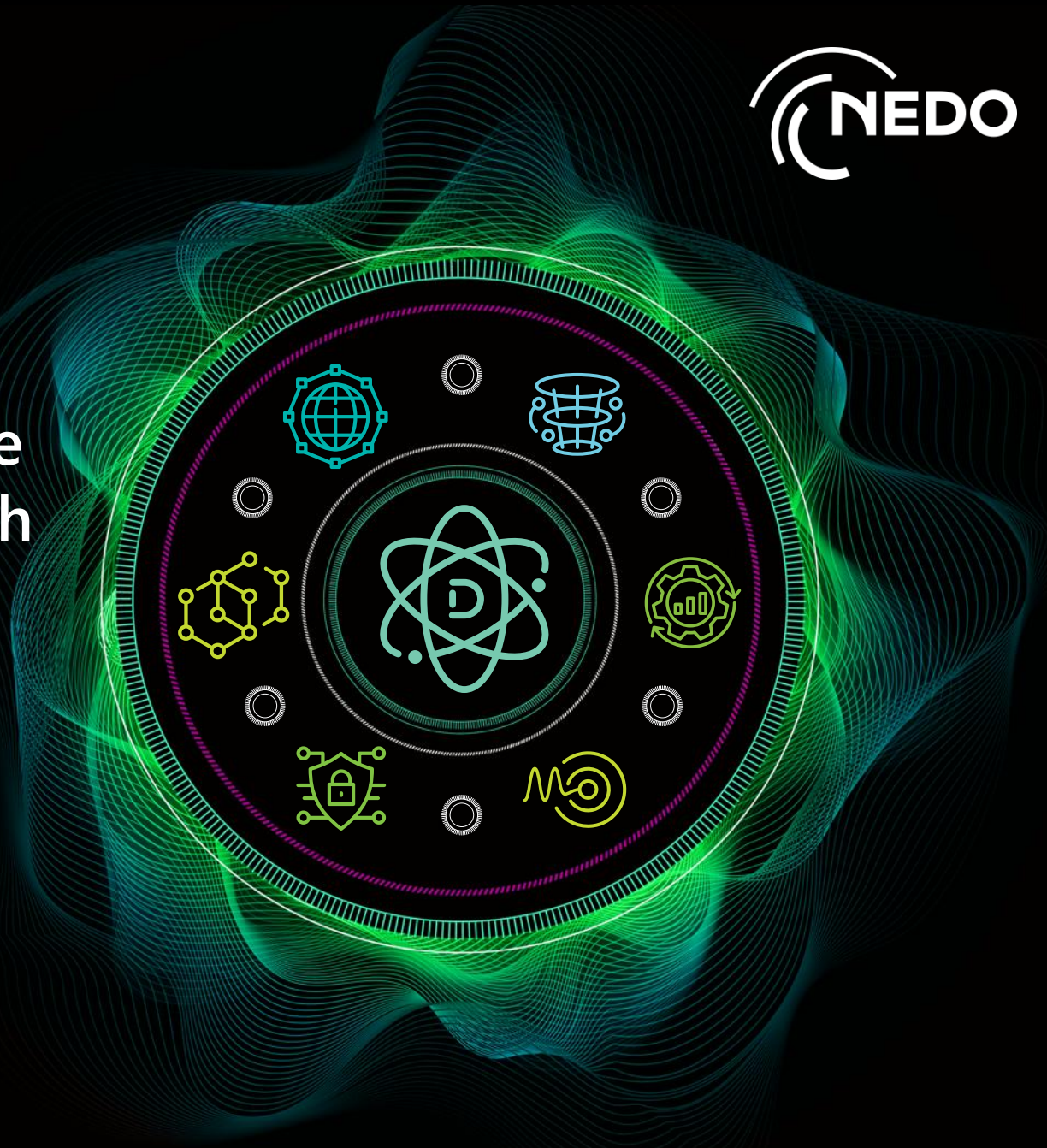
Quantum Computing Use Cases

Using quantum data to predict the properties of physical systems with higher accuracy

