EC 601 Project 1 Report

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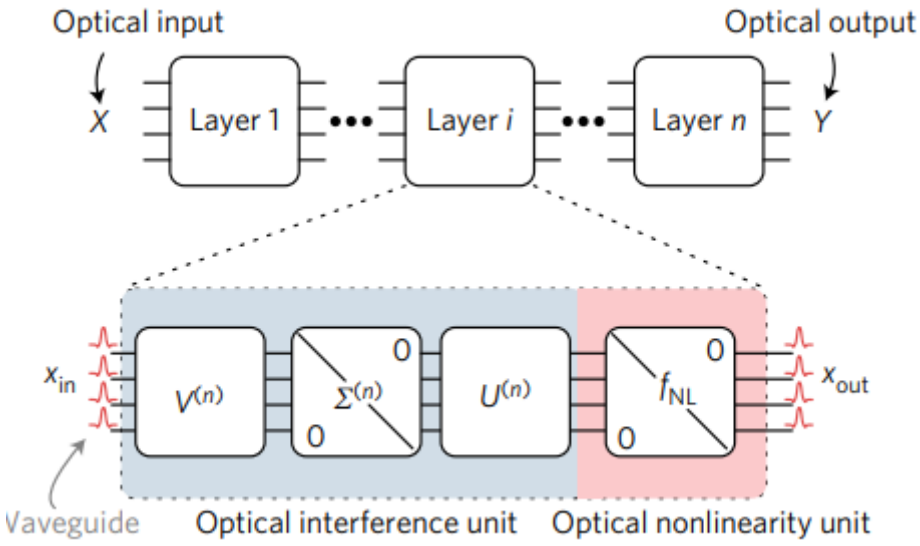
For companies or labs who have already have a specific problem that should be best solved with machine learning and are urged to update their neural network, the photonic chip is a kind of method that could speed up the network and reduce the energy cost comparing to the electronic chips.

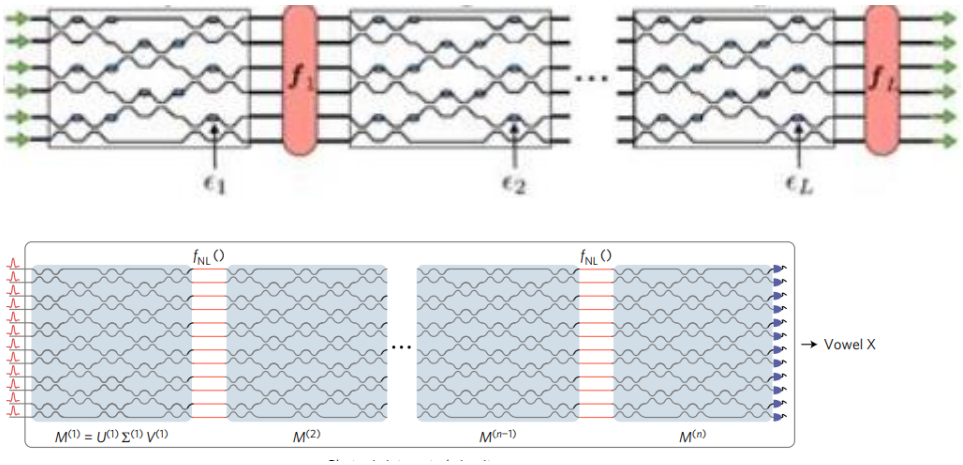
According to the research, photonic chips used on machine learning is a kind of products that has come to experimental phase in world range. There are several prototypes announced and performed well in lab testing but none of them is on sale. For example, Lightmatter, as one of the leading company in the field, has accomplish the world's first general-purpose photonic AI (artificial intelligence) accelerator in march 10th this year. There are mainly two structures of the photonic machine learning chips that is adapted by companies: MZI structure and the structure based on '4f system'. This report will first give a brief introduction of the two structures and then show the research progress or the test result of three typical companies that is producing the photonic chips.

