State-of-the-art quantum computing technology and quantum software

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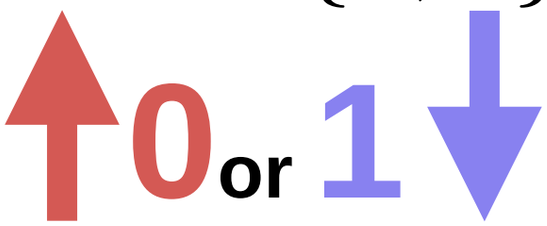
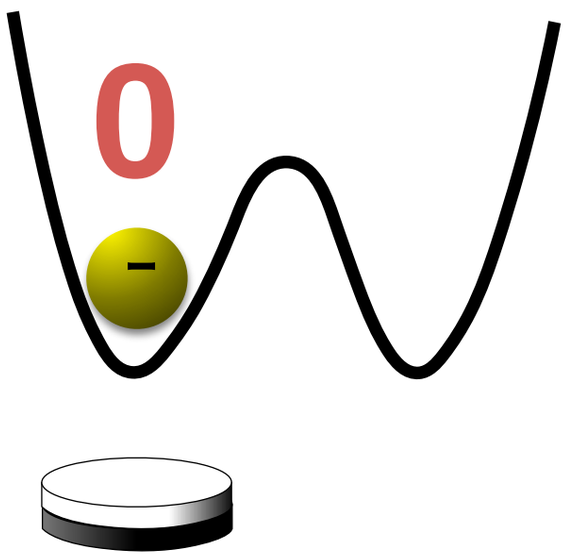
Osaka University
OTRI, Quantum Information and Quantum Biology Division,
Osaka University
JST PRESTO

What is quantum information

Classical bit:

$$x \in \{0, 1\}$$





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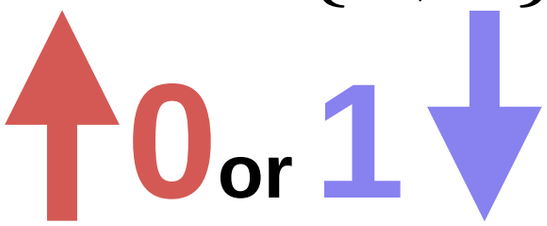

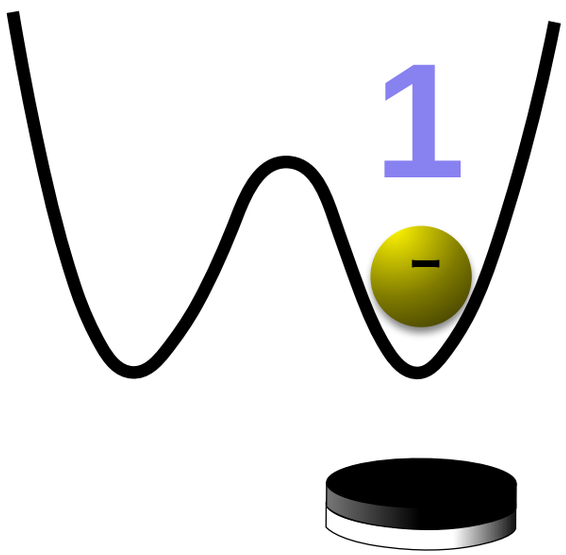

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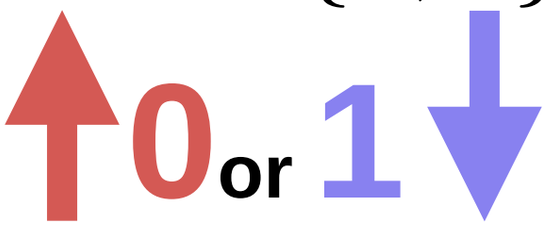
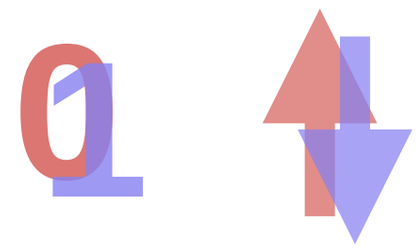
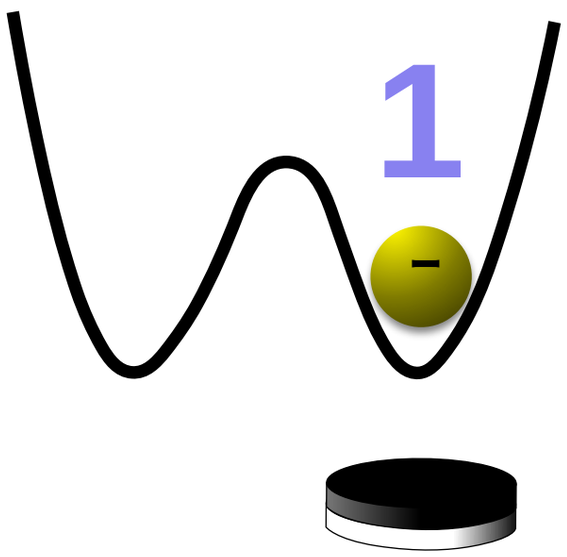


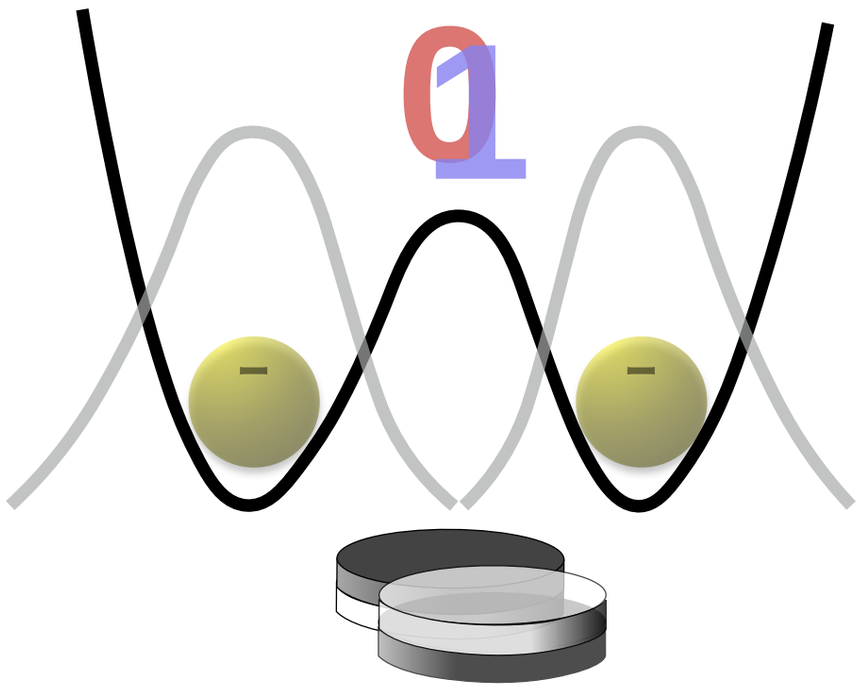
Quantum bit (qubit):

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$



superposition of 0 and 1





$$|\psi\rangle = \begin{pmatrix} \alpha \\ \beta \end{pmatrix}$$

state vector
on complex Hilbert
(vector) space

What is quantum information

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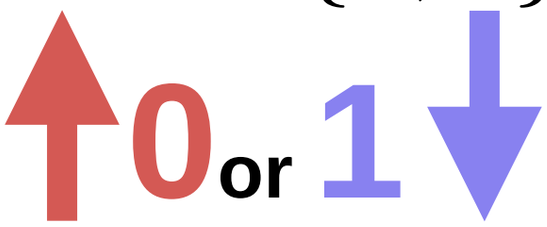

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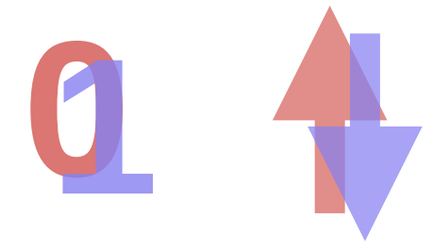

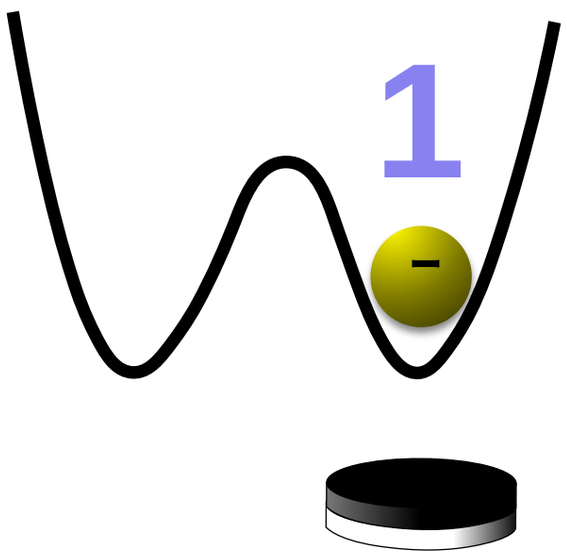

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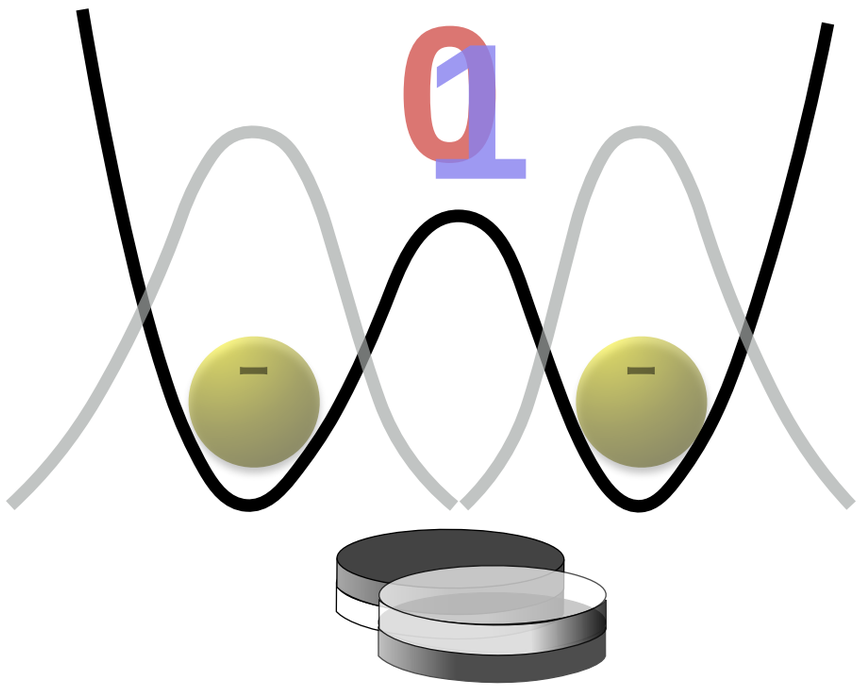

