Report for MERIT Long-Term Overseas Dispatch

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Place: Technical University of Munich
Collaborator: Prof. Frank Pollmann
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Overview

I stayed at the Technical University of Munich (TUM) for two months, collaborating with Prof. Frank Pollmann. Our joint research focused on developing tensor network methods, an approximation technique for quantum many-body systems. The goal was to create a novel network capable of efficiently representing quantum states with high entanglement, overcoming the limitations of conventional approaches.

Research

Simulating quantum many-body systems requires computational costs that scale exponentially with system size, restricting current computational resources to handling only very small systems. Various approximation methods have been proposed to address this challenge, among which tensor network methods achieve significant success. These methods aim to manage quantum many-body systems efficiently by decomposing quantum states into network structures and truncating less significant components. For example, the matrix product state (MPS) is effective for representing quantum states with low entanglement (i.e., those obeying the area law). While MPS has proven to be a powerful tool for many low-energy states, it is not applicable to general quantum states with high entanglement (i.e., those obeying the volume law).

In this study, we developed a tensor network method capable of representing quantum states with the volume law entanglement. Our design principles based on two key factors: complexity and entanglement. Complexity refers to the types of operations performed on a given tensor network state; for instance, repeated application of gates in time evolution involves high complexity. While performing such high-complexity operations on states with high entanglement would require quantum computers, MPS can efficiently handle high-complexity operations at the cost of limiting entanglement to the area law. Conversely, our approach restricted the complexity of target operations to design a network capable of representing states with high entanglement.

To evaluate the fundamental properties of our network ansatz, we analyzed randomly initialized states within the network. As intended, these typical states exhibited volume-law entanglement. However, during time evolution, the entanglement collapsed after only a few steps. Consequently, despite these limitations in complexity, we successfully constructed a tensor network state capable of efficiently representing volume-law quantum states that were unmanageable with conventional methods. In the future, we aim to evaluate the extent of complexity that the network can handle and explore applications for elucidating diverse quantum states.

Life

TUM is located in the suburbs, about a 30-minute subway ride from the city center. Munich has a highly developed transportation network, and the experience of transferring on subways that run approximately every 10 minutes feels quite similar to Tokyo—except for the frequent delays. On weekends, I traveled to various German cities by train from the on-campus accommodation, visiting Oktoberfest and Christmas markets. Many members of the lab were outdoor enthusiasts, often discussing plans to go hiking together if the weather was good on weekends. However, the autumn and winter seasons in Munich were mostly gloomy or rainy, and we never managed to go hiking. Instead, we went bouldering every week. Interestingly, many physicists, including students from TUM and the Max Planck Institute, were regulars at the gym. Sitting on the mats to rest our arms, we often found ourselves engrossed in lively scientific discussions, which became a weekly highlight for me.

In the condensed matter theory group at the TUM, several labs work in close collaboration. For instance, when asking a student if they are part of the Pollmann Group, you might get an ambiguous response like, “Probably?” With a large group of 50–60 members, active discussions are held daily at blackboards all around. During my stay, these exchanges allowed me to expand my knowledge across diverse fields. Building many friendships was another significant outcome of my time there. I had in-depth weekly discussions with Prof. Pollmann, allowing us to make steady progress on a challenging topic. His consistently positive, optimistic, and cheerful attitude is something that I aspire to emulate in my own academic and personal life.

Fig. 1：The Physics building and the first snowfall in November.

Fig.2: A scene from the gym. When I asked whether bouldering is popular in Germany, the response was, “At least among physicists, it is.”

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