IBM Q Quantum Computer Hub at NTU

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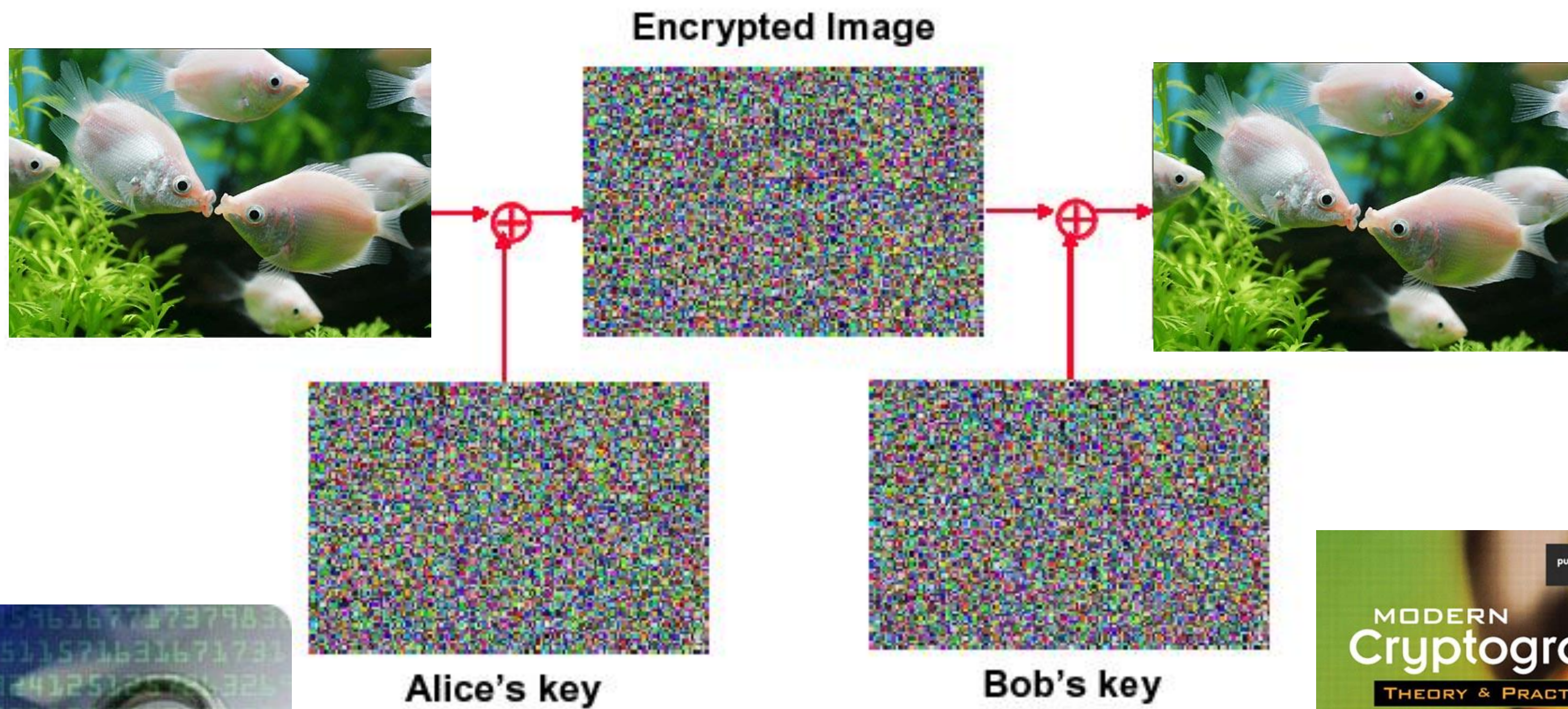
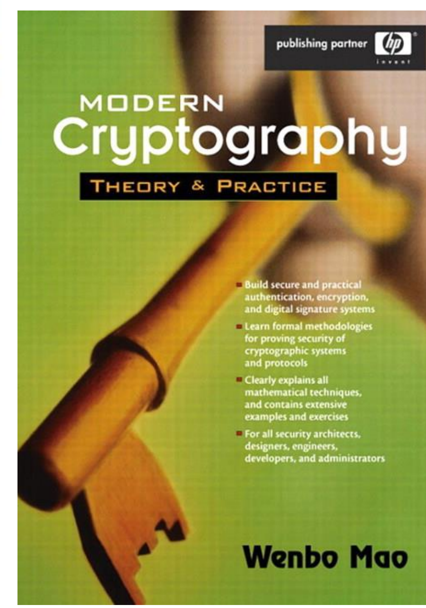
Cryptography: private key method