$$|\psi\rangle = \begin{pmatrix} \alpha \\ \beta \end{pmatrix}$$

state vector
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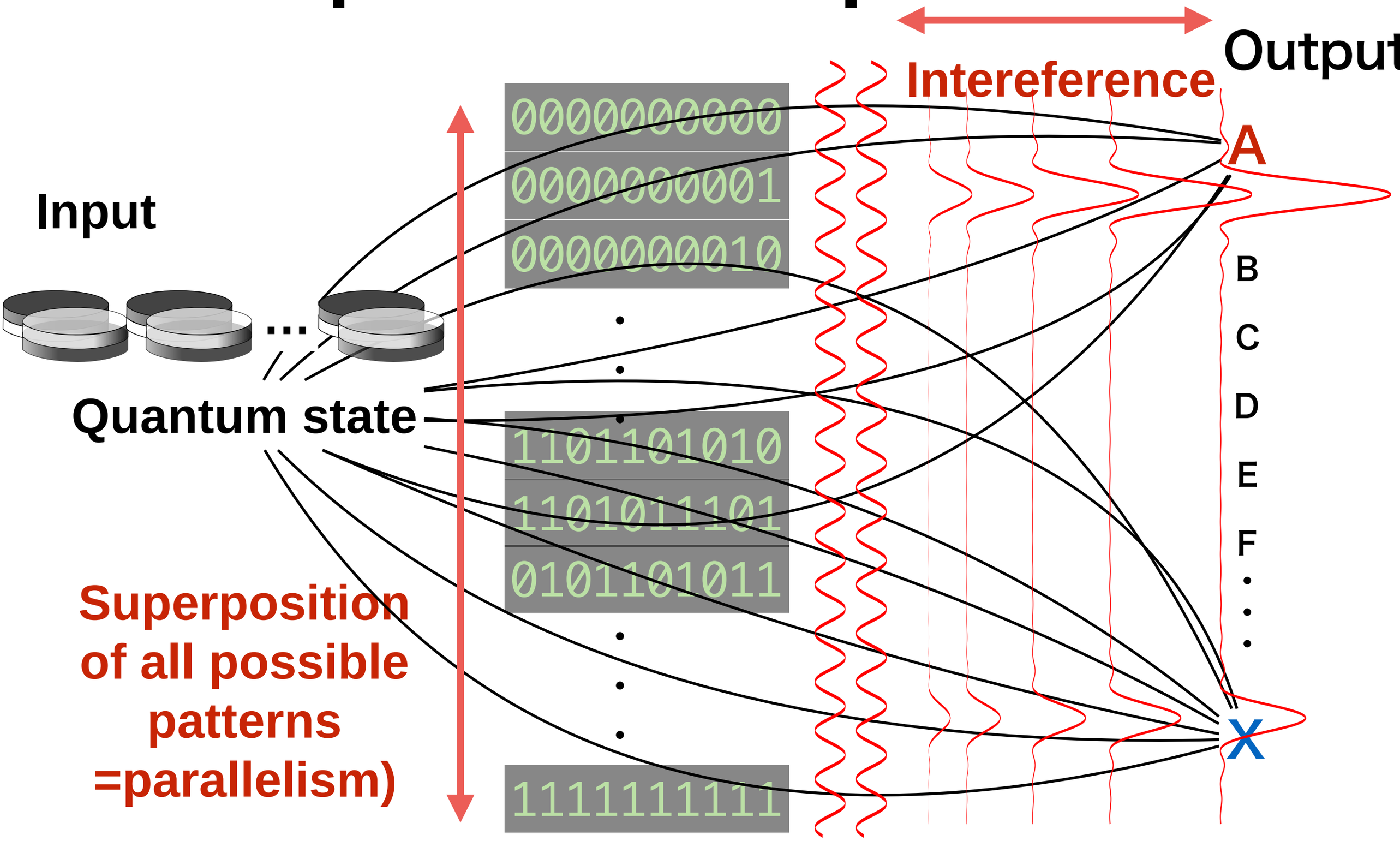
It is not yet determined whether the state is 0 or 1!

How quantum computer works



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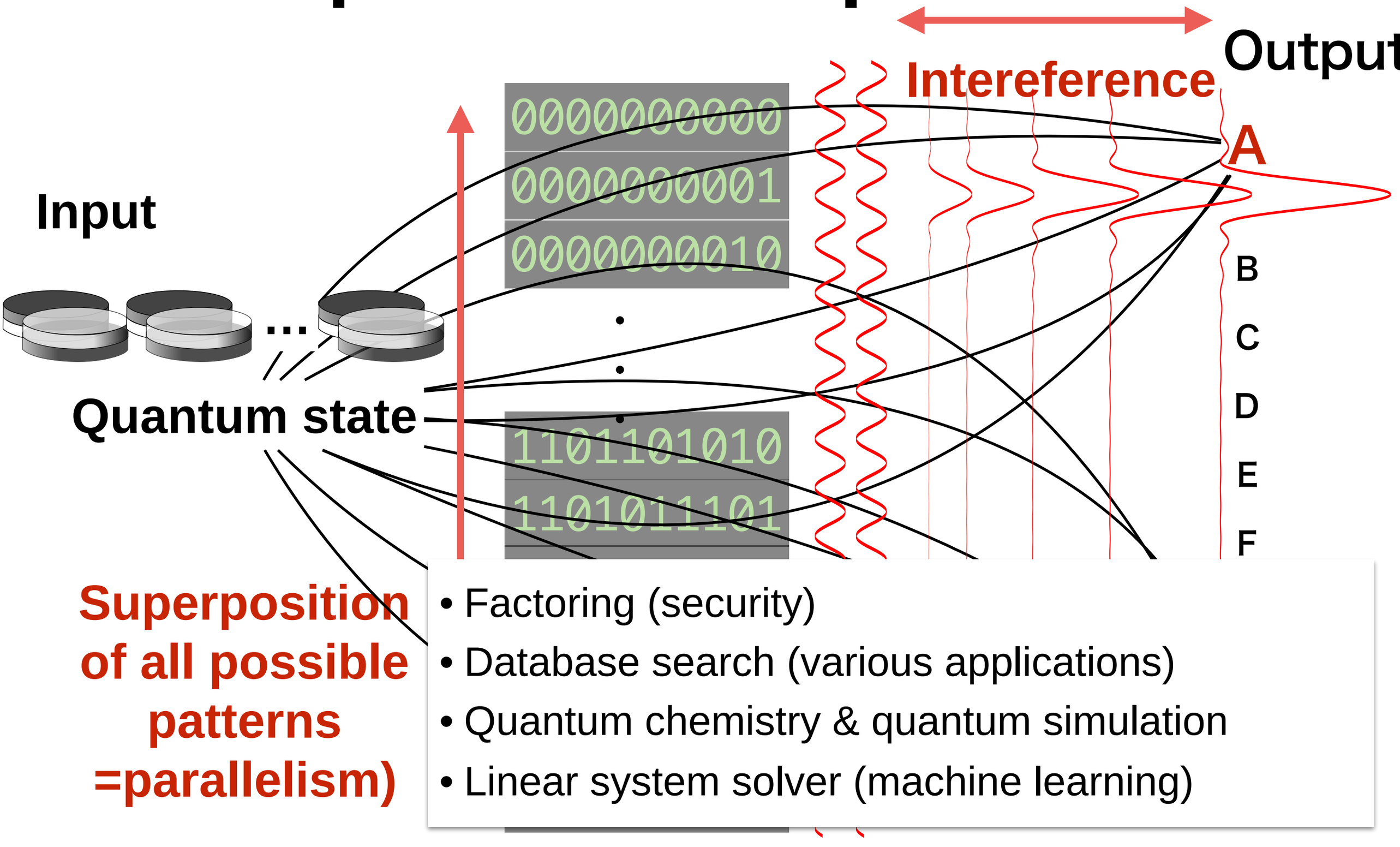
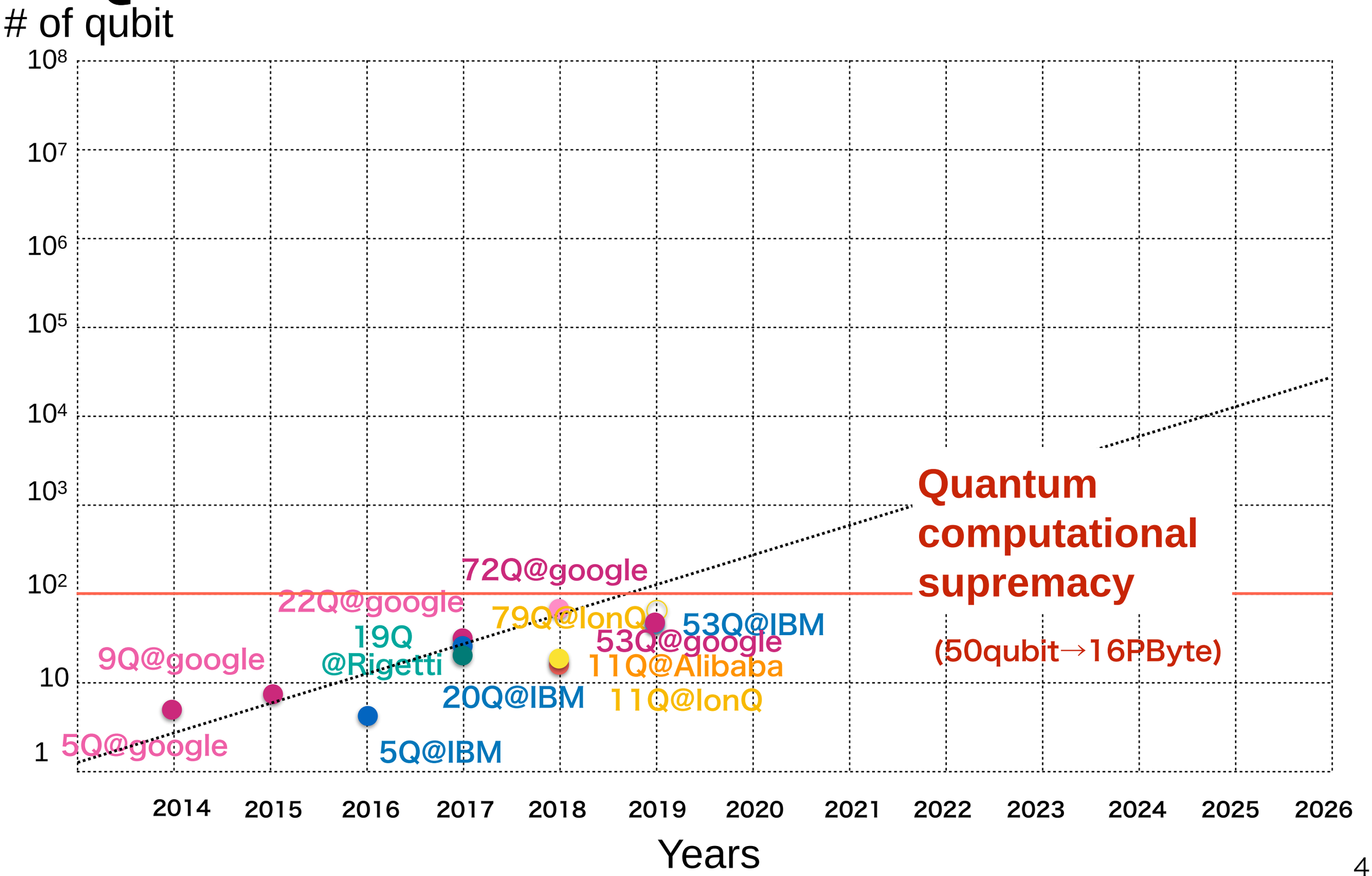


Superposition of all possible patterns =parallelism)

- Factoring (security)
- Database search (various applications)
- Quantum chemistry & quantum simulation
- Linear system solver (machine learning)

“Quantum” Moore’s law?

