Introduction to Quantum Programming


IBM
IBM Q
System One

What do you think this is?

What your computer think that is....

- The classical bits = specific combination of zeros and ones

- One bit contains a single binary value — either "0" or "1"

Classical World

- There are only 10 types of people in the worl binary, and those who don't.

→ 世界上只有10種人，一種懂二進位的、一種不懂的。

- (Another joke)
  - Why do mathematicians confuse Halloween anc
    - Because 31 Oct = 25 Dec.

$$31_8 = 25_{10}$$

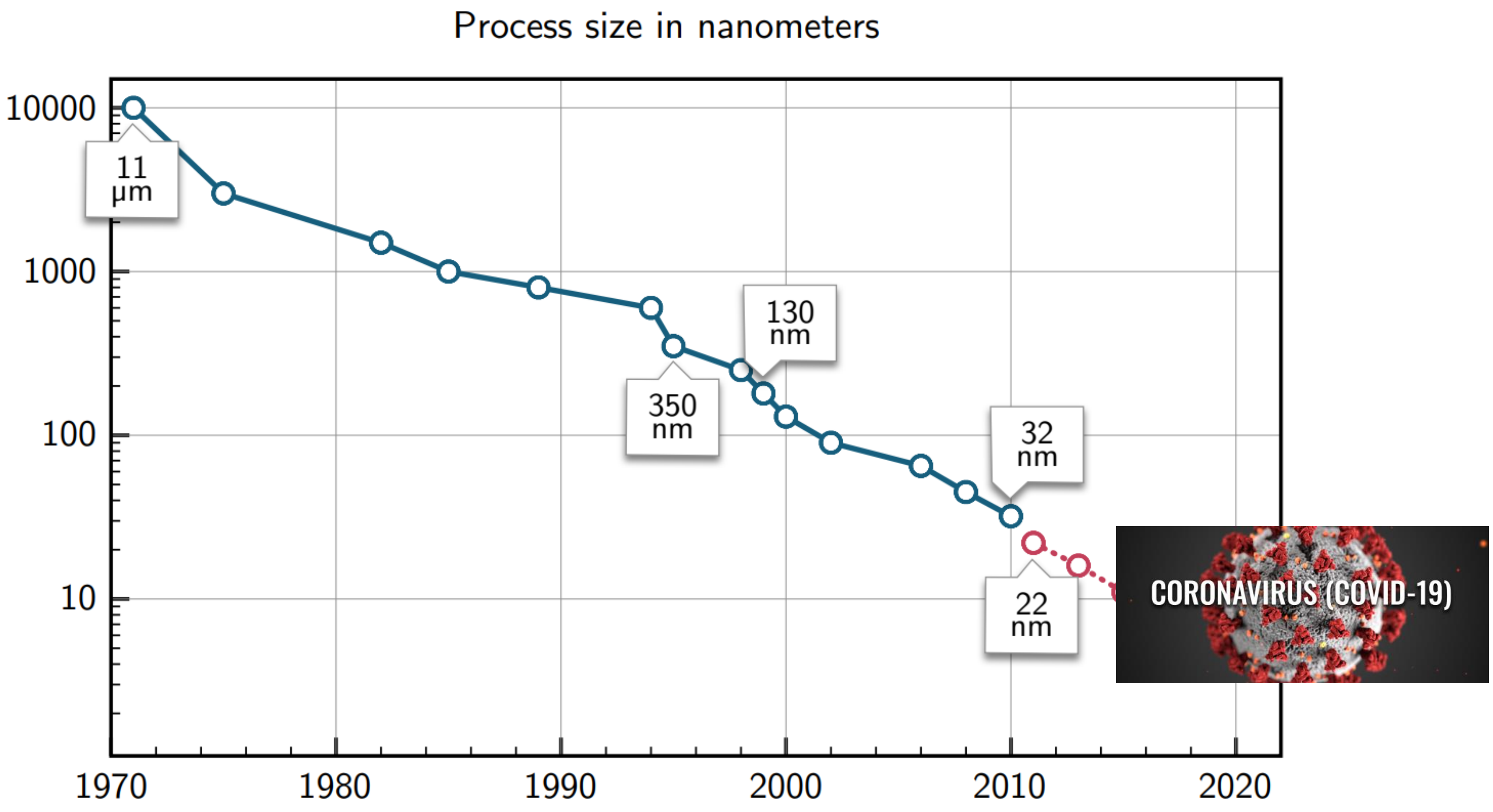
Quantum Computer

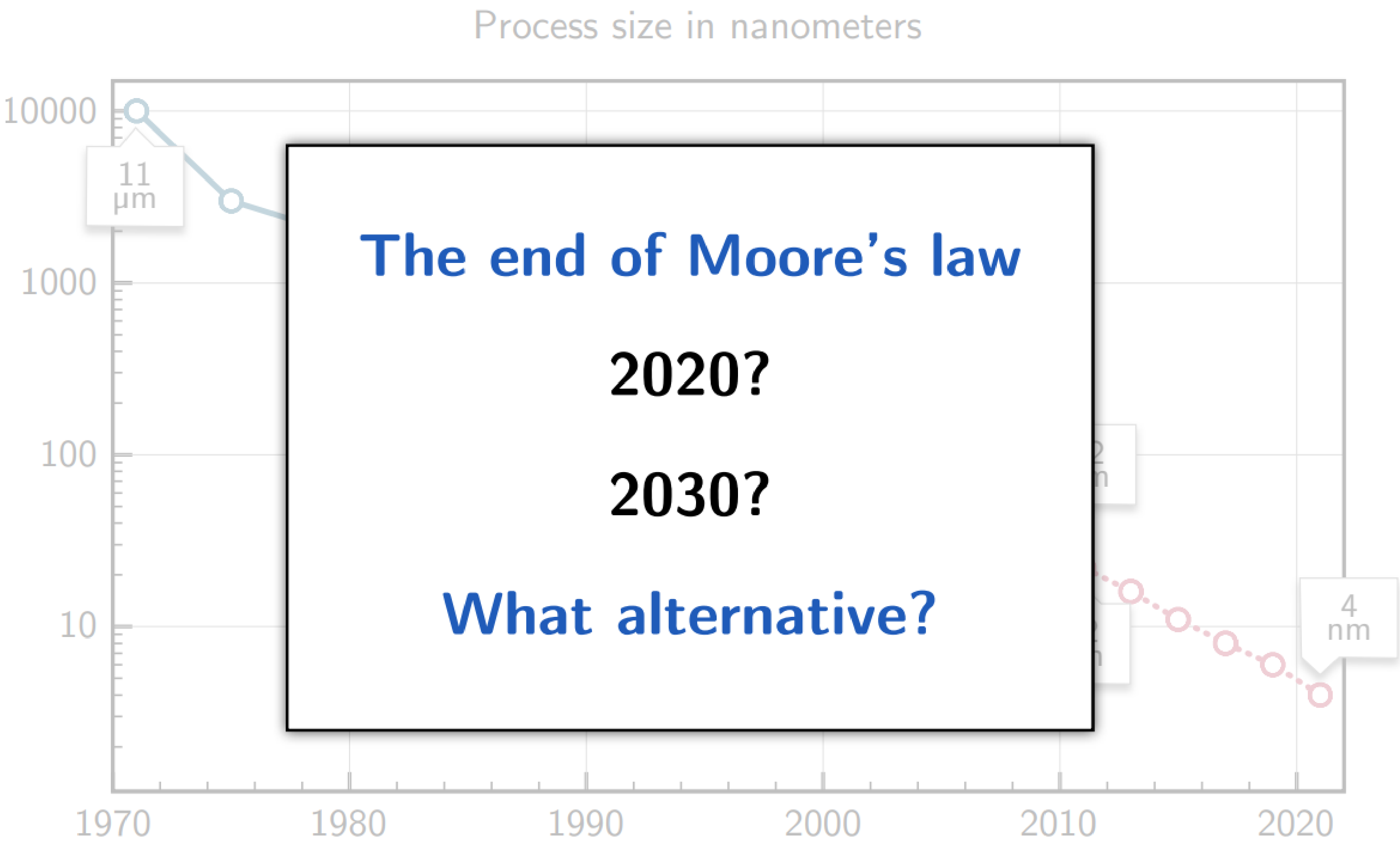
- What is Quantum? Why Quantum?
  What is Quantum Computer? Why we need Quantum Computer?

