Variational Waveguide-QED simulators

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Variational Quantum Algorithms (VQAs) [1] use a classical optimizer to train a parametrized quantum circuit (PQC). These have emerged as a practical way to exploit state-of-the-art quantum computers. Currently, most VQAs have been designed for fully digital approaches, in which the error ends up accumulating for circuits with many parameters. A possible way out is the use of analogue quantum simulators (AQS) instead. AQS allow a global evolution of the system and are more resilient to errors. This is why they have been recently pointed out as one of the most promising directions to achieve "practical quantum advantage" [2]. However, current proof-of-principle demonstrations with trapped ions [3] and cold atoms [4], as occurs with fully digital VQAs, are ultimately limited by the connectivities that can be achieved with these devices.

In this work we discuss a variational AQS inspired by the tunable range interactions that can be obtained in waveguide-QED platforms [5]. We show that by using the range of the interaction as a variational parameter one can design a novel class of PQCs. We compare their performance against state-of-the-art VQAs with fixed connectivities, and demonstrate that they can accurately capture the ground state of critical spin models with fewer gates and variational parameters. In summary, our results highlight the potential of variational waveguide-QED quantum simulators as a promising platform for implementing VQAs.

References

[1] M. Cerezo et al., Nature Review Physics 3, 625-644 (2020).
[2] A. J. Daley et al., Nature 607, 667–676 (2022).
[3] C. Kokail et al., Nature 569, 355 (2019).
[4] C. Kaubruegger et al., Phys. Rev. X 11, 041045 (2021).
[5] C. Tabares et al., arXiv:2302.01922 (2023).

Figures

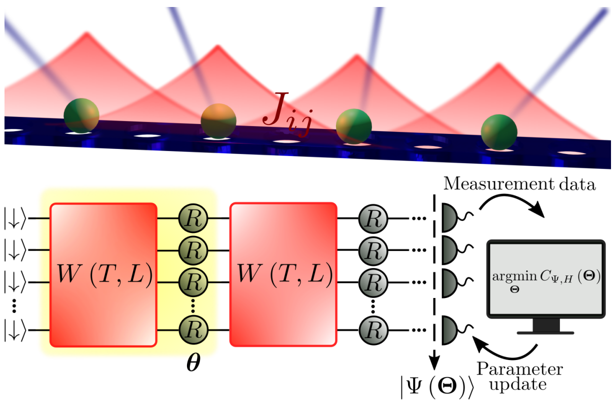

Figure 1: Top: scheme of a possible experimental setup, with quantum emitters addressed with lasers and coupled to a waveguide. Bottom: variational workflow using the analog waveguide-QED interactions.

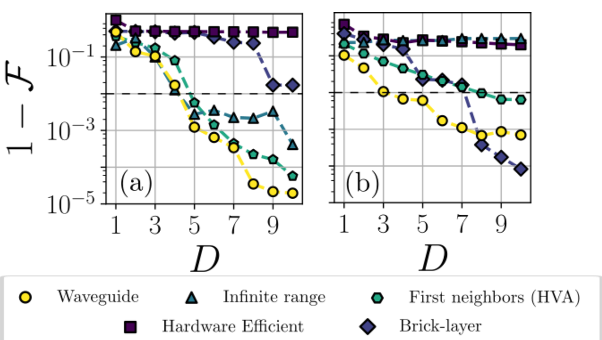

Figure 2: Infidelity between the exact ground state and the variational ones using different ansätze as a function of the layers *D* for the XXZ (a) and transverse-field Ising (b) models at critical regions of their parameter space.