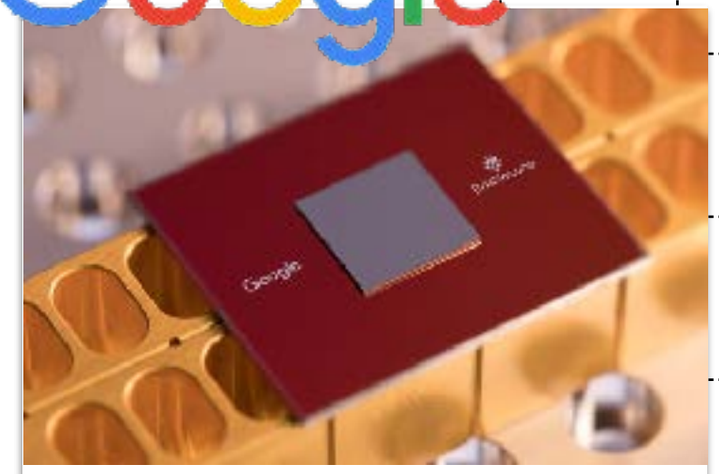


“Quantum” Moore’s law?

of qubit

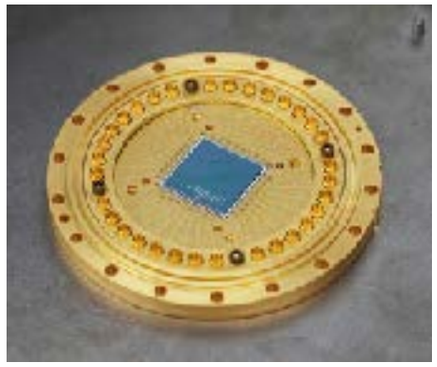
10^8

Google



gemon18Q
1Q:99.9% 2Q:99.2% M:97%
bristolcone 72Q
1Q 99.9%
Sycamore 53Q

rigetti



IonQ 79Q (11Q)
1Q:99.9% 2Q:98%

IBMQ SystemOne 20Q
1Q 99.9, 2Q 98%

10^2

10

1

5Q@google
9Q@google
22Q@google
72Q@google
19Q
@Rigetti
5Q@IBM
20Q@IBM
79Q@IonQ
53Q@google
11Q@Alibaba
11Q@IonQ
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Quantum computational supremacy

(50qubit→16PByte)

2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026

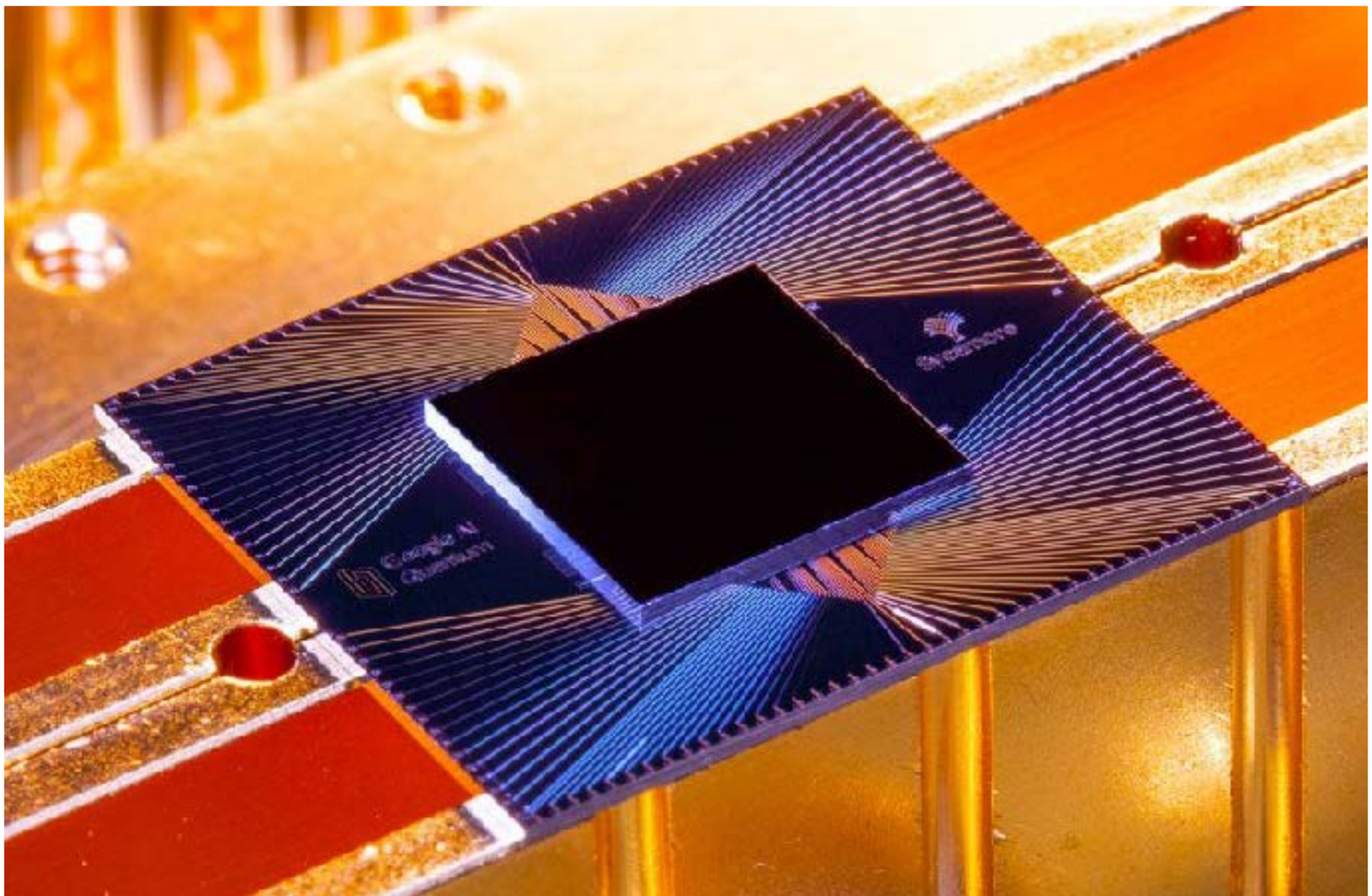
Years

NEWS · 23 OCTOBER 2019

Hello quantum world! Google publishes landmark quantum supremacy claim

The company says that its quantum computer is the first to perform a calculation that would be practically impossible for a classical machine.

