S. Sakauchi, *"Toward creation of a system architecture for quantum computers"*, NTT Technical Review, vol. 21, no. 11, pp. 1-21, Nov. 2023.

Quantum Security Course - *Paper Presentation*

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Innovative Optical and Wireless Network

Innovative Optical and Wireless Network consists in the next-generation network and computing infrastructure concept

This will require a new computing infrastructure to support **Digital Twin Computing**, which requires processing huge amounts of data at unprecedented speeds

Current State of Quantum Computing

Quantum computers use *qubits* to solve complex problems **faster**, created with methods like **superconductivity**, **photons** and **ion trapping**.

Ising machines solve optimization problems using the Ising model and are already commercialized, though they **have fewer applications**.

Qubit computers have more potential, but **Ising machines are more practical**.

Ising Machines

Energy Minimization: Finds the lowest-energy spin configuration to solve optimization problems.

Spin Dynamics: Uses interactions between spins and external fields to model the problem and update states.

Implementation Flexibility: Can be built with quantum annealers, optical circuits, or classical algorithms.

Real-World Applications: Used in logistics, finance, and scheduling for efficient problem-solving.

NTT's Research Focus Areas

NTT is developing Ising machines, NISQ computers, and **working toward fault-tolerant quantum computers** (FTQCs).

The LASOLV™ Ising machine uses **light** for operations, with ongoing research into quantum computing hardware like **optical and superconducting systems**.

NTT is bridging the gap to FTQCs by researching "early-FTQC" technology, aiming to **create practical computing infrastructure**.

Challenges in Quantum Computing System Architecture

Challenge 1: Difficulty in Application Development

Processing **general problems** with quantum computers requires complex algorithms to **translate them into a form compatible with quantum systems**.

Challenge (1)	• Application development for quantum computers is difficult. • To be able to process problems in general form with quantum computers, it is necessary to use complex quantum algorithms to convert general form into a form suitable to quantum computers.

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Challenge 2: Limited Applicability

Quantum computers excel as **accelerators for specific tasks** but rely on seamless integration with classical systems to achieve their full potential.

Designing hybrid systems that balance quantum and classical computing is key to maximizing efficiency and functionality

Challenge (1)	• Application development for quantum computers is difficult. • To be able to process problems in general form with quantum computers, it is necessary to use complex quantum algorithms to convert general form into a form suitable to quantum computers.
Challenge (2)	• To maximize the computational-processing capabilities of quantum computers, including pre-processing and post-processing, it is essential to distribute and link them with classical-computing hardware.

Challenge 3: Scalability Issues

To achieve useful quantum computation, increased scalability is essential.

The **current quantum computing hardware is still lacking the number of *qubits*** required for meaningful operations, and the *qubits* that are available are **highly susceptible to noise**.

Additional *qubits* are needed to correct errors and enable reliable operations.

Challenge (1)	• Application development for quantum computers is difficult. • To be able to process problems in general form with quantum computers, it is necessary to use complex quantum algorithms to convert general form into a form suitable to quantum computers.
Challenge (2)	• To maximize the computational-processing capabilities of quantum computers, including pre-processing and post-processing, it is essential to distribute and link them with classical-computing hardware.
Challenge (3)	• To execute useful operations on quantum computers, it is necessary to improve scalability by increasing the size of qubits and enhancing noise immunity.

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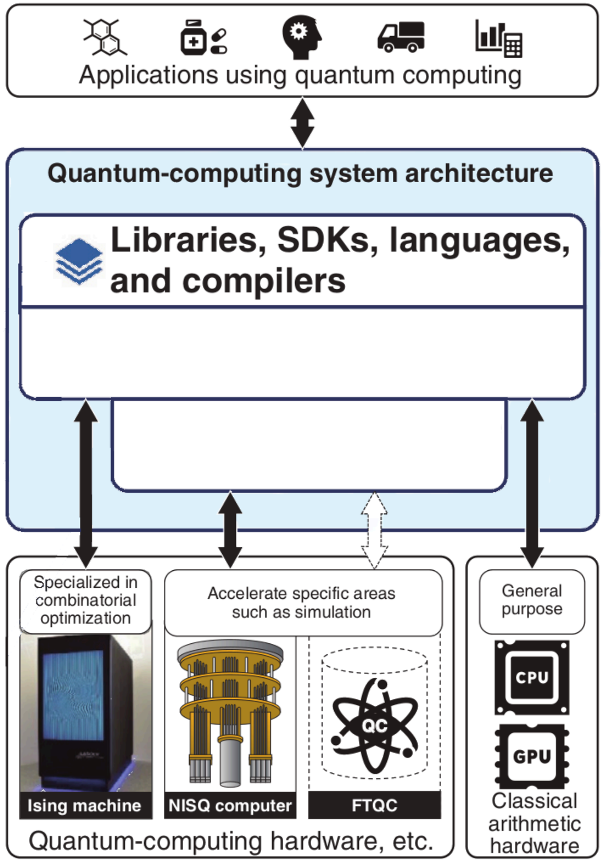
NTT's Approach to Address Challenges