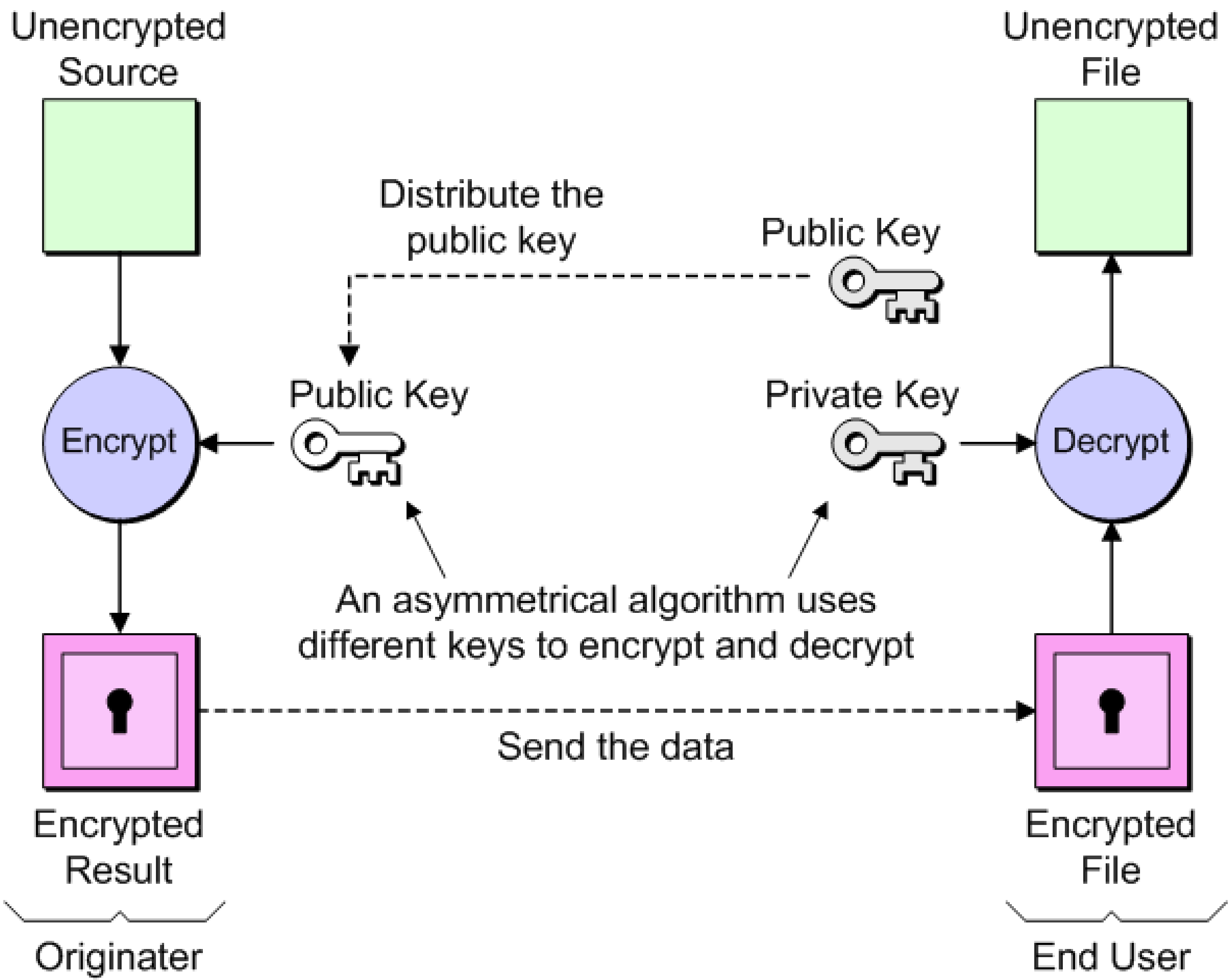


encryption private key

decryption private key



Cryptography: public key method



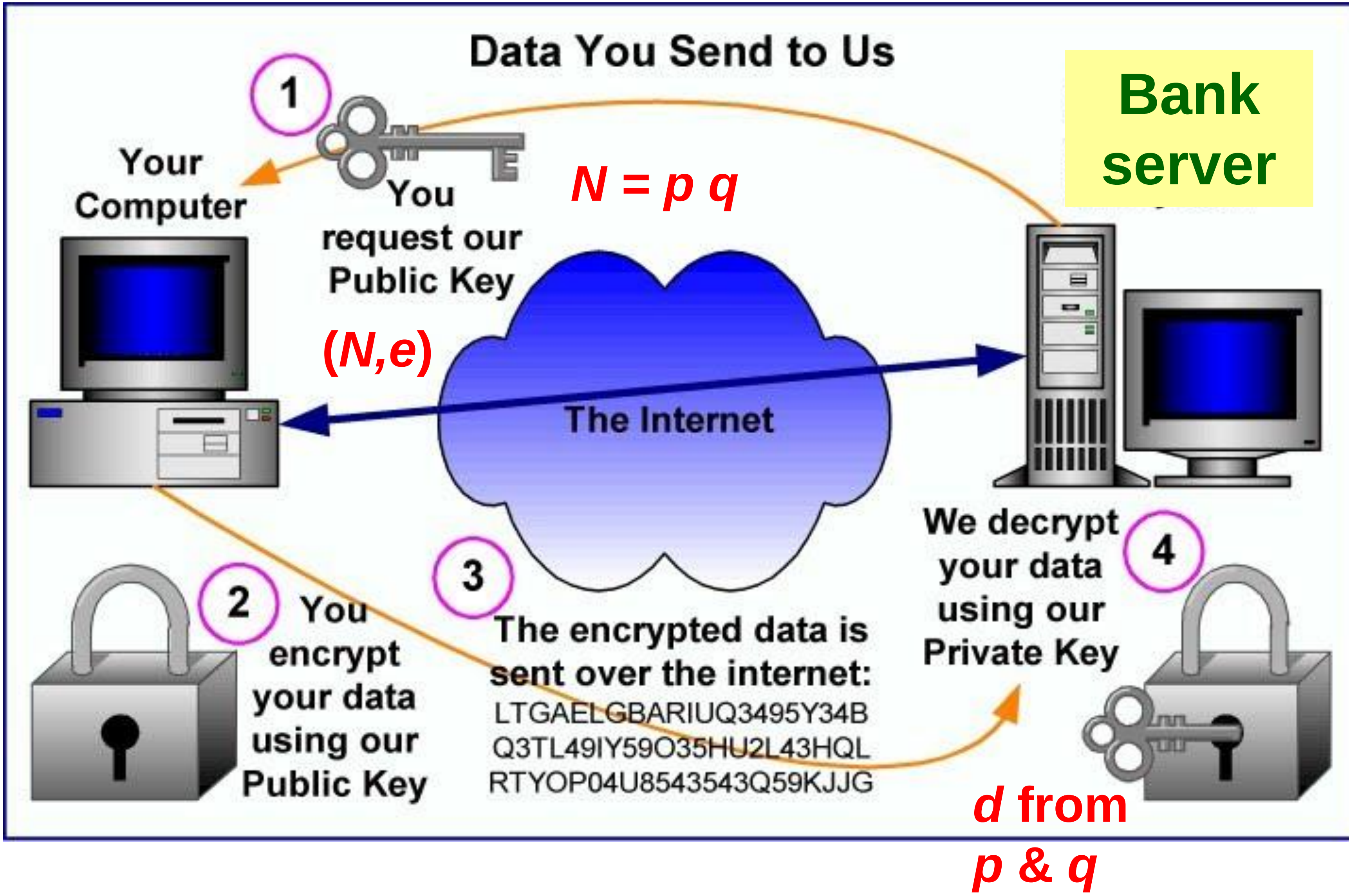
RSA cryptography

- The difficulty of factorizing large numbers forms the basis of RSA encryption system: standard industrial strength encryption on the Internet
  - Example: 4633 = 41 x 113
- RSA systems offers each prizes to people who factor number like (US $200K for this one):