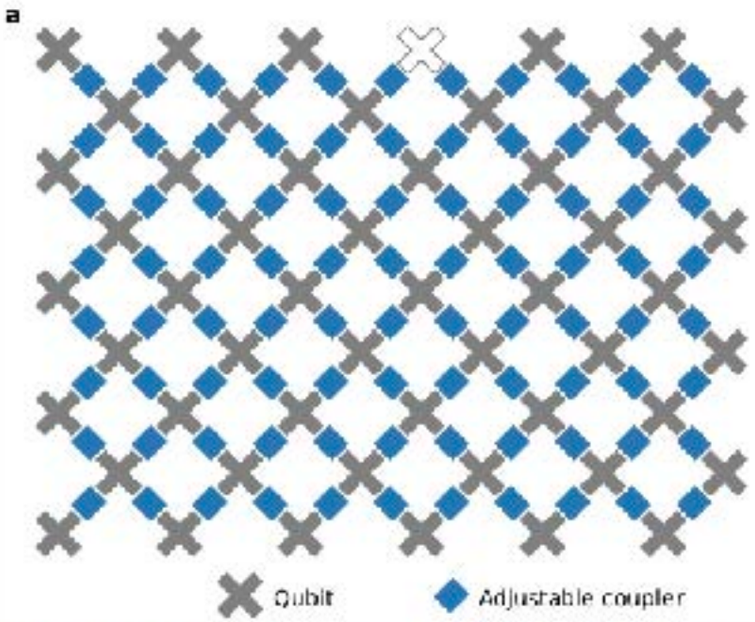
Elizabeth Gibney

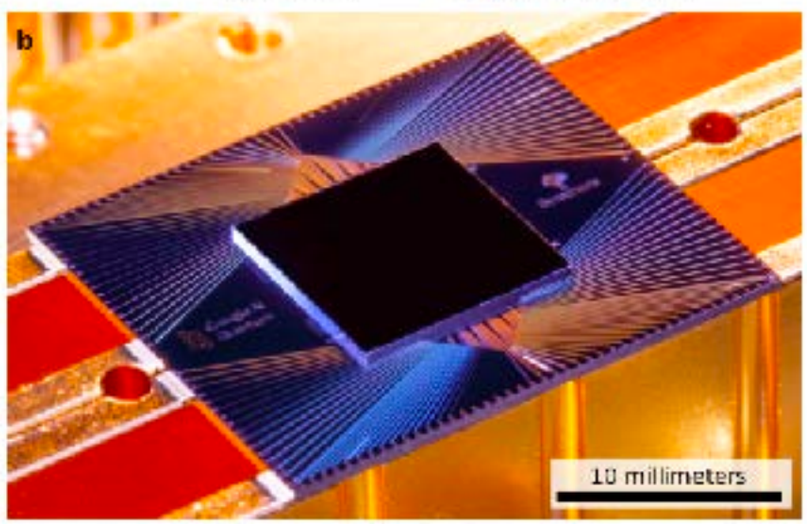


What is quantum computing supremacy by Google

53 Qubits

~ 8×10^{15} dimension





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

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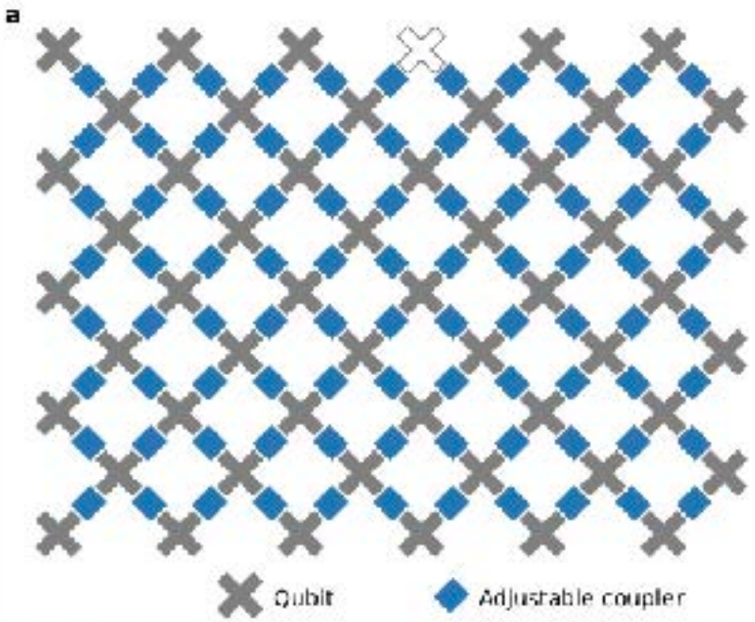
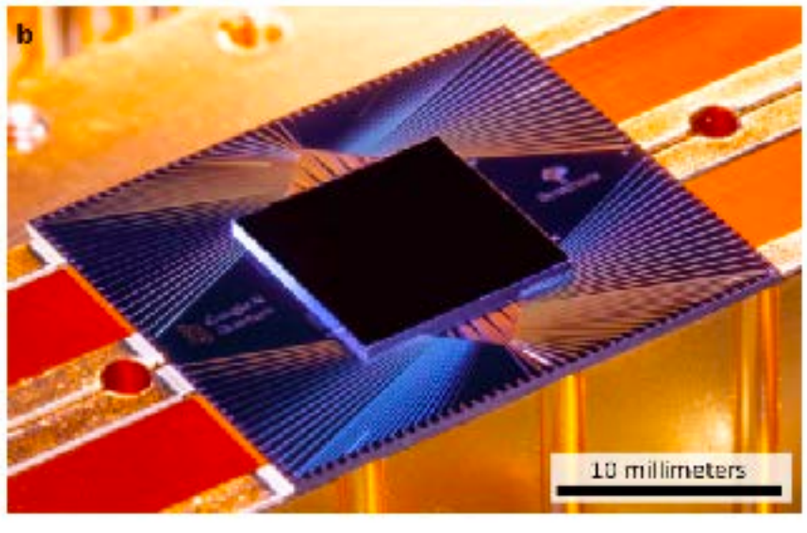
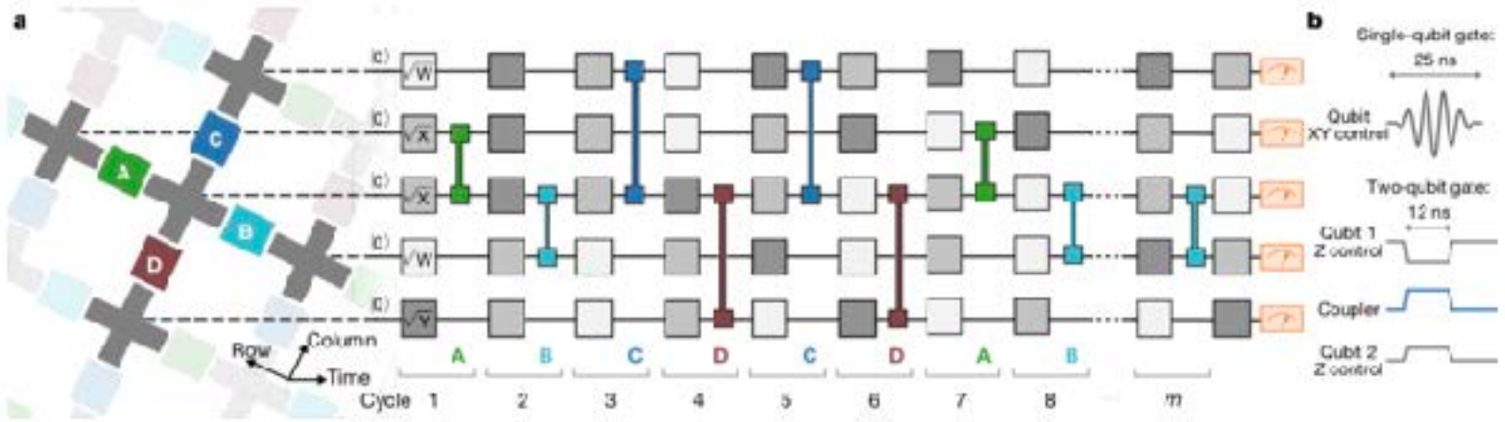




Random quantum circuit on qubit arrays



2Q gate **1Q gate** **Measurement** **Total fidelity**

$(0.9938)^{430} \times (0.9984)^{1113} \times (0.962)^{53} = 0.0015$

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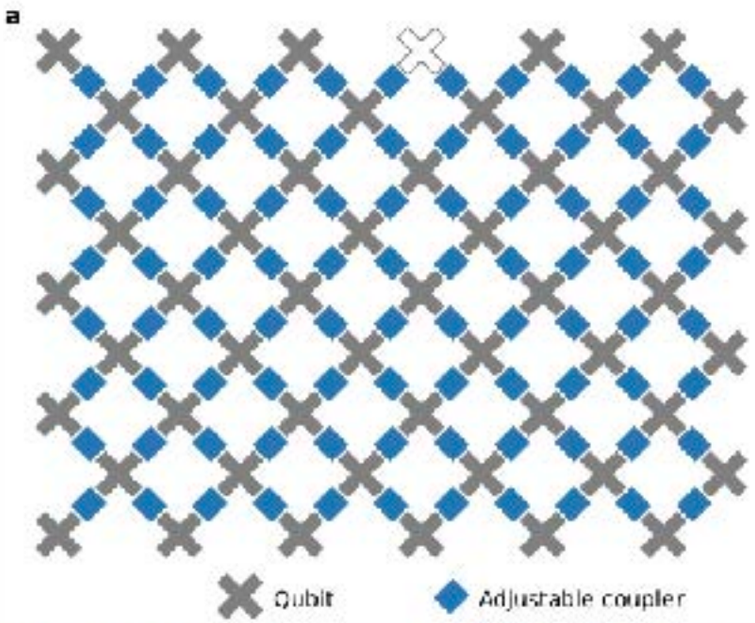

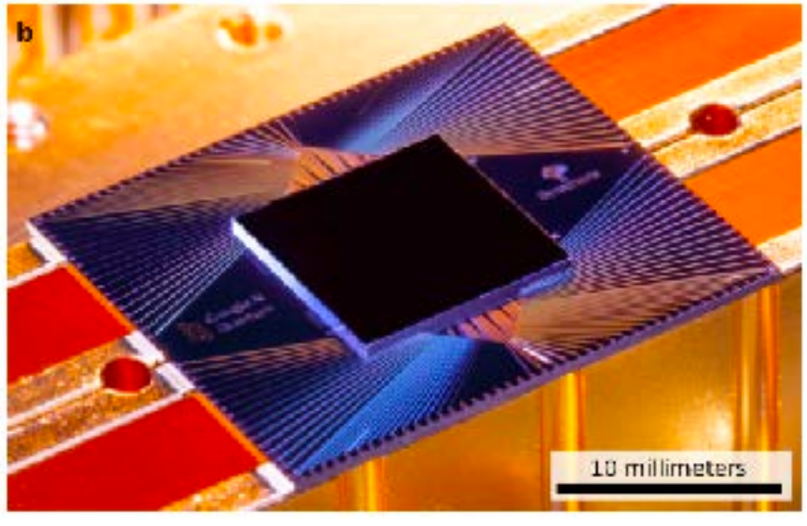

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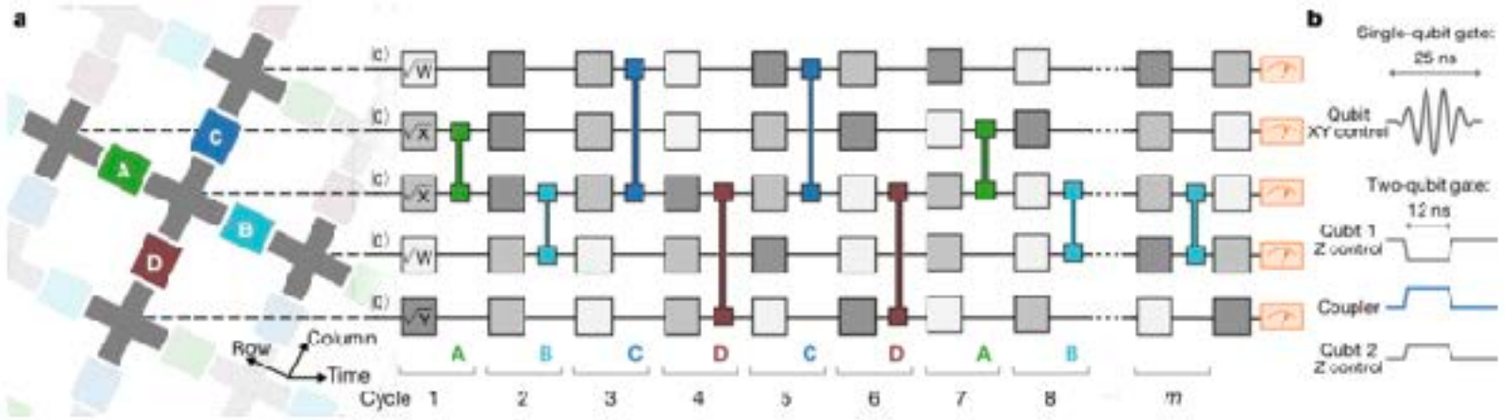

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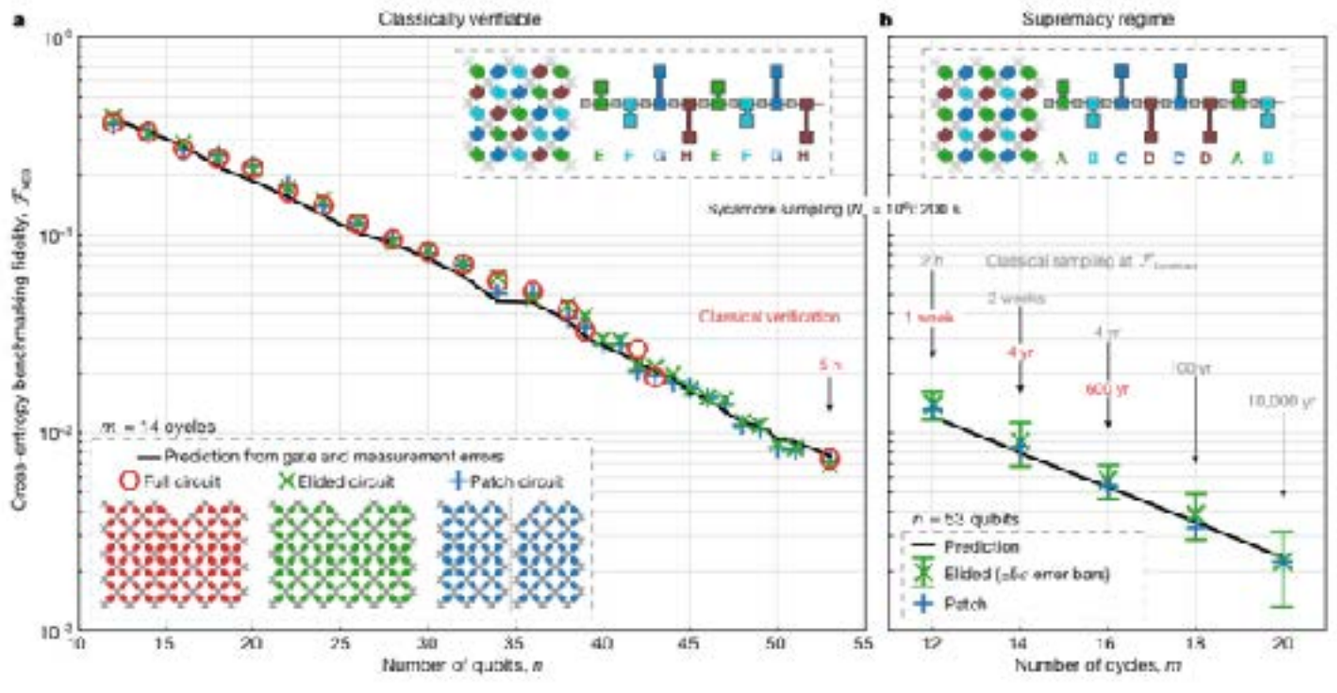

Compare Google's QC with classical super computer

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

What is quantum computing supremacy by Google

rebuttal from IBM

200 seconds

VS

1000years (2.5 days)

The benchmark task is meaningless,
just sampling random bit strings in a quantum way.

