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The interview with the author of the PhD thesis:
„Ergodicity breaking in quantum systems: from exact time evolution to machine learning"

Could you describe in simple terms the main objective of your research, which formed the basis of your doctoral thesis?

Referring to the classical world we know, let us imagine a situation in which we place a large number of gas molecules in one corner of a sealed, cubic box. After releasing the particles, after a short time they will fill the box evenly in its volume, and the chance that they will all return to their initial state is practically equal to zero.

Although this principle generally applies to the quantum world, some models for which the memory of the initial conditions is very persistent have recently been discovered. This phenomenon is called many-body localization because it results from the complex, but in a sense coordinated, interaction of quantum objects isolated from their environment. It could potentially be used in quantum computers as a stable memory.

However, not everything is known about the mechanisms leading to many-body localization or its destruction. The main goal of the research that forms the basis of my doctoral thesis was to understand whether an initially small area of such a „frozen" system of a dozen to several dozen qubits, which accidentally lost its special, „frozen" properties (it is referred to as an „ergodic bubble"), will be able to „unfreeze" the rest of the localized system. This is a fundamental question if we ever want to create a large quantum system with long-term memory. On a large scale, such a bubble will certainly occur, the only question is how the rest of the system will react with it. As part of my PhD, I researched, among other things, how not only spontaneous but also „planted" bubbles grow over time, how they connect with each other, and under what conditions they lead to the destruction of the localization phenomenon.

How did the resources offered by Cyfronet contribute to the use of machine learning in your research?

Firstly, as the name suggests, in many-body localization research, we are dealing with a system with a large number of degrees of freedom, governed by the laws of quantum mechanics. In theoretical physics, we often make approximations and simplifications to describe and understand an initially complex system, but in this case, the effects of interactions are so subtle that such attempts typically fail. Therefore, we are left with a brute force approach: computer simulations taking into account all microscopic interactions. Access to large-scale CPU computing clusters at Cyfronet enabled me to obtain datasets for further analysis. Secondly, even when we have the data, it is not always obvious how to extract the information we are interested in. Some signals, especially those coming from such counterintuitive areas as quantum mechanics, sometimes prove too complex for humans to analyze. This is where machine learning comes in handy, allowing us to automate data analysis processes to a certain extent. I used a neural network to track how ergodic bubbles grow over time based on their quantum observations over time. Here, in turn, I used GPU cards available at Cyfronet to train and test my models.

Did you encounter any challenges in combining theoretical physics with artificial intelligence methods?

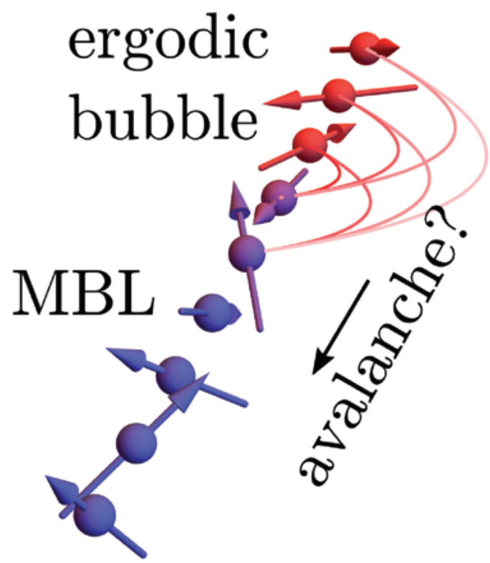
I believe that one should be very careful when „delegating" data analysis to a deep neural network. It is easy to fall into the trap of thinking that we have solved the problem when the model gives us correct answers based on the training and test data available to us. However, all this comes at the cost of interpretability – we rarely know exactly how the mechanisms inside large networks work. Methods for explaining the basis on which a neural network made a particular decision are still being developed. It is always necessary to thoroughly analyze how the model works, preferably by comparing the obtained results with other, better understood methods of analysis. Ultimately, it is always the scientist who is responsible for the reliability of the results obtained in this way.

During your research, were you able to observe new phenomena or confirm existing theories?

By studying the behavior of ergodic bubbles, we were able, at least to a limited extent, to confirm earlier hypotheses by other researchers that even a small, spontaneously formed ergodic bubble can grow over time, destroying the localization in the entire system. We also demonstrated that a strongly localized system, even after a very long time, delocalizes very slowly when a relatively small bubble is connected to it, which was quite surprising.

What are the next steps in your scientific career? Do you plan to continue your research in the field covered by your doctoral dissertation?

I am currently at a postdoctoral fellowship at the University of Hamburg, where I am also working on many-body quantum physics, in this case focused on practical applications of quantum computers. I am investigating how classical data, such as tables or photos, can be loaded onto a quantum computer for further processing. I will definitely use my experience with many-body localization in my current research. I am also continuing the projects I started during my doctoral studies.



An ergodic bubble, in contact with a many-body localized system (MBL), can destroy localization in the so-called quantum avalanche process.