FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

Department of DATA SCIENCE

Fraunhofer IIS

Bachelor thesis:

Error-Aware Token Swapping for Quantum Algorithm Compilation

Topic description

Token swapping is a combinatorial optimization problem which has applications in quantum algorithm compilation [1]. For an undirected connected graph G on n vertices $v_1, \dots, v_n$ we are given a set of tokens $\mathcal{T} = \{T_1, \dots T_n\}$. Initially, each vertex v_i holds exactly one token $T_{\pi(i)}$ where π is a permutation of $\{1, \dots, n\}$. The goal is to sort the tokens such that vertex v_i holds token T_i for all $i \in \{1, \dots, n\}$. Sorting is performed by *swaps* along the edges of G. A swap along an edge $\{v_i, v_j\}$ interchanges ("swaps") the tokens of v_i and v_j. The goal is to minimize the number of swaps required for sorting. For general graphs, token swapping is an NP-hard problem [2]. However, an efficient 4-approximation algorithm exists [3].

In the context of quantum algorithm compilation, vertices and edges of G represent hardware components and swaps represent certain logic operations. Quantum hardware components have error rates of different magnitude, making certain swaps more error-prone than others. Moreover, executing certain swaps simultaneously triggers large error rates. Recently, an error-aware token swapping approximation algorithm has been proposed [4] which, however, does not consider errors triggered by simultaneous swap execution.

The goal of this thesis is to develop, analyze, implement and evaluate a error-aware token swapping algorithm which includes the penalization of simultaneous swap execution.

Preknowledge in quantum computation is not required, however basic familiarity with discrete optimization is preferred.

This thesis will be supervised jointly by the the Department of Data Science (Frauke Liers) and the Fraunhofer IIS.

Contact

Friedrich Wagner: `friedrich.wagner@iis.fraunhofer.de`

In case of interest please send an email including a Transcript of Records, a short Letter of Motivation as well as a preferred starting date.

References

[1] Friedrich Wagner, Andreas Bärmann, Frauke Liers, and Markus Weissenbäck. Improving quantum computation by optimized qubit routing. *Journal of Optimization Theory and Applications*, 197(3):1161–1194, may 2023.

[2] Katsuhisa Yamanaka, Erik D. Demaine, Takehiro Ito, Jun Kawahara, Masashi Kiyomi, Yoshio Okamoto, Toshiki Saitoh, Akira Suzuki, Kei Uchizawa, and Takeaki Uno. Swapping labeled tokens on graphs. *Theoretical Computer Science*, 586:81–94, 2015.

[3] Tillmann Miltzow, Lothar Narins, Yoshio Okamoto, Günter Rote, Antonis Thomas, and Takeaki Uno. Approximation and Hardness of Token Swapping. In Piotr Sankowski and Christos Zaroliagis, editors, *24th Annual European Symposium on Algorithms (ESA 2016)*, volume 57 of *Leibniz International Proceedings in Informatics (LIPIcs)*, pages 66:1–66:15, Dagstuhl, Germany, 2016. Schloss Dagstuhl – Leibniz-Zentrum für Informatik.

[4] Asim Sharma and Avah Banerjee. Noise-aware token swapping for qubit routing. In *2023 IEEE International Conference on Quantum Computing and Engineering (QCE)*, volume 01, pages 82–88, 2023.