- [Quantum History]

- [Quantum Computers Explained]

Moore’s Law


Process size in nanometers
10000
1000
100
10
11 µm
350 nm
130 nm
32 nm
22 nm
1970
1980
1990
2000
2010
2020
CORONAVIRUS (COVID-19)



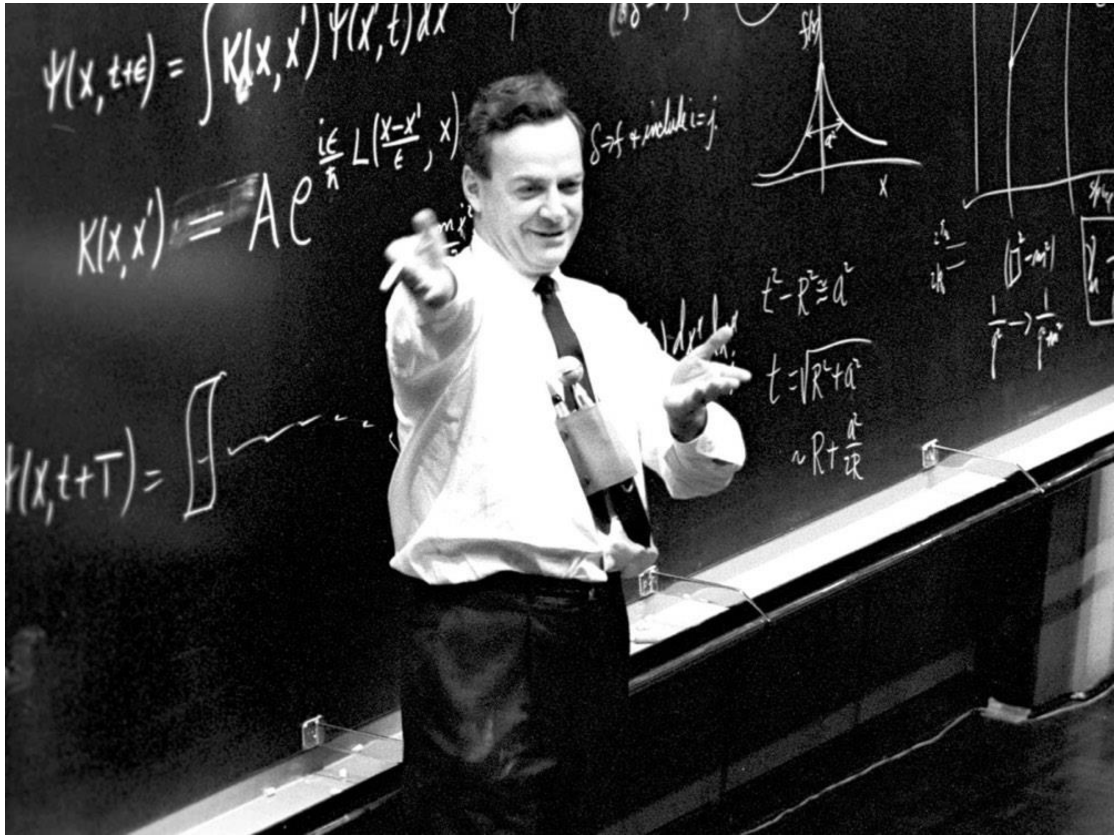
The end of Moore’s law

2020?

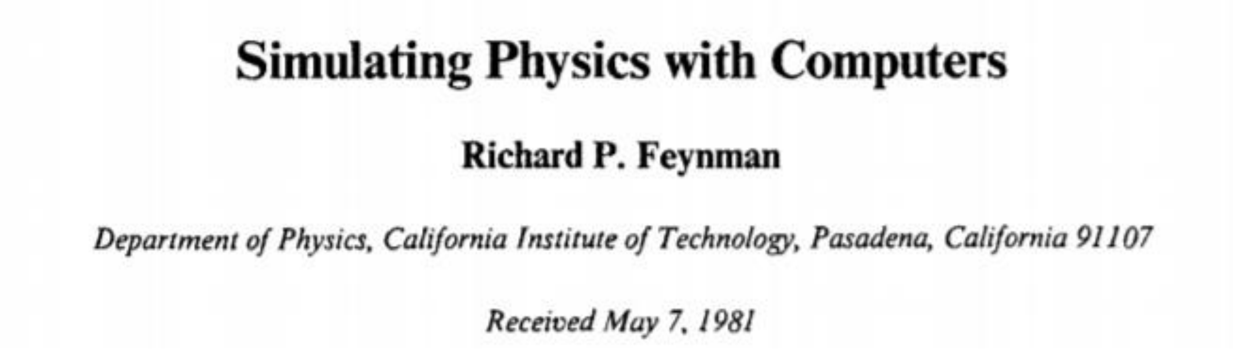
2030?

What alternative?

Why Quantum Computing?




Richard Feynman


Simulating Physics with Computers

Richard P. Feynman

Department of Physics, California Institute of Technology, Pasadena, California 91107

