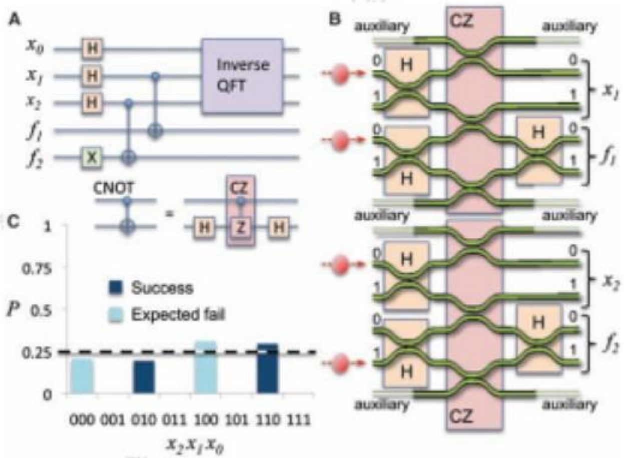
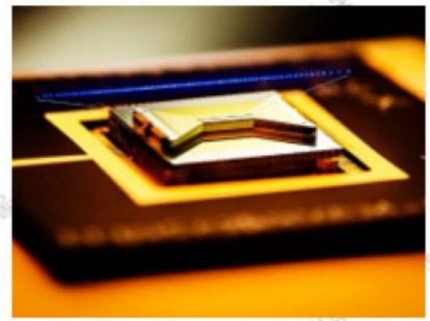
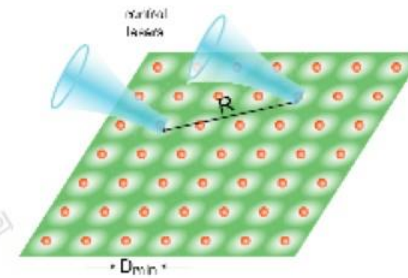
(Incomplete) List of Physical Implementation

- Photon

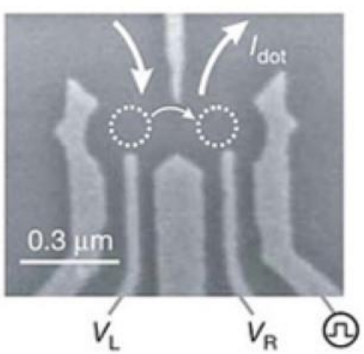


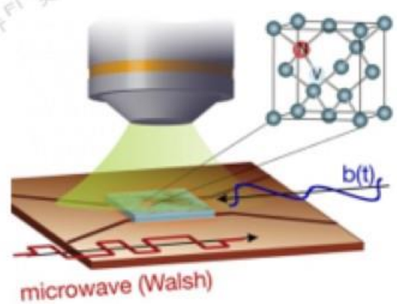
- Ion trap/neutral atoms



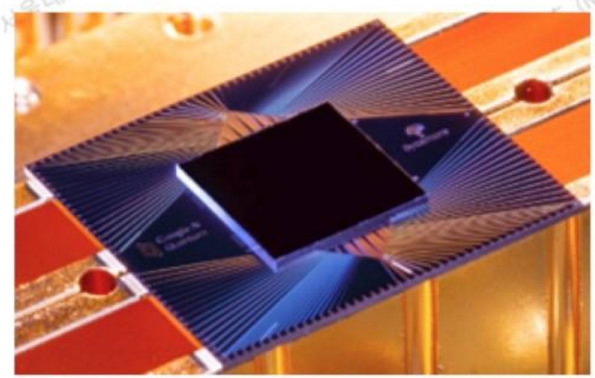


- Quantum Dot/NV center





- Superconductor



Global Players in Quantum Computing

Quantum Computer Hardware

Google
intel
IBM
D-Wave
The Quantum Computing Company
IONQ
Microsoft
Honeywell
Alibaba Group
阿里巴巴集团
NTT
QuTech
Q-CTRL
TURING
qci
rigetti
XANADU
TUNDRA SYSTEMS GLOBAL LTD
Qubitekk
FATHOM COMPUTING
QILIMANJARO
QUANTUM COMPUTING AT YOUR FINGERTIPS
Oxford Quantum Circuits
Alpine Quantum Technologies

