through each other. An additional application is photonic sensors with embedded computing [2]. The product calculates the signal based on the input light spot, and then outputs the position information of the light, which means that it does not require an external controller for calculation processing. In the absence of an external controller, the sensor can be designed in a smaller size and at a lower cost. Furthermore, due to its high-speed readout and automatic light tracking, the sensor can be used in a wide range of automated equipment.

However, using optical computing poses huge challenges as we still don't know how to protect optical networks from hackers. Once optical computing can be used for self-driving cars, we will be able to detect objects that affect the car's motion much faster. Based on previous research, having lower price and smaller size, larger capacity, and preventing the interaction between magnetism and electrons will be the social significance of photonic chips.

Through my studies, I found that Photonic Neural Networks is a part that I am really interested in. In August 2018, Julie Chang et al. of Stanford University published a paper titled "Hybrid optical-electronic convolutional neural networks with optimized diffractive optics for image classification" on SCI, proposing a method based on diffractive optical elements. Optoelectronic Hybrid Neural Network. The network adds a layer of optical convolution operation before the electronic calculation. Due to the optical convolution, the calculation amount of the entire network is greatly reduced, as shown in Figure 2 below. The "4f system", consisting of two convex lenses with a focal length of f, can realize two Fourier transforms in cascade. In this system, there are two convex lenses with both focal lengths f. The first lens is at a distance f from the object surface, and the back of the lens is the Fourier surface, and the distance is also f; The lens, again, has a second Fourier surface behind the lens, and the distance is also f. This constitutes the "4f system". In order to realize the optical convolution process, we put the Fourier plane in the middle of the "4f system" into the phase plate to modulate the amplitude and phase of the incident light, and divide the phase plate into multiple tiled convolution kernels, just Multiple convolution processes can be implemented.

In June 2018, researchers at the University of California, Los Angeles (UCLA) in the United States innovatively proposed an all-photon diffraction deep learning framework, which the researchers called diffractive deep neural network (D^2NN)). The D^2NN photonic neural network consists of multiple layers of diffractive surfaces to form a physical layer. By cooperating with these diffractive surfaces, the computing function of the neural network can be performed in the form of photons. The training and learning part of the diffractive neural network is completed on an electronic computer, and then reasoning and prediction are performed in the photonic neural network. Simulations and experiments on the MNIST dataset demonstrate its reasoning ability [5]. Each layer in the D^2NN network is regarded as a projection layer or a reflection layer. The point on the layer represents a neuron, which can reflect and transmit light waves, and connect to subsequent layers through optical diffraction, realizing the forward propagation process.
Photonic neural network, as an interdisciplinary product of photonic technology and artificial intelligence technology, can combine the advantages of photonic technology and artificial intelligence to build a high-speed, low-power, large-bandwidth network structure, breaking through the bottleneck of traditional electronic neural network. After the research and experiments of the researchers, it is believed that in the near future, the photonic neural network will be able to solve some of the current bottleneck problems, and can better play the advantages of high speed and low power consumption brought by the combination of optoelectronic technology and artificial intelligence technology, and better to build a green and intelligent world. .

References

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