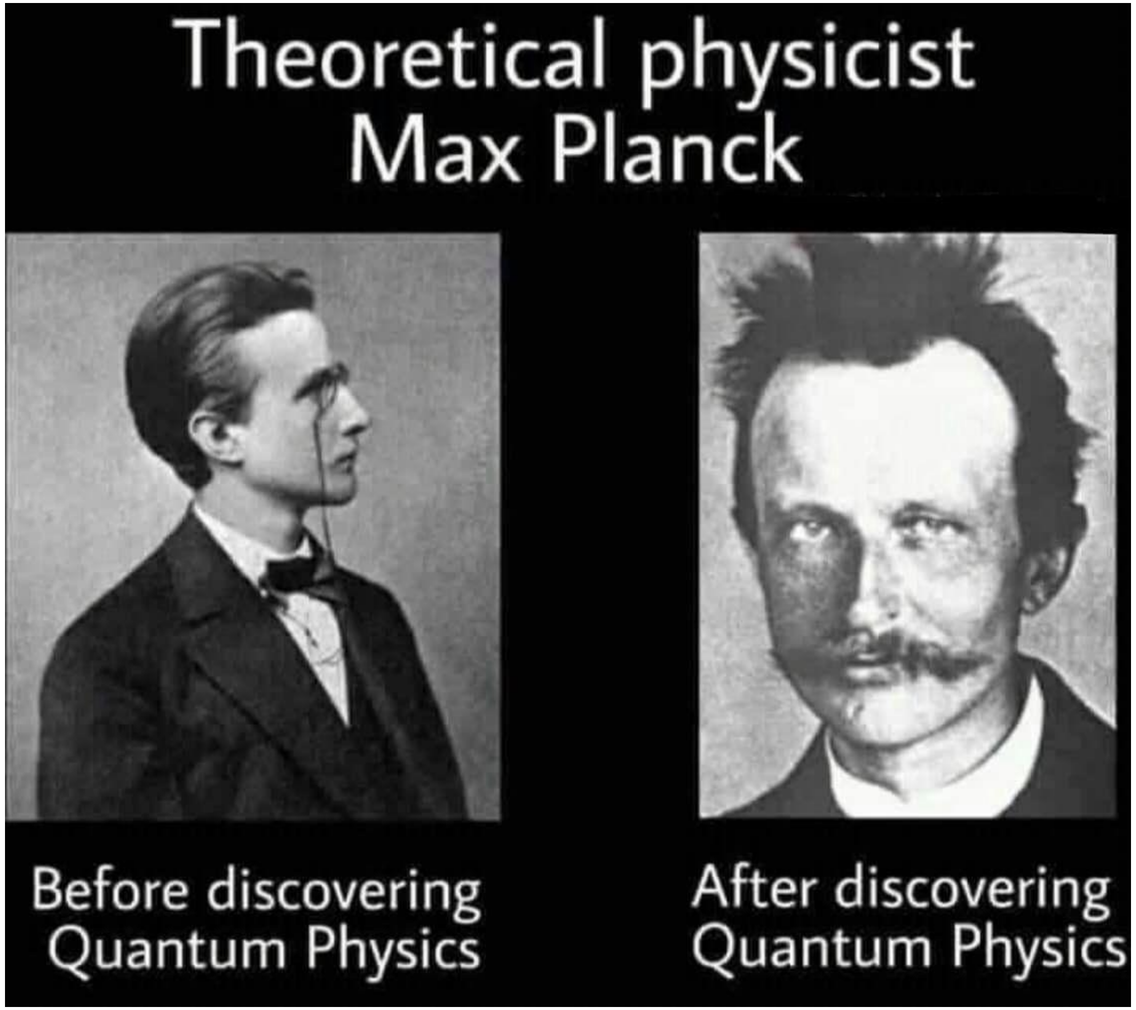
Received May 7, 1981

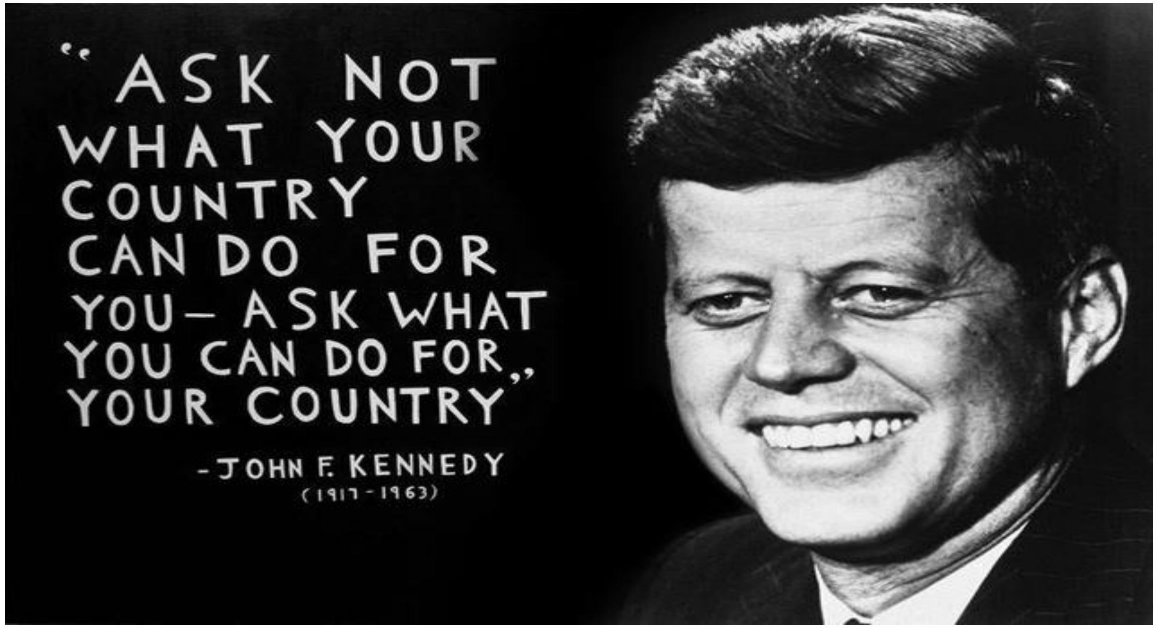
"…nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy."

"Let the computer itself be built of quantum mechanical elements which obey quantum mechanical laws."

Be Careful !


物理跟我比起來
到底哪個重要？
如果你選擇物理
東京 6月4日(土)
13:30～16:45
■会場 キャンパス・イノベーションセンター東京
2階 多目的室2
大阪 6月18日(土)
13:00～17:00
■会場 大阪大学理学研究科 物理系総合研究棟
7階 大セミナー室H701
詳しくはコチラ
阪大 物理学専攻
検索
大阪大学大学院 理学研究科 物理学専攻
http://www.phys.sci.osaka-u.ac.jp/index-jp.html
大阪大学大学院 理学研究科 物理学専攻
博士前期課程 入試説明会(東京・大阪)
—平成24年(2012年)4月入学—
68名
筆記試験：8月31日(水) 場所：キャンパス・イノベーションセンター東京
口頭試問：9月 2日(金) 場所：大阪大学
筆記試験：8月31日(水) 場所：大阪大学
口頭試問：9月 1日(木)・2日(金) 場所：大阪大学


Theoretical physicist
Max Planck
Before discovering
Quantum Physics
After discovering
Quantum Physics

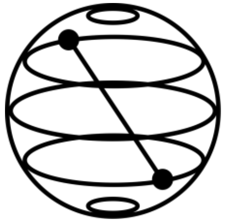


Ask not what you can do for quantum computer, ask what quantum computer can do for you!

IBM Quantum Experience

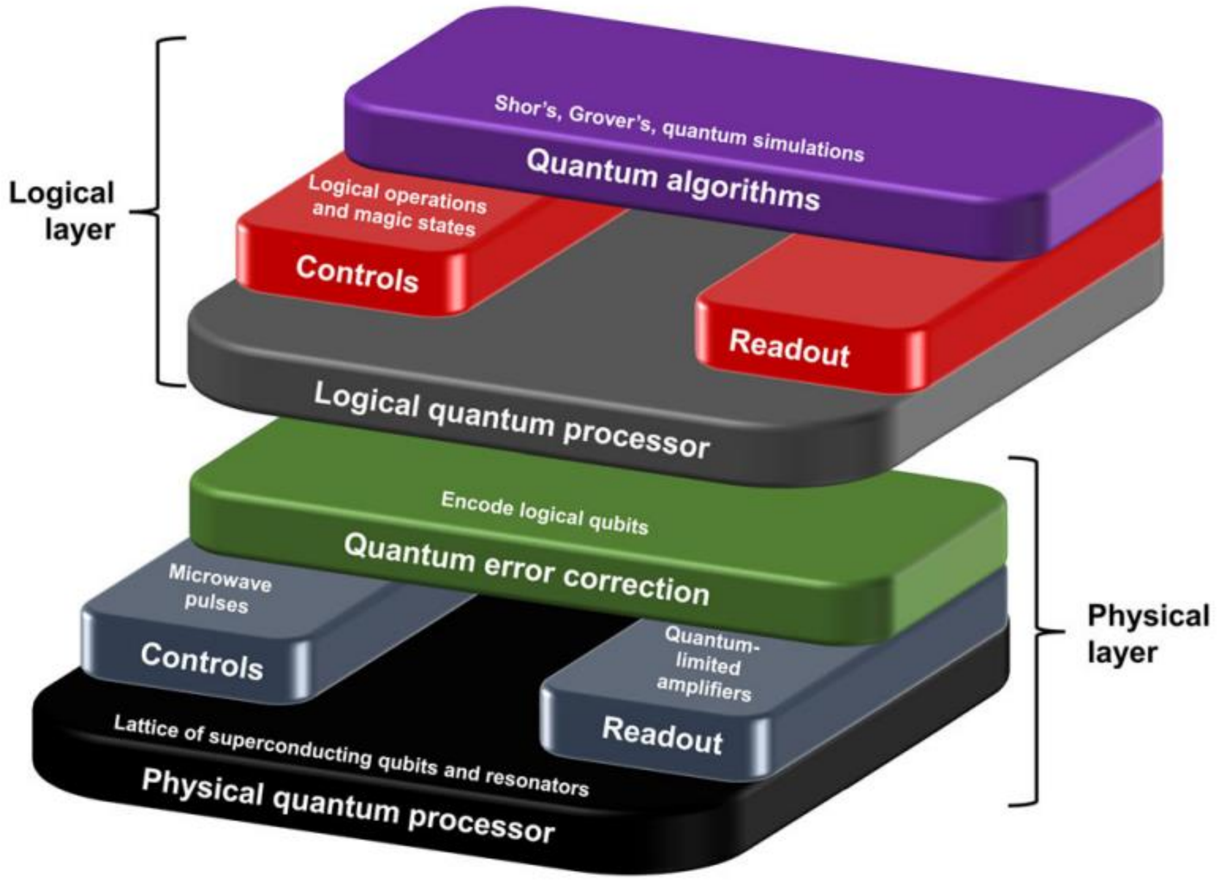
- IBM Quantum Computer

- Qiskit



  - Qiskit is an open source SDK for working with quantum computers at the level of pulses, circuits and algorithms.

Quantum Computing Stack



Source: Gambetta, J.M., Chow, J.M. & Steffen, M. Building logical qubits in a superconducting quantum computing system. *npj Quantum Inf* **3,** 2 (2017).

Qiskit Overview

Institution	IBM
First Release	0.1 on March 7, 2017
Open Source	Yes
License	Apache-2.0
HomePage	https://qiskit.org/
Github	https://github.com/Qiskit
Documentation	https://qiskit.org/documentation/
OS	Mac, Windows, Linux
Language	Python
Quantum Language	OpenQASM

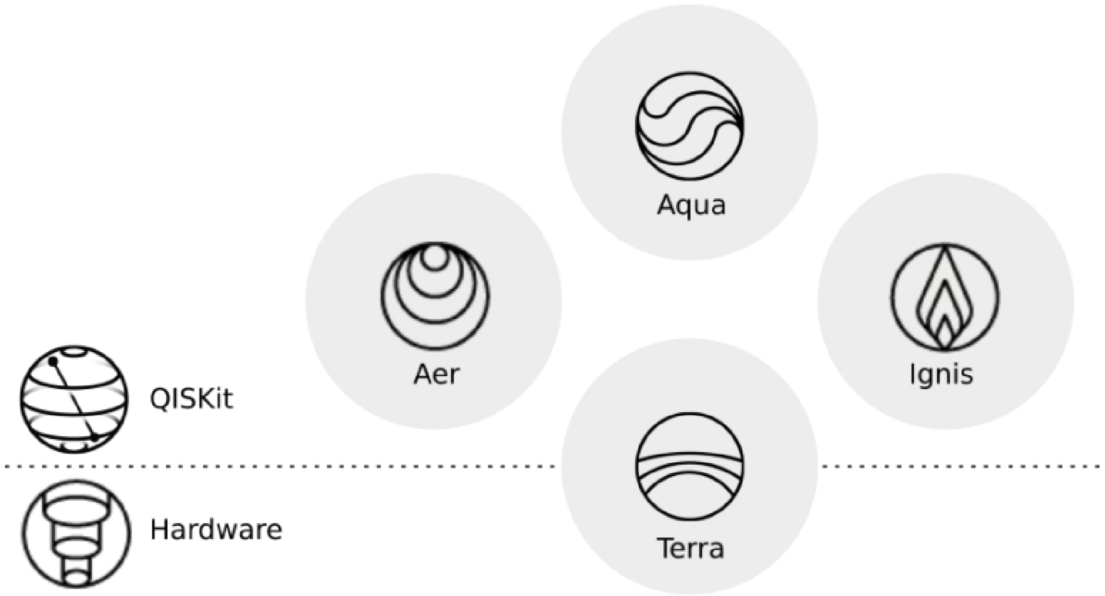
Version Information

Qiskit Software	Version
Qiskit	0.21.0
Terra	0.15.2
Aer	0.6.1
Ignis	0.4.0
Aqua	0.7.5
IBM Q Provider	0.9.0

Four Elements of Life

Element Ambigrams from Angels & Demons

The Qiskit Elements



Terra, the ‘earth’ element, is the foundation on which the rest of the software lies.