But enough to refute extended-Church-Turing thesis! That is,
we have at least one task,
which cannot be done on classical computers but can be done on the quantum computer.

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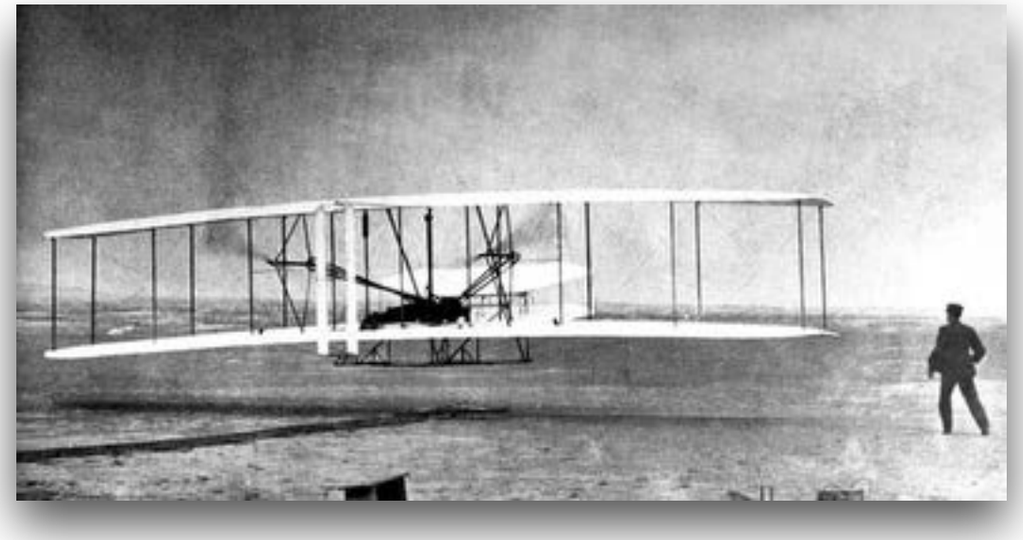

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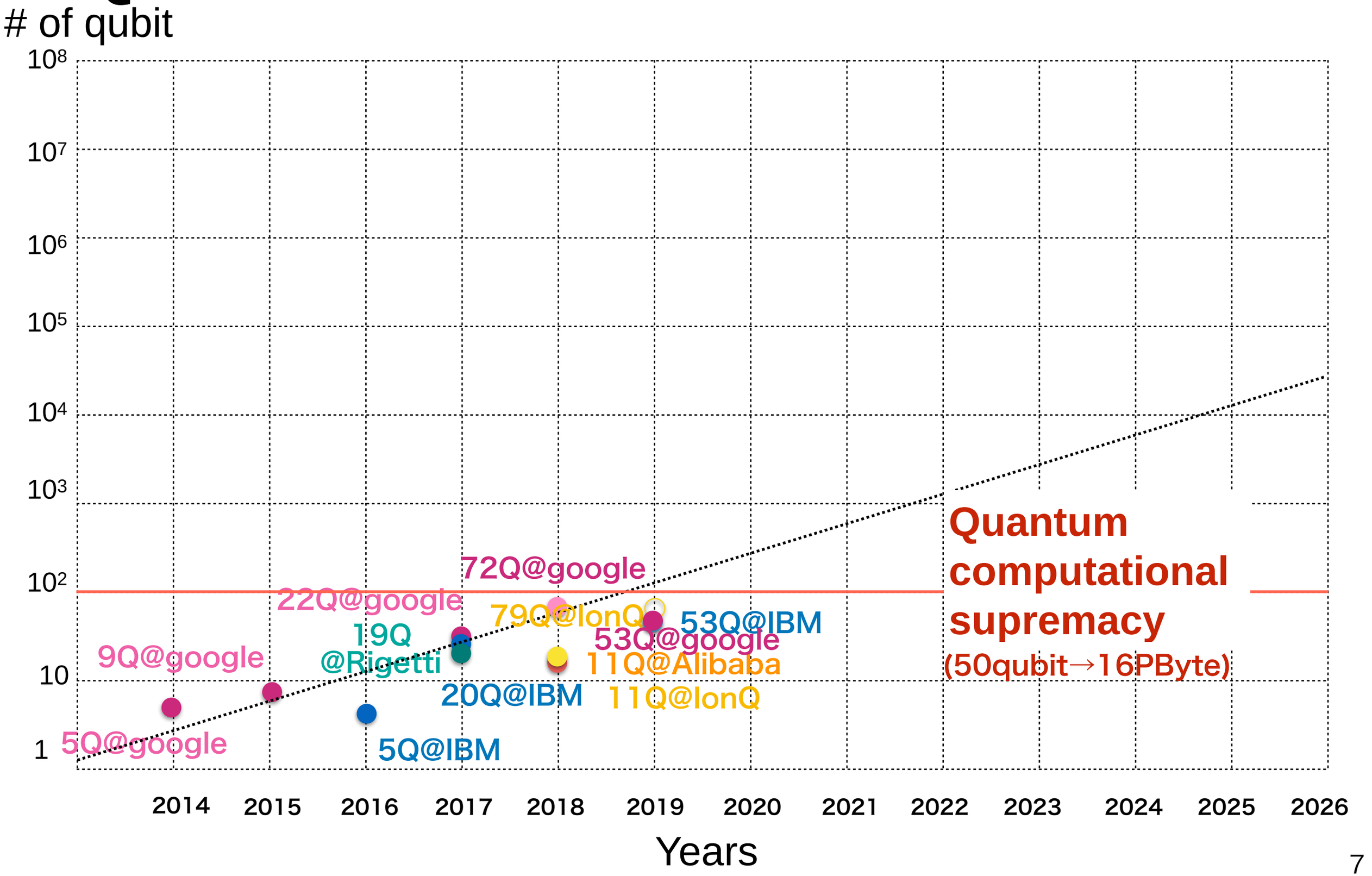
“Quantum” Moore’s law?



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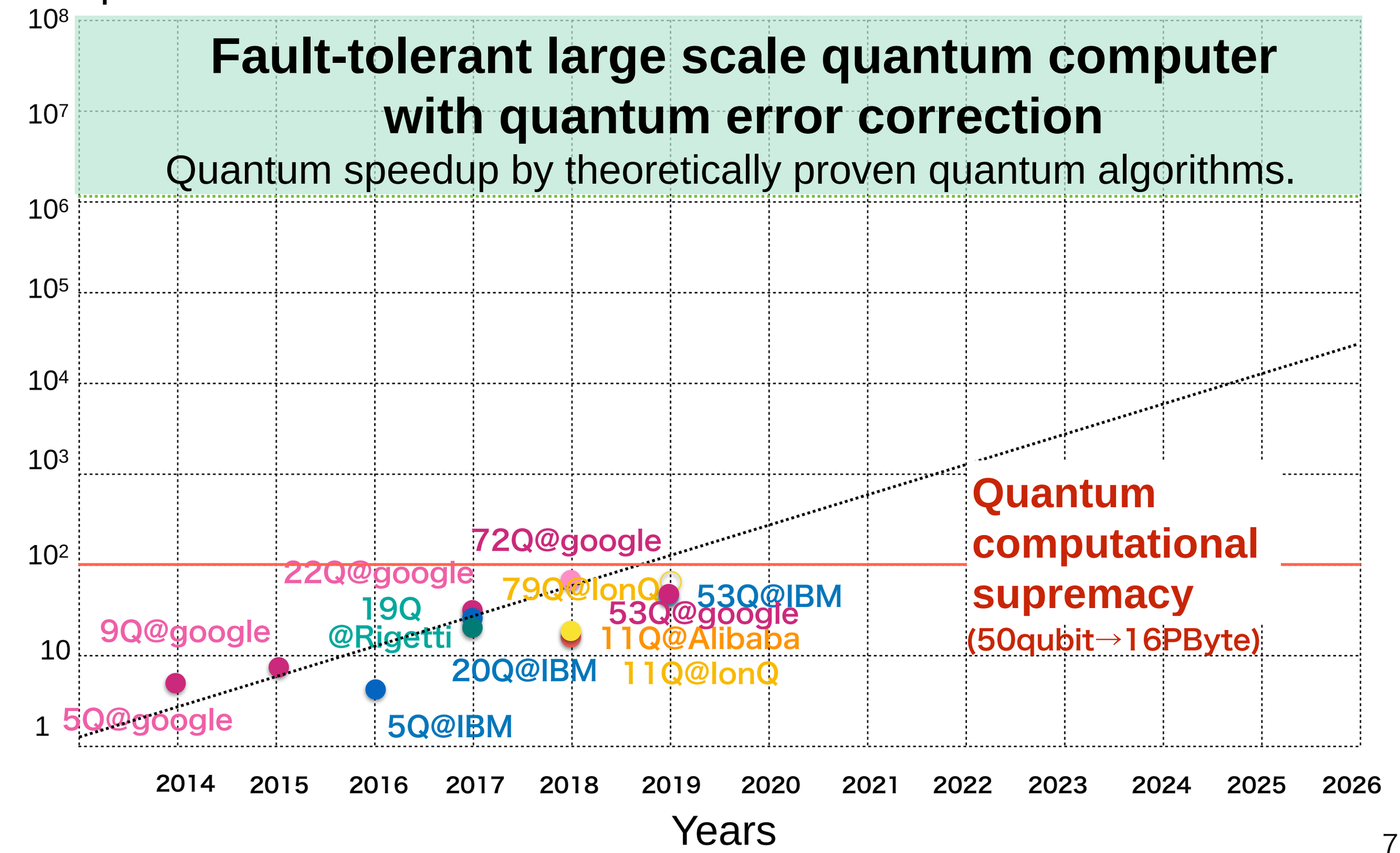

