Polaritonic Neuromorphic Computing Outperforms Linear Classifiers

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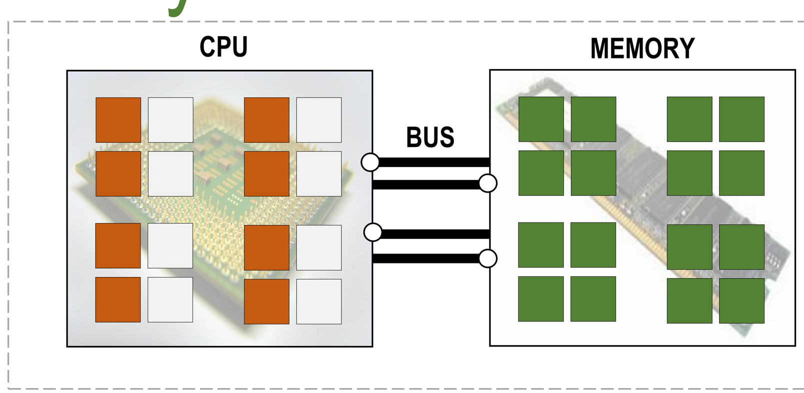
[1] Nano Lett. 20, 3506−3512 (2020)

ABSTRACT: Machine learning software applications are ubiquitous in many fields of science and society for their outstanding capability to solve computationally vast problems like the recognition of patterns and regularities in big data sets. In spite of these impressive achievements, such processors are still based on the so-called von Neumann architecture, which is a bottleneck for faster and power-efficient neuromorphic computation. Therefore, one of the main goals of research is to conceive physical realizations of artificial neural networks capable of performing fully parallel and ultrafast operations. Here we show that lattices of exciton-polariton condensates accomplish neuromorphic computing with outstanding accuracy thanks to their high optical nonlinearity. We demonstrate that our neural network significantly increases the recognition efficiency compared with the linear classification algorithms on one of the most widely used benchmarks, the MNIST problem, showing a concrete advantage from the integration of optical systems in neural network architectures. [1]

