（別紙様式５）

変革を駆動する先端物理・数学プログラム（FoPM）

国外連携機関長期研修　報告書

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I did a research internship at Google for 12 weeks (from 4 March, 2024 to 24 May, 2024). I worked on quantum error correction with Quantum Error Correction Protocols Team at Google Quantum AI.

Purpose of this internship

The purpose of this internship was to gain experience in quantum error correction in a research environment that integrates theory and experiment. Quantum error correction is an essential element to develop a large-scale quantum computer. In the master course, I mainly worked on higher-order quantum computation to transform unitary and isometry channels [1-3], and in the PhD course, I started the research on quantum error correction [4], i.e., I was a "newcomer" in the field of quantum error correction when I started this internship. Since quantum error correction is a challenging topic both in theory and experiment, good collaboration between theory and experiment is essential for the quantum error correction research. Google is one of the leading companies in the field of quantum error correction, having big groups both in theory and experiment, and reported a lot of important research results (e.g., [5-6]). From this, I consider it extremely important to experience how research is carried out in companies, especially when pursuing research in quantum error correction in the future, and I did a research internship at Google.

Research activities

I worked at Shibuya office of Google. Since most of the group members of Quantum Error Correction Protocols Team are in the US, I mainly discussed with them remotely. In the team, we usually have 30-minuite 1:1 discussion, which can be easily scheduled using the Google internal system. I often had discussion in the afternoon considering the time difference with the US. I mainly discussed with Craig Gidney, Matt McEwen, and Adam Zalcman. Craig Gidney developed powerful tools for quantum error correction circuits, Stim and Crumble. He gave me instructions to use Stim and Crumble and insightful advice on this internship project. Matt McEwen is an expert in both theory and experiment. He taught me experimental restriction on the realization of quantum error correction, which inspired me to improve the quantum error correction circuit. Adam Zalcman is a host of my internship. He gave me a lot of interesting research ideas and supported me during my time working at Shibuya office. I also discussed with various members in Google Quantum AI, who are experts in quantum error correction circuits and decoding algorithms, and I learned a lot about these fields. I also joined seminars in the teams, discussing on recent papers on quantum error correction.

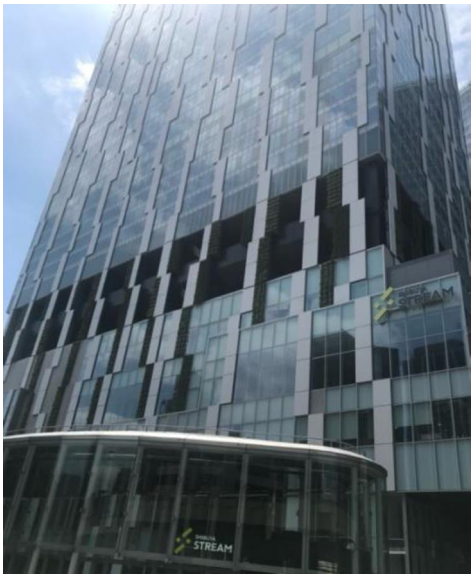

Figure 1. Exterior view of the Shibuya office of Google

I worked on quantum error correction by trial and error. To work on quantum error correction, it is indispensable to precisely track how the stabilizer evolves during the quantum circuit. However, it is in general very complicated, and many mistakes can happen. To deal with this, I first tried some quantum circuit, used Stim and Crumble to detect my error, and tried another circuit. I locally optimized my work in this way, but sometimes I fell into a local optimum. To escape from a local optimum and approach the global optimum, I constantly discussed with group members, and I made a course correction if needed. As a result, we have constructed an improved quantum circuit for quantum error correction.

Working environment

Google provided me a perfect working environment. In the office, I worked in various locations. I was given my own desk, but I was able to use free desks at the office area and cafeteria. I was also able to use a napping room and a gym. Sometimes I worked in free desks or using a napping room and a gym to refresh my mind. All the meals are provided at the cafeteria, so I did not have to care about things other than research. I also met other research internship students and old classmates in different teams, and the chatting with them also gave me a new perspective and inspired new thinking.

What I learned from this internship

I learned a lot on quantum error correction from the leading researchers in Google Quantum AI. I also experienced the well-organized research environment, which may be incorporated into my research in the university. For instance, research discussion often takes longer than expected, but this may not be efficient. All the discussions in Google were in 30 minutes, and this make us to avoid unnecessary conversation and directly jump into the core of the research. As a result, the 30-min discussion was denser than much longer discussion.

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Reference

[1] Satoshi Yoshida, Akihito Soeda, Mio Murao, Universal construction of decoders from encoding black boxes, Quantum 7, 957 (2023).
[2] Satoshi Yoshida, Akihito Soeda, Mio Murao, Reversing Unknown Qubit-Unitary Operation, Deterministically and Exactly, Phys. Rev. Lett. 131, 120602 (2023).
[3] Satoshi Yoshida, Akihito Soeda, Mio Murao, Universal adjointation of isometry operations using transformation of quantum supermaps, arXiv:2401.10137 (2024).
[4] Satoshi Yoshida, Shiro Tamiya, Hayata Yamasaki, Concatenate codes, save qubits, arXiv:2402.09606 (2024).
[5] Google Quantum AI, Suppressing quantum errors by scaling a surface code logical qubit, Nature 614, 676-681 (2023).
[6] Google Quantum AI, Quantum error correction below the surface code threshold, Accepted in Nature.