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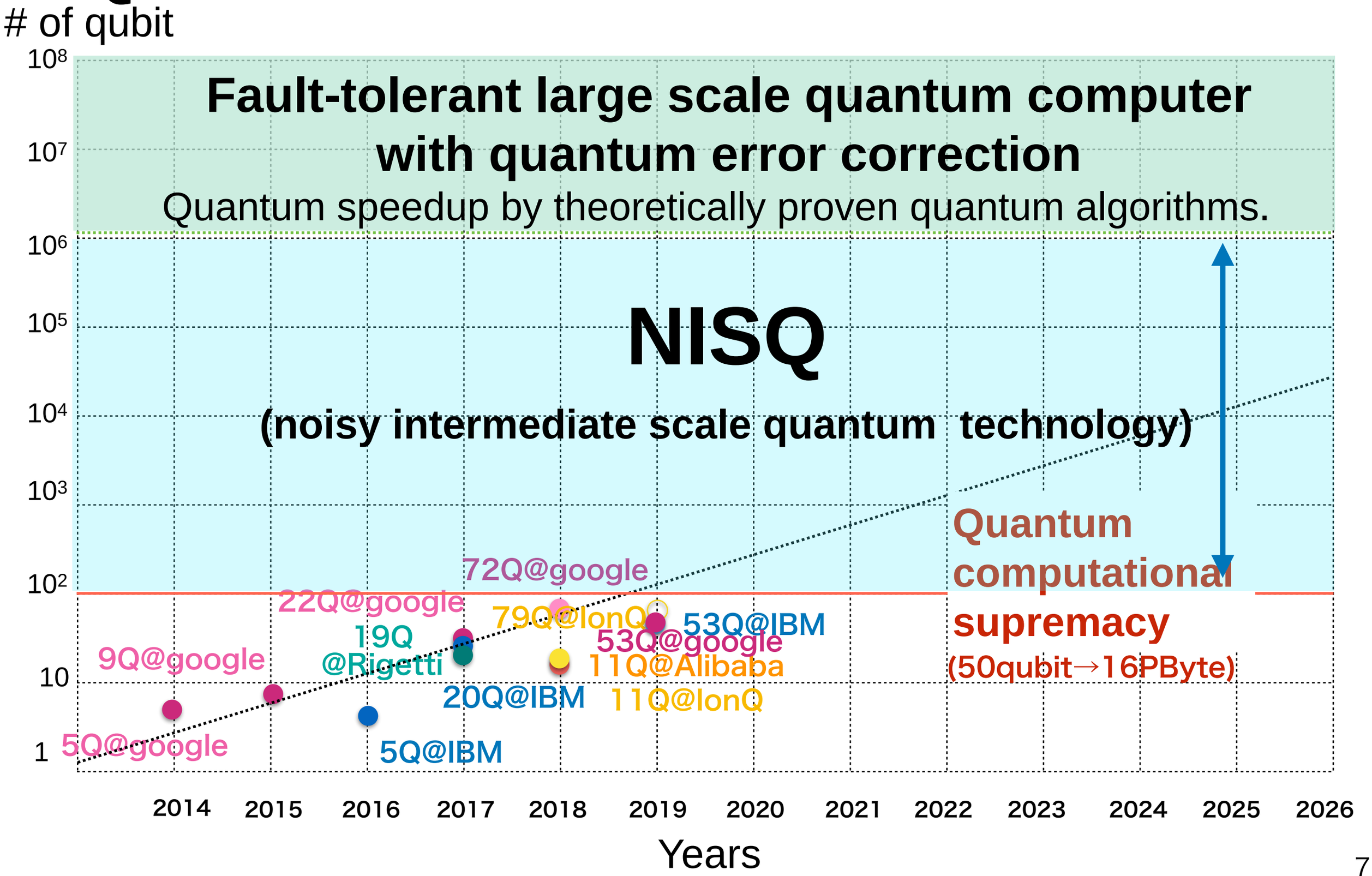

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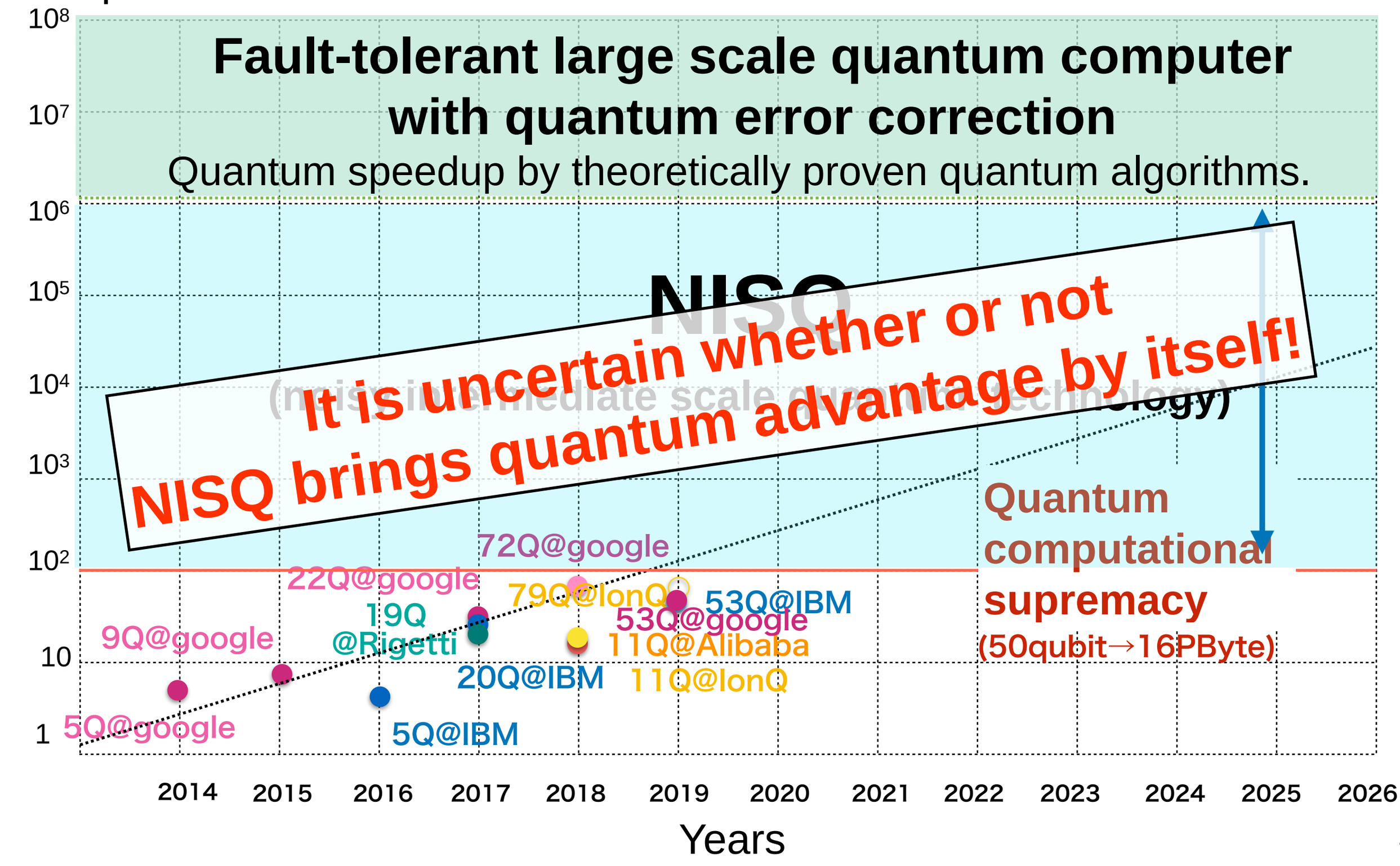

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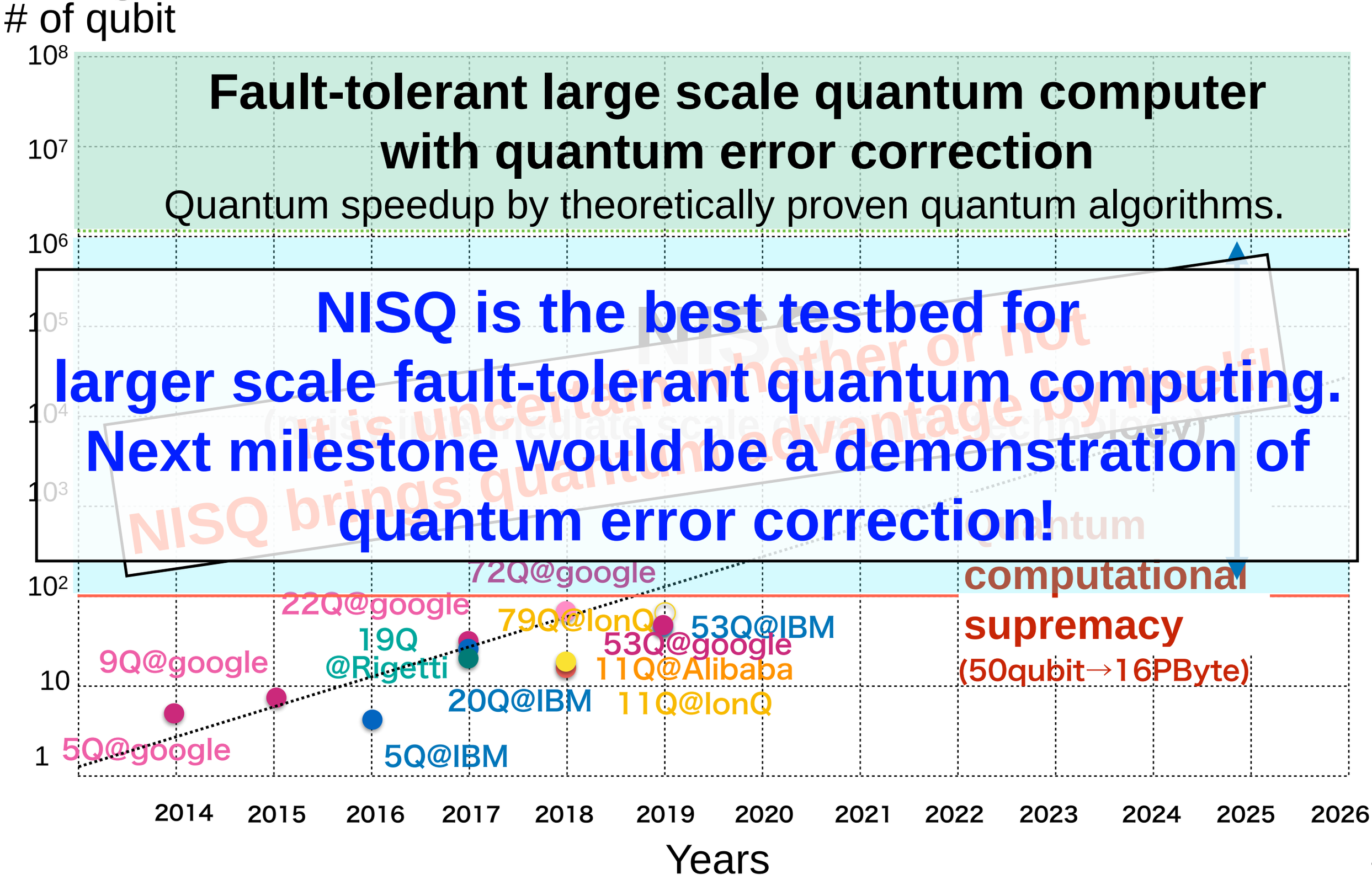
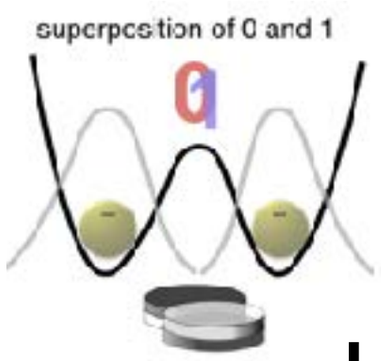


Toward fault-tolerant quantum computing

Qubit



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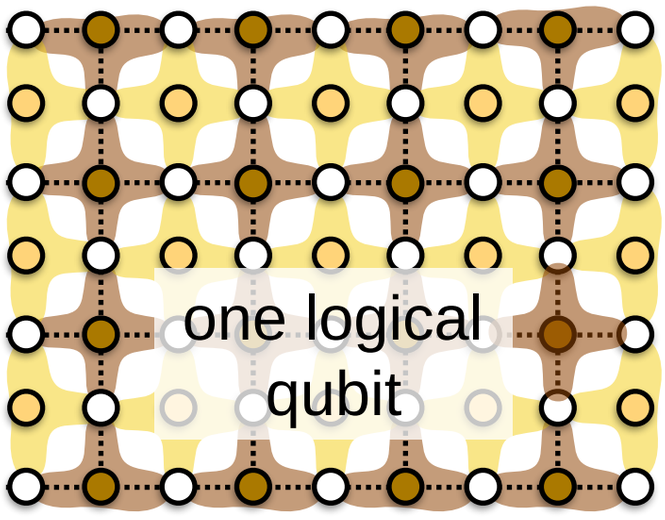
state vector
on complex Hilbert
(vector) space

Encoded



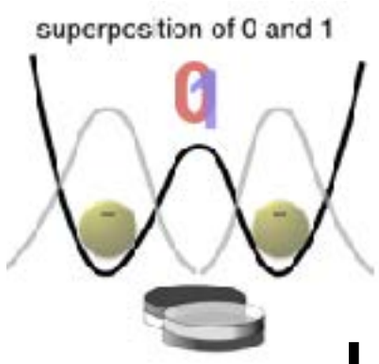
O(50)
physical
qubits

In the near future…

Lifetime of “logical” quantum information is not limited by physical life time!