1. INTRODUCTION

1.1 Why do we need neuromorphic computing?

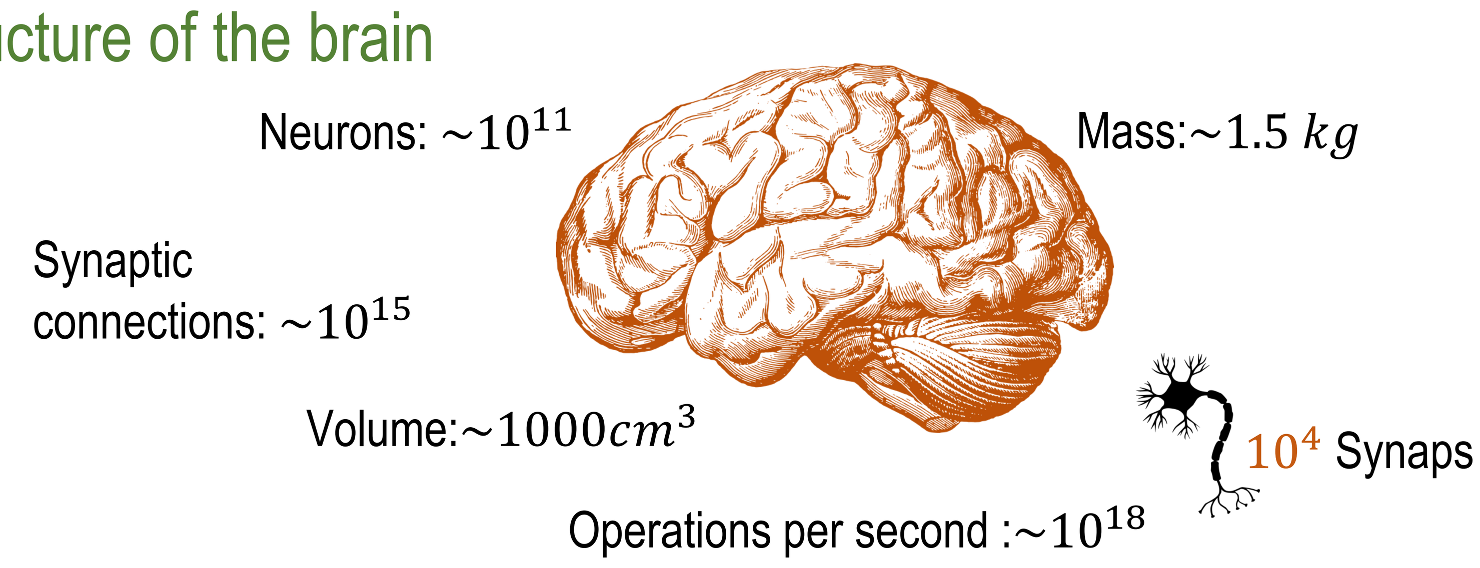


Arithmetic logic unit
Control unit
Memory unit

Limit: The capacity of channels connecting working memory and the central processing unit is limited.

„von Neumann Bottleneck"