25195908475657893494027183240048398571429282126204
03202777713783604366202070759555626401852588078440
69182906412495150821892985591491761845028084891200
72844992687392807287776735971418347270261896375014
97182469116507761337985909570009733045974880842840
17974291006424586918171951187461215151726546322822
16869987549182422433637259085141865462043576798423
38718477444792073993423658482382428119816381501067
48104516603773060562016196762561338441436038339044
14952634432190114657544454178424020924616515723350
77870774981712577246796292638635637328991215483143
81678998850404453640235273819513786365643912120103
97122822120720357

Example: factor a 309-digit number; Best algorithm: takes 10^{24} steps;
On computer at THz speed: 150,000 years

Internet banking cryptosystem



Quantum algorithms and computational speed-ups

- *Algorithm:* a detailed step-by-step method for solving a problem
- *Computer:* a universal machine that can implement any algorithm
- Quantum factoring algorithm : exponential speed-up (Shor's Algorithm)
  Example: factor a 300-digit number

Best classical algorithm: 10^{24} steps	Shor's quantum algorithm: 10^{10} steps
On classical THz computer: 150,000 years	On quantum THz computer: <1 second

Peter Shor

- Quantum search of an unsorted database: quadratic speed-up (Grover's Algorithm)
  - Example: name → phone number (easy)
  - phone number → name (hard)
  - Classical: $O(n)$, Grover's: $O(\sqrt{n})$
- Simulation of quantum systems: up to exponential speed-up.

RSA cryptography and Shor's Factoring Algorithm

- The details of Shor's factoring algorithm are more complicated than Grover's search algorithm, but the results are clear.
- On December 12, 2009, the 768-bit, 232-digit number RSA-768 was successfully factored by the number field sieve.

with a classical computer

# bits	1024 (309)	2048 (617)	4096 (1233)
factoring in 2006	10^5 years	5×10^{15} years	3×10^{29} years
factoring in 2024	38 years	1×10^{12} years	7×10^{25} years
factoring in 2042	3 days	3×10^8 years	2×10^{22} years

with potential quantum computer
(e.g., clock speed 100 MHz)

# bits	1024	2048	4096
# qubits	5124	10244	20484
# gates	3×10^9	$2 \mathrm{X} 10^{11}$	$\mathrm{X} 10^{12}$
factoring time	4.5 min	36 min	4.8 hours

R. J. Hughes, LA-UR-97-4986

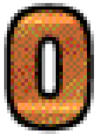
What is a quantum computer?

- A device that harnesses quantum physical phenomena such as entanglement and superposition.
- The laws of quantum mechanics differ radically from the laws of classical physics.
- The unit of information, the qubit can exist as a 0, or 1, or, simultaneously, as both 0 and 1.

什麼是量子位元(quantum bit)?

- Classical bit: 0 or 1; voltage high or low
- **Quantum bit (qubit):** QM two-state system
- 一個量子位元有兩種可能的狀態 $|0\rangle$ or $|1\rangle$
- 一個量子位元狀態可以處在 $|0\rangle$ and $|1\rangle$ 的線性疊加態

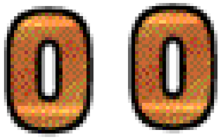
$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$



α 和 β 可以是複數 (complex numbers) 並且 $|\alpha|^2 + |\beta|^2 = 1$

- 兩個量子位元的狀態可以處在此線性疊加態

$$|\psi\rangle = C_0|00\rangle + C_1|01\rangle + C_2|10\rangle + C_3|11\rangle \text{ 且 } \sum_{j=0}^{3}|C_j|^2 = 1$$



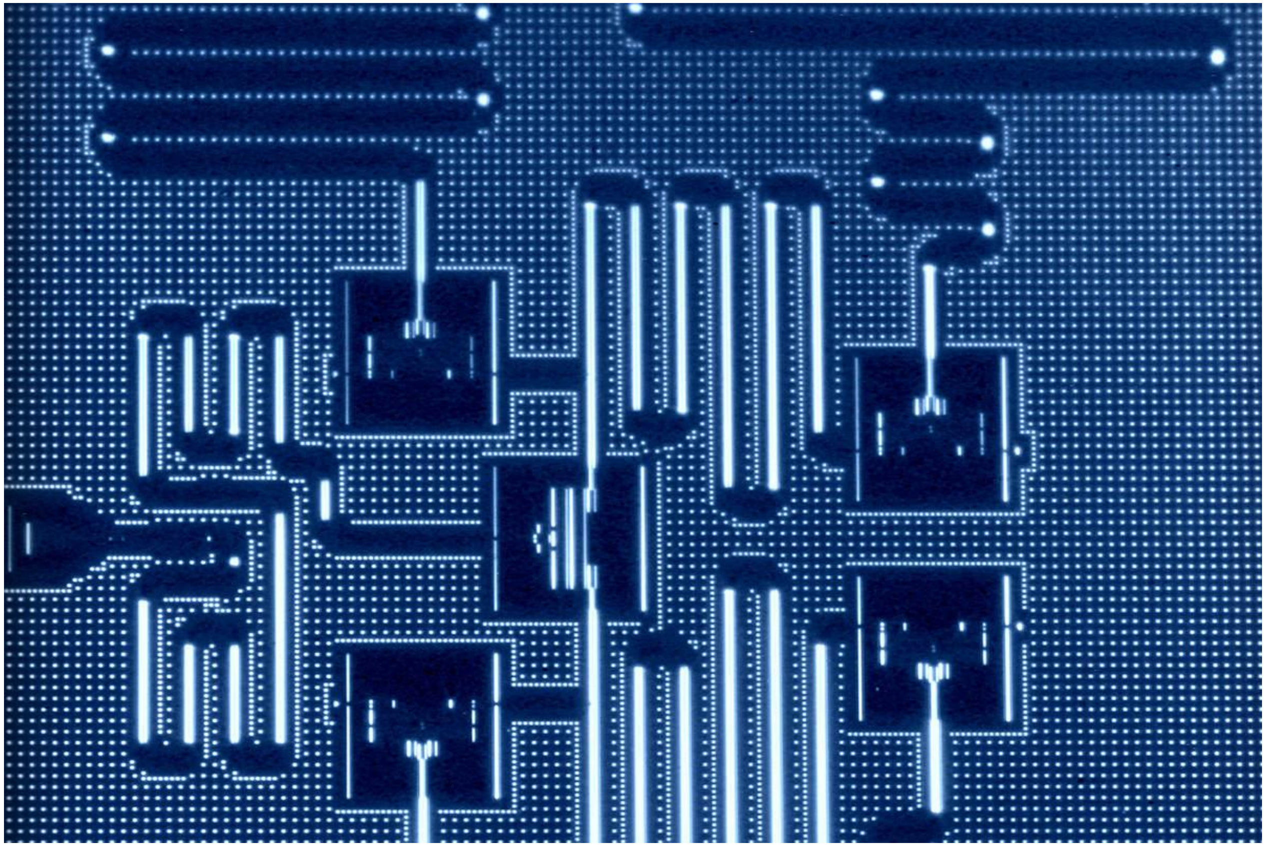
- 封閉的量子系統隨時間的演化是 Unitary: $|\psi'\rangle = U|\psi\rangle$

Does quantum computing represent the frontiers of computing?