Google



New Energy and Industrial Technology Development Organization (NEDO)

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Validation

Industry	Other
Method	AI
Process	Input
Category	Gate*

Background

- The use of machine learning/deep learning is advancing, and its application is progressing not only in industrial and commercial applications but also in R & D areas such as new material development.
- **Quantum computers, which have advantages in large scale and high speed computation, have been applied to machine learning.**
  - ✓ One direction is for quantum computers to speed up learning of "classical data" such as text and image data in machine learning and LLM learning in generative AI.
  - ✓ The other is **efficiency improvement through direct analysis and learning of quantum data and its superposition state by a quantum computer,** such as quantum states of physical systems (wave functions described by quantum mechanics, such as electronic states in molecules) and programs for quantum computers, as in this project.

Issues and motivation to be solved

- The strength of quantum computers in directly processing quantum states, such as simulating quantum mechanical processes in physical systems, motivates quantum machine learning on quantum data.
- **For this purpose, quantum machine learning is required by combining quantum sensors that input experimental data to a quantum computer with quantum computer processing.**
- In light of the above, Google used NISQ machines, which are affected by noise, to conduct **a study to compare the prediction performance of quantum data obtained from physical experiments that are stored in a quantum computer and trained by a quantum machine learning algorithm without performing any measurement that destroys the quantumness (superposition state), and the prediction performance of learning after converting the data to classical data measured by a quantum computer**

Reference: J-STAGE "Machine learning using quantum computers" (https://www.jstage.jst.go.jp/article/oubutsu/93/1/93_19/_pdf/-char/ja)
*Gate（gate-based）: A computing approach in which operations are applied sequentially to qubits to perform calculations. Similar in concept to logic circuits in classical computers, it can address a wide range of problems.

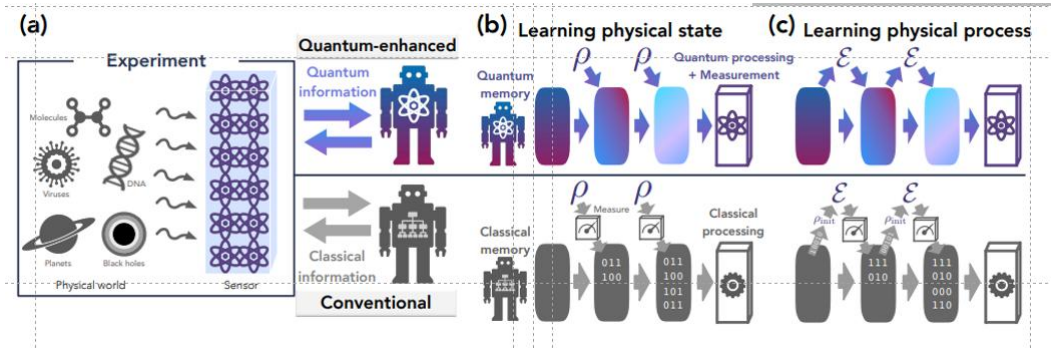
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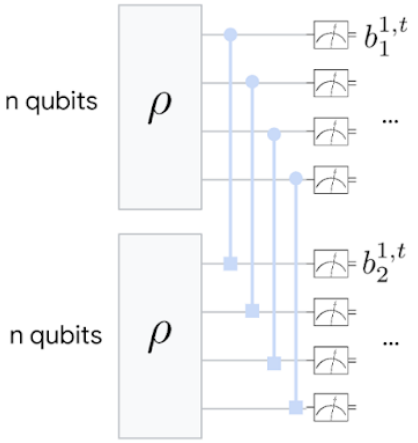
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Problem setting as a quantum computer

- Without measuring the wave function of the physical system in the superposition state, **learning by directly inputting 'quantum data' holding the quantum state to quantum machine learning** was performed.
  - ✓ In machine learning using classical computers, a physical system is learned using classical data whose quantum state is destroyed by measurement.
- **Using Quantum Sensors to Extract Experimental Data from Physical Systems for Quantum Machine Learning**
- The HW is powered by Google's Sycamore quantum processor.



