Nonlinear photonics machine learning with exciton polaritons

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Photonics provides a powerful platform for machine learning, offering ultrafast processing and high-bandwidth for information encoding [1]. The incorporation of nonlinearity enhances computational capabilities, enabling more efficient and expressive learning architectures. Exciton polaritons, as hybrid light-matter quasiparticles, naturally introduce strong nonlinearity while retaining the advantages of photonic propagation. This combination makes polaritonic systems a promising candidate for advanced machine learning tasks, particularly in scenarios where nonlinear interactions play a key role in data processing.

In the series of works, we explore several problems where exciton-polaritons facilitate machine learning applications. First, we investigate graph-based problems using polaritonic machine learning. By considering optically pumped polaritonic lattices, we demonstrate that polaritonic feature selection can effectively identify cliques in various graphs. This enables classification of different graph configurations based on the intrinsic nonlinear response of the system, illustrating how physical interactions can naturally encode complex graph structures (Fig. 1). Importantly, the results highlight the separation between nonlinear and linear systems in terms of generalization — features that emerge in nonlinear photoluminescence allow better training for smaller datasets [3].

Next, we study photonic circuits designed for graph classification based on positional embeddings. Here, spectroscopic properties of the polaritonic system serve as features that encode structural information about the graph. By using the spectral response of nonlinear photonic modes and correlation functions between the modes, we show that these circuits can distinguish different graph topologies, providing a robust and scalable method for graph classification in photonic architectures. We apply the approach to photonic lattices where hopping terms model relevant graphs, and test on datasets with molecular structures, as recently done with atomic quantum walks [3].

Finally, we explore generative modeling within nonlinear photonics, focusing on both the quantum and quasi-classical regimes. The motivation comes for the boson sampling experiments [4], which show promise in terms of complexity of in silico sampling on the contrary to physical device implementations. We investigate how photodetection can be used to sample from complex distributions and transform them into relevant datasets. This approach uses the intrinsic stochasticity and nonlinearity of exciton-polariton systems to generate structured data, offering a new tool for machine learning applications. Collectively, these results highlight the promise of polaritonic and nonlinear photonic machine learning for solving selected computational problems with enhanced efficiency and scalability.

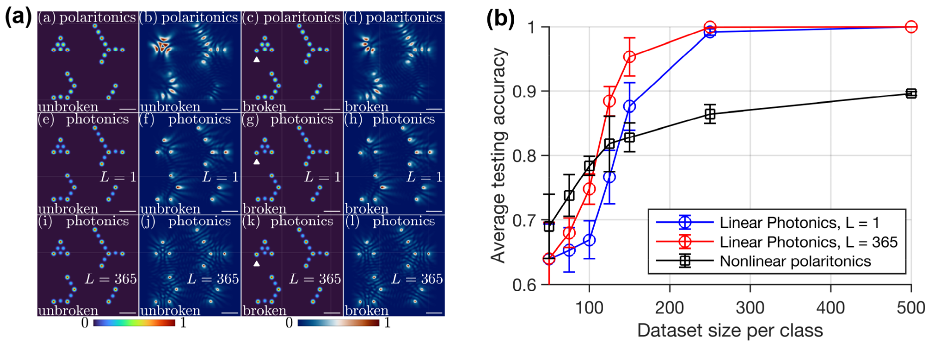

Figure 1: (a) Polaritonic and photonic (linear) photoluminescence profiles as feature selectors for graph problems. (b) Generalization of polaritons as limited dataset size.

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