Software & Consultants

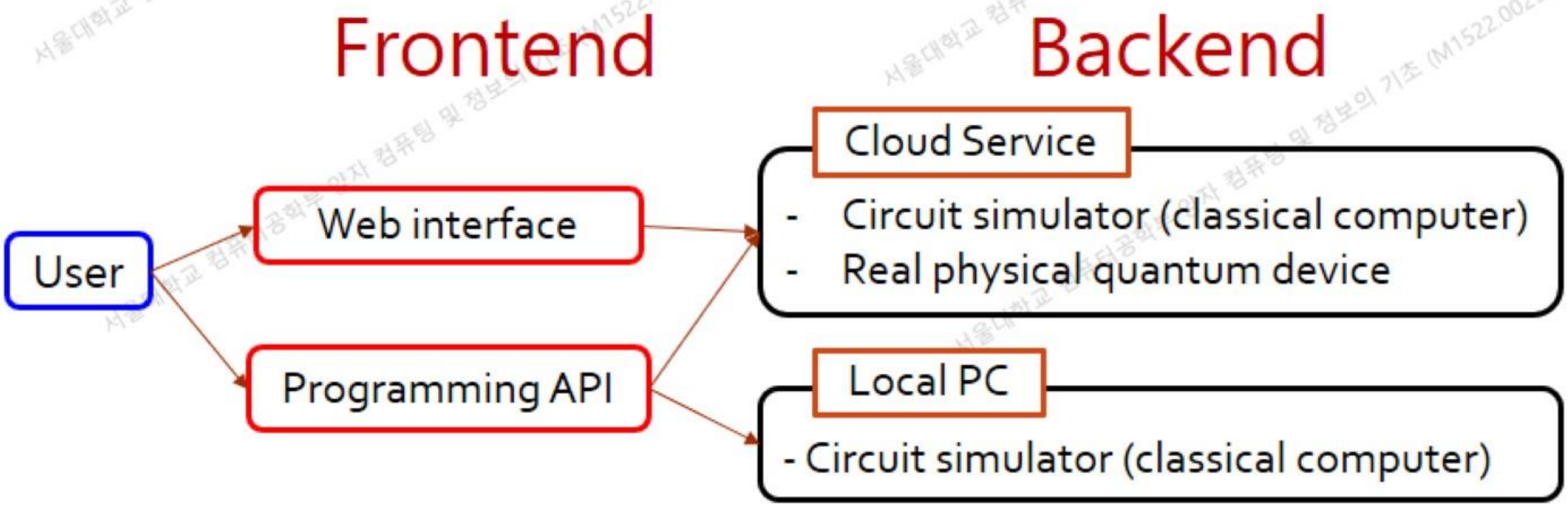
SeeQC
CQC Cambridge Quantum Computing Limited
QC WARE
1QBit
Baidu 百度
Tencent 腾讯
artiste-qb.net
ANYON
NQCG
QBITLOGIC
Tokyo Quantum Computing
Q^x Branch
OXFORD QUANTUM
A core for quantum science and technology
AIRBUS GROUP
Atos
accenture
High performance. Delivered.
Booz | Allen | Hamilton
LOCKHEED MARTIN
| Entanglement Partners_ >
$\langle Qubit|Era\rangle$
Zapata Computing
$|\hbar\rangle$ Quantum Consultants
|EeroQ⟩

New Funding Strategies

Qubit Protocol
Quantum Wave Fund
Riding the wave of quantum technology revolution
QuantumX
Quantum Valley INVESTMENTS
The Quantum Revolution Fund

