Working Group 6

Creating innovative non-traditional sciences and technologies based on quantum and related phenomena

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The Moonshot Area, Vision, and MS Goal Example

[Area] Exploring frontiers with science and technology

[Vision] Measuring, computing, and visualizing unexplored spaces

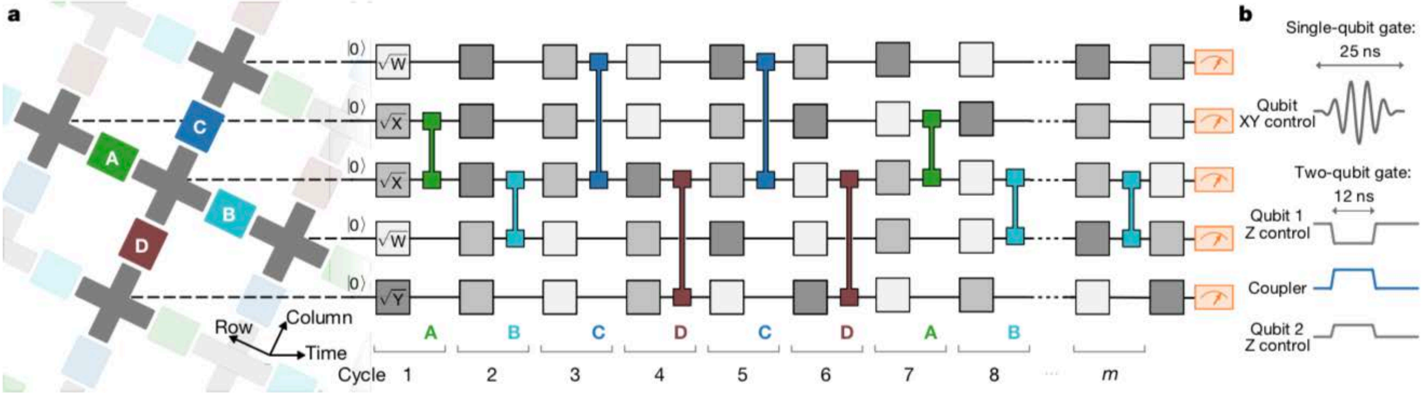
[Example of MS goal] 22) General-purpose quantum computer network

Background

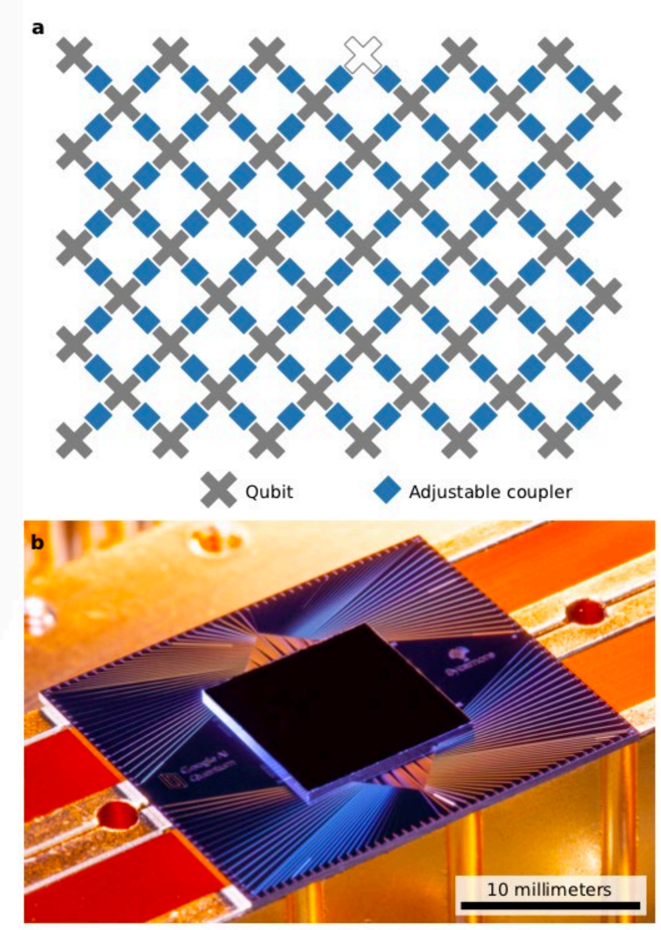
- The progress of semiconductor technology has been the driving force behind the today's rapidly growing information society. Toward the realization of Society 5.0, the demand for the computers will increase explosively. However, computer progress in such a conventional style will soon come to a limit.
- A number of important computational tasks are known to be difficult or impossible to perform using current style supercomputers. Many of such difficult tasks are expected to be efficiently calculated by using a large-scale "fault-tolerant universal quantum computer".

WG6: Hot topic

Random quantum circuit on qubits arrays



53 Qubits ～ 8×10^{15} dimensions



Google team, *Nature* **574** 505 (2019)

Total fidelity: $0.00176 = (0.9938)^{430} \times (0.9984)^{1113} \times (0.965)^{53}$

- Output of random quantum circuit.
- Practically generate from quantum computer = 200 sec.
- Calculate with supercomputer > 10,000 years
- It only showed an advantage over the problems that quantum computers are good at. Things that are impossible with supercomputers can now be done with quantum computers.
- Experts agree that it takes only 20—30 years to realize a quantum computer that is only a milestone and can calculate useful problems.

Proposal of the MS Goal

The WG6 reviewed and discussed candidates of the MS goals from various perspectives, considering societal demands toward developing quantum computers, global trends in research and technical challenges, such that the MS goal will be accepted by many as a viable goal achievable by 2050.

Finally, WG6 proposed the following MS Goal:

Realizing a fault-tolerant universal quantum computer that will revolutionize economy, industry, and security by 2050

Initiative Report of WG6

MOONSHOT
RESEARCH & DEVELOPMENT PROGRAM

2050 [Moonshot Goal candidate]
Realization of fault-tolerant universal quantum computers

2040 **Demonstration of distributed NISQ computer & Calculation of useful tasks under quantum error correction**

2030 **Development of NISQ computers of a certain scale & Effectiveness demonstration of quantum error correction**

NISQ: noisy intermediate-scale quantum

Network

Development of quantum memory, establishment quantum interface technology between photons and quantum memory.

- Photon source & detector
- Quantum memory
- Quantum interface technology

Hardware

System design and implementation of quantum error correction, establishment of quantum bit and gate platforms.

Stage gate
Identify suitable & feasible physical system.

- Super-conducting qubits
- Photons
- Trapped-ions
- Silicon quantum dots

Software

Development of low overhead quantum error correction code and quantum algorithms, development of measurement and control software.

- Quantum error correction theory
- Middleware, compiler
- Algorithms, applications

Related Quantum Technology

- Quantum sensors
- Quantum materials
- Basic and Fundamental Research

WG6: Today's presentation

MOONSHOT
RESEARCH & DEVELOPMENT PROGRAM

Hardware

- Superconducting qubits, trapped-ions, photons and Si quantum dots
- No winning technology identified.
- Qubit integration with better fidelity and highly density is important R&D Theme.

Quantum software

- NISQ is the testbed for larger scale fault-tolerant quantum computing.
- Next milestone is demonstration of quantum error correction.
- Application, algorithms, programing, architecture and hardware control are important R&D theme.

Quantum network

- Quantum Internet, Quantum repeater (ion, atom, photon, diamond)
- Quantum memory and quantum repeater are important R&D theme.

WG6: Suggestive comments and expectations for Japan

- The MS goal is certainly ‘inspiring’ and ‘imaginative’. But, regarding the ‘credibility’ of the goal, we need more discussion.
- The European scientific community welcomes the establishment of a large-scale quantum program in Japan. Progress towards such very ambitious goals requires a strong strategic coordination across the whole spectrum from basic research to industrial innovation. International cooperation is important.
- The Moonshot approach represents a potential for dramatic acceleration of the current research ecosystem in Japan.
- The opportunity the quantum computing community provides here is demonstrating the success of this new pathway. Focusing on the long term technical and scientific goal while maintaining a series of outputs – intellectual and commercial spin-offs and spin-outs – will be essential.
- A community approach that integrates industrial interest and supporting technology efforts with the scientific advances may provide a powerful pathway to achieve this meta-goal.

WG6: Conclusion

MS Goal candidate

Realize a fault-tolerant universal quantum computer that will revolutionize economy, industry, and security by 2050

Milestones

- Development of NISQ computers of a certain scale, and effectiveness demonstration of quantum error correction (by 2030)
- Demonstration of distributed NISQ computer and calculation of useful tasks under quantum error correction (by 2040)
- Realization of large-scale/fault-tolerance (by 2050s)