The proposed project aims to develop a theoretical understanding of the effects of quantum phenomena in optical neural networks and design their optimal physical implementations. Recent decades have witnessed an incredible progress in communications, information processing, and mobile technologies. The amount of easily available data has surged, leading to the era of big data. The need to process an exponentially increasing amount of information was accompanied by a substantial progress of parallel computing, and in artificial intelligence and neural networks in particular. Nowadays, machine learning and artificial intelligence are an important part of the economy, and are widely used in natural language processing, image and sound recognition, autonomous vehicles, finance, marketing, and research. However, these data- and power-hungry algorithms put a strain on computing systems, which have to fulfill the requirements of fast and efficient data processing. The overall energy consumption of information processing and communication systems is rapidly increasing. It is expected to reach over 20% of global electricity use by 2030, and possibly even 50% in the pessimistic scenario. Consequently, there is an urgent need to develop new technological platforms that will allow us to process data in a more efficient way. Among the existing proposals, optical neural networks and quantum computing systems are particularly promising candidates.

In the first task of the project, we aim to study quantum effects in optical neural networks at the single photon level and below. It was recently demonstrated that information processing using less than one photon per operation is possible in optical neural networks. Implementation of this idea in practical devices could lead to enormous improvements in energy efficiency. So far the existing proposals are based on optoelectronic devices which are inherently limited by the electronic component. We will investigate the possibility of implementing optical neural networks in all-optical systems, and their potential advantages in terms of speed and energy.

In the second task, we will investigate physical neural network implementations in exciton-polariton systems. We recently demonstrated that among the possible platforms for all-optical information processing, microcavity exciton-polaritons are particularly promising in terms of the fundamental limits of speed and energy efficiency. We aim to develop physical implementations of polariton neural networks by extensive theoretical analysis and numerical modeling. This task will be performed in close collaboration with experimental groups. We will develop possible designs for large scale networks, and determine the effects of sample disorder and node cross-talk.

The third tasks considers the so-called quantum reservoir computing. This idea extends artificial neural networks to the quantum regime. The system contains a network of quantum nodes connected by static, non-trainable connections. Despite its simplicity, it was demonstrated that quantum reservoir computing can be used to realize a wide range of quantum and classical machine learning tasks with very high accuracy. In this project we aim to extend these studies to large scale systems of many nodes by employing the positive-P phase space method, which we recently developed. We will use it to model a quantum reservoir realizing challenging quantum tasks such as quantum state tomography, quantum state classification, quantum state generation, and simulation of large-scale quantum circuits.

Although the project is aimed at fundamental research, it has wide potential economic and societal benefits. Overcoming the slowdown of efficiency of computational devices is a necessity, given the pace of the development of the modern world. It is clear that photonic technology and quantum computing are among the most promising candidates for such applications. If optical neural networks enter the market, they could increase the speed and reduce energy consumption by orders of magnitude with respect to electronic devices. Moreover, fast and energy efficient optical neural networks could be used in edge devices where resources are limited or connection to the cloud is not always available, such as smartphones, autonomous cars, medical equipment. Quantum computing could be used to solve problems that are not possible to solve currently. For example, quantum chemistry simulations and the development of new drugs and advanced materials requires computational power that often is beyond the capabilities of traditional computing systems.