Comparison of Quantum and Classical Machine Learning Algorithms



Basic schematic of a quantum machine learning algorithm
(stores two copies of a quantum state and uses Bell measurements to entangle each pair and measure their correlation)

See: Science"Quantum advantage in learning from experiments" (https://www.science.org/doi/10.1126/science.abn7293),
J-STAGE "Machine Learning with Quantum Computers" (https://www.jstage.jst.go.jp/article/oubutsu/93/1/93_19/_pdf/-char/ja)
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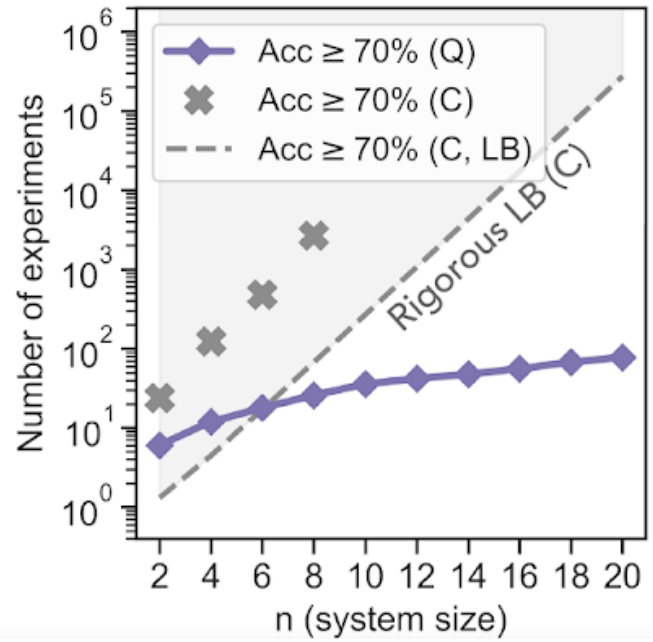
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Expected business benefits

- Regarding information (wave function) of physical systems that can be predicted by machine learning, **the difference between quantum and classical machine learning in the number of experiments (training) required to achieve 70% prediction accuracy grows exponentially with system size**
- **Combining quantum sensors and memory with quantum computers will accelerate efficiency with quantum machine learning**
- **Quantum machine learning may be used to predict the properties of physical systems with high accuracy, which is difficult in classical machine learning from the viewpoint of machine power and resources.**
  - ✓ However, quantum memory that can maintain coherence for a long time is still under development, and further research and breakthroughs such as connection to quantum computers are required.



Experimental Comparison of Quantum and Classical Machine Learning for predicting observables of quantum states.

- Q: Data from a quantum computer is directly stored in quantum memory without being “measured ” and learned using QML algorithms
- C: “Measured ” quantum computer data (classical data) is stored in classical memory and machine learning is executed
- C, LB: Theoretical lower limit of the number of experiments required for classical learning

Reference: Fujitsu Limited, "Up to this point, HPC✕ Electromagnetic Field Analysis" (https://www.hpci-office.jp/documents/workshop/cae-ws.240308_Kochibe.pdf)
*Gate（gate-based）: A computing approach in which operations are applied sequentially to qubits to perform calculations. Similar in concept to logic circuits in classical computers, it can address a wide range of problems.

More use cases are available on our website. We invite you to explore them.
https://www.quantum-computing-use-cases.nedo.go.jp/english/

More Use Cases

New Energy and Industrial Technology Development Organization (NEDO)
AI and Robotics Department (e-mail: quantum_ai@ml.nedo.go.jp)

This collection of use cases was obtained as a result of the work commissioned by the New Energy and Industrial Technology Development Organization (NEDO) "Cyber-Physical Development Business of Quantum/Classical Hybrid Technology/Study of Use Case of Quantum Technology" and the "Post-5G Information and Communications System Infrastructure Reinforcement R & D Project (Quantum Industrialization)/Comprehensive Study for Promoting the Industrialization of Quantum Computers".