<u>Project title:</u> Probabilistic machine learning with self-configuring arrays of Mach-Zehnder interferometers

<u>Supervisor:</u> Dr. Charles Roques-Carmes (Stanford University)

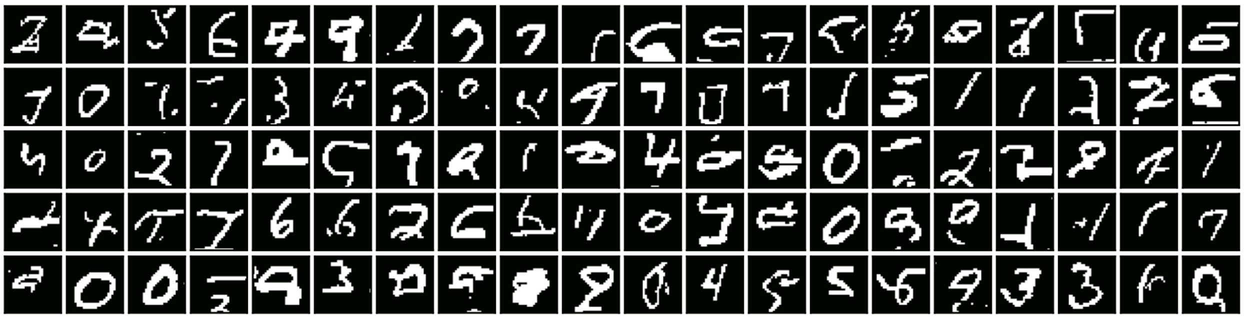

Figure: One hundred MNIST images generated using quantum noise as a random seed in a generative neural network. Reproduced from [1].

Classical and quantum light can be used for information processing. By encoding information into optical degrees of freedom (amplitude, phase, frequency, polarization, spatial mode, etc.), and by mixing beams of light together, one can realize various computational tasks, with applications across machine learning [2] and combinatorial optimization [3].

Noise is present in all photonic systems and is typically considered to be detrimental for computational tasks (e.g., reducing the computational accuracy). In various tasks, such as combinatorial optimization, Bayesian machine learning, and probabilistic modeling, noise can be used as a computational resource [3-5].

This project is aimed at exploring the implementation of probabilistic machine learning methods (e.g., Boltzmann machines) for generative and discriminative tasks in integrated photonics. The system to be studied is an array of Mach-Zehnder interferometers, which is a well-established platform for coherent light processing (with a recent proposal for partially coherent light processing [6]), pumped with partially coherent classical or quantum light. The expected outcome of the project is a proposal for implementing probabilistic machine learning tasks using reconfigurable Mach-Zehnder interferometer arrays pumped by partially coherent light. This proposal might lead to experimental realization at Stanford University or with other collaborators.

The project will be a mix of theoretical and numerical endeavors (about 50:50) and you will meet the research supervisor periodically over Zoom (with the possibility of meeting in person when the supervisor is in France). The candidates are expected to have a solid background in physics (especially optics and quantum mechanics) and/or machine learning.

If you are interested, please reach out directly to Charles Roques-Carmes (chrc@stanford.edu) with a copy of your resume and a short paragraph describing your general research interests.

Relevant references:

[1] Choi, S., Salamin, Y., Roques-Carmes, C., Dangovski, R., Luo, D., Chen, Z., Horodynski, M., Sloan, J., Uddin, S.Z. and Soljacic, M., 2024. Photonic probabilistic machine learning using quantum vacuum noise. arXiv preprint arXiv:2403.04731.

[2] Wetzstein, G., Ozcan, A., Gigan, S., Fan, S., Englund, D., Soljačić, M., Denz, C., Miller, D.A. and Psaltis, D., 2020. Inference in artificial intelligence with deep optics and photonics. Nature, 588(7836), pp.39-47.
[3] Roques-Carmes, C., Shen, Y., Zanoci, C., Prabhu, M., Atieh, F., Jing, L., Dubček, T., Mao, C., Johnson, M.R., Čeperić, V. and Joannopoulos, J.D., 2020. Heuristic recurrent algorithms for photonic Ising machines. Nature communications, 11(1), p.249.
[4] Roques-Carmes, C., Salamin, Y., Sloan, J., Choi, S., Velez, G., Koskas, E., Rivera, N., Kooi, S.E., Joannopoulos, J.D. and Soljačić, M., 2023. Biasing the quantum vacuum to control macroscopic probability distributions. Science, 381(6654), pp.205-209.
[5] Srivastava, N., Hinton, G., Krizhevsky, A., Sutskever, I. and Salakhutdinov, R., 2014. Dropout: a simple way to prevent neural networks from overfitting. The journal of machine learning research, 15(1), pp.1929-1958.
[6] Roques-Carmes, C., Fan, S. and Miller, D., 2024. Measuring, processing, and generating partially coherent light with self-configuring optics. arXiv preprint arXiv:2402.00704.