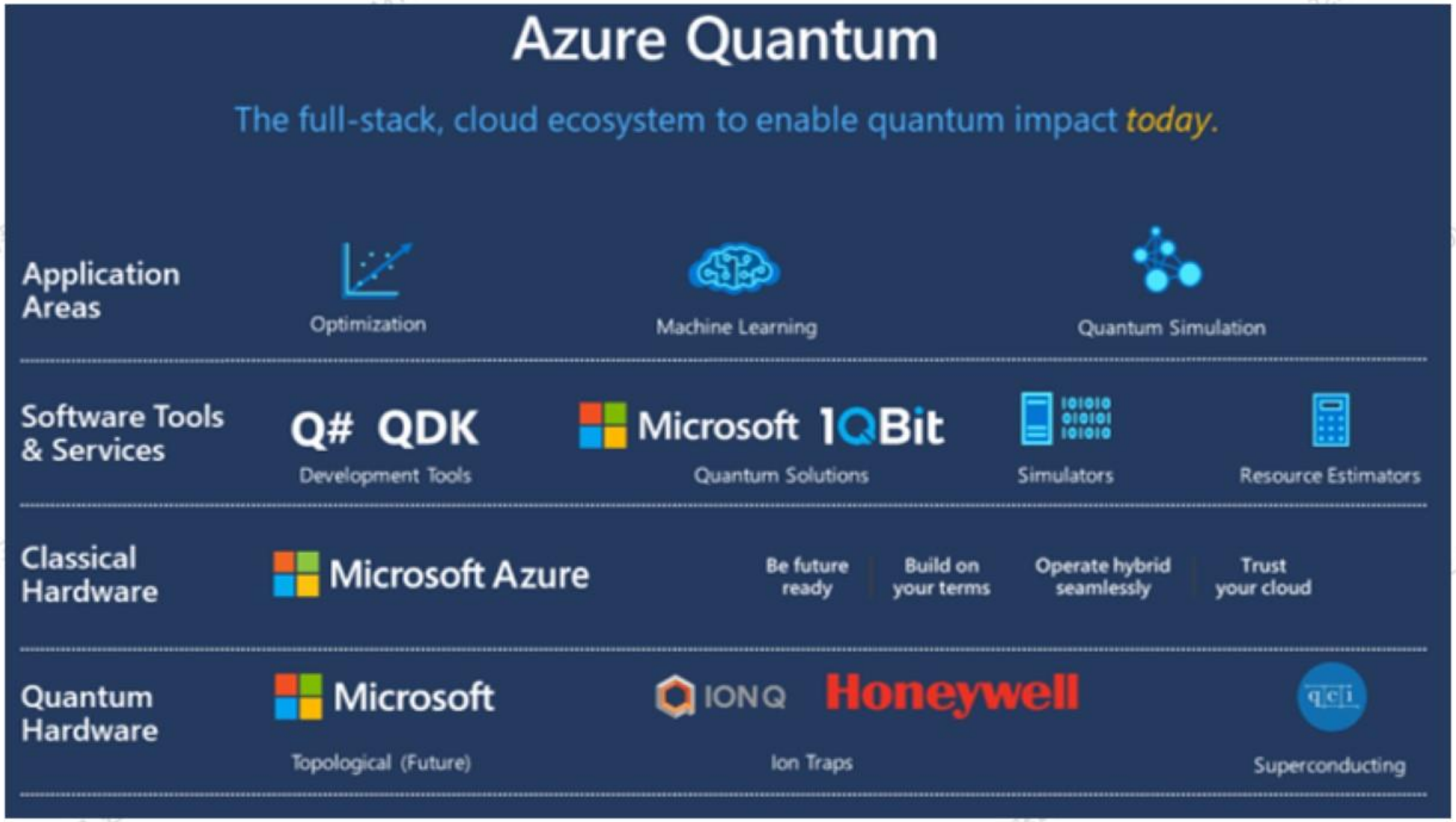
Quantum Computing Cloud Service

- There are several companies that already provide or are preparing to provide quantum computing cloud service
- (Incomplete) list of services
  - IBM Q
  - Microsoft Azure Quantum Stack
  - Amazon AWS Bracket
  - Google
  - https://www.quantiki.org/wiki/list-qc-simulators
- Typical model for the system