Toward fault-tolerant quantum computing

Qubit



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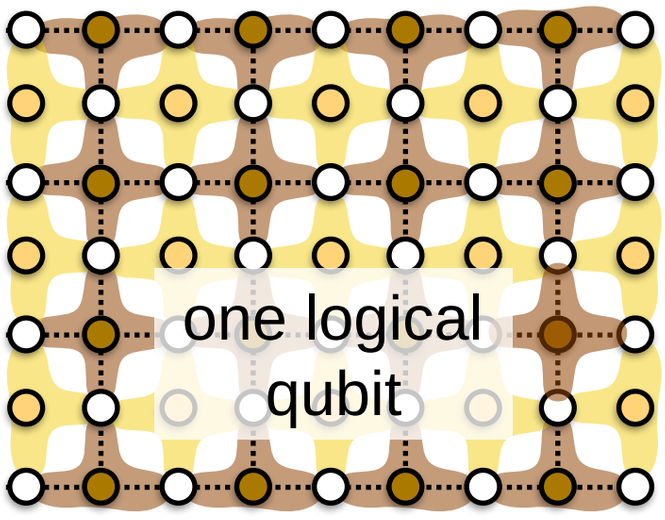

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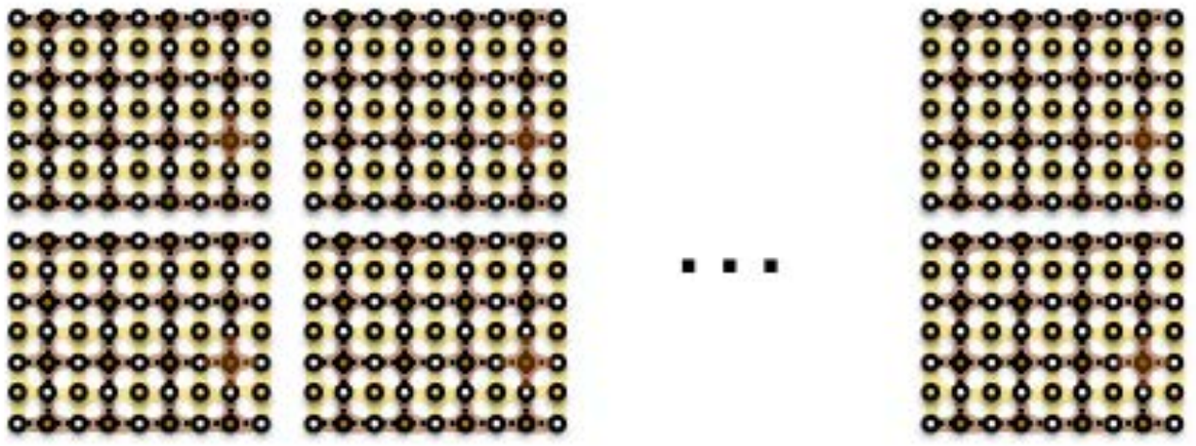
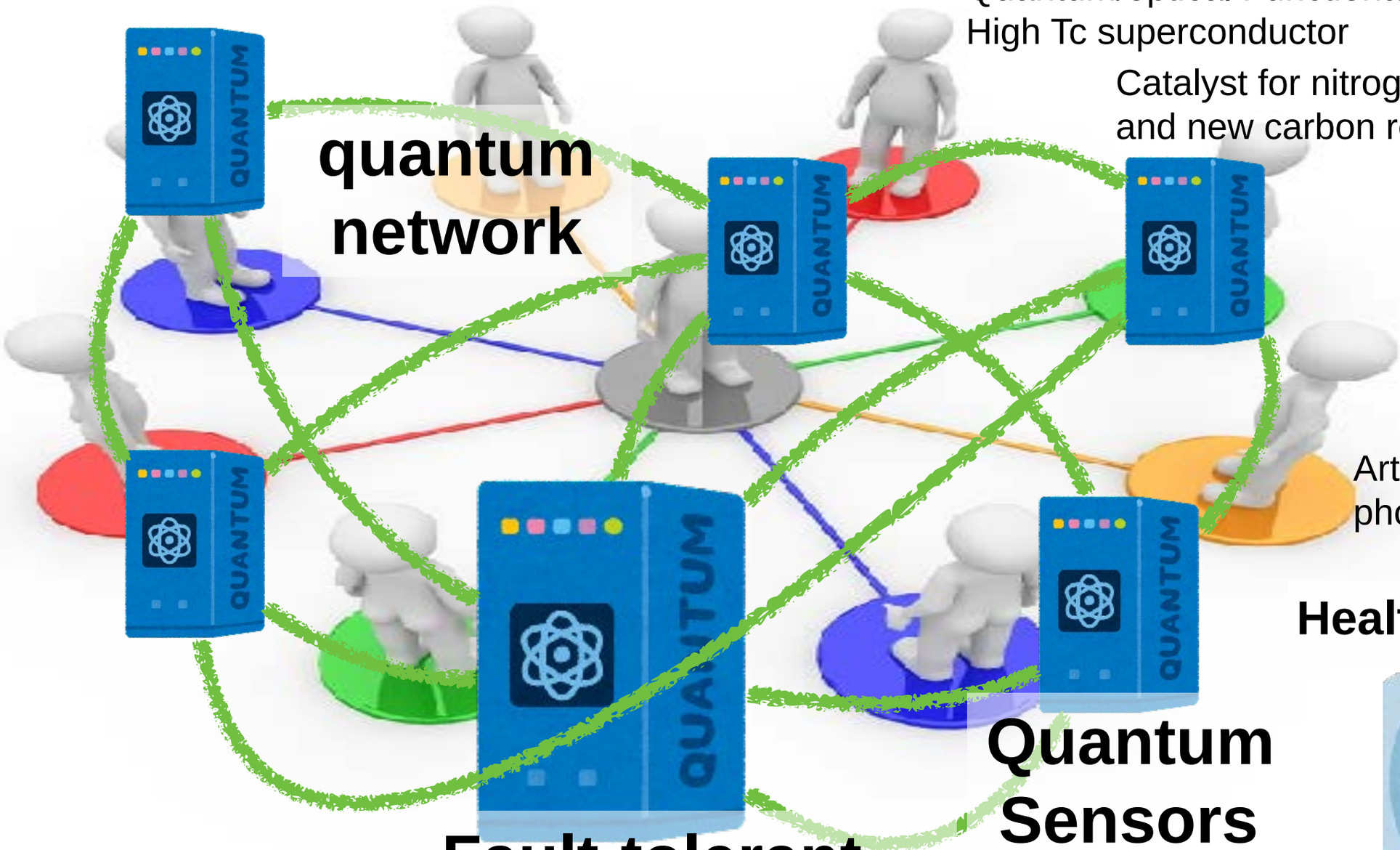
For fully fledged fault-tolerant quantum computing…



$O(10^5\text{-}10^6)$ physical qubits

It could be monolithic or distributed…

Quantum ICT society in 2050



Quantum/optical Functional materials,
High Tc superconductor

Catalyst for nitrogen fixation
and new carbon resources

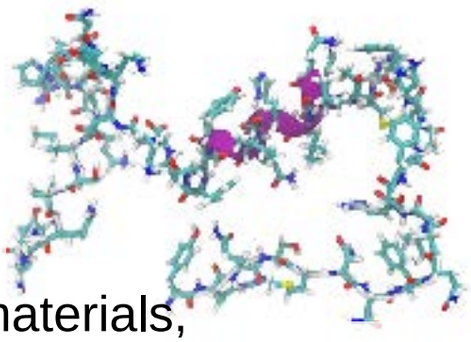
Artificial
photosynthesis

Quantum Sensors

Health care

Quantum ICT society in 2050

https://commons.wikimedia.org/wiki/File:Meissner_effect_p1390048.jpg



Material & Chemistry

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Medicine

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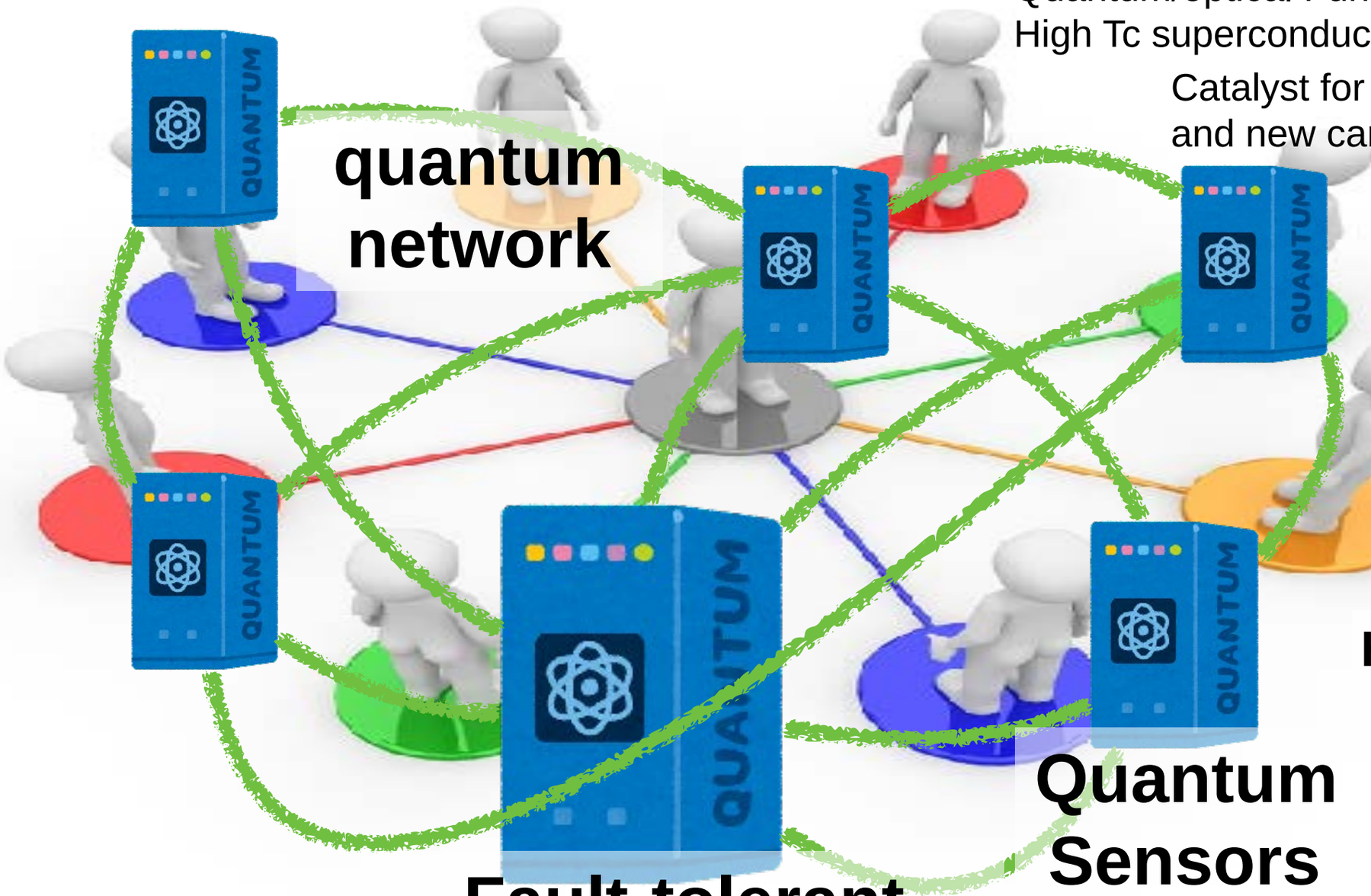

