LABORATOIRE DE PHYSIQUE ET MODELISATION
DES MILIEUX CONDENSES – UMR 5493

PhD thesis proposal

Subject: **Theory of quantum reservoir computing with light in random media**
Laboratory: Laboratoire de Physique et Modélisation des Milieux Condensés (LPMMC UGA/CNRS)
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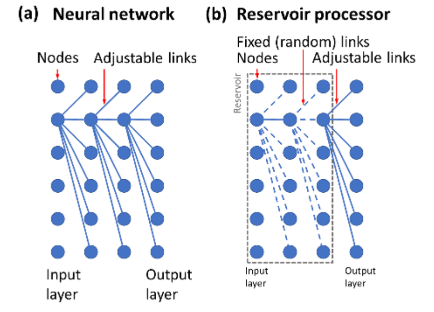

Fig. 1 Schematic representations of a neural network **(a)** and a reservoir processor **(b)**. All the nodes of a given layer are linked with all the nodes of the next layer, but links are explicitly shown in the figure for one node only. In contrast to the neural network, the most of the links between nodes of the reservoir processor are fixed and only the links of the last layer can be adjusted (trained).

Context: The concept of reservoir computing builds on the general idea of neural networks – ensembles of nodes connected by links [1]. The signal received by each node is given by a weighted sum of (nonlinear) functions of the signals on all other nodes. Nodes of neural networks are often separated in layers and the links are assumed only between nodes of consecutive layers; propagation of the signal is assumed in one direction only, see Fig. 1a. A neural network is fed with an input signal at the input layer and the result of the calculation performed by the network is read from the output layer. By adjusting the weights of the links, the network is trained to perform the desired computational task.

In *reservoir computing*, one preserves the complexity of the neural network as a whole but restricts the possibility of training to the last layer only, see Fig. 1b [2]. Because it is not necessary to be able to control the weights of the internal links of the network, the latter can be replaced by an arbitrary complex, random physical system (a "reservoir") with the only requirement for the system to be "complex" enough to mix all the input signals in a nontrivial way. In *quantum reservoir computing*, the nodes and the links become quantum and the complex dynamics of the resulting quantum system is harnessed to perform quantum computational tasks: recognition of an entangled state or estimation of nonlinear functions of it, for example [3–5]. Quantum reservoir computing is a part of a wider and rapidly developing research area of quantum neuromorphic computing [6] that aims at combining principles of information processing in the brain with quantum physics to propose a new paradigm of quantum information processing.

This project: We propose to consider a large ensemble of cold (immobile) atoms located at random positions and coupled by the electromagnetic field as a physical realization of a quantum reservoir processor. Such a system is known to exhibit a number of interesting physical phenomena: Anderson localization of light [7], random lasing [8], formation of photonic band gaps [9], topological phenomena [10] etc. We want to explore the potential of these phenomena in the context of quantum reservoir computing where only much simpler systems (e.g., systems of qubits with nearest-neighbor couplings) are most often considered. For example, the strongly nonlinear dynamics of a random laser operating above the lasing threshold or strong interactions between atoms in a dense atomic cloud may open new opportunities that we wish to explore theoretically.

Candidate: Successful candidate should have a taste for theoretical physics, analytical calculation skills, and a minimum of experience in numerical calculations.

Bibliography

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