- Is it for real? Can we actually build quantum computers? - Very likely, but it will take some time….
- If so, what would a quantum computer allow us to do that is either unfeasible or impractical with today's most advanced systems? – Exact simulation of physical systems, among other things.
- Once we have quantum computers do we need new algorithms? – Yes, we need quantum algorithms.
- Is it so different from our current thinking that it requires a substantial change in the way we educate our students in EE and CS? – Yes, it does.

IBM Makes Quantum Computing Available on IBM Cloud to Accelerate Innovation

- **In May 2016**, **IBM** made quantum computing with superconducting 5-qubit processor available as a service of **Quantum Experience** through **IBM Cloud.**



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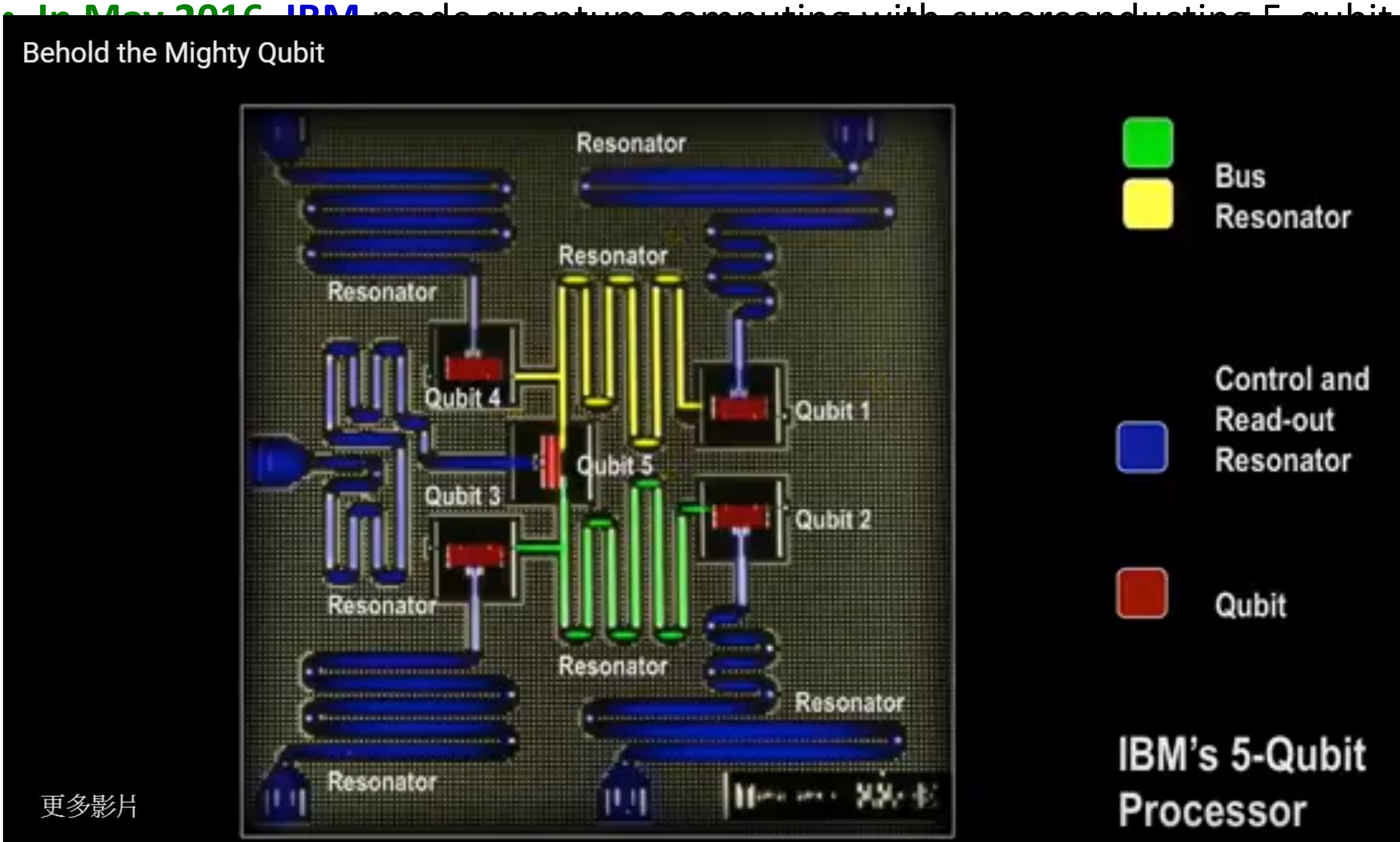
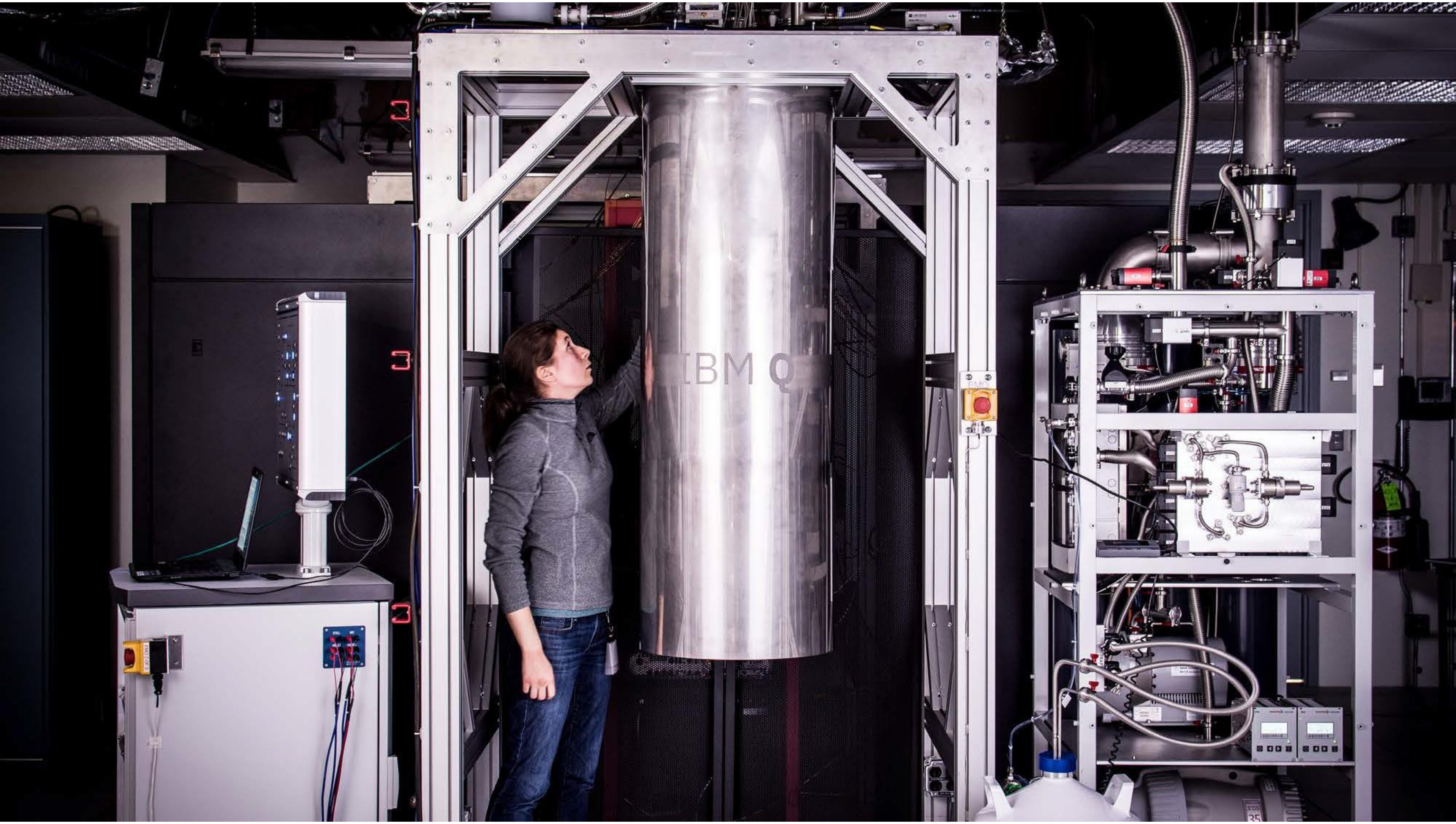