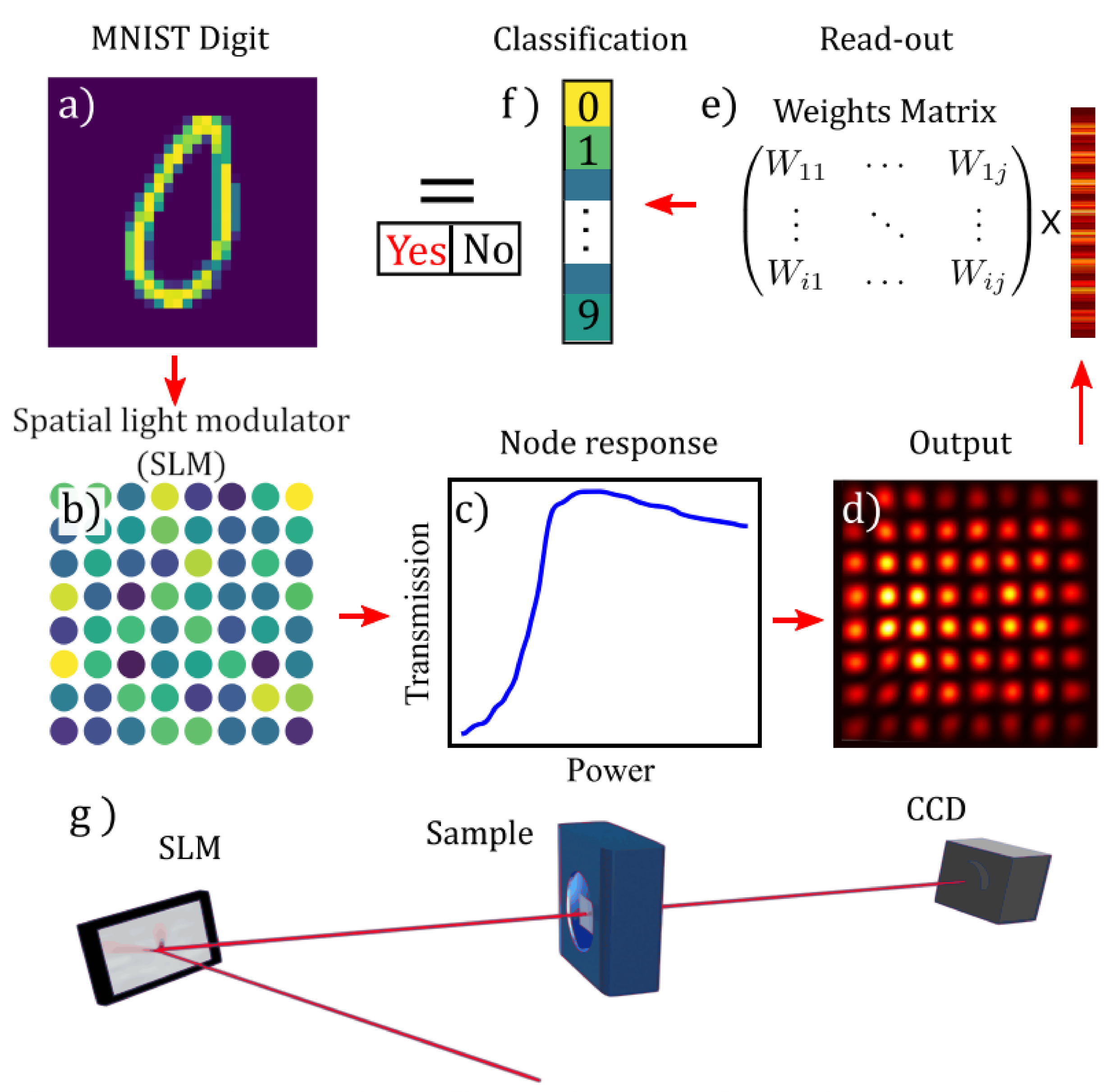
Structure of the brain



The limitations of modern electronics, manifesting with the end of the applicability Moore's law, became one of the most important global problems. Arguably, the best solution to avoid the technological impasse is using modern computing methods inspired by biological systems, which go beyond by the conventional computing architecture. One of the most promising ways to further technological progress is to use optoelectronic systems in information processing. Recent research has shown that the network of exciton- polariton condensates (in short polaritons) provide a perspective for creating a unique platform for the implementation of the brain-inspired neuromorphic computing.