Addressing Challenge 1

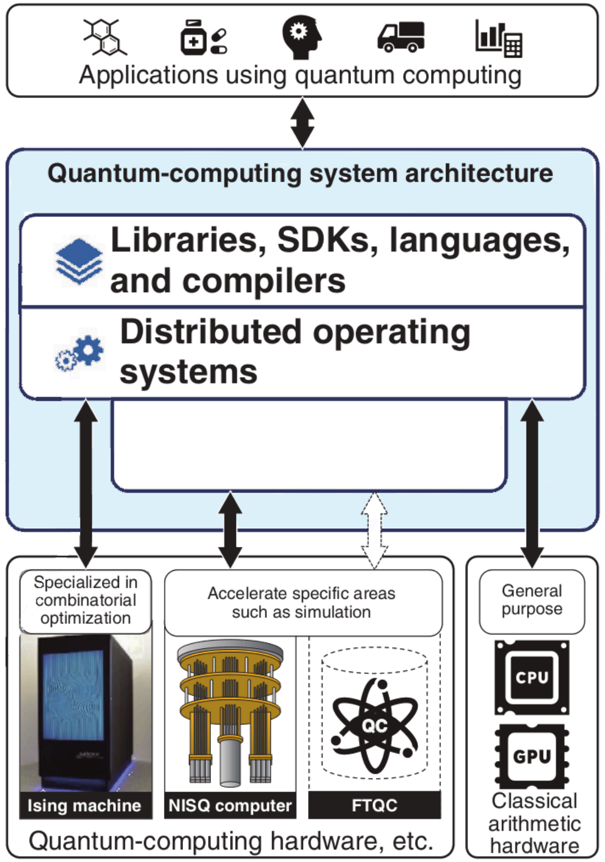
We're **abstracting quantum hardware with libraries and SDKs** to simplify development, enabling **optimized processing** across quantum and classical resources through instruction sets and compilers.



Addressing Challenge 2

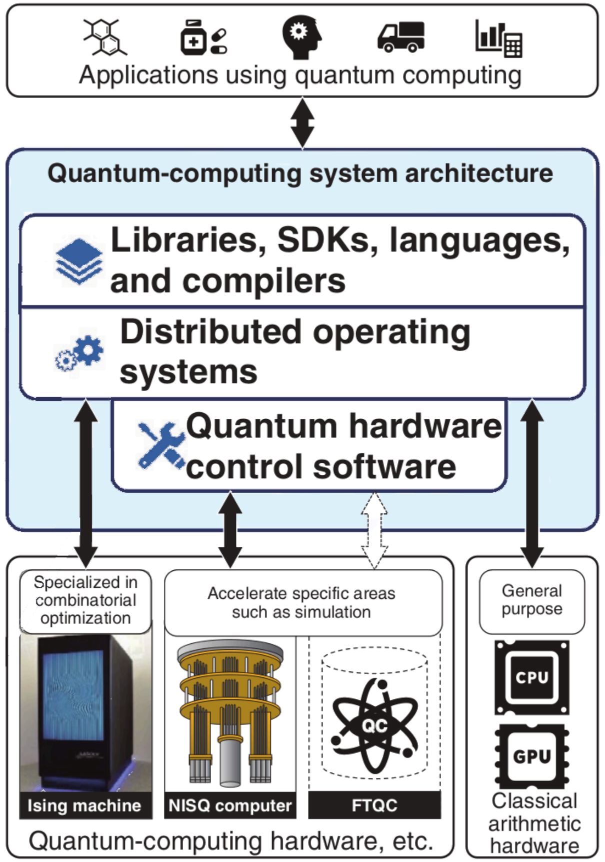
Creating **system architectures that seamlessly combine the two**, distributing processing efficiently.

Enabling **optimized task allocation**



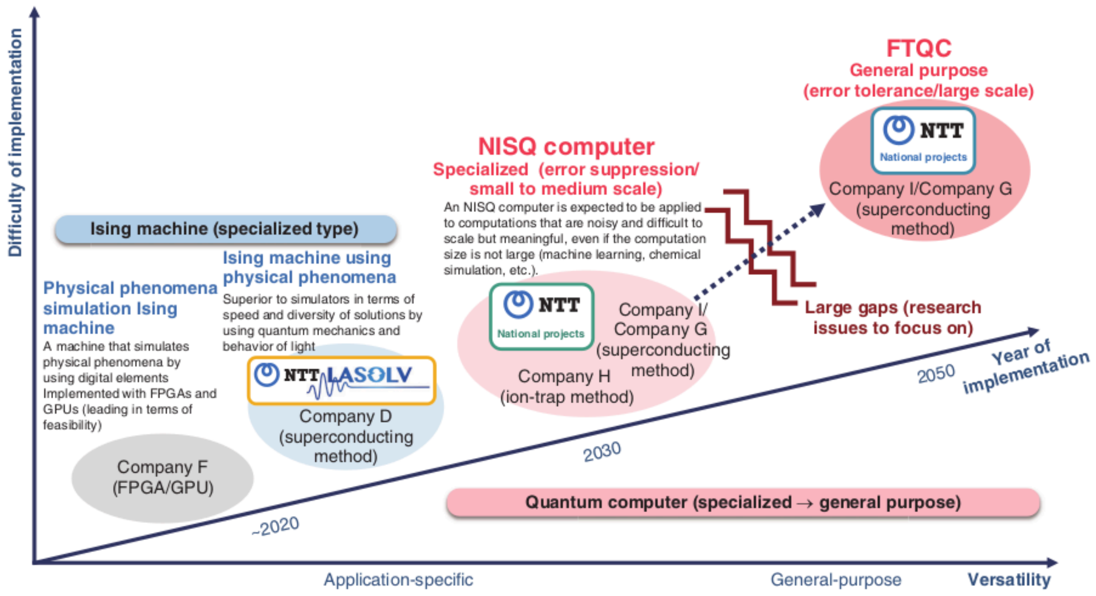
Addressing Challenge 3

Enhancing quantum hardware **utility through software** by integrating high-precision, high-speed, compact technologies with advanced error-suppression and correction methods.



Future Prospects and Conclusion

Quantum computers offer ultra-fast solutions to problems beyond classical limits. NTT is developing architectures from Ising machines to NISQ computers and FTQCs.



FPGA: field-programmable gate array
GPU: graphics processing unit

Questions ?