Title: Do computers dream of the microscopic world?

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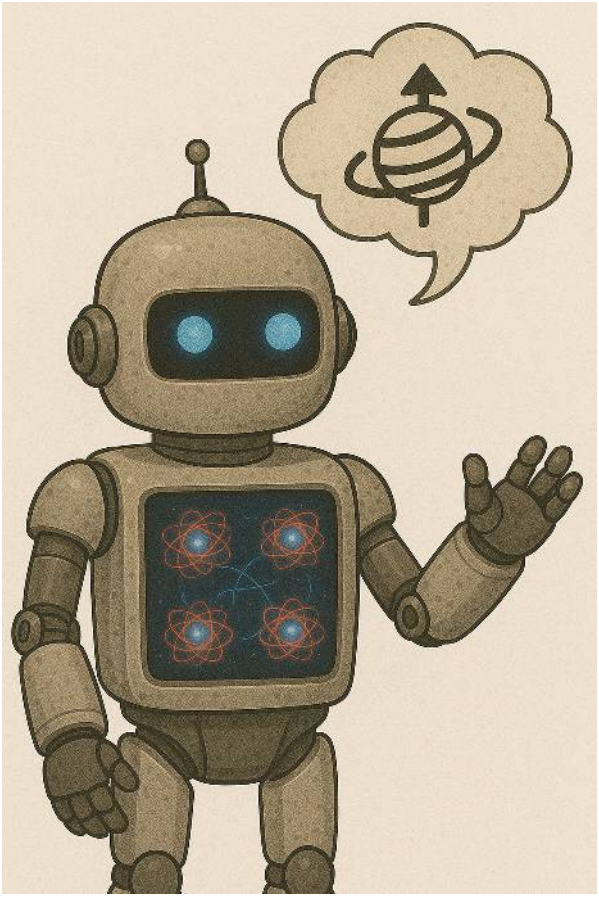

Hi, my 12-year-old self! I am your 23-year-old self and a first-year master's student at the University of Tokyo. I will give you a talk on what and why I am studying here.

In the university, I am majoring in physics, which tries to explain all events in our universe with some simple rules. In a lot of things that physics deals with, I am especially interested in quantum many-body systems, the system consisting of an enormous number of quantum particles. The word "quantum" means that the system is following quantum mechanics, which is different from classical mechanics, the world we see. Let's see an example. When we throw two balls in the same condition, they follow the same trajectory and fall to the ground at the same

time. However, even if we prepare two quantum particles in the same condition and measure their position at the same time, the result can be different. Well then, what can we know about quantum mechanical particles? The answer is the probability. We cannot know where the particle is, but we can know how likely the particle is at a position. This is the feature of quantum mechanics. We get this probability by solving the Schrödinger equation, the governing equation of quantum mechanics.

Quantum many-body systems are known to show some interesting phenomena, which can be useful in our everyday life. For example, superconductivity, in which electricity flows without resistance, enables us to use electricity with no energy loss. Also, ferromagnetic materials behave as a strong magnet on their own without any external magnetic field and are used in computers and motors. In this way, understanding these phenomena is significant for an engineering application. This is why I find quantum many-body systems interesting.

In such phenomena, the interaction between particles plays an important role. The above phenomena emerge as a result of particles interacting with each other and adding up their effect through the enormous number of particles in the system. However, the interaction makes the analysis of quantum systems difficult. In general, a system with some interactions is difficult to solve the Schrödinger equation in a mathematically exact way or with high-performance computers. So, we need methods of simulating quantum many-body systems efficiently but without losing important physical properties.

I am now researching the application of machine learning techniques to the simulation of quantum many-body physics. Machine learning is a family of algorithms to perform many kinds of tasks systematically without human help. It has been successful in many tasks such as recognizing features or patterns in audio or images, predicting

missing or future data, and so on. Especially, generative AI, artificial intelligence that generates images or texts responding to our message, has a significant effect on our lives. Now, instead of using search engines, we can ask many kinds of questions to generative AI. Enjoying such benefits of machine learning, I came to think that machine learning can be applied to physics simulations. In detail, I believe that machine learning has the potential to extract important physical properties from systems, find characteristic patterns in the system, and predict what physical phenomena will occur. In practice, researchers have reported that machine learning can be used successfully to distinguish which things are similar or difficult under certain rules [1], and to search for the lowest energy the system can have and what the system looks like in that case [2]. I want to develop better ways of simulating quantum many-body systems with the power of machine learning.

At the end of my talk, I will give you some advice on becoming a researcher. First, you should read more books. Reading experience develops our ability to process the sentence, understand the author’s opinion, and represent our ideas in our own words. Such ability will be helpful for the researcher's life, in which you must read a thesis on previous results and write a thesis on our results. In addition, books will take you to a new world that you have not experienced yet. Through reading books, you can get new knowledge and another point of view of the world, which sophisticates your personality and then expands your possibilities as a researcher. For this purpose, talking with people around you is also effective. You should learn from as many people as possible to acquire a sophisticated personality.

Second, you should both think for yourself and investigate with some media in a well-

balanced way. In the age you are living in, the internet is spreading, so you can easily get the answer or a hint to the problem you face. However, you should use such media after considering the problem without any help. This will develop your ability to think, which is necessary for researchers.

Lastly, you should get more exercise. In the research life, you have to do trial and error continuously and patiently. This process requires you to have enough physical strength. However, you cannot get physically strong in a short time. So, not only should you read books inside, but you should make it a habit to work out outside.

I hope you will enjoy your research life in the future. At that time, let us talk about our interests. See you someday!

I would like to thank Dr. Mark VAGINS and Masahito MORI for their useful comments to improve this essay. I used Grammarly to improve the grammar in this essay. The image at the head is produced by ChatGPT.

<References>

[1] N. Sadoune et al., “Learning symmetry-protected topological order from trapped-ion experiments,” Aug. 09, 2024, arXiv: arXiv:2408.05017. doi: 10.48550/arXiv.2408.05017.

[2] G. Carleo and M. Troyer, “Solving the Quantum Many-Body Problem with Artificial Neural Networks,” Science, vol. 355, no. 6325, pp. 602–606, Feb. 2017, doi: 10.1126/science.aag2302.