Microsoft Azure

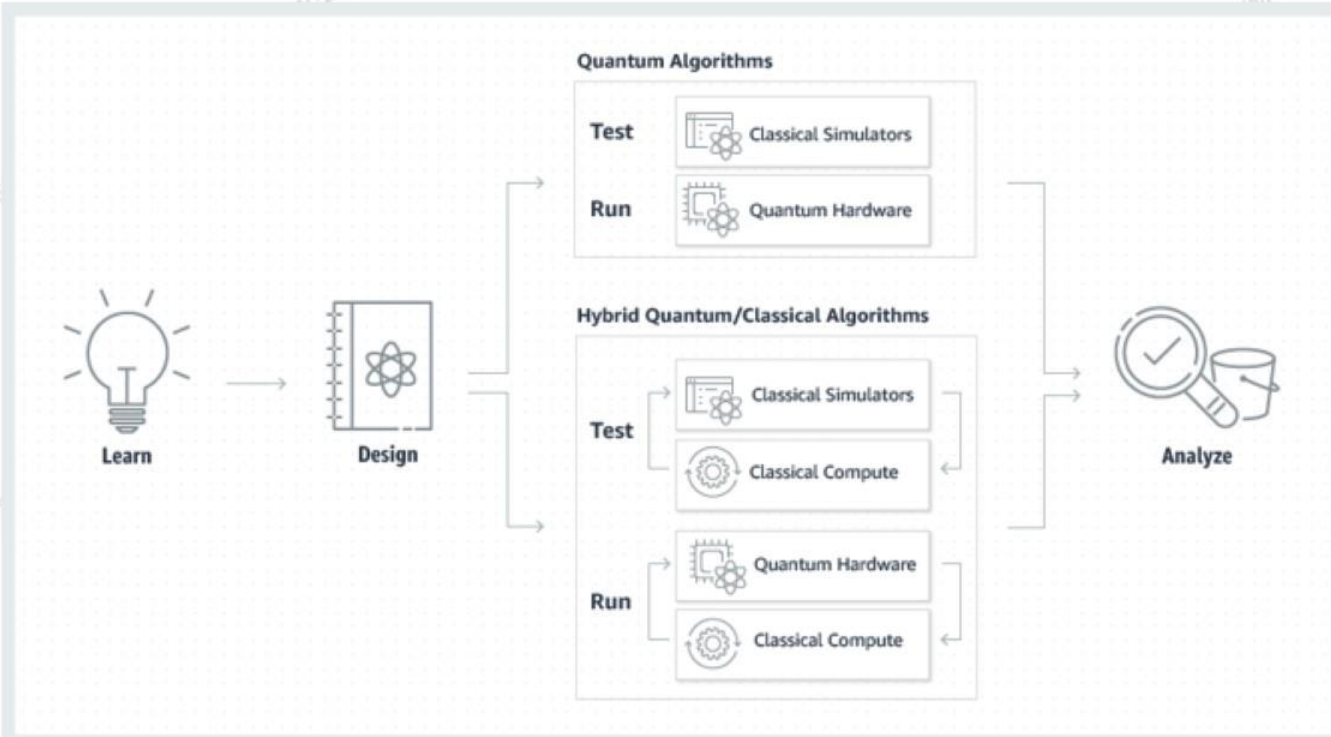
- From https://azure.microsoft.com/en-us/services/quantum/#features



- QDK (Quantum Development Kit)
  - Supported via .NET framework, C#.
  - Q# programming language
  - Local quantum machine for circuit simulation up to 30 qubits as of May 2019