IBM

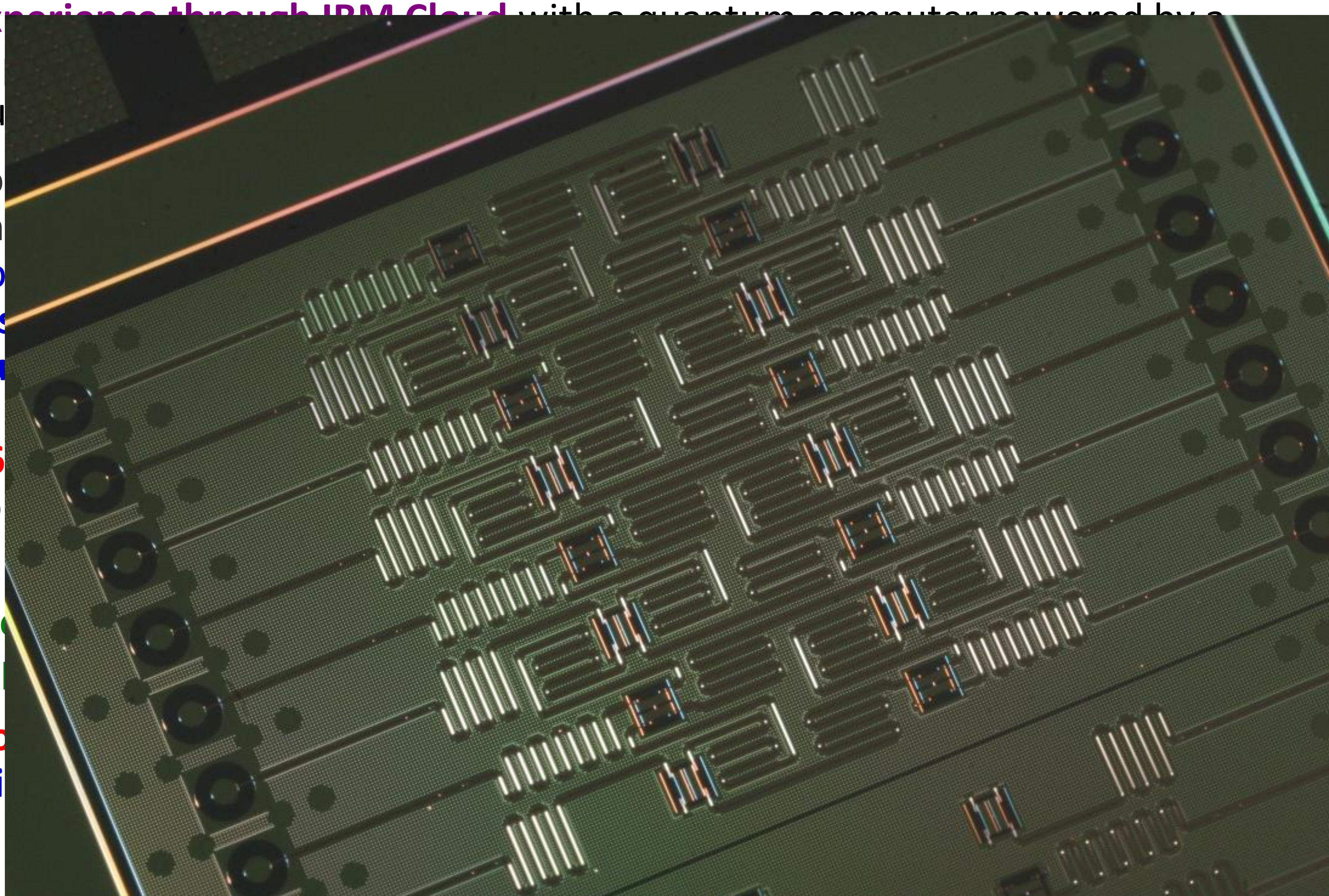


IBM Builds Its Most Powerful Universal Quantum Computing Processors

- **In May 2016,** IBM made quantum computing available as **a service of Quantum Experience through IBM Cloud** with a quantum computer powered by a **superconducting 5-qubit processor**. Users can run experiments on the IBM quantum processor.
- **Yorktown Heights, N.Y. - 17 May 2017:** IBM announced it has successfully built and tested its most powerful universal quantum computing processors. The first upgraded **processor with16 qubits will be available for use by developers, researchers, and programmers to explore quantum computing using a real quantum processor at no cost via the IBM Cloud**. The second is a new prototype of **a commercial processor with 17 qubits (offering twice the performance of the 16-qubit machine**), which will be the core for the first IBM Q early-access commercial systems.
- **In Nov. 2017, 20 qubit machine became available. IBM plans to scale future processors to include 50 or more qubits** and demonstrates computational capabilities beyond today's classical computing systems
- **Google that has built a nine-qubit machine hopes to make a 49-qubit chip that will prove quantum computers can beat classical machines.**