Aer, the ‘air’ element, permeates all Qiskit elements. For accelerating development via simulators, emulators and debuggers

Aqua, the ‘water’ element, is the element of life. For building algorithms and applications.

Ignis, the ‘fire’ element, is dedicated to fighting noise and errors and to forging a new path

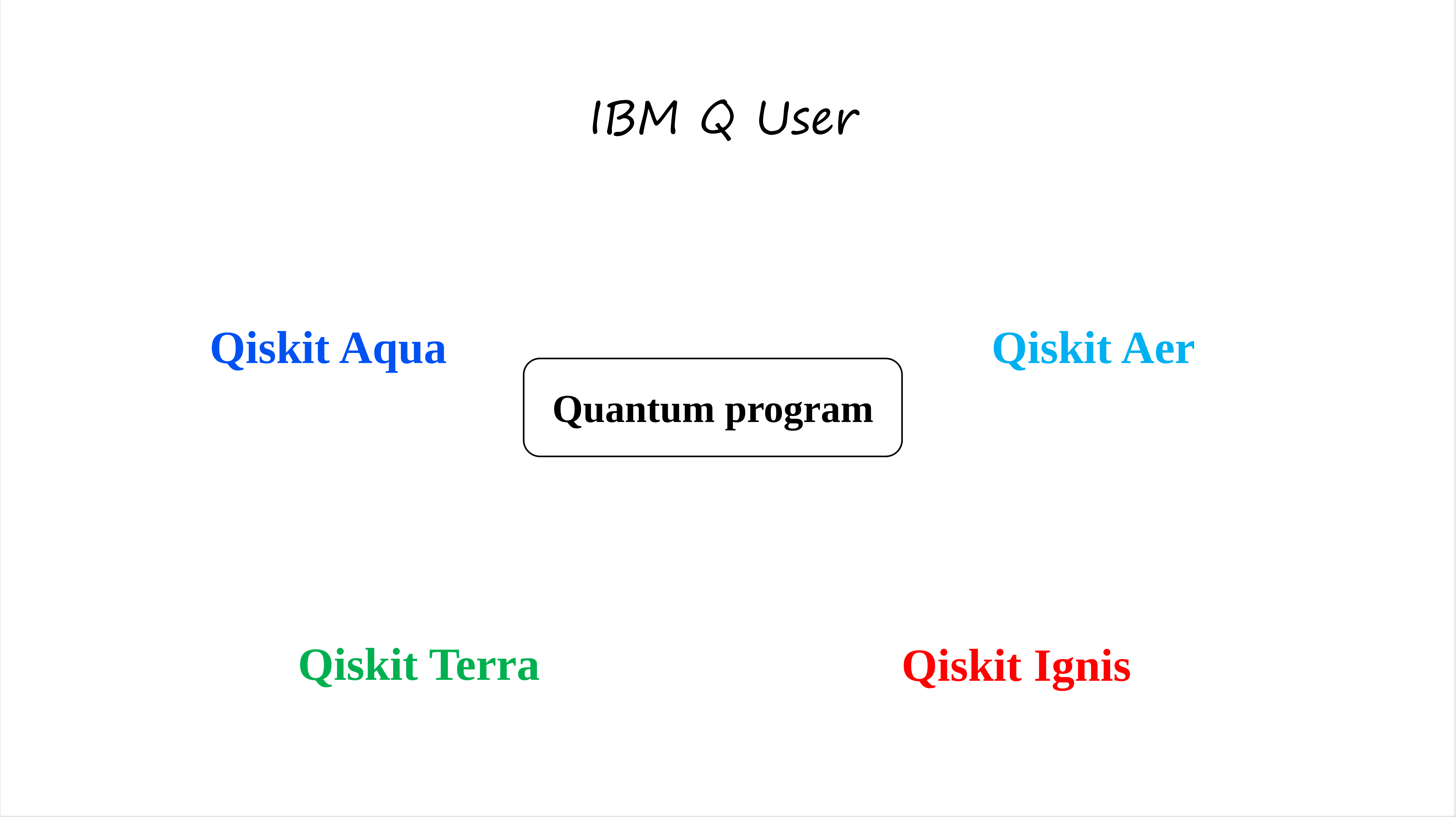
IBM Q User

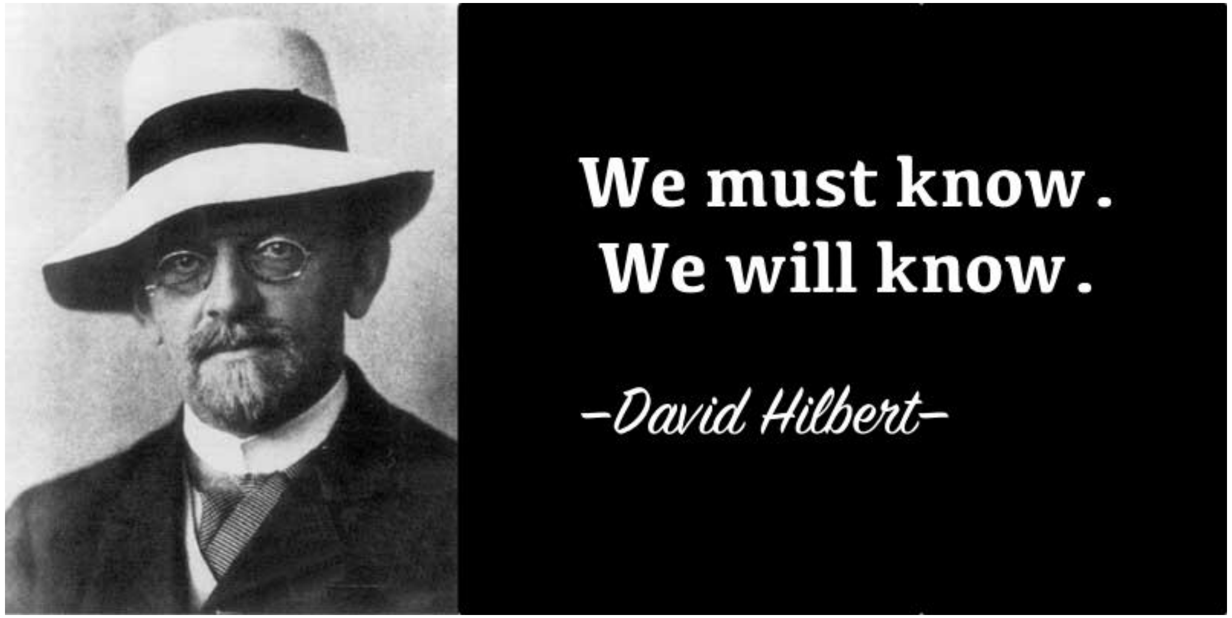
Qiskit Aqua

Qiskit Aer

Qiskit Terra

Qiskit Ignis


IBM Q User
Qiskit Aqua
Qiskit Aer
Quantum program
Qiskit Terra
Qiskit Ignis



We must know, we will know.

我們必須知道，我們必將知道。
David Hilbert.

Quantum Properties

- Superposition (疊加)
- Entanglement (糾纏)
- Interference (干涉)

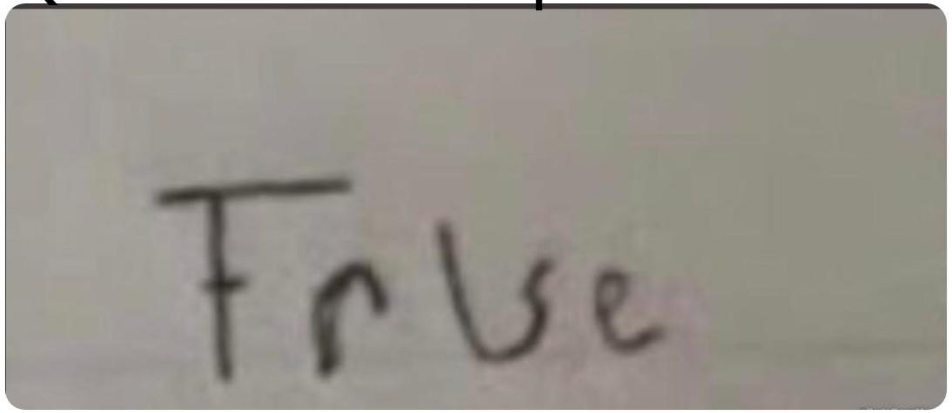
Superposition

- Superposition refers to a combination of states we would ordinarily describe independently. To make a classical analogy, if you play two musical notes at once, what you will hear is a superposition of the two notes.

