Training Polariton Stuart-Landau Oscillatory Neural Networks via Equilibrium Propagation

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Neuromorphic computing architectures inspired by the brain's efficiency have gained significant attention [1], with oscillatory neural networks (ONNs) offering a promising alternative due to their synchronization dynamics and variety of physical systems showing oscillatory behaviour [2]. In this work, we propose a Stuart-Landau oscillatory neural network (SLONN) as sketched in Fig. 1(a), based on a fully connected lattice of exciton-polariton condensates (polaritons herein) [3], see Fig. 1(b). The network is trained using Equilibrium Propagation (EqProp) [4], an energy-based learning optimisation algorithm that does not rely on traditional backpropagation pathways for error correction during training. The EqProp approach optimizes the weight connections between neurons, which can be experimentally performed by tuning condensate couplings through spatial light modulators or imprinted optical barriers [5, 6]. Unlike approaches based only on phases of coupled condensates, our method leverages the final output on condensate amplitudes, simplifying experimental realization through photoluminescence measurements in well-established polariton condensate microcavities. Both training and inference can be achieved by all-optical means only. Our findings demonstrate high classification accuracy for XOR and MNIST benchmarking machine learning tasks, with only seven neurons, highlighting the efficiency of polariton-based neural networks for machine learning applications.

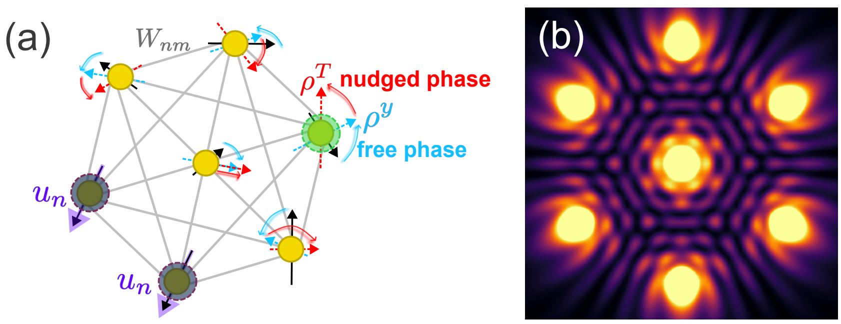

Figure 1: **(a)** SLONN scheme with EqProp training. The network consists of seven all-connected neurons (yellow circles), with connections W_{nm} (grey lines). Black arrows indicate oscillators with different initial amplitudes and phases. Two neurons are biased by u_n to drive their initial amplitudes (input units), and a dashed green circle marks the output unit. In the free phase, the system relaxes to equilibrium (blue arrows). In the nudged phase, the output unit amplitude ρ^Y is weakly perturbed towards the target ρ^T, shifting the energy equilibrium configuration (red arrows) slightly. The difference between these two equilibria states allows to optimise W_{nm} and train de system. **(b)** An example of polariton condensate lattice that can be used as a platform for our proposal. The image shows the real-space condensate density numerically obtained from Gross-Pitaevskii equations.

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