Performances and limitations of variational quantum algorithms under realistic noise models

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Abstract

We are entering an era where we can achieve increasing control of quantum systems which may pave the way toward many new technologies, like quantum computing. An intriguing question is if the currently available NISQ devices, despite their lack of error correction, can be used to obtain a quantum advantage over classical computation. While in 2019 quantum supremacy for a specific task was shown by Google [1], it remains an open question if the current NISQ devices can deliver a quantum advantage for practical applications. In this regard, promising candidates are the so-called Variational Quantum Algorithms (VQAs). They proceed by using a parametrized quantum circuit to compute a cost function that gets minimized by a classical optimizer. Recently it was shown that a quantum state undergoing a variational quantum circuit with general Pauli noise approaches the completely mixed state with increasing circuit depth [2]. This phenomenon is called "Noise-induced Barren Plateau" and limits the performance of VQAs under noise.
In this ongoing project, we study the question of how variational quantum circuits behave under more realistic noise models, like dephasing or amplitude damping noise. We use the Quantum Approximate Optimization Algorithm (QAOA), which is a specific VQA, to solve combinatorial optimization problems. Considering the problem of MaxCut on d-regular graphs, we run the circuit for many instances of randomly chosen circuit parameters, which means we do not use the optimizer. We find that for weak amplitude damping or dephasing noise the average purity of the output state of the circuit approaches the purity of the completely mixed state while the variance of the purity approaches zero with increasing circuit depth. The decrease of the average purity is well described by an exponential decay, where the decay rate is approximately linear in the noise strength λ. We check this for different d-regular graphs with different qubit numbers.

References

[1] Frank Arute et al., Nature, 574 (2019) 505-510
[2] Samson Wang et al., Nature Communications, 12 (2021),6961

Figures

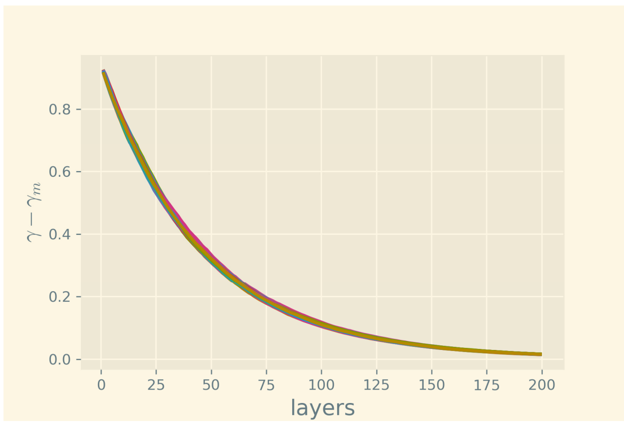

Figure 1: Purity difference between the purity of the output state of the circuit and the purity of the completely mixed state. Here we consider a 3-regular graph with 4 qubits under amplitude damping of strength λ=0.001. We show data for 100 samples of randomly chosen circuit parameters.