Quantum Computing PHYS-541, Project 4

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Quantum error mitigation

In class we have introduced two strategies to deal with errors in quantum hardware, namely fault tolerant codes and hybrid/shallow algorithms on NISQ hardware. There is a third strategy called *quantum error mitigation*. Quantum error mitigation encompasses a variety of techniques to reduce the effect of errors on the output of a quantum circuit. Here we are interested in one of the most effective among these techniques, the *zero-noise extrapolation*. As the term suggests, zero-noise extrapolation consists of running the same quantum circuit at various levels of noise, then studying the outcome as a function of the noise level and trying to extrapolate this function to its limit for zero noise. The idea originates from the simple remark that, while it is very challenging to improve noise levels in quantum hardware, it is, on the other hand, easy to make them worse. Then, one can vary the noise level from large down to the smallest possible for a given hardware to obtain a functional dependency and attempt the extrapolation.

In practice, noise levels can be varied by tweaking the hardware and, most importantly, via quantum software. This is achieved in the following simple way. Support the unitary $\hat{U}$ represents a particular layer of a quantum circuit. One can run different circuits in which $\hat{U}$ is replaced by $\hat{U}(\hat{U}^\dagger\hat{U})^\lambda$. The quantum code is formally the same, but the corresponding circuit is deeper, therefore having more errors. The parameter λ determines the amount of error and will be ultimately used for extrapolation. This technique is known under the name of *circuit folding* or *layer/gate folding*.

Quantum zero-noise extrapolation has been reviewed in this recent work, which must be read as part of this exam project, with a particular focus on the circuit and layer folding techniques.

The goal of the project is:

1. Read and understand the main article and present its results.

2. Choose a quantum algorithm (either one on which we had hands-on assignments in class or another if you feel brave) and apply both circuit and layer folding techniques

3. Carry out the zero-noise extrapolation through careful quantitative analysis and show in which cases the outcome of the algorithm can be improved by this error mitigation technique. You may want to choose an algorithm whose depth can be varied (e.g. a Grover search in a database of varying size) in order to study the efficiency of the folding technique as a function of the depth of the original algorithm.

4. Think critically about the limitations of the folding technique and discuss them.