The MZI structure

The MZI structure is a kind of structure of Neural synapse that applied MZI (Mach Zehnder interferometers). In 2017, Yicheng Shen and others of MIT proposed a new architecture of all-optical neural network. In silicon photonic integrated circuits, 56 cascaded arrays of MZI were used to form PNP (programmable nanophotonic processor) for vowel recognition. The network structure is shown in the figure below, which is composed of input layer, output layer and hidden layers in the middle. The middle hidden layers include OIU (optical interference unit) and ONU (optical nonlinear unit), which play the role of matrix multiplication and nonlinear function respectively. OIU is realized by a programmable nano photonic device based on Mach Zehnder interferometer array. The Mach Zehnder interferometer consists of two 3dB directional couplers connected to the upper and lower silicon waveguide branches. The inner phase shifter controls the output splitting ratio by changing the waveguide refractive index, and the outer phase shifter controls the differential output and phase delay. ONU can be realized by optical hardware with nonlinear characteristics such as saturated absorber and optical bistability. The neural network with two full connection layers made by this method has a correct rate of 76.7% when it first came out. The accuracy of equivalent electronic neural network is 91.7%. This method still has great room for improvement. Subsequently, the research group carried out further research on the basis of MZI all-optical neural network, and realized the optical convolution neural network with the cooperation of electronic devices. However, because the optical neural network must have electronic devices to realize the vectorization of the image and the summation of the convolution operation results transformed into multiplication, the calculation can not be completed at the speed of the real optical neural network.



Decomposition of the general neural network into individual layers. c, Optical interference and nonlinearity units that compose each layer of the artificial neural network.[1]

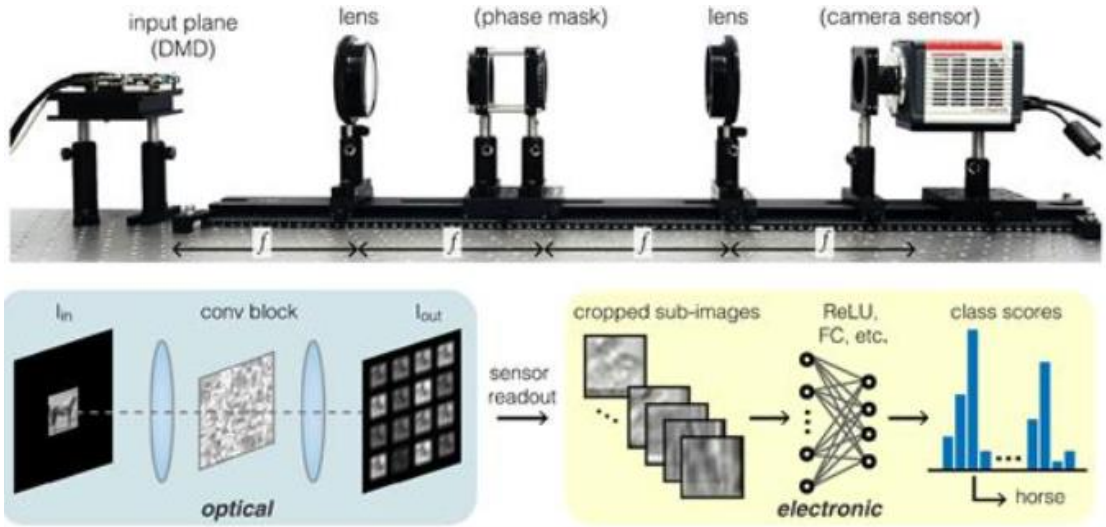


Two examples of the all-optical, fully integrated neural network

The structure based on '4f system'

In 2017, Julie Chang of Stanford University proposed a photoelectric hybrid neural network based on diffractive optical elements, which also adds a layer of convolution operation before electronic calculation, so as to reduce the amount of calculation of the network. A diffractive optical element is used here.

In order to achieve the convolution task in photonic chips, a '4f system' is adapted. The "4f system" composed of two convex lenses with focal length f can realize cascaded two Fourier transforms. As shown in Fig. 5, the first lens is placed far away from the object surface F, and the Fourier surface of the first lens is at the back f of the lens. The second lens is placed at a distance f behind the Fourier surface and generates a conjugate image plane at a distance 4f from the object surface. If a phase plate is placed in the Fourier plane in the middle of the "4f system" to modulate the amplitude and phase of the incident light, this process is convolution.



