Time-Series Processing with Quantum Measurements

Pere Mujal
Rodrigo Martínez-Peña, Gian Luca Giorgi, Miguel C. Soriano, and Roberta Zambrini

IFISC, Institut de Física Interdisciplinària i Sistemes Complexos (UIB-CSIC), UIB Campus, E-07122 Palma, Mallorca, Spain

peremujal@ifisc.uib-csic.es

Reservoir computing has a remarkable advantage over other supervised learning strategies, i.e. recurrent neural networks, since the training process is simpler and faster. The extension of this unconventional computing method to the quantum domain, firstly proposed in [1], adds benefits to this feature. Quantum systems are notorious for their large state space entailed by the principle of quantum superposition and by the possibility of displaying entanglement between their constituents. Quantum reservoir computing and related approaches harness these features and exploit the natural dynamics of quantum systems for computational purposes to perform a wide variety of machine-learning tasks, both classical and quantum [2]. In the last few years, there has been an increasing interest in this field that has led to the development of proposals suitable for various quantum platforms [2–4]. Additionally, recent theoretical studies have elucidated how to design and operate quantum reservoirs in order to maximize their performance. For instance, through the input encoding [5], by choosing an appropriate dynamical regime [6], or by analytically showing the origin of the required nonlinearities for qubits and continuous-variable systems [7]. A still challenging aspect is to consider measurement effects. Quantum systems are infamous for the crucial influence of measurements on their quantum state which could be detrimental for information processing purposes. Typically, a time-dependent input series is encoded into and processed by the quantum reservoir and the observable quantities of the system are used to produce the final output to address the task at hand. It is commonly assumed that, experimentally, the system will need to be restarted several times to be measured, or, alternatively, many copies of the system should be accessed. We propose various measurement strategies to tackle this problem which can be followed in order to obtain the expectation values of the observables at each time step [8]. Importantly, the best choice may depend on the specific features of the experimental platform or the task. We discuss this question from a fundamental point of view accounting for the backaction effect of the measurements on the system, and also from a practical perspective, i.e. with a finite number of measurements available. By means of numerical simulations, we analyze the impact of the measurement procedure into the performance of a quantum reservoir of spins in terms of memory and predictive capacity with a focus on the required experimental resources.

References

[1] K. Fuji, K. Nakajima, Phys. Rev. Applied 8, 024030 (2017).
[2] P. Mujal, R. Martínez-Peña, J. Nokkala, J. García-Beni, G. L. Giorgi, M. C. Soriano, R. Zambrini, Adv. Quantum Technol., 2100027 (2021).
[3] S. Ghosh, A. Opala, M. Matuszewski, T. Paterek, T. C. Liew, npj Quantum Inf. 5, 1 (2019).
[4] J. Chen, H. I. Nurdin, N. Yamamoto, Phys. Rev. Applied 14, 024065 (2020).
[5] J. Nokkala, R. Martínez-Peña, G. L. Giorgi, V. Parigi, M. C. Soriano, R. Zambrini, Comm. Phys. 4, 1 (2021).
[6] R. Martínez-Peña, G. L. Giorgi, J. Nokkala, M. C. Soriano, R. Zambrini, Phys. Rev. Lett. 127, 100502 (2021).
[7] P. Mujal, J. Nokkala, R. Martínez-Peña, G. L. Giorgi, M. C. Soriano, R. Zambrini, J. Phys. Complex. 2, 045008 (2021).
[8] P. Mujal, R. Martínez-Peña, G. L. Giorgi, M. C. Soriano, R. Zambrini, [In preparation, soon in arXiv] (2022).