Superposition

boolean: exists

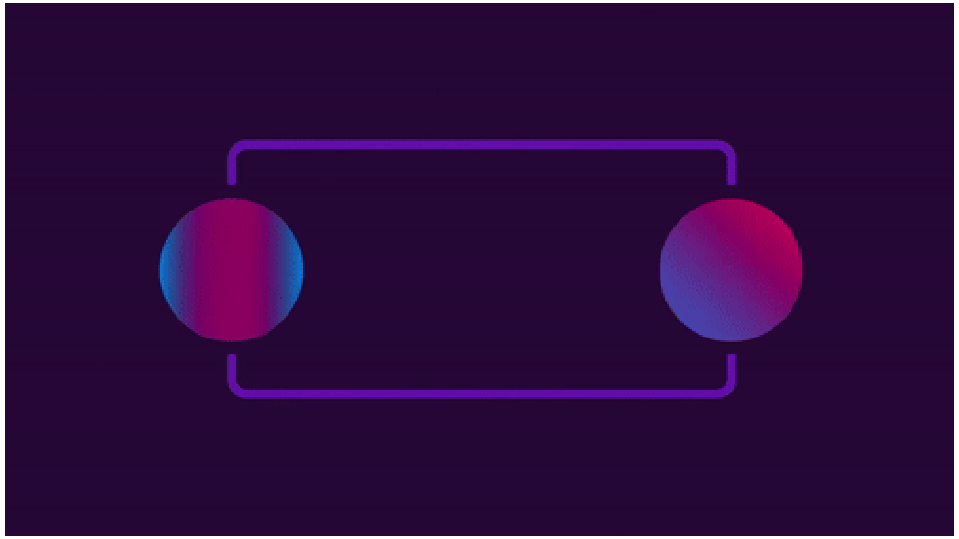
Quantum computer:



Entanglement

- Entanglement is a famously counter-intuitive quantum phenomenon describing behavior we never see in the classical world. Entangled particles behave together as a system in ways that cannot be explained using classical logic.

Measurement of one system is correlated with the state of the other system

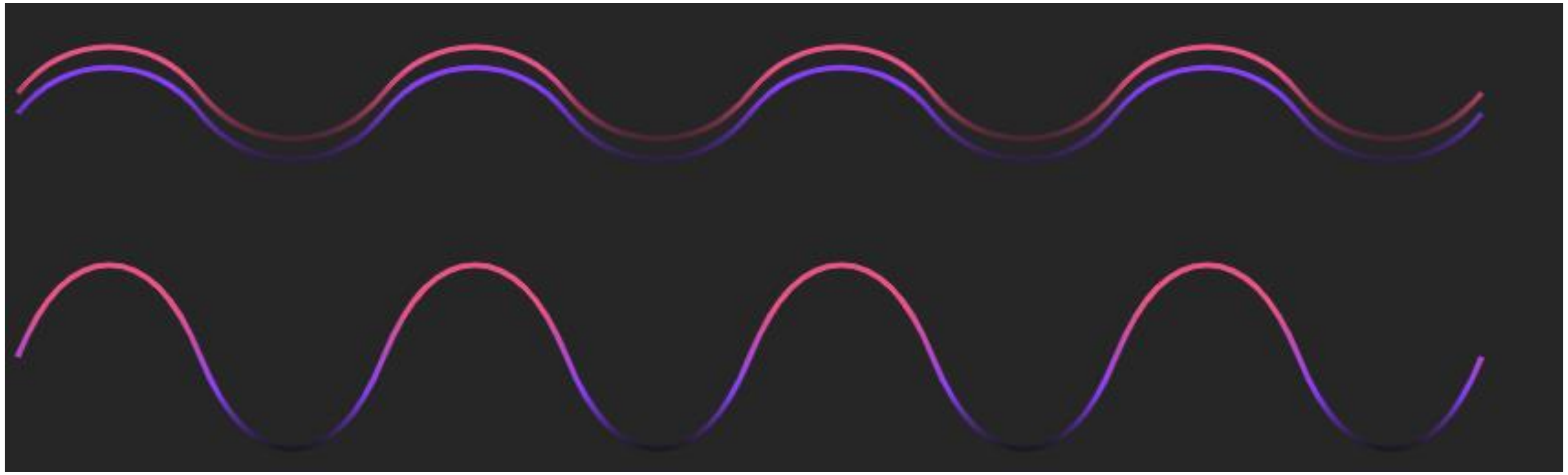


Entanglement

- Schrödinger's cat and quantum entanglement

Interference

- Finally, quantum states can undergo interference due to a phenomenon known as phase. Quantum interference can be understood similarly to wave interference; when two waves are in phase, their amplitudes add, and when they are out of phase, their amplitudes cancel.



What is Quantum Computer?

- A quantum computer is a device that leverages specific properties described by quantum mechanics to perform computation.

- A quantum computation is a collection of three elements
  - A quantum register or a set of quantum register.
  - A unitary matrix, which is used to execute a given quantum algorithm.
  - Measurement to extract information we need.

Animation again

- [Make Quantum Great again!]

One of IBM's quantum computers, technology that the company is racing to commercialize, along with competitors such as as Honeywell and D-Wave. | Photo: Misha Friedman/Getty Images

POWER

The White House wants to win the race to quantum supremacy

《國際政治》拚AI、量子運算 白宮砸10億美元搶先機

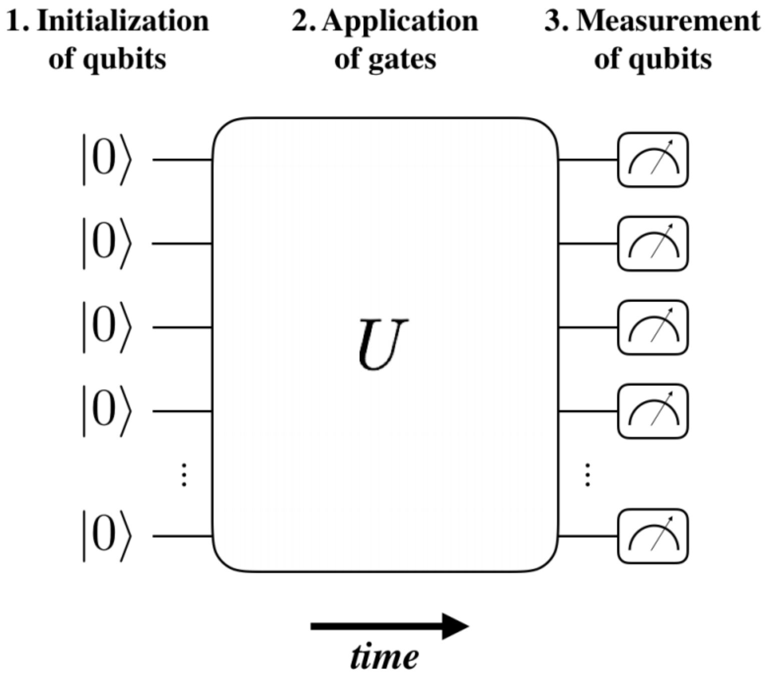
時報資訊
2020年8月27日 上午7:46

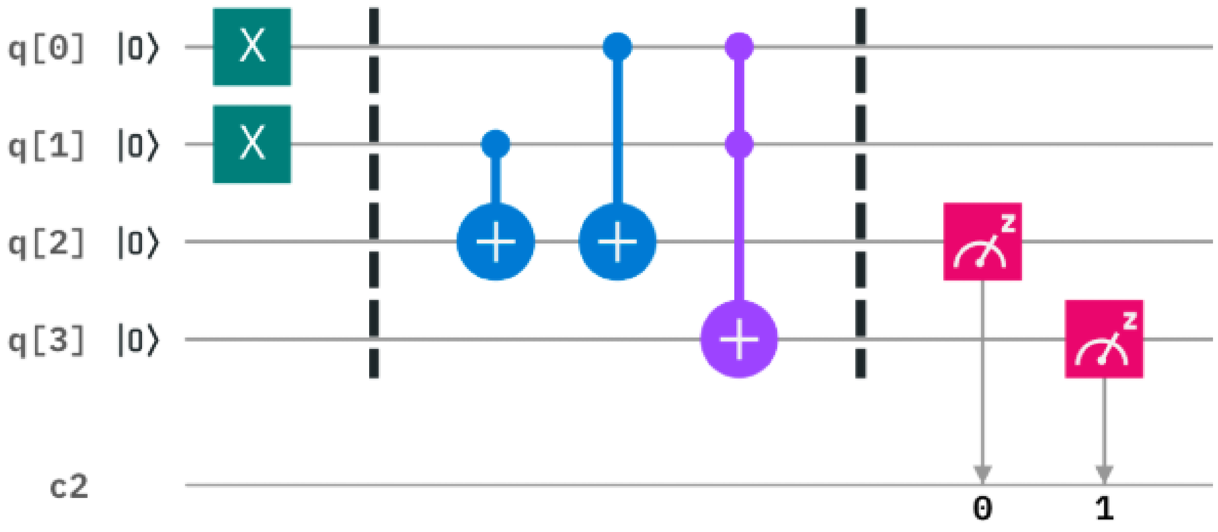
留言

【時報-台北電】白宮26日宣布價值超過10億美元的人工智慧（AI）、量子運算發展計畫，預定未來五年內將和民間企業合作，建立12間研究機構全力發展AI及量子資訊科學，以免美國競爭力落後中國大陸及歐洲。