Amazon Bracket

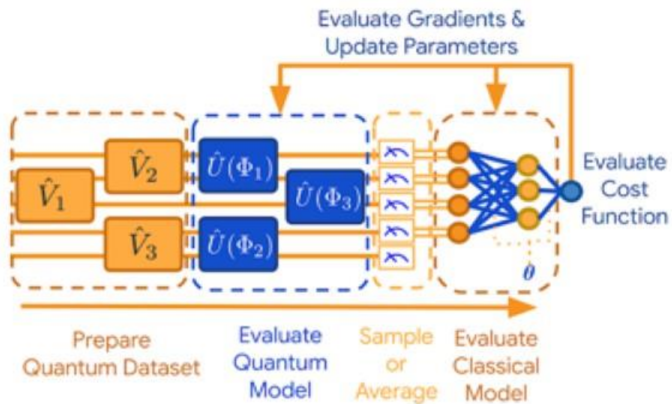
- From https://aws.amazon.com/braket/



Google

- Cirq
  - A python framework for writing, manipulating, and optimizing quantum circuits and then running them against quantum computers and simulators
  - Documentations: https://cirq.readthedocs.io/en/latest/
  - Designed to allow access to its own hardware via Quantum Engine API, but not yet open for public access as of May 2020.

- Tensorflow Quantum
  - Integrated tool to use quantum circuit for machine learning application



From https://ai.googleblog.com/2020/03/announcing-tensorflow-quantum-open.html

- Hardware
  - Demonstration of quantum advantage (quantum supremacy) using 53 superconducting qubits

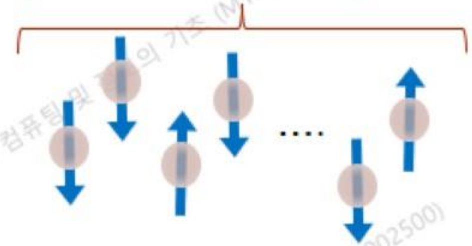
Challenge in Quantum Circuit Simulation

- Memory estimation for simulation
  - Assumption: single precision floating point for complex number ➔ need 2×4 bytes memory
  - Necessary memory to represent quantum state of 2 qubits?
    - $|\Psi\rangle = c_{00}|00\rangle + c_{01}|01\rangle + c_{10}|10\rangle + c_{11}|11\rangle$
    - ➔ $8 \cdot 2^2 = 2^{2+3}$ bytes
  - Necessary memory to represent quantum state of 50 qubits?
    - $8 \cdot 2^{50} = 8 \cdot (2^{10})^5 \approx 8 \cdot (10^3)^5 = 8 \cdot 10^{15}$ bytes ➔ 8 Peta bytes
- Comparison with classical computer
  - According to TOP500 list for supercomputers at Nov. 2019, rank 1 supercomputer is Summit at Oak Ridge National Lab.
  - Memory size of Summit: 2.8 PB
  - Cannot hold all the necessary coefficients for 50 qubits

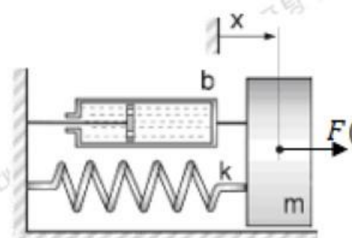
Quantum (Analog) Simulation

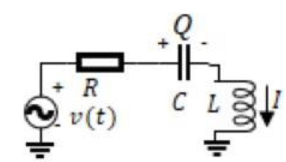
- Different from quantum circuit simulation (based on classical computer)
- Quantum chemistry and solid state physics
  - Prediction of quantum mechanical phenomena with many atoms
  - Simulation with controllable system that follows the same quantum mechanical law
  - Example: calculation of N particles with spin ½ following quantum physics law

N particles with spin ½



- Analogy with an analog simulation
  - Mechanical system with mass, spring, and damper
  - RLC circuit
  - Follows 2nd–order differential equation