Using 4f system to achieve concolution[2]

The introduction of three companies

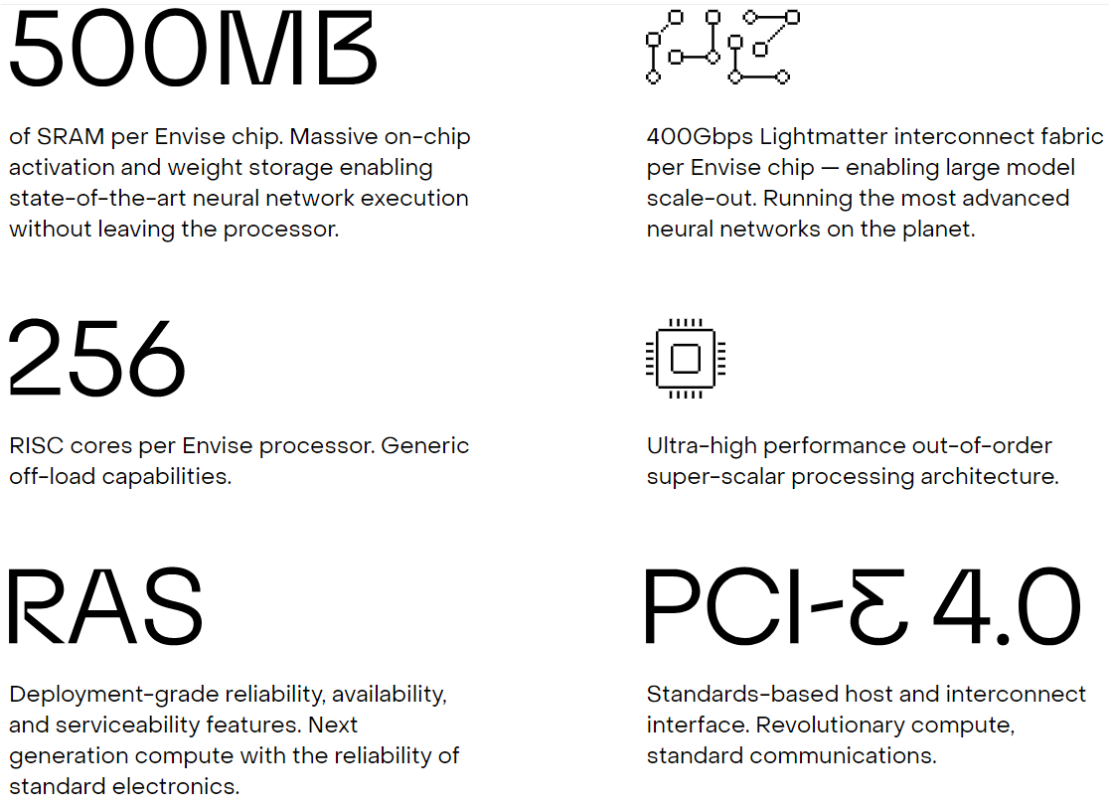
This part will give a comparison of Lightintellgence, Lightmatter and optalsys companies about their develop direction, develop progress and related technologies (papers and patents) by table and list some of their data.

	Lightintellgence	Lightmatter	optalsys
Develop direction	MZI method	MZI method	4f system
Product develop progress (latest news)	unveiling of its optical AI accelerator prototype on April 2019	Introducing Envise, Idiom and Passage — Next Generation AI Compute, Compile and Interconnect Platforms On March 2021	Echips testing in lab
Main technologies (paper and patents)	1. propose a new architecture for a fully-optical neural network that using unique advantages of optics 2.Present a new archi--tecture for imple--menting an Efficient Unitary Neural Network (EUNNs)	1. Systems And Methods For Training Matrix-Based Differentiable Programs 2. High-efficiency multi-slot waveguide nano-opto-electromechanical phase modulator	1. A spatial light modulating , SLM 2. An optical processing system using spatial light modulator(s) for convolution operations used by a neural network

Some data about the produced AI chips

Comparison	NVIDIA A100	TPUv3	AMD Ryzen 7 1800X	Intel Xeon E3-1220v3	Arm Cortex-A15
TOPS	312	90	0.24	0.2	0.011
FT TOPS	2.5	0.05	0.045	0.047	0.007
EChip Speed-up	2x	84x	93x	89x	600x
EChip Efficiency Gain	33x	836x	445x	354x	222x

The Echip from optalsys perform 4.2 FT TOPS at 20W



The data of Envise chips from lightmatter

Lightintellgence describe their chip as 'Processing information with light could one day enable such devices to run AI algorithms ten to a hundred times faster than today's best AI chips'.

References

[1] Shen, Y. et al. Deep learning with coherent nanophotonic circuits. 11, 441 (2017).
[2] Chang, J., Sitzmann, V., Xiong, D., Heidrich, W. & Wetzstein, G. J. S. R. Hybrid optical-electronic convolutional neural networks with optimized diffractive optics for image classification. 8, 12324- (2018).
[3] Lightelligence - Empower AI with light
[4] Lightmatter - The photonic (super)computer company.
[5] Optalysys