依照這項計畫，美國國家科學基金會（NSF）、美國農業部及其他聯邦政府單位將共同投資1.4億美元，聯手打造七間AI研究機構。美國能源部將投資6.3億美元建立5間量子資訊科學研究機構。

Quantum Circuit

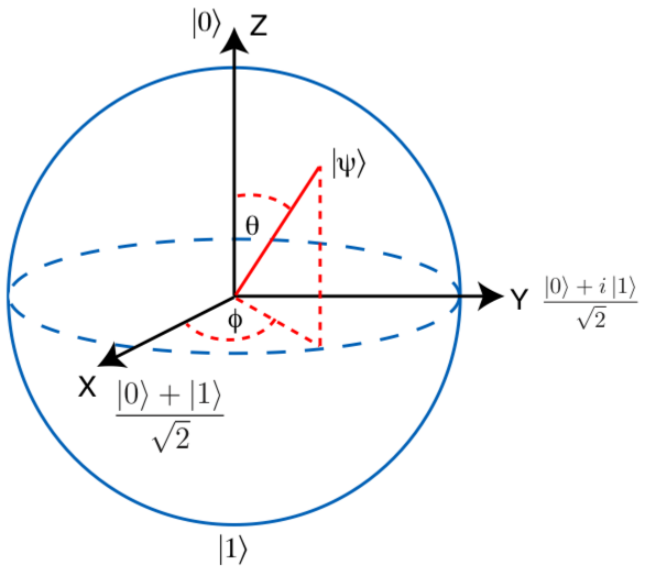




Source: https://qiskit.org/textbook/ch-states/introduction.html

Quantum Gates

- Quantum Operators
  - In gate-based quantum computers, these operator used to evolve the state.
    - Unitary and reversable.
    - Single qubit gate: rotation in block sphere.

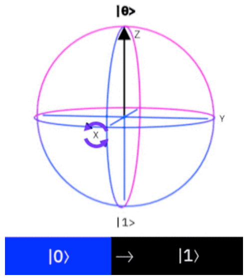


- There exist universal quantum gates set.

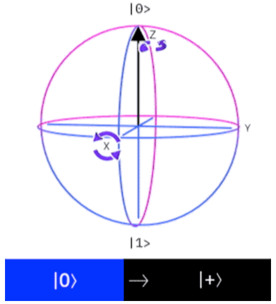
Reference: https://quantum-computing.ibm.com/docs/circ-comp/q-gates

Single Qubit Gates

$$X \equiv \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}; \quad Y \equiv \begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}; \quad Z \equiv \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$



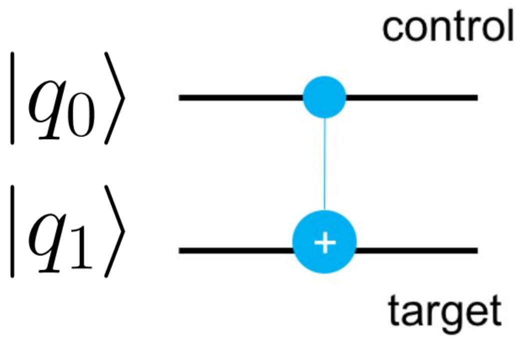
$$H = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}; \quad S = \begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}; \quad T = \begin{bmatrix} 1 & 0 \\ 0 & \exp(i\pi/4) \end{bmatrix}$$



Quantum Gates in Qiskit

- Very Important!
  - The LSB (Least Significant Bit) is from right to left in qiskit.

$$|q_{n-1}, \cdots, q_1, q_0\rangle = |q_{n-1}\rangle \otimes |q_{n-2}\rangle \otimes \cdots |q_1\rangle \otimes |q_0\rangle$$



Starting state		Ending State
|00>	→	|00>
|10>	→	|10>
|01>	→	|11>
|11>	→	|01>

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

$$|0\rangle\langle 0| \otimes I + |1\rangle\langle 1| \otimes X$$

$$q_0 \otimes q_1$$

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

$$X \otimes |1\rangle\langle 1| + I \otimes |0\rangle\langle 0|$$

$$q_1 \otimes q_0$$

若我們不可拆，那我們必有糾纏。

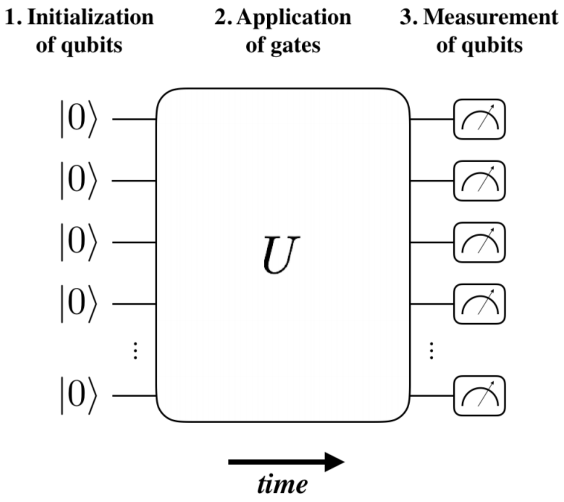
→ Also, this show the difference between entangle and separate state

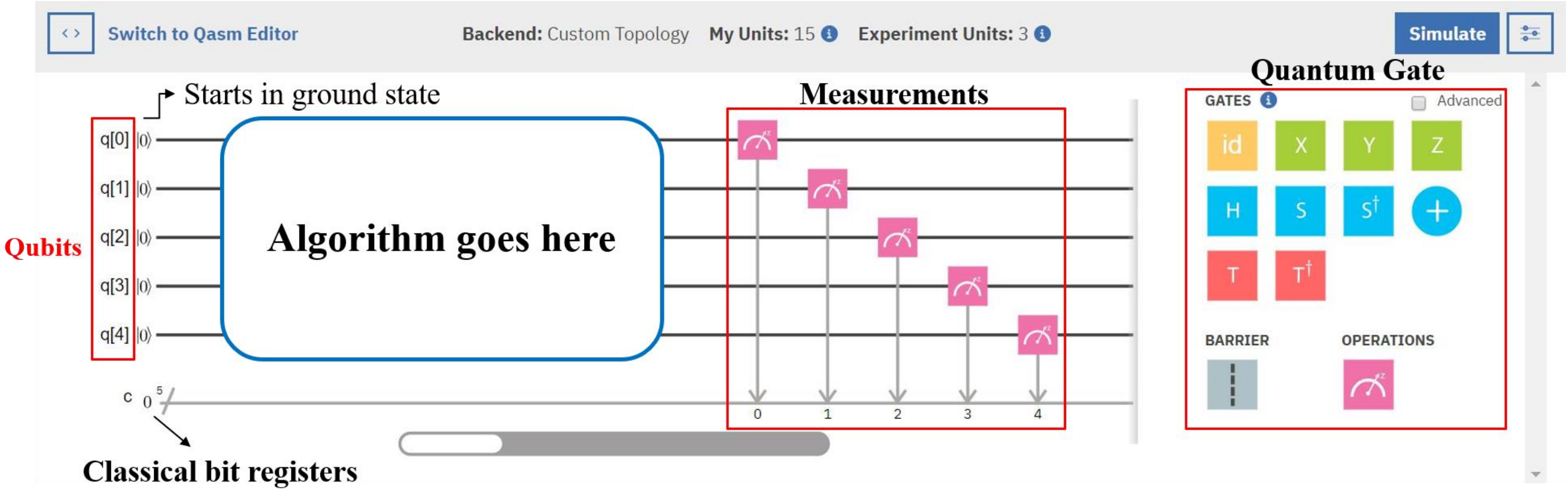
Reference: https://qiskit.org/documentation/stubs/qiskit.circuit.QuantumCircuit.html#qiskit.circuit.QuantumCircuit

Getting Started with Qiskit

- The workflow of using Qiskit consists of three high-level steps:

- **Build**: design a quantum circuit that represents the problem you are considering.
- **Execute**: run experiments on different backends (***which include both systems and simulators***).
- **Analyze**: calculate summary statistics and visualize the results of experiments.



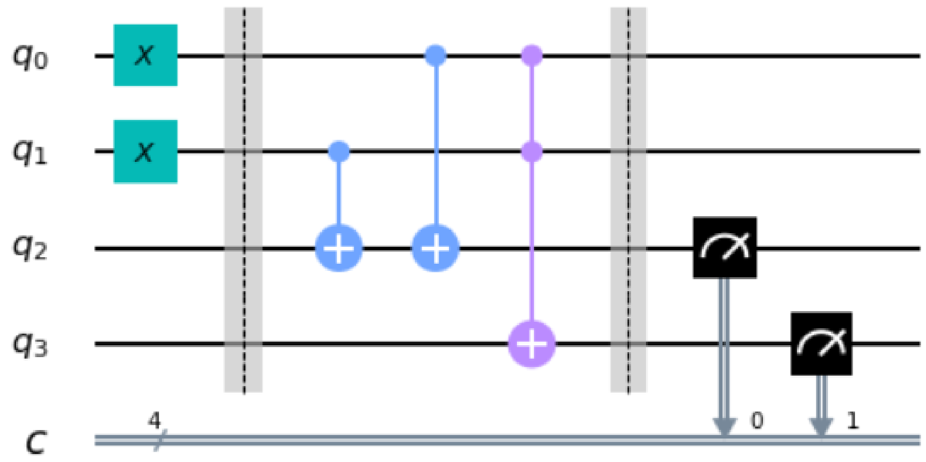


Example

In [1]:

```
from qiskit import QuantumCircuit

# Create quantum circuit with 4 qubits and 4 classical bits
q_circ = QuantumCircuit(4, 4)
q_circ.x([0,1])       # x gate on q0 & q1
q_circ.barrier()
q_circ.cx(1,2)        # control not gate  (control,target)
q_circ.cx(0,2)
q_circ.ccx(0,1,3)     # control control not gate (control1,control2,target)
q_circ.barrier()
q_circ.measure([2, 3], [0, 1])      # measurement    (target_qubitlist,classical_bitlist)

q_circ.draw(output='mpl',plot_barriers=True)  # draw circuit  you can also use: print(circuit_name)
```

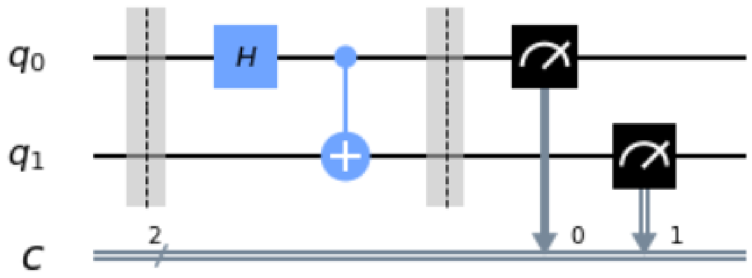
Out[1]:



Qiskit Code Example

In [1]:
```python
from qiskit import QuantumCircuit

q_bell = QuantumCircuit(2, 2)
q_bell.barrier()
q_bell.h(0)
q_bell.cx(0, 1)
q_bell.barrier()
q_bell.measure([0, 1], [0, 1])


q_bell.draw(output='mpl',plot_barriers=True)
```

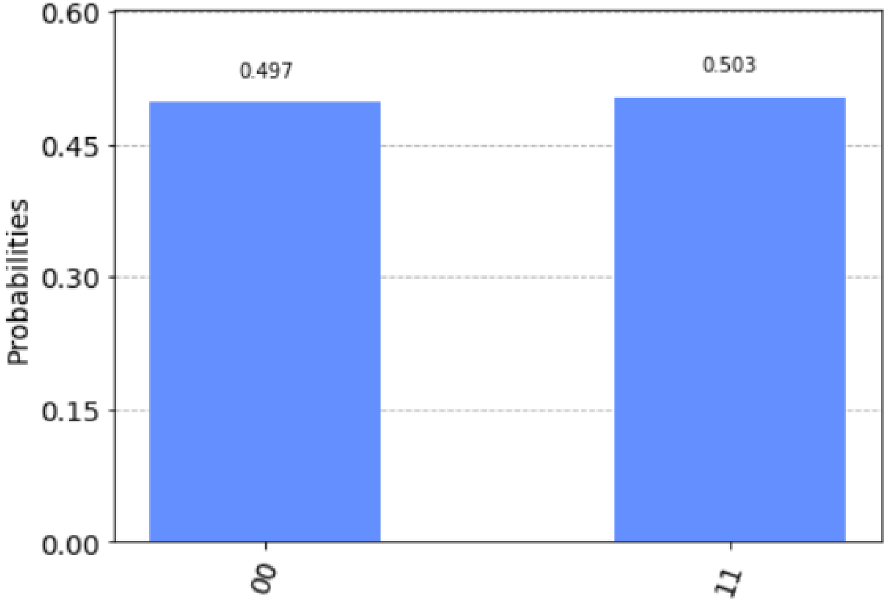
Out[1]:



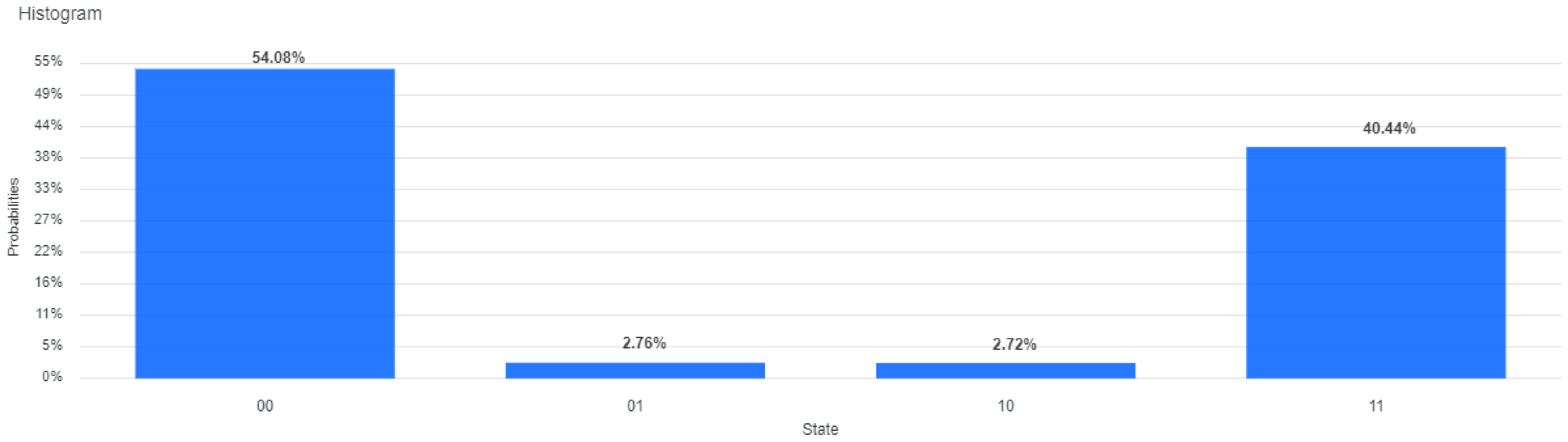
In [2]:
```python
from qiskit import Aer, execute
from qiskit.visualization import plot_histogram
backend = Aer.get_backend('qasm_simulator')
job_sim = execute(q_bell, backend,shots=100000)
sim_result = job_sim.result()

print(sim_result.get_counts(q_bell))
plot_histogram(sim_result.get_counts(q_bell))
```

{'11': 50254, '00': 49746}

Out[2]:

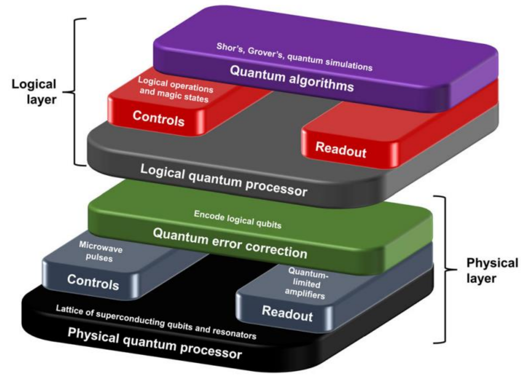


Real QC


Histogram
54.08%
2.76%
2.72%
40.44%
55%
49%
44%
38%
33%
27%
22%
16%
11%
5%
0%
Probabilities
00
01
10
11
State

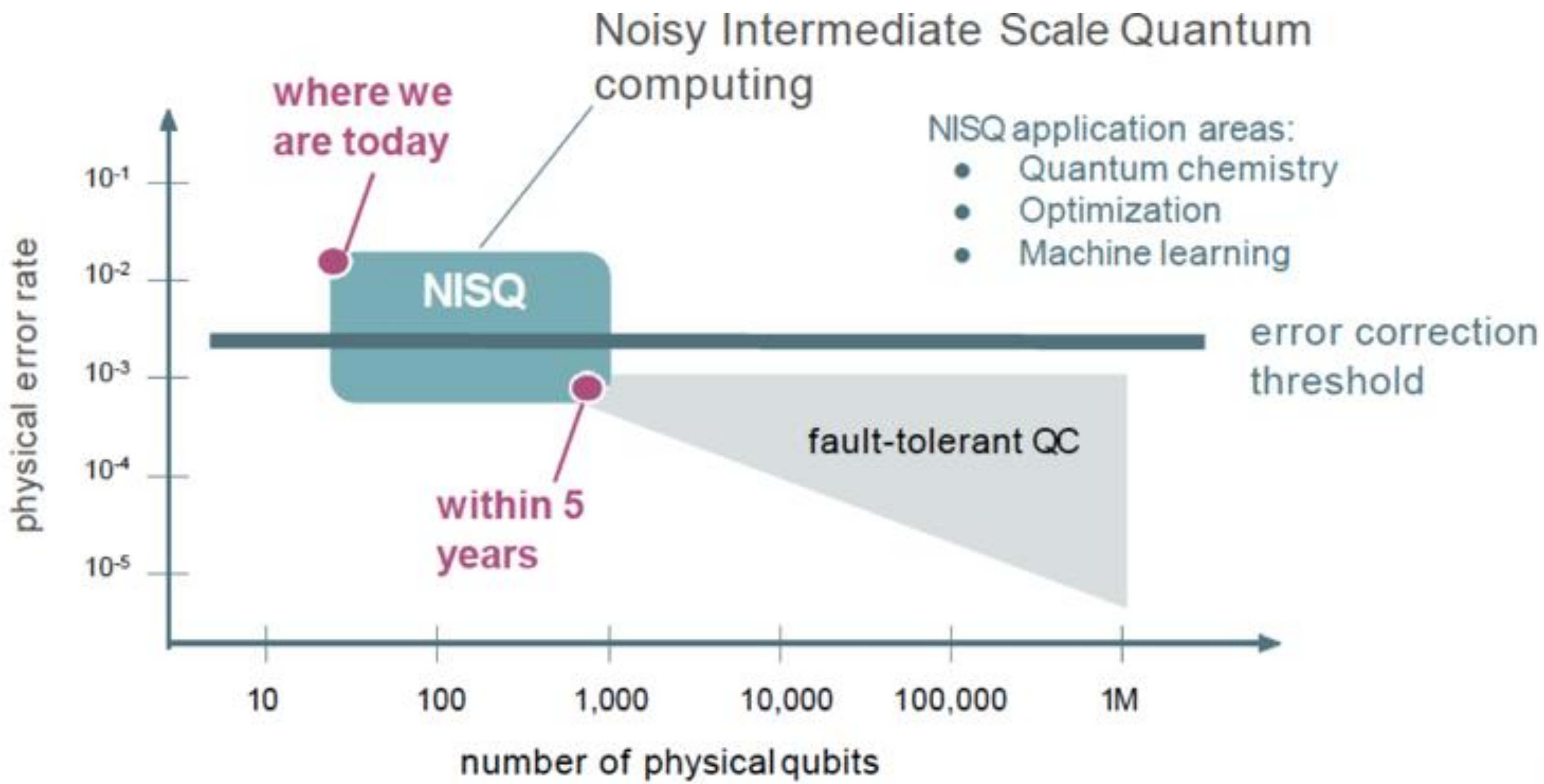
Where are we now?

Resource	Current Capability	Estimate for 2048-bit Shor's factorization*
Operational Fidelity	~99%	99.99%
# of physical gate operations	100s	1.5×10^{21}
# of physical qubits	53	98,000,000
# of FT logical operations (perfect operations)	0	450,000,000,000
# of FT logical qubits (ideal qubits)	0	12000



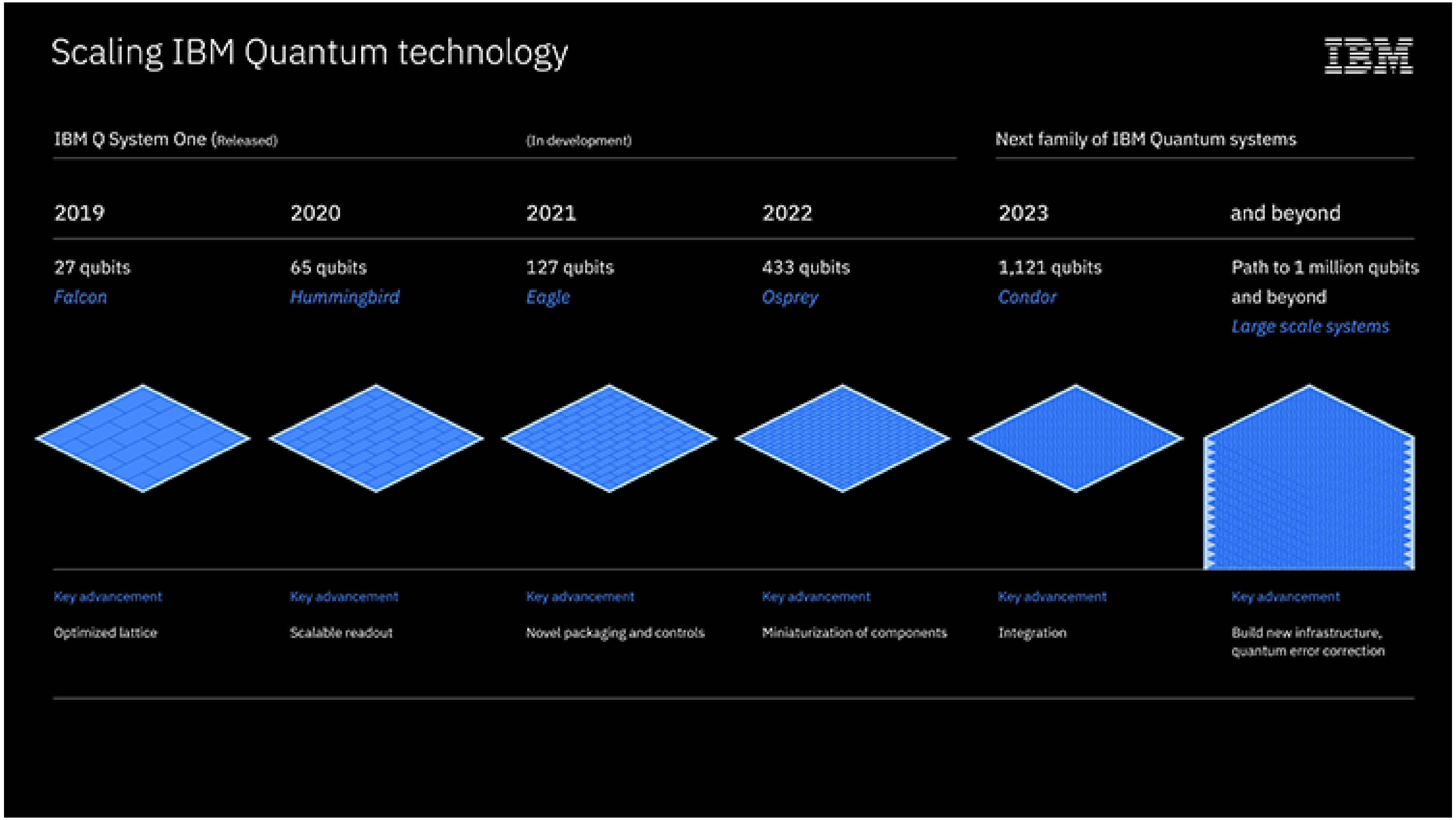
*N. C. Jones, R. Van Meter, A. G. Fowler, P. L. McMahon, J. Kim, T. D. Ladd, and Y. Yamamoto, Layered Architecture for Quantum Computing, Phys. Rev. X 2, 031007 (2012).

Where are we now?



"Quantum computing in the NISQ era and beyond" Preskill, 2018 https://arxiv.org/abs/1801.00862

IBM’s Roadmap For Scaling Quantum Technology



Join US!

That is! NO CHINA!

Become an IBM Quantum Hub

IBM Quantum Hubs are regional centers of quantum computing education, research, development, and implementation that provide collaborators online access to IBM quantum technology.

Each Hub is enabled by IBM Q systems, and collaborates with IBM Quantum experts to advance quantum computing. The Hubs disseminate IBM Quantum technology access to their own members and support members in advancing and experimenting with quantum computing.

慶應義塾 Keio University

Universität der Bundeswehr München

The University of Melbourne

CSIC

Institut Quantique Université de Sherbrooke

Fraunhofer

Oak Ridge National Laboratory

Cambridge Quantum Computing Limited

University of Oxford

東京大学 The University of Tokyo

INL International Iberian Nanotechnology Laboratory

Los Alamos National Laboratory Est. 1943

NC State University

國立臺灣大學 National Taiwan University

Learning Resource

- Qiskit Textbook
- Quantum Computing Reference
- Email me

Learning Resource

- Qiskit Textbook
- Quantum Computing Reference
- ~~Email me~~

Try it!

- 140.112.102.248:2045
- Password: summerq