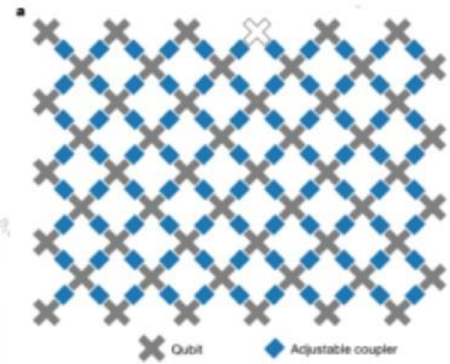


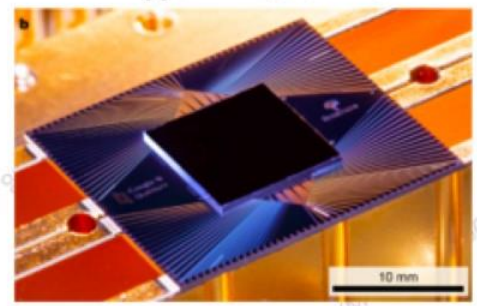
$$m\frac{d^2x}{dt^2} = F(t) - kx - b\frac{dx}{dt}$$

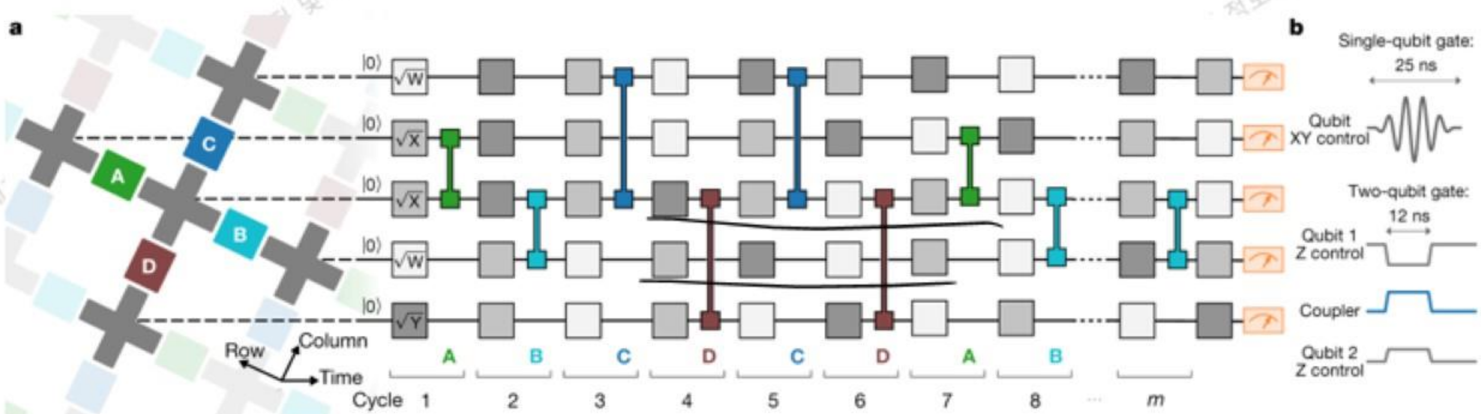
$$L\frac{d^2Q}{dt^2} = v(t) - \frac{1}{C}Q - R\frac{dQ}{dt}$$

Quantum Advantage

- 2019년 10월말 Google은 자체 양자컴퓨터 제작을 통해 양자 우월성(Quantum Supremacy)을 실험적으로 검증했다고 논문 발표
- 53개의 양자 비트로 이루어진 양자컴퓨터를 만들고 아래와 같이 임의의 회로를 만들었을 때 이 결과를 양자컴퓨터로는 200초 만에 예측할 수 있는데 비해 슈퍼컴퓨터로는 1만년 (Google 주장, IBM은 2.5일 주장) 걸리므로 양자컴퓨터가 고전컴퓨터에 비해 성능면에서 훨씬 뛰어나다고 주장함
- 이 결과는 양자회로를 이용하지만, 실질적으로는 양자 시뮬레이션에 해당하는 결과로 복잡한 암호 해독과는 성격이 다름.
- All the figures from Nature 574, 505–510 (2019)







IBM Quantum Experience

- Main page
  - https://www.ibm.com/quantum-computing/
- Online graphical quantum circuit editor and system overview
  - https://quantum-computing.ibm.com/