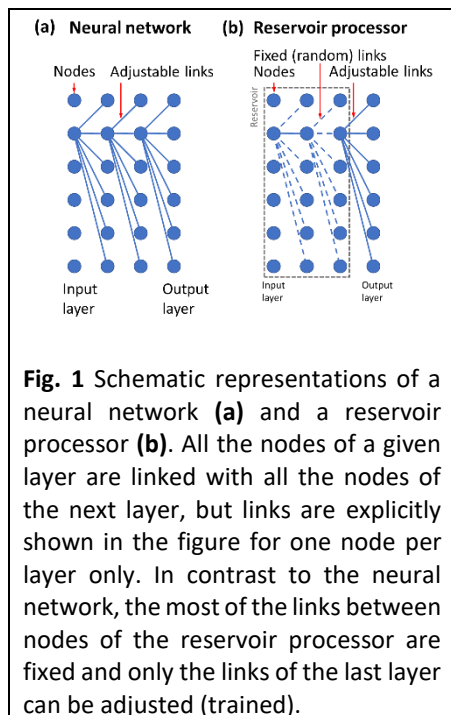


M2 internship proposal

Subject: Theory of quantum reservoir computing with cold atoms
Laboratory: [Laboratoire de Physique et Modélisation des Milieux Condensés \(LPMMC UGA/CNRS\)](#)
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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 an ensemble of cold (immobile) atoms in free space, coupled by the electromagnetic field, as a physical realization of a quantum reservoir processor. During this internship, ensembles of a few atoms (2-5) will be studied and their computational performance in standard classical computational tasks (prediction of chaotic signals, classification task, etc.) will be characterized. The proposed research will follow the lines of Refs. 7 & 8, but in contrast to Ref. 7, no external cavity will be involved, whereas in contrast to Ref. 8, the full quantum treatment of the atomic system will be attempted. For this purpose, the intern will use a number of theoretical and numerical tools: density matrix, optical Bloch equations, Lindblad master equation, etc. Differential equations for correlators of atomic operators will have to be derived and solved numerically. The quantum-optics aspect of the problem will be combined with concepts from machine learning (training, benchmarking, error analysis, etc.).

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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