IBM Builds Its Most Powerful Universal Quantum Computing Processors

- **In May 2016**, IBM made quantum computing available as **a service of Quantum Ex**... **su**... qu...

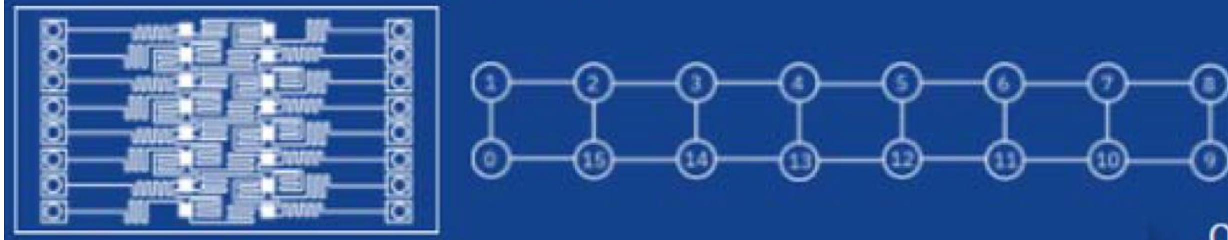


- **Yo**... an ... st up... **res**... **qu**... pe of ... **the 16**... co...
- **In** ... **pr**... ca...
- **Go** ... **nt wi**...

IBM Q quantum computer systems

Devices' specification and performance

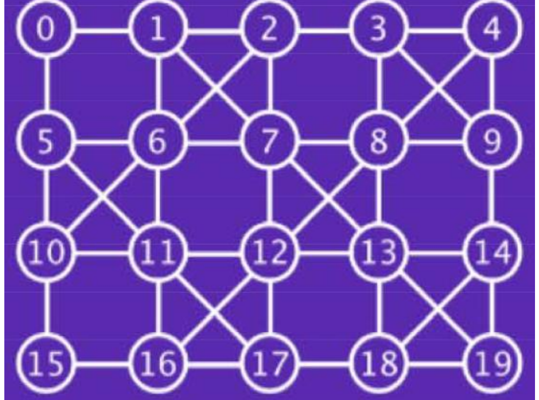
IBM Q 16 Rueschlikon [ibmqx5]



Last Calibration: 2018-06-24 10:42:26

	Q0	Q1	Q2	Q3	Q4	Q5	Q6
Frequency (GHz)	5.26	5.40	5.28	5.08	4.98	5.15	5.31
T1 (μs)	48.20	31.20	37.20	58.10	47.20	49.50	57.90
T2 (μs)	29.00	50.10	56.60	93.30	96.20	45.10	86.50
Gate error (10^{-3})	1.89	4.17	3.89	1.98	1.33	4.21	1.43
Readout error (10^{-2})	6.51	5.99	8.25	5.58	6.35	4.76	4.95
MultiQubit gate error (10^{-2})		CX1_0	CX2_3	CX3_4		CX5_4	CX6_
		5.01	2.84	4.33		4.83	8.89
		CX1_2		CX3_14			CX6_
		4.50		3.84			2.45
							CX6_
							2.96

IBM Q 20 Tokyo [ibmq_20_tokyo]

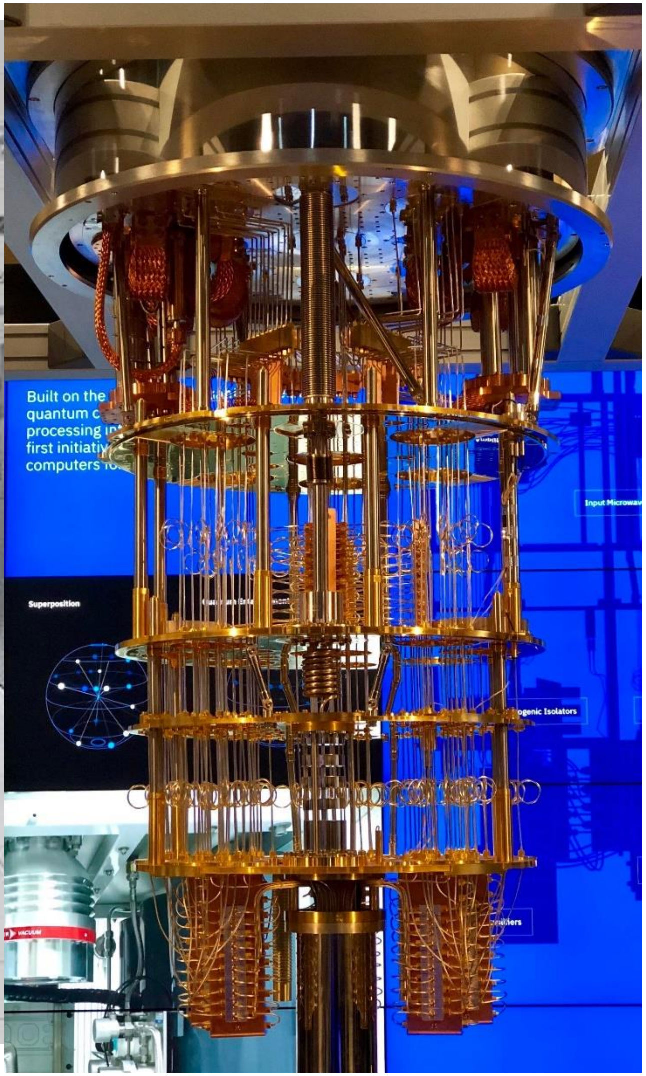


Last Calibration: 2018-06-24 07:19:10

AVAILABLE TO HUBS, PARTNERS, AND MEMBERS OF THE IBM Q NETWORK

	Average
Frequency (GHz)	4.97
T1 (μs)	82.14
T2 (μs)	56.35
Gate error (10^{-3})	5.18
Readout error (10^{-2})	8.54
MultiQubit gate error (10^{-2})	AVG 3.39

