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Study of the effect of noise on efficient quantum search algorithms

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Introduction

- The errors resulting from noisy quantum gates and decoherence make quantum devices far from perfect
- NISQ era algorithms strive for shallow depth to reduce the impact of noise from environment[1]
- There are three different strategies to improve accuracy and efficiency of the Grover's search algorithm on the NISQ processors[2]

[1] Noisy intermediate-scale quantum (NISQ) algorithms

[2] Zhang, K., Rao, P., Yu, K., Lim, H., & Korepin, V. (2021)

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The problem

1. Implement the algorithm improvements described in the article
2. Create an environment for testing different variations of the algorithm with different noise models and different number of qubits
3. Conduct a series of experiments and explore noise impact on variations of the algorithm

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Implementation

- Using Qiskit and IBMQ[3]
- Using thermal relaxation model[4]
- Error coupling map on qubits as on the real device "Melbourne"
- Toffoli gate implementation through Qiskit function .mct()[5]

[3] public repository

[4] qiskit thermal relaxation noise model

[5] .mct() function

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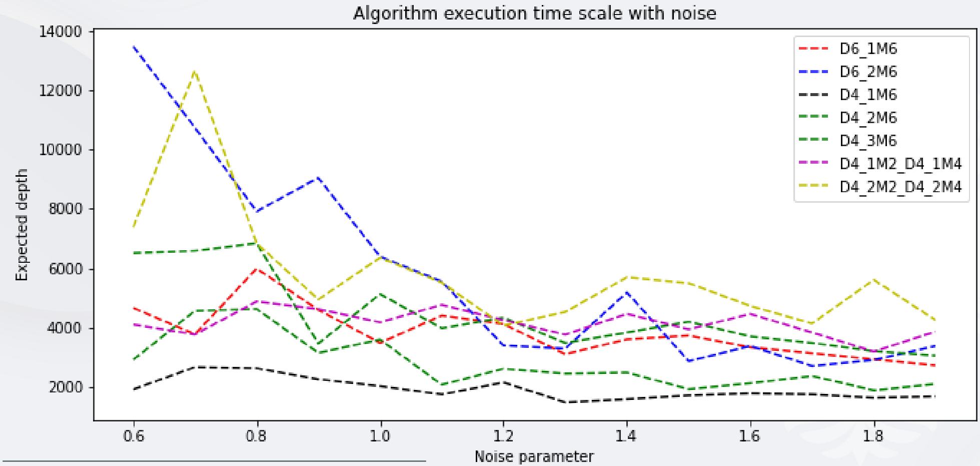
Tests on 6 qubits[6]



[6] as the noise parameter increases, the amount of noise decreases. At 1 it simulates noise as on the real device

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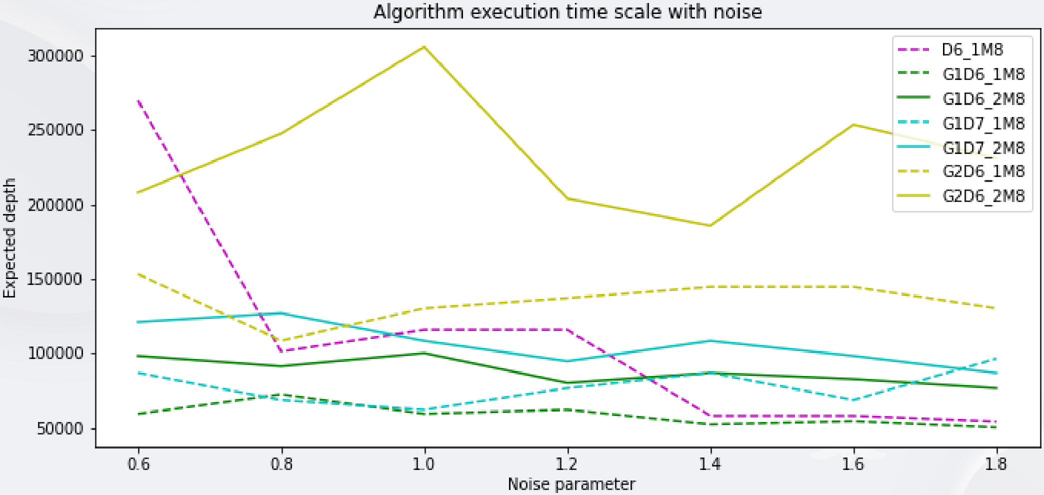
Tests on 6 qubits: results

- Dm_iM6 stands for algoritm with local Grover operator applied i times
- We can see that some algorithms perform better than the others
- Some algorithms scale better with noise parameter. D6_2M6 has lower expected depth than D4_1M2_D4_1M4 at low noise parameter values, but greater at large noise parameter values

Tests on 8 qubits



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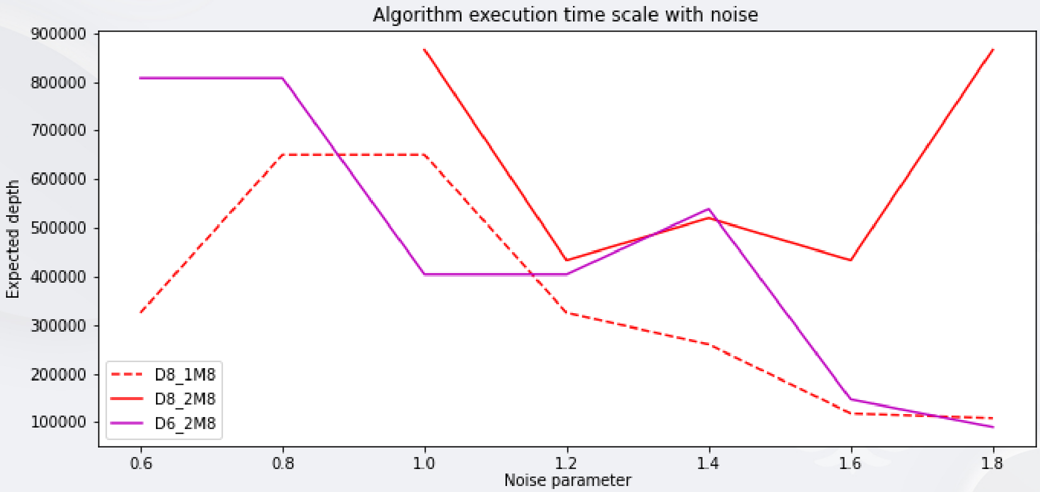
Tests on 8 qubits



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Tests on 8 qubits: results

- the number of Grover operator calls for 8 qubits should be $\frac{\Pi\sqrt{2^8}}{4} \approx 12$
- with such number of Grover operators it already takes much time to test an algorithm. Not only because of it's depth, but also because of the large minimum sufficient number of shots. And it is basically useless to test an algorithm with more than four Grover operators, because the result won't be much different from pure noise
- All tests were done on intel i5 8th gen processor

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Noise parameter

Noise parameter scales the constants T1 and T2 in thermal relaxation noise model[7]. This parameter describes the physical ability to store and apply operations on qubits without unnecessary noise. In order to find minimum sufficient value for the noise parameter, we want to test algorithms on different number of qubits and much more different values of noise parameter.

[7] T1/T2 thermal relaxation noise model

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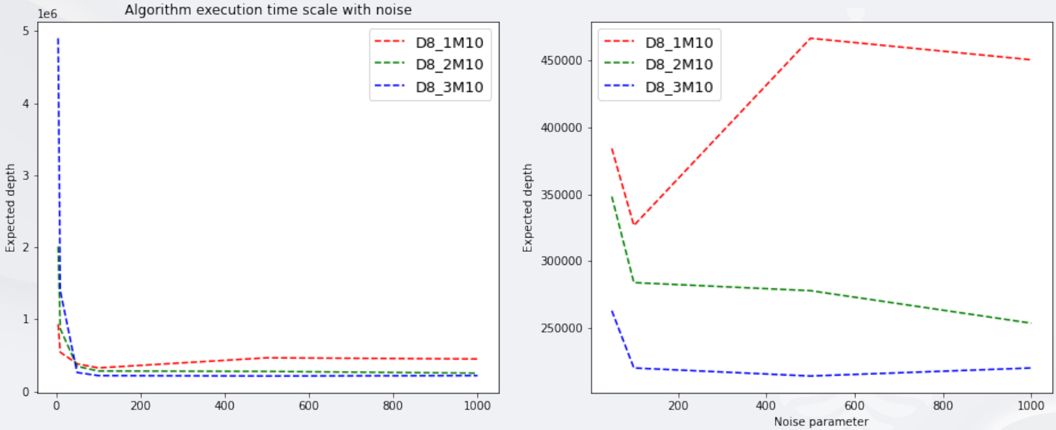
10 qubit tests



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10 qubit tests: results

- There is a definite value of noise parameter, after which there is no visible decrease of expected depth. We want to know how this value scales with the number of qubits
- Unfortunately we only have so much processing power, it barely reaches the 10th qubit front. Further experiments should be carried out on processors more adapted for such quantum simulations

Summary

- We implemented a useful playground for tests with different noise models
- Conducted a set of experiments to show limitations of efficient quantum search algorithm

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github repository