

Quantum walks on quantum computers for applications – first steps

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The main application of quantum walks (QW), so far, is the search algorithms [1]. For instance, the Grover algorithm is based on quantum walk on a complete graph. Our aim is to study emerging applications of QW to other type of problems like optimization and spectral graph clustering [2,3].

In optimization we are looking at QW assisted QAOA (QWAO) algorithms [4]. In a standard setting of QAOA the mixer Hamiltonian is adjacency matrix of a hyper-cube spanned on solution space and thus its operation is equivalent to a continuous time QW on this graph. In some cases, the solution space is only a subgraph of the hyper-cube. For this, it was suggested [4] to use other type of QW on a graph restricted on the solution space. We used QW on a circulant graph [4] as well as a modification of staggered QW [1], see Fig 1. The parametrized QWOA unitary is the following:

$$U(\tau, t) = e^{-i\tau A} e^{itC}, e^{-i\tau A} = F e^{-i\tau \Lambda} F^\dagger,$$

in which A is adj. matrix of a circulant graph, C is a diagonal cost operator, F is quantum Fourier transform and Λ is a diagonal of eigenvalues of A .

In spectral graph clustering “non-backtracking random walk” (NBW) plays a crucial role (see. e.g. [3]). In NBW walker cannot travel a link forth and back. NBW is described by a directed graph between links, showing allowed steps. We defined quantum non-backtracking walk (NBQ) as a QW on such a directed graph (A. Montenaro 2007). For this we tested QW on directed graphs using quantum computers,

see Fig. 2. We study such QW for future applications and find out its major properties. Error mitigation on QC is tested.

References

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- [3] M. Bolla, H. Reittu, A. Fatma, Clustering the Nodes of Sparse Edge-Weighted Graphs via Non-Backtracking Spectra, Proc. of FICC, 2025
- [4] S Marsh and J.B. Wang, A quantum walk-assisted approximate algorithm, Quantum Inf. Process. 18(3), 2019

Figures

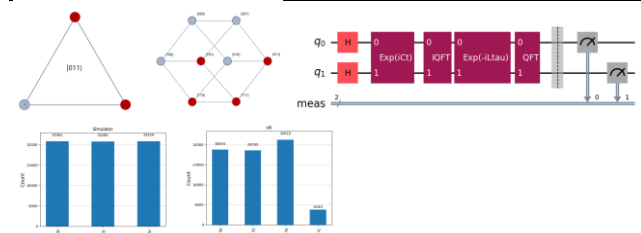


Figure 1: From up left: red nodes form a solution of the minimum vertex cover of the triangle (has 3 minimal covers), corresponding solution space in the cube, gates for finding minimum covers and results of simulation (100% correct) and QC (94% correct)

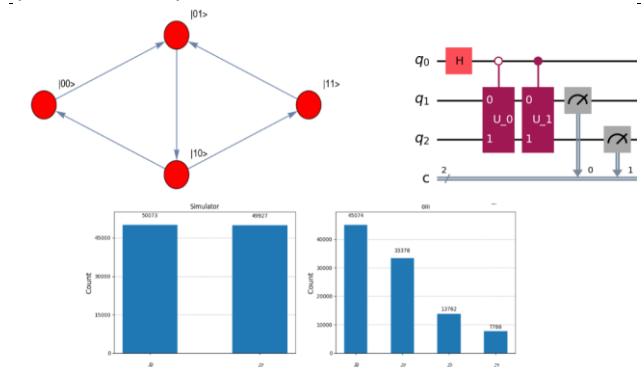


Figure 2: A step of coined QW on directed 4-node graph, starting from $|00\rangle$, and corresponding quantum circuit. 1st qubit is coin, the controlled unitaries correspond to the two cyclic permutations. Simulated result is $\{|00\rangle + |01\rangle\}/\sqrt{2}$, QC (right histogram) produces some errors, which can be reduced by an error mitigation techniques, to be tested.