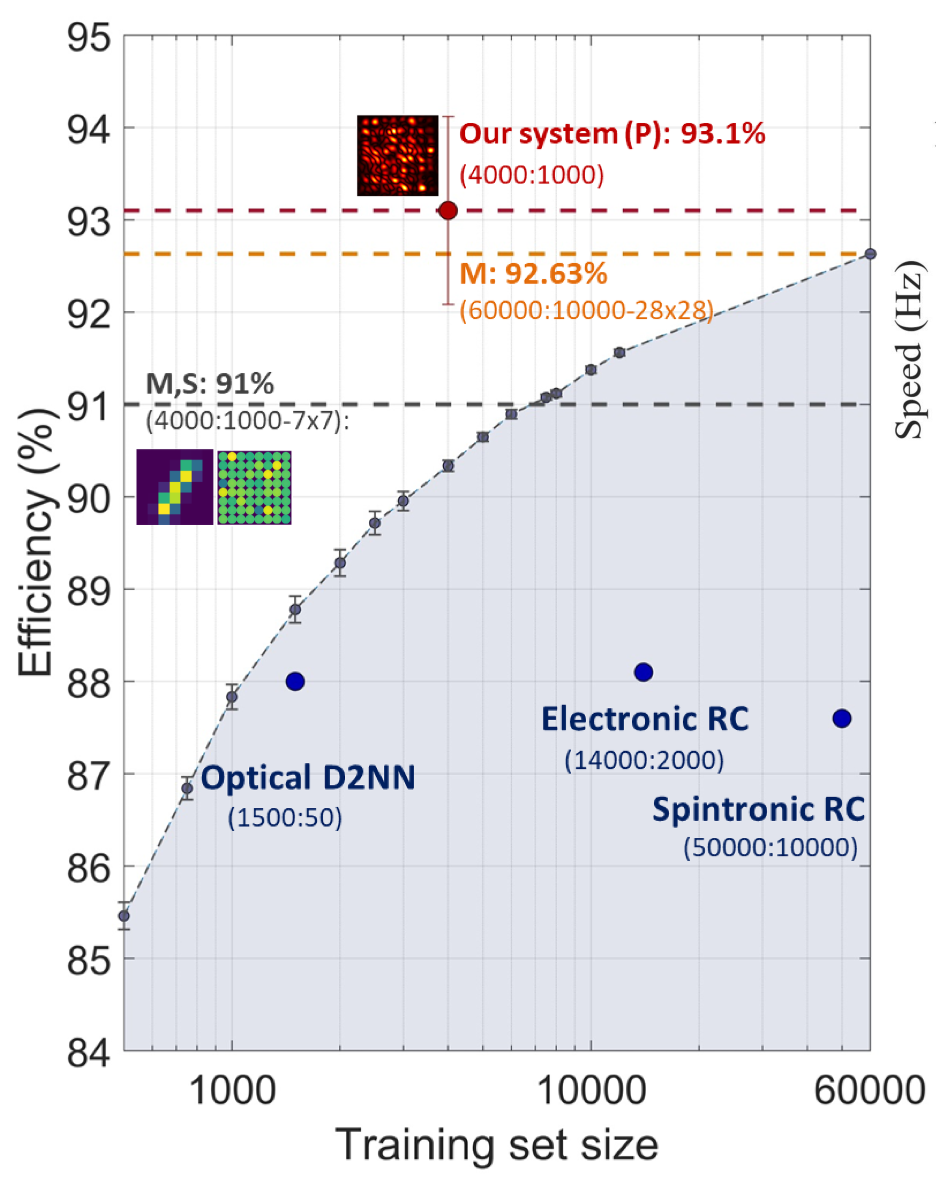
2. RESULTS

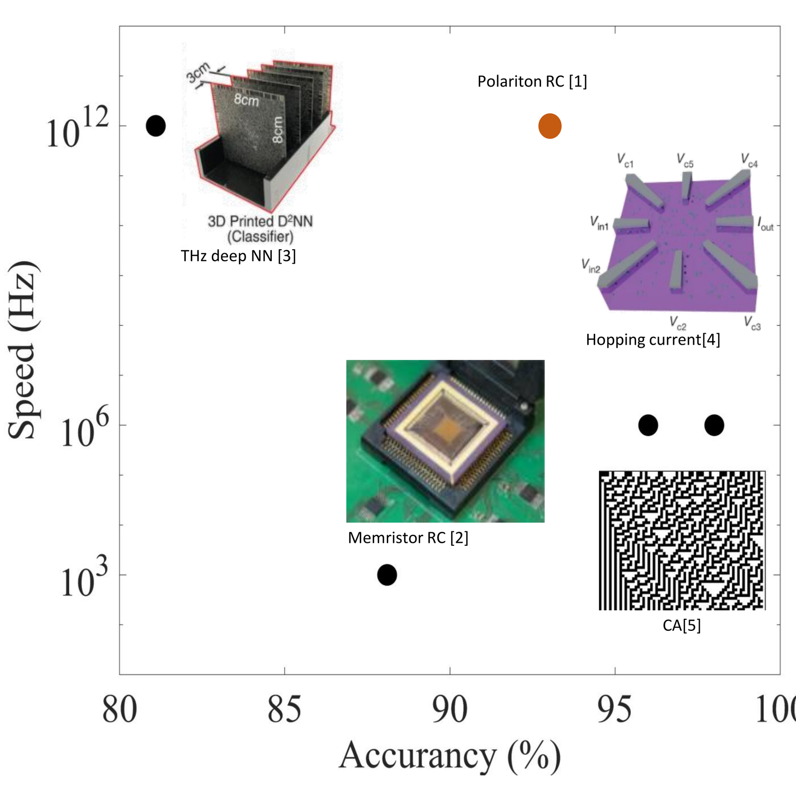
2.1 Scheme of the experimental configuration



Scheme of the experimental configuration. (a) An index j is assigned to each pixel of an $n \times n$ input image, such that the input intensities are a_j. These inputs are multiplied by an $64 \times n^2$ sparse random matrix, giving the input as $b_i = W_{ij} a_j$. Here i indexes different pixels of an 8×8 image that is directly coupled to the 8×8 sites of the reservoir. The same procedure is used for all input images. (b) The resulting data set is sent to the SLM to pattern the laser beam. The nonlinear transmission (c) of the polariton RC produces an output (d), which is recorded by a CCD camera and multiplied by the weight matrix (e) to obtain the digit classification (f). (g) Scheme of the experimental setup corresponding to the steps described in (b–d). [1]

2.2 Comparison of Different Hardware Neural Network Performance on MNIST dataset





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system	MNIST	training	testing	resolution	speed
polariton RC	93%	4000	1000	7×7	THz
memristor RC	88.1%	14000	2000	28×28	kHz
THz deep NN	81%	1500	50	28×28	THz
hopping current	96%	60000	10000	28×28	MHz
FPGA ReCA	98%	60000	10000	22×20	MHz

3. CONCLUSION

In conclusion, neuromorphic computing in a physical network of multiple connected nonlinear nodes is demonstrated. We show that exciton-polaritons are a suited system thanks to their mixed light−matter components: polariton− polariton interactions bring the desired nonlinearities, while the photonic component assures the connectivity between nodes and high operational speeds. We measured the recognition efficiency on the MNIST data set and found a significant increase in the accuracy with respect to linear classifiers and previous examples of photonic Neural networks. We note that a further increase in the recognition rate can be obtained in polariton networks by exploiting the spin degree of freedom and the phase difference between nodes. With larger polariton arrays, success rates comparable to software implementations of reservoir models can be achieved with present technologies, moving toward a realistic integration of applied artificial intelligence based on optical systems. [1]