Quantum reservoir computing with Gaussian states

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Abstract. We establish the potential of continuous-variable Gaussian states in performing reservoir computing with linear systems. Reservoir computing is a machine learning approach to processing of temporal signals. It exploits the computational power, high-dimensional state space and memory of generic complex systems to achieve its goal, avoiding the need for precise engineering. We prove that universal reservoir computing can be achieved without requiring non-linearity or non-Gaussianity resources, show that universal reservoir computing can be powered by quantum fluctuations such as squeezed vacuum and demonstrate how information processing can be tuned by just changing the input encoding while keeping the reservoir fixed.

Keywords: quantum optics, machine learning, unconventional computing

Extended abstract. Observables of physical systems driven by time-dependent inputs can become functions of the input history. The central principle behind reservoir computing is to exploit this by combining the observables with a simple readout function to achieve nontrivial information processing, such as real-time speech recognition or chaotic time series prediction. Since both the memory of past inputs and bulk of the processing is offloaded to the reservoir this can potentially lead to extremely compact and energy efficient reservoir computers. In recent years proposals have been made to harness the dynamics of quantum systems for reservoir computing [1-6]. In our work, available online at [7], we establish the potential of continuous-variable Gaussian states for reservoir computing in a quantum framework, going beyond previous optical approaches in the classical regime [8-11].

We consider linear networks of interacting quantum harmonic oscillators. The classical input is injected into the network by periodically resetting the state of one of the oscillators—the ancilla—while the rest of the network plays the role of the reservoir. The output is a function of the first and second moments of reservoir operators. The scheme is depicted in Figure 1. Measurement back-action is not considered; addressing the role of measurements is still a mostly open challenge for quantum reservoir computing and outside of the scope of present work. We analyse the proposed model using contemporary reservoir computing theory.

We show that the proposed model is universal, i.e. any continuous function of a finite number of past inputs can be approximated. We show that the encoding of the input to states of the ancilla acts as both a source and means to control the reservoir memory. Finally, we show that reservoir computing with nonclassical states retains both the power and versatility of, e.g., coherent states. Our results introduce a new research paradigm for the fledgling field of quantum reservoir computing and the engineering of Gaussian quantum states. Using Gaussian states brings the model within experimental reach. Possible follow-up research includes experiments, going beyond classical temporal tasks and exploring the potential benefits of experimentally feasible non-Gaussian operations.

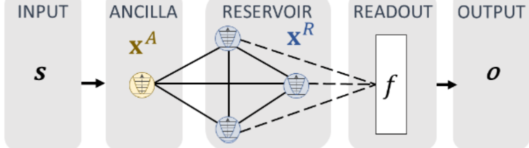

Figure 1 Reservoir computing scheme. Periodical state resets of the ancilla inject the time-dependent input into the reservoir. The output is a simple function of reservoir observables, trained to realize a desired input-output map.

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