AI discovering Strategies for Quantum Technologies

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The rapid progress of machine learning and artificial intelligence in all branches of science and technology also acts as a catalyst in the domain of quantum technologies. In fact, the goal to build quantum machines and quantum computers of ever-increasing complexity serves as a perfect challenge that can be addressed by this novel toolbox.

In this talk I will give an overview of our recent results in this area. In the domain of quantum error correction, we are showing how the use of reinforcement learning (RL) can help discover novel strategies. Goals like the preservation of a quantum state in the presence of noise are encoded in a reward function and the machine learning algorithm is tasked with discovering from scratch quantum circuits and suitable feedback strategies to help preserve the fragile quantum coherence.

After introducing this line of research in our early article in 2018 (Fösel et al, PRX), we have been working on extending this approach and making it more efficient. Recently, we have shown how one can drastically scale up the discovery of quantum error correction strategies. We are now able to discover encoding circuits and QEC codes as well as fault-tolerant logical state preparation circuits for physical qubit numbers ranging up to 30-40, all while taking into account the connectivity and gate set and error model of a specific hardware platform [1,2,3]. In another development, we have taken first steps towards experimental realizations of RL [4]. This involved implementing a highly optimized neural network on an FPGA with an overall feedback latency of less than one microsecond, and performing RL-training directly on a superconducing-qubit experiment.

While these achievements relied on so-called model-free RL, which is the main approach famously used for applications like games and language-model enhancement, we have recently demonstrated the power of model-based RL for quantum feedback. We have shown how one can extend the widely used GRAPE (gradient ascent pulse engineering) optimization technique from pure quantum control without feedback to the domain of feedback, resulting in a framework we call feedback GRAPE [5]. We have already employed this framework to discover [6] a novel strategy for the stabilization (error correction) of Gottesmann-Kitaev-Preskill states, which are the leading candidate for hardware-efficient bosonic codes.

More generally, AI-based approaches can also help to discover experimental setups. We have contributed to this rapidly developing area by setting up a framework [7] that enables users to discover scattering setups like circulators, non-reciprocal amplifiers etc. Phrasing these tasks in the language of scattering matrices and coupled-mode theory and introducing an efficient comprehensive search algorithm allows us to present a set of irreducible setups that would be able to solve a particular task. These setups can then be implemented in any given hardware platform.

References

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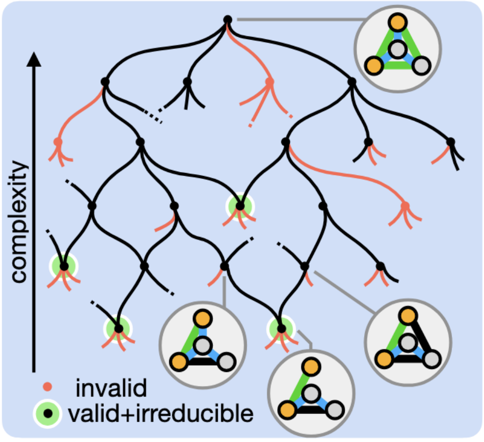

Figures

Figure 1. Automatic discovery of coupled-mode setups: Graph of setups, ranging from complex (top) to simple (bottom), with black nodes representing valid setups that implement a desired scattering functionality.