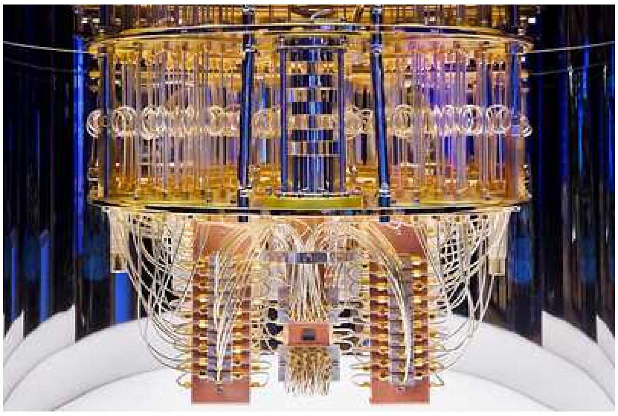
Can Quantum Computers help Artificial Intelligence?

Keisuke Murota



"Interior of IBM Quantum computing system". Taken on October 22, 2019 (Credit: IBM)
link to the image: https://www.flickr.com/photos/ibm_research_zurich/50252942522/in/photostream/

The development of Artificial Intelligence (AI) and Machine Learning (Machine Learning is the main parts of AI) technology is essential for the development and prosperity of humankind in the future. Indeed, AI has already played an indispensable role in our lives. Recently, by introducing AlphaFold2, a state-of-the-art AI program developed by Google's DeepMind, they were able to identify the structure of several proteins, making up the new coronavirus (SARS-CoV-2), that was almost unknown until then in a fairly short time. Also, AI contributes to food security, for example, by gene-editing. Gene-editing picks up and combines certain characteristics in the plant, and as a result, a plant modified to grow large in size, becomes resistant to a certain virus or obtain a longer shelf life. An emergent gene-editing technique is called CRISPR, and scientists use it for replacing part of the gene or stop the function if DNA behaving wrongly. CRISPR is already being used, but one of the biggest problems is achieving precise and effective cutting without accidentally affecting other parts of the gene. Until recently, scientists would have to manually test all the possible cut locations to obtain the best one and requires a lot of time and money. However, AI can accelerate this process by creating the computational model trained on the huge gene data and analyzing the regularities and patterns of DNA sequences.

Besides these two examples, AI has been solving many social problems such as drug discovery and earthquake forecasting. One may think that AI is developed enough to handle all the problems, but considering the possibility of facing new pandemics, like the COVID-19 Pandemic, we can never satisfy with the current performance level of ML and AI. Of course, such efforts have already been made and achieve significant results so far. We can confirm this fact by checking the rapid increase in the number of parameters used in the AI model since the number of parameters partially represents the power of the AI model. Let's see how the number of parameters for natural language processing(NLP) model called GPT-n series created by OpenAI, a San Francisco-based artificial intelligence research laboratory (Fig1).

Fig 1. change in the number of parameters for NL model over time

You can notice that GPT-3 contains 175 billion parameters, making it 17 times as large as GPT-2, but as the number of parameters increases, the computational resource (refers to computational time: the number of steps necessary to solve a problem and memory space: the amount of storage needed while solving) also increases. So, why is this dramatic increase possible? It is a rapid development of semiconductors that has realized this improvement in the performance of the machine learning model. As you may know, there is an empirical law with respect to the development speed of semiconductors called "Moore's law". This law states that the number of transistors on doubles about every two years. Therefore, as long as semiconductors develop according to this law, exponentially improvement in the performance is guaranteed, thus, we don't worry about the future of the AI industry. However, of course, it can't go on forever because of physical limits. Therefore we need a breakthrough in order for the AI industry to progress after the end of Moore's law.

One of the solutions for the breakthrough is, I think, the combination of Quantum Computers and Machine Learning. So what are Quantum Computers? Quantum computers perform calculations based on qubits instead of classical bits, just representing 1s and 0s. Qubits can represent numerous possible combinations of 1s and 0s at the same time, which means they have the potential to process exponentially more data and exponentially faster compared to classical computers. Recently the term "Quantum Computing" has become a hot word in the world. This is because it is expected that Quantum Computer can solve a problem that no classical computer can solve in any feasible amount of time, which is called “quantum supremacy”. This expectation is indeed supported by the news that the Chinese research team, based primally at the University of Science and Technology of China in Hefei reported that a system, called Jiuzhang, produced results in a few minutes calculation, which would have needed to take more than 2 billion years by the world’s third most powerful supercomputer [1]. If their statements are certainly correct, it is thought that “quantum supremacy” is achieved. Therefore, it is very natural to try to leverage Quantum Computers to Machine Learning: Quantum Machine Learning (QML).

So, how to incorporate quantum computers into machine learning? First and the most important difficulty is the difference in storage systems for classical computers and quantum computers. The former store the information for training the machine learning model in RAM. RAM is computer’s short-term memory, and none of your computers would work without this. RAMs are also composed of bits and information, represented by the sequence of the binary number, which can be encoded into RAM. On the other hand, quantum computers store the information in qRAM, which is the quantum counterpart of classical RAM. Since the information, such as data used for training machine learning model, is stored in classical RAM at first, we have to send them to qRAM to handle in quantum computer. The original paper for qRAM is published in 2008 and many related papers are published afterward [2]. With qRAM, there are many QML models are suggested. One of the most reputed QML models is Quantum SVM [3]. SVM is machine learning models to analyze and predict data, and as the name suggests, Quantum SVM is the quantum version of SVM. It is found that computational time for QSVM grows logarithmically with number of parameters and data size. This is extremely fast compared classical case where computational time is polynomial in both the number of parameters and data size. For example, if the number of parameters is one billion = 10^9, the computational time for QSVM is proportional to 30 while for SVM, at least proportional to 10^9.

Although QML is promising, we cannot implement this in the current quantum computer, due to a shortage of qubits. IBM has 127 qubits quantum computer called Eagle, but we need more than one million-qubit for quantum algorithms. However, the is bright: IBM promises a 1000-qubits quantum computer by 2023, and also, has a plan to install one million qubits quantum computer. Therefore, I believe that QML has the potential to achieve further breakthroughs in the field of AI.

[1] Han-Sen Zhong *et al,* "Quantum computational advantage using photons", Science 18 Dec 2020, Vol. 370, Issue 6523, pp. 1460-1463.

[2] Vittorio Giovannetti, Seth Lloyd, and Lorenzo Maccone, "Quantum Random Access Memory" Phys. Rev. Lett. 100, 160501 – Published 21 April 2008

[3] Patrick Rebentrost, Masoud Mohseni, and Seth Lloyd, "Quantum Support Vector Machine for Big Data Classification" Phys. Rev. Lett. 113, 130503 – Published 25 September 2014.