Elmore Family School of Electrical and Computer Engineering

All-Optical Neural Networks for Artificial Intelligence

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Abstract Computer-based artificial neural networks with large number of neurons and interconnections require huge computational resources and power consumption. While there are many efforts to pursue the development of AI electronic chips with various architectures [1, 2], such as Google Tensor Processing Units (TPU) and IBM TrueNorth, all-optical implementation of AI modules would provide an alternative and much more powerful solution because of its intrinsic parallelism, high-speed computation (at the speed of light), and potential low energy consumption [3]. However, the experimental realization of massive optical nonlinear activation functions, which are necessary for deep machine learning, remains the bottleneck for pushing hybrid optical-electronic neural networks towards all-optical implementation. Here, we demonstrate the first fully functional multi-layer all-optical neural network (AONN) scheme with tunable linear optical operations and nonlinear optical activation functions [4]. The linear operations are realized using spatial light modulators and Fourier optics. The optical nonlinear activation functions are realized with electromagnetically induced transparency in an atomic ensemble. The AONN system is error-tolerant and scalable due to the independence of errors from different neurons [5]. As examples of application, we applied a two-layer AONN for classifying different phases for a prototypical Ising model in condensed matter physics [4], recognizing handwritten digits and fashions [5], as well as performing photonic qubit quantum-state tomography [6]

[1] A. Shafiee, et al. "ISAAC: a convolutional neural network accelerator with arithmetic in crossbars," Proc. ISCA 43, 14–26 (2016). [2] J. Misra and I. Saha, "Artificial neural networks in hardware: a survey of two decades of progress," Neurocomputing 74, 239–255 (2010). [3] L. de Marinis, M. Cococcioni, P. Castoldi, and N. Andriolli, "Photonic neural networks: a survey," IEEE Access 7, 175827—175841 (2019). [4] Y. Zuo, B. Li, Y. Zhao, Y. Jiang, Y.-C. Chen, P. Chen, G.-B. Jo, J. Liu, and S. Du, "All-optical neural network with nonlinear activation functions," Optica 6, 1132 (2019). [5] Y. Zuo, Y. Zhao, Y.-C. Chen, S. Du, and J. Liu, "Scalability of all-optical neural networks based on spatial light modulators," Phys. Rev. Applied 15, 054034 (2021). [6] Y. Zuo, C. Cao, N. Cao, X. Lai, B. Zeng, and S. Du, "All-optical neural network quantum state tomography," Adv. Photonics 4, 02604 (2022).

Bio Dr. Shengwang Du is currently a Professor of Physic and the Francis S. and Maurine G. Johnson Chair at The University of Texas (UTD) at Dallas. Prior to joining UTD in 2021, he was a Professor of Physics and Professor of Chemical and Biological Engineering, and the Director of Super-Resolution Imaging Centre, at The Hong Kong University of Science and Technology; and an elected member of The Hong Kong Young Academy of Sciences. Dr. Du's interdisciplinary and cross-field research activities range from fundamental quantum physics to applied optical engineering, including AMO physics, quantum optics, atom chip and atomtronics, quantum networks, quantum computing, quantum sensing, optical neural networks for artificial intelligence, optical microscopy for solid mechanics and bioimaging. Dr. Du's PhD work on atom chips made an important contribution to the start-up of ColdQuanta, now a leading company in cold atom technologies and neutral atom quantum computing. Dr. Du is a co-founder of the Light Innovation Technology USA Inc for developing and commercializing advanced optical microscopies and bioimaging techniques. Dr. Du is a Fellow of The American Physical Society (APS) and of Optica (formerly The Optical Society of America - OSA).

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