Neuromorphic computing with quantum fluids of light

Description for the general public:

One of the most important global problems is searching a technological solution allowing to avoid the impasse associated to the limitations of modern electronics, manifesting in the end of Moore's law applicability. Modern computational methods inspired by biological systems, going beyond of the conventional computing architecture, may prove a proper direction to enabling further technology development. Recent research has shown that the one of the most promising way to further technology progress is to use so called neuromorphic system inspired by the human brain architecture. However, a platform that ensures the implementation of such systems in an efficient ultra-fast and energy-efficient manner is still searched. In this project, we meet the challenges of modern technology and describe real physical system that can provide ideal conditions for neuromorphic computing.

The goal of this project is to investigate a new type of neural network that can be realized using quantum states of matter, such as exciton polariton condensates. Exciton polaritons are quantum particles with unique properties resulting from the interaction of light and matter. The process of creating polaritons can be observed in specially designed semiconductor microcavities in which the quantum of light - photons strongly interact with the elemental excitation of the semiconductor crystal - exciton. Exciton polaritons behave like the famous "Schrödinger cats" being a quantum of light and excitation of matter in the same time. Due to their hybrid nature, they purchase unique properties inaccessible to other quantum particles in semiconductor crystals - they are extremely light and at the same time can interact strongly with each other.

Additionally exciton polaritons are bosons and tend to occupy the same quantum states with the probability distribution which increases with the number of bosons. Bosons in the low-density limit do not feel each other's presence and we can treat them as particles of an ideal gas. However, when the density of bosons in the system becomes large and the temperature of the system is low, the particles begin to feel each other. The dominant role in the system is played by quantum mechanical effects related to the wave-particle duality phenomena. We treat such system as a single collective quantum wave state, not as a collection of individual particles. The collective state of many bosons system can be compared to a liquid or gas state, in which we can observe effects available only in the quantum world, such as spontaneous creation of quantum vortices. Quantum polariton liquids by their dual nature, also called quantum light liquids can be "poured" into variously shaped structures whose shape may resemble a network of cells. The dynamics of the quantum liquid is then strongly spatially limited, but it can be used in an innovative way, which is the construction of artificial neural networks inspired by the human brain.

The artificial neural network, like biological systems, consists of neurons. Such neurons are connected to each other and their systems can also form layers. By choosing appropriate weights between connections of individual layers, we can "teach" such a network to perform various tasks. We can use the neural network, for example, to recognize images, predict and reproduce signals, analyse and look for similarities in large data sets. The aim of the project is to use quantum liquid states, to generate a new type of neural networks, and examine their basics properties. *The systems studied in the project constitute a completely new class of neural networks, which in the future may outperform electronic circuits.*