Optical Neural Network, 2022-2023

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Neural networks are useful computational tools for an array of problems including image classification. At the industrial scale, there are massive inefficiencies such as the memory bottleneck in standard (von Neumann) computer architectures that alternative computational approaches can address. Here, we will explore an alternative approach: optical computing.

We will build an optical embodiment of a neural network. Light will be patterned with an input structure, passed through lenses and modulation devices, and land on a camera to parse the output.

Background

Optical computing has a long history, but silicon computing devices have stayed ahead until recently. With the closing of Moore's Law era, and the broad application of artificial neural networks, there is renewed interest in optical computing, including fiber-based and integrated photonics approaches. Here we are focused on one strength of optical computing: free space fanouts. In a conventional CMOS platforms, it takes a large and complex fanout to connect one matrix to another. In freespace optics, it is trivial to make such connections, and they scale well.

The company *LightOn* already has a device on the market. It performs large scale, random (but repeatable) matrix multiplications using freespace optics. Similarly, Lin, Rivenson, Yardimci, et al. developed a freespace optics multilayer network for MNIST classification (but fixed, and without any nonlinearities).

Use the system to classify MNIST digits. Use backpropagation to tune the SLM to maximize the discriminability of the output.

It may be good to initially use the camera output pattern as an input to a neural net on a computer, complete with nonlinearities. Then, the SLM will be acting to increase separability of the MNIST digits, somewhat like the LightOn device. It may be possible to later dispense with that component, and have the camera output itself provide the classification, as in the Lin et al. paper.

Outline of work

The last year's capstone team (2021-2022) did excellent work and provides a great springboard for deep investigations of this technology. The hardware system is built,

plus there is a full physical model in software. Using these foundations, this year the capstone team will:

- Optimize learning and performance.
- Examine how the optimal strategies and performance depend on the statistics of the input data / categorization task.
- Characterize the speed of computation, devise approaches for improved speed, estimate what the feasible speed limits are.
- Characterize the energy used in computation, devise approached for reduced energy usage, estimate what the feasible lower limit to energy usage is.
- Examine variations of the configuration, e.g., using the SLM as an amplitude mask instead of a phase mask. Or using a microlens array for further parallelizing computations.

All-optical machine learning using diffractive deep neural networks
X Lin, Y Rivenson, NT Yardimci, M Veli, Y Luo… - Science, 2018

https://lighton.ai