quantum network

Fault-tolerant quantum computer

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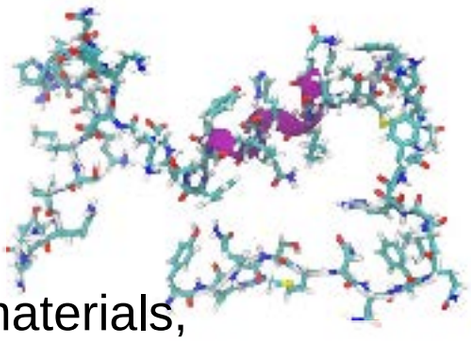

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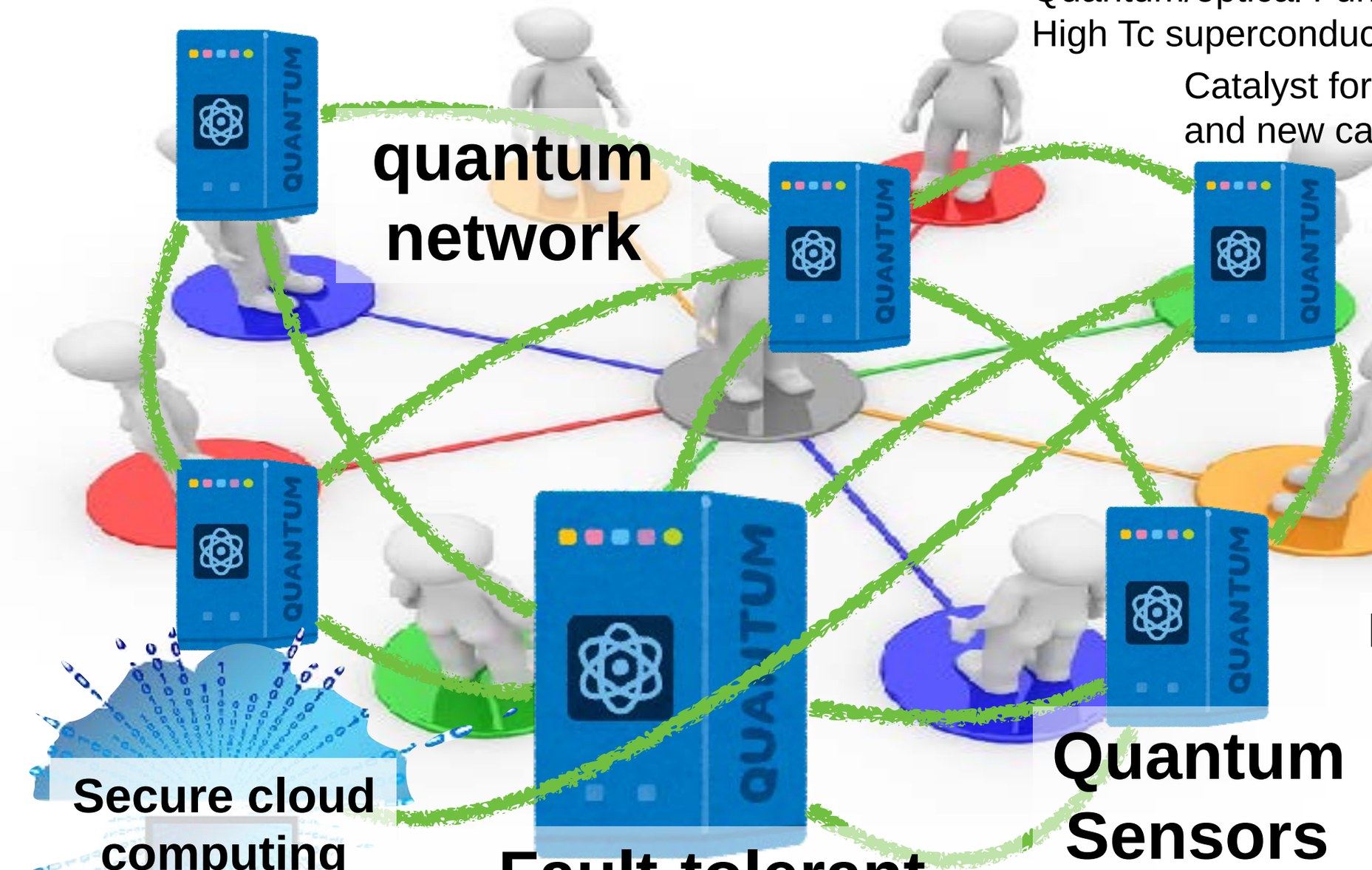

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Energy

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Health care

Secure cloud computing

Fault-tolerant quantum computer

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Quantum data generated by
quantum ICT infrastructures.

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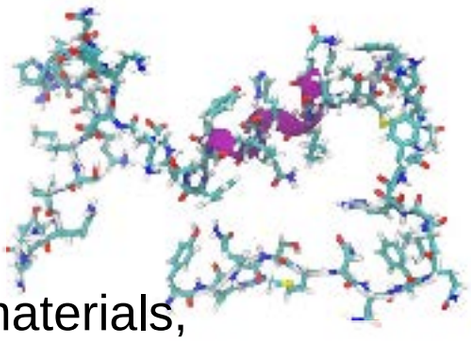

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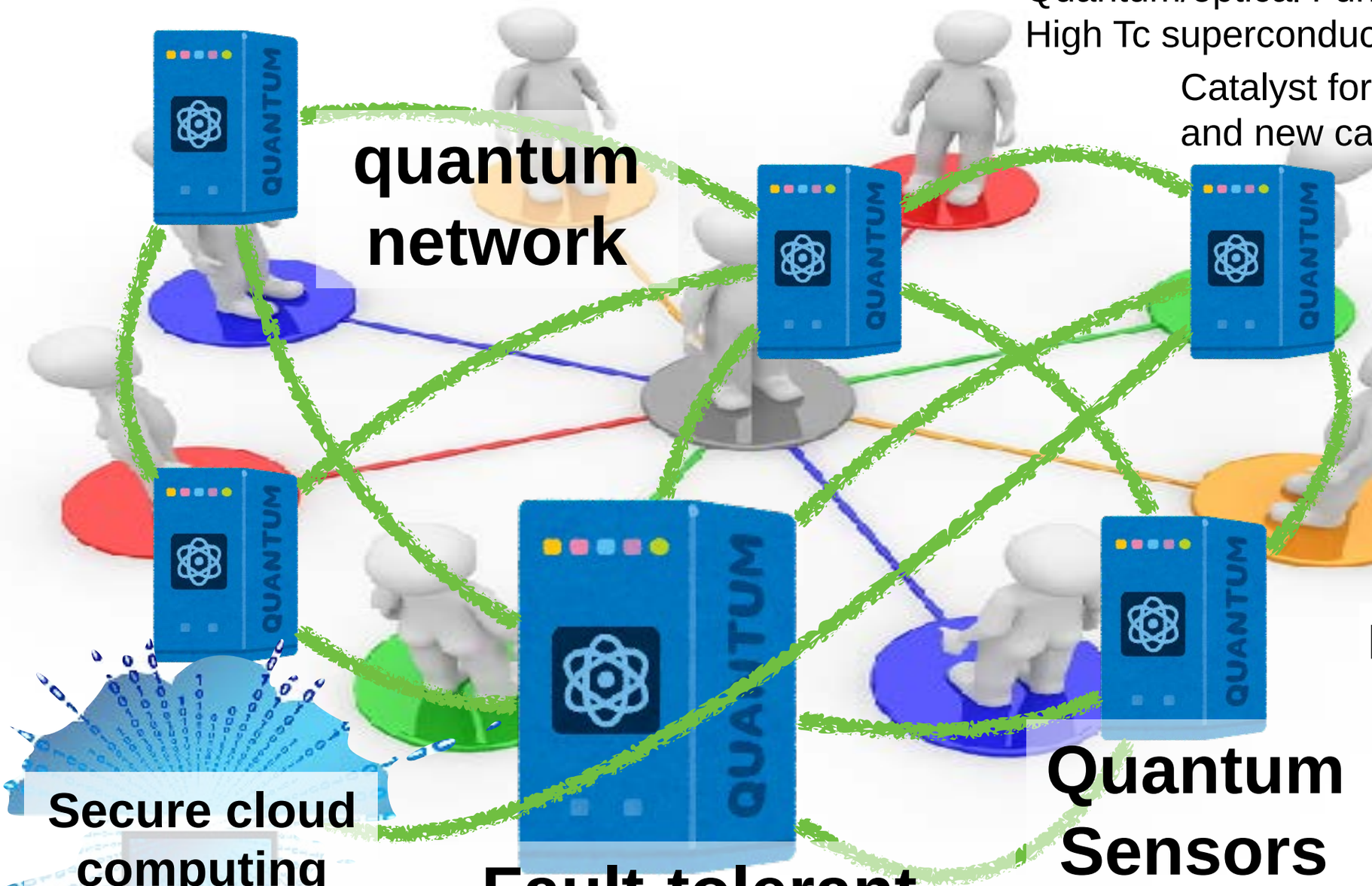

quantum network

Secure cloud computing

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Quantum Sensors

Quantum software (theory) stack

Physics, Machine learning, Material science,
Quantum chemistry, Biology/Life science
Data science, Network/Security etc

Applications

Mathematics

Quantum algorithms
Near and long terms

High performance computing

Information Science

Quantum programing
SDK, API, Compiler

Software Engineering

Quantum architecture
Fault-tolerant system and quantum error correction

Computer architecture

Physics

Quantum hardware control
Middleware, quantum classical interface

Quantum computing devices

(superconducting qubits, ion trap, photons, spins tec)

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Quantum computing would be a good opportunity to meet researchers in different disciplines together and explore our scientific and engineering frontier!