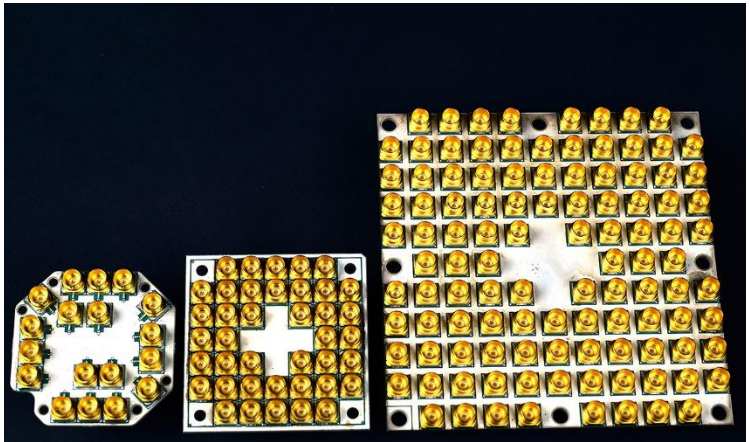
IBM Q system



Based at IBM Thomas J. Watson Research Center in New York, USA

CES 2018: Intel's 49-Qubit Chip Shoots for Quantum Supremacy

- Intel has passed a key milestone while running alongside Google and IBM in the marathon to build quantum computing systems. The tech giant has unveiled a superconducting quantum test chip with 49 qubits (code-named Tangle Lake): enough qubits to possibly enable quantum computing that begins to exceed the practical limits of modern classical computers, i.e., the so-called **"quantum supremacy."**
- But practical quantum computing also requires much more than ever-larger arrays of qubits. One important step involves implementing "surface code" error correction that can detect and correct for disruptions in the fragile quantum states of individual qubits. Another step involves figuring out how to map software algorithms to the quantum computing hardware. A third crucial issue involves engineering the local electronics layout necessary to control the individual qubits and read out the quantum computing results.

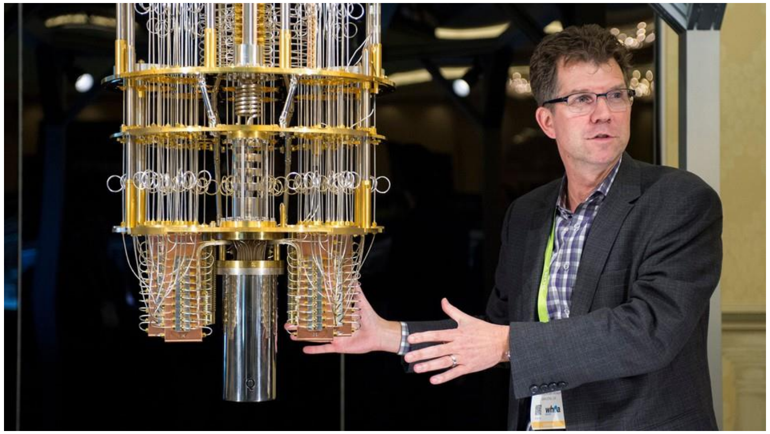


Intel's 7-qubit, 17-qubit, and 49-qubit superconducting quantum chips.

- Intel's roadmap suggests researchers could achieve 1,000-qubit systems within 5 to 7 years.
- 17-qubit arrays have the minimum number of qubits necessary to perform surface code error correction.
- Intel has developed packaging to prevent radio-frequency interference with the qubits, and uses flip chip technology, enabling smaller and denser connections to get signals on and off the chips.

CES 2018: IBM Shows Off The World's Largest Quantum Computer

- The promise of the quantum computer is to solve problems that typical computers will never be able to tackle, by bringing unheard-of power and speed to computing through leveraging the principles of quantum physics.
- Developing new synthetic materials, allowing for faster machine learning, and providing an advanced back-end to power consumer apps. These are just some of the potential applications of the **first ever 50-qubit quantum computer prototype** displayed at this year's CES conference in Las Vegas, Nevada.



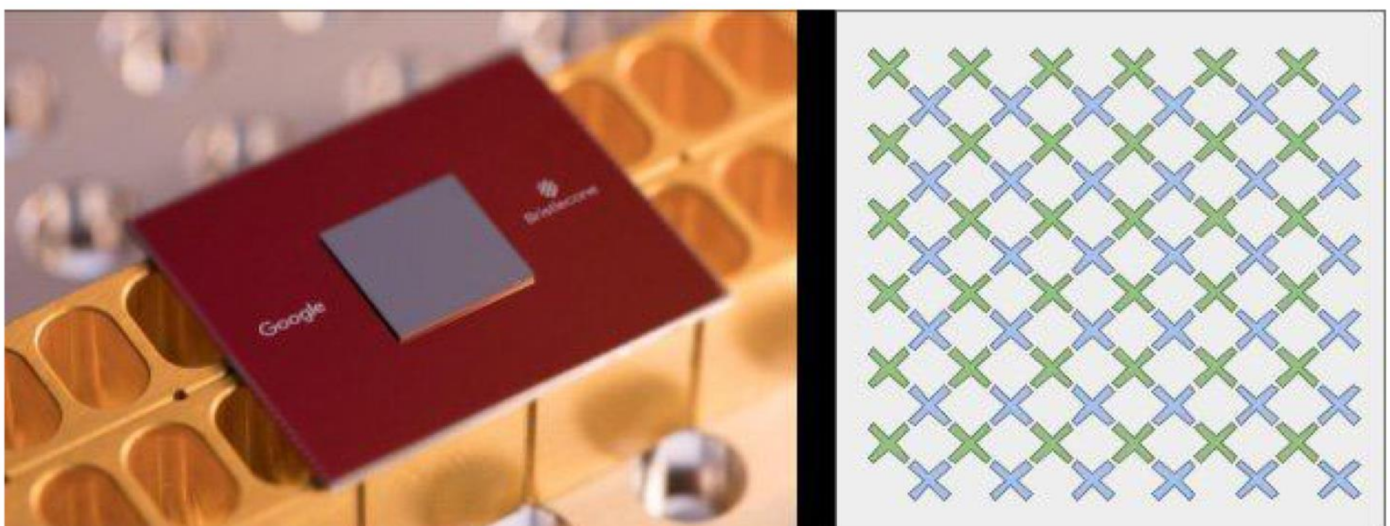
IBM is also working with commercial partners in the finance, materials, automotive, and chemistry industries by allowing them access to the groundbreaking computing power these devices offer.

A Bristlecone chip being installed by researcher Marissa Giustina at the Quantum AI Lab (Google)

Google Just Unveiled The World's Most Advanced Quantum Processor by Far

72 qubits! 72 qubits!

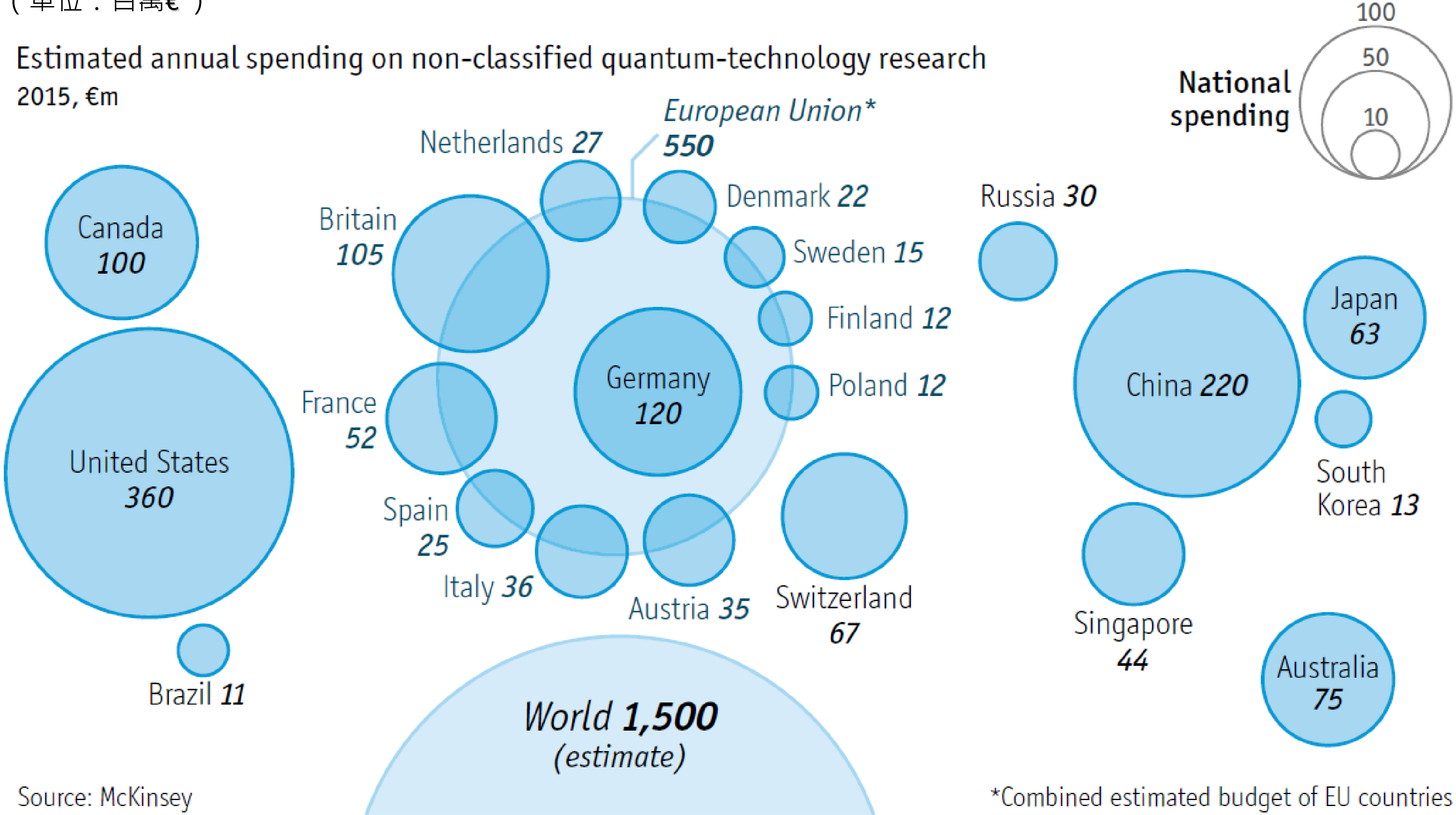
BRAD JONES, FUTURISM
7 MAR 2018



Bristlecone, Google's New Quantum Processor

全球量子科技研發投入

（單位：百萬€ ）

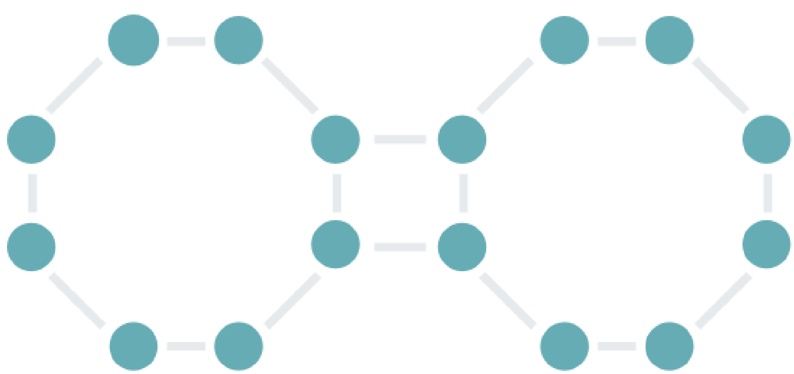


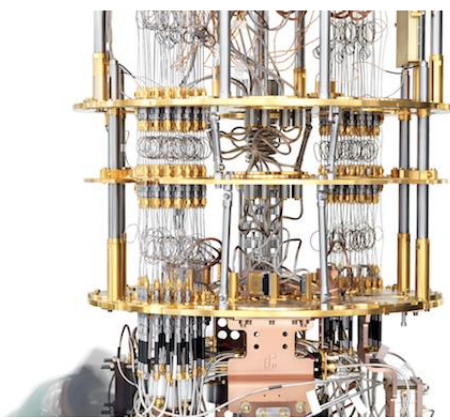
資料來源: The Economist March 11th 2017

Rigetti plans to build and deploy a 128-qubit system

Aug 9, 2018

- Rigetti Computing, founded in 2013 and based in Berkeