【Flagship Project】 “ Quantum information technology （Quantum computer, Quantum simulator） ”

Project Name

Research and Development of Superconducting Quantum Computers

Project Organization

Head quarter: Center for Emergent Matter Science, RIKEN (Project leader: Yasunobu Nakamura)
Collaborators: The University of Tokyo, National Institute of Advanced Industrial Science and Technology, National Institute of Information and Communications Technology, QunaSys, MDR, Toshiba, NEC, NTT, Kyoto University, Osaka University, Nagoya University, Tokyo Medical and Dental University

Overview

1. **Construction of a superconducting quantum computing platform** outperforming classical devices
2. Integration of **100 or more quantum bits (qubits)** with novel 3D packaging techniques
3. Development of **quantum applications** accessible via a **cloud-based service**

Goals of R&D

- Integration of **100 or more qubits** into a three-dimensional package
- Readily accessible **applications** available on a **cloud-based service**

Milestones

- **5 Year Plan:**
  - Implementation of a **50-qubit system with high-fidelity* control and readout**
  - Creation of a **cloud service** for the 50-qubit device
- **10 Year Plan:**
  - Growth to a **100-qubit system with higher-fidelity** control and readout**
  - Expansion of the **cloud service** for a 100-qubit device, applications for **practical use**

(* 1-qubit gates ＞99.9%, 2-qubit gates ＞99%, Readout ＞ 99%)
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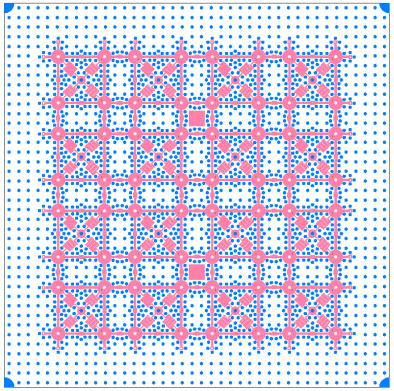


20 mm × 20 mm

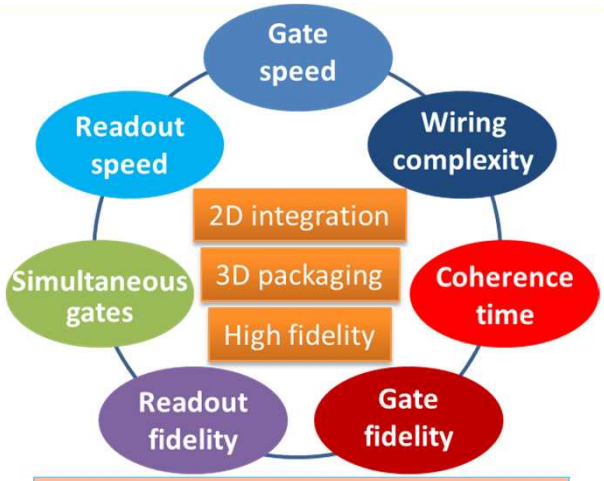
Integrated quantum chip (CAD image)

Exit Strategies

- Construction & operation of a cloud system in **collaboration with partners in the private sector**
- Development of **practical quantum computers** through an academic-industrial alliance

Strengthening of the research infrastructure & development of human resources of the next generation

- Recruitment of young **Principal Investigators** as leaders in the next generation
- Employment of **PhD students** as researchers in the next generation
- Close collaborations with worldwide research groups for the **exchange of international talents** to jointly spread quantum technologies across the globe
- Foundation of a **consortium** for quantum information research and development
- Support for the procurement and establishment of **career paths** for researchers and students



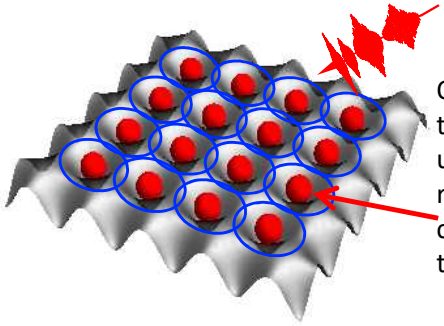
Towards the improvement of integrated quantum circuit performance

Project Name **Development of cold-atom based quantum simulators by optical control with precisions on the attosecond temporal and nanometer spatial scales and their applications to quantum computing**

Project Leader **Prof. Kenji Ohmori, Institute for Molecular Science, National Institutes of Natural Sciences**

Overview Development of an **Ultrafast quantum simulator** with attosecond (10-18 sec) precision and **High-functioning Hubbard quantum simulator** that precisely controls short-range interactions of ground-state atoms.

Complementary and synergistic effects with the Flagship project:
Development of methods different from those of the Flagship project to contribute to the formation of a platform for quantum information processing.



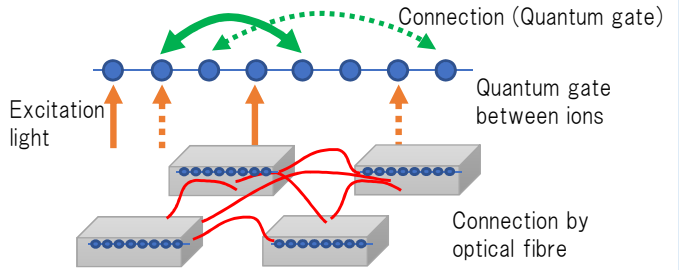
Coherent control with attosecond precision

Project Name **Multi-degree-of-freedom complex quantum simulator using cooled ions**

Project Leader **Specially Appointed Associate Prof. Kenji Toyoda, Institute for Open and Transdisciplinary Research Initiatives, Osaka University**

Overview Development of multi-degree-of-freedom complex **quantum simulator** using **cooled ion system** in which full connectivity is presumed to be satisfied to perform analog **quantum simulation** of 20-100 ions

Complementing and synergy effects with the Flagship project:
Development of methods which are different from the Flagship project to contribute to the formation of a platform of quantum information processing



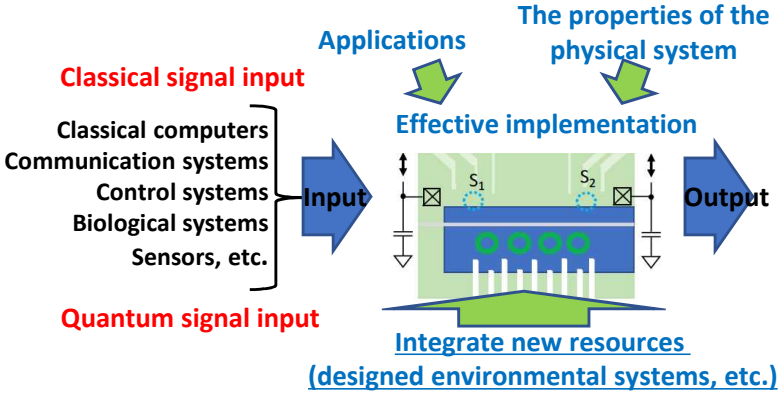
Quantum simulator with cooled ions

Project Name **Architecture and applications for small to large scale quantum computation**

Project Leader **Prof. Kae Nemoto, Principles of Informatics Research Division, National Institute of Informatics**

Overview Development of **applications** dedicated to small-scale quantum information processing and their implementation

Complementing and synergy effects with the Flagship project:
Develop an architecture to maximize the potential of quantum computers and create new market values of quantum computation.



Hardware development to integrate the application and the architecture

Project Name **Development of quantum software applications by fast classical simulator of quantum computers**

Project Leader **Prof. Keisuke Fujii, Graduate School of Engineering Science, Osaka University**

Overview Building of the **simulation environments of quantum computers** using classical computers and the building of **machine learning and quantum chemistry algorithms** on the base of quantum acceleration

Complementing and synergy effects with the Flagship project:
Develops the software of gate-type quantum computers and accelerates social implementation of gate-type quantum computers

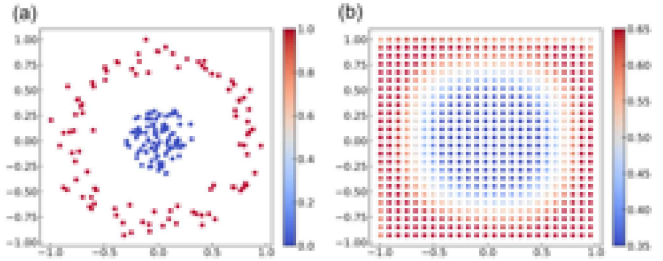


Image of quantum circuit learning for 2-class classification task

Project Name **Large scale integration of silicon qubits to realize quantum computer**

Project Leader **Senior Researcher, Takahiro Mori, Nanoelectronics Research Institute, National Institute of Advanced Industrial Science and Technology**

Overview Integrates high-fidelity **silicon qubits** using **LSI integration technologies** and realizes 2-**qubit coupling** appropriate for integration

Complementing and synergy effects with the Flagship project:
Development of methods which are different from the Flagship project to contribute to the formation of a platform of quantum information processing

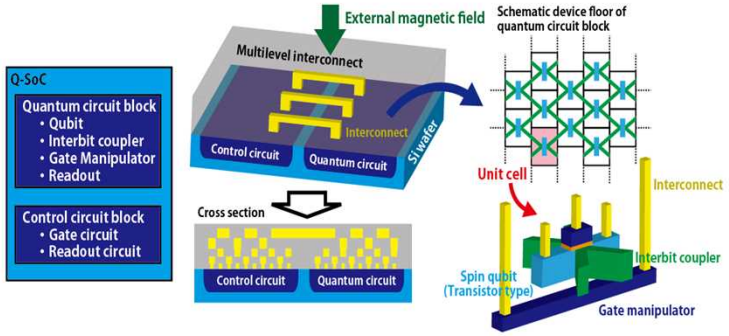


Image of chip integration

Project Name **Quantum software**

Project Leader **Prof. Naoki Yamamoto, Faculty of Science and Technology, Keio University**

Overview Uses an actual machine of an intermediate-scale gate-type quantum computer, **IBM Q**, to formulate theories of quantum algorithms for solving the issues of the real world and to **develop software** for implementing actual machines

Complementing and synergy effects with the Flagship project:
Develops the software of gate-type quantum computers and accelerates the social implementation of gate-type quantum computers

Quantum Computing Center, Keio University

【Flagship project】 “Quantum information technology (Quantum AI)”

Project Name Development of quantum software by intelligent quantum system design and its applications

Project Leader Professor Keisuke Fujii, Deputy Director of the Center for Quantum Information and Quantum Biology (QIQB), Osaka University.
Collaborators: Keio University, Nagoya University, The University of Tokyo, Kyoto University, NTT, e-Trees Japan, etc.

Overview

- **Development of software** designed to **elicit the performance of quantum computers,** putting **architecture designs** into practice, and **implementing them through venture companies, etc.**
- **Theoretical analysis of hardware performance**, development of **tools that will analyze quantum advantage,** Development of **quantum algorithms with theoretical guarantees**
- Development of **quantum circuit design methods using NISQ devices. Application of this to practical issues such as machine learning, quantum chemistry, and material science and financial engineering**

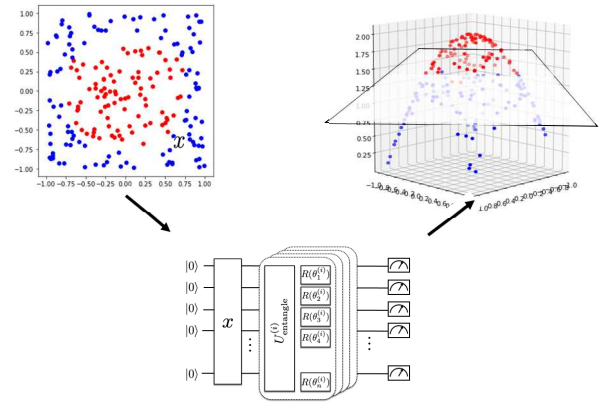
Goals of R&D

- **Construction of software/architecture** to intelligently elicit the performance of NISQ devices. **Working toward implementation in superconducting quantum computers**
- **Provide users** with **applications that take advantage of quantum advantage. Analysis of real-world problems by quantum AI**

Milestones

5 Year Plan: **Public release of a library of algorithms** for data classification, chemical reaction simulations, and financial engineering analysis
Development of **quantum circuit analysis tools** and their release to the cloud, construction of **physical emulators** and their release to the cloud

10 Year Plan: **Application of quantum AI** methodologies with respect to **machine learning and condensed matter physics to practical topics**
Development of **quantum circuit design tools** using NISQ computers and their **release to the cloud**
Collaboration with projects to develop **superconducting quantum computers, and implementation of software to operate these machines**



Quantum machine learning with use of quantum circuits as a model

Exit Strategies

Establishment of a quantum computer development ecosystem consisting of hardware/software research and development institutions/companies.
Feeding back social needs and technology for implementation.

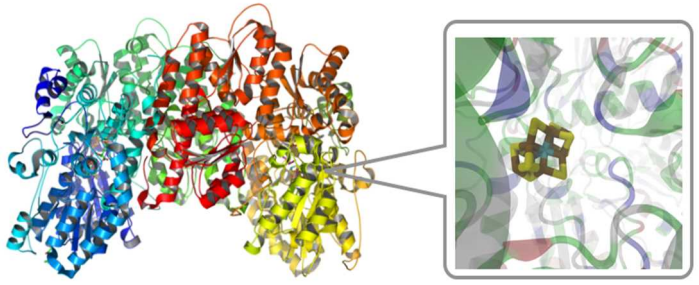
- Construction and use of software/architecture for NISQ devices: **To be led by collaborating institutions/companies**
- Implementation of technology that is difficult to release to the public: **Start a business, commercialize, etc.**

Strengthening of the research infrastructure & development of human resources of the next generation

- **Outreach** aimed at high school students and technical college students, **schooling** for undergraduate students and researchers in other fields.

Aiming to popularize the quantum computing field through **tutorials** and **hackathons** for the academic as well as general participants

- **Financial support** for doctoral students **through RA activities**
- Support for **sending** young researchers **to foreign research institutions** and **accepting researchers from foreign research institutions**
- Acceptance of doctorate students and researchers from collaborative institutions. Working towards raising the level of quantum technology by **accepting visitors and interns** from companies, etc.



M. Reiher et al., PNAS 114, 7555-7560 (2017)

Nitrogen-fixing enzyme (left) and its center (right). Use of quantum computation is expected to clarify its functionality