Quantum algorithms implementation on noisy quantum computers: from digital modeling of spin dynamics to quantum machine learning

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Abstract:

Quantum computers are prospective for the resolution of problems which are hard to solve using conventional computing systems. However, state-of-the-art quantum machines still suffer from decoherence and quantum gate errors. The implementation of efficient error correction codes is associated with the enormous overhead of quantum resources. Therefore, the important question is what tasks can be performed without full error correction? In the present contribution, we suggest some ideas on what could be done, on new benchmarks of capabilities of quantum computers; we also develop various ideas how error mitigation can be accomplished.

Our ideas are illustrated with 5- and 16-qubit superconducting quantum machines of IBM Quantum Experience.

In the first part [1], we point out that programmable quantum computers are prospective for the simulation of far-from-equilibrium dynamics of many-body systems and perform proof-of- principle digital simulations of unitary evolution for two spin models. We argue that this task does not require phase estimation algorithms, which are very fragile with respect to gate errors. Besides, there is no need for the chemical accuracy. We also show that, in such simulations, errors can be mitigated even if noise is signi cant - moreover, in some cases, noise can help extracting valuable information from raw data.

In the second part, we argue that quantum communication protocols can be implemented in quantum computers by measuring entropy-based characteristics of their performance and exploring whether "quantum advantage" is achieved. This modeling provides deep benchmarks for capabilities of noisy quantum machines. We implement superdense coding and quantum key distribution BB84 and focus on efficiency of information transfer between distant parts of the processors by placing Alice and Bob at different qubits. We also examine the ability of quantum chips to serve as quantum memory used to store entangled states for quantum communication.

In the third part, we develop algorithms, which can classify "patterns", these "patterns" being purely quantum and characterizing an entanglement. We concentrate on circuits, which solve a classi cation problem for maximally entangled states in low-dimensional Hilbert spaces and also perform proof-of-principle simulations supplemented by error mitigation.

[1] A. A. Zhukov, S. V. Remizov, W. V. Pogosov, Yu. E. Lozovik, Quantum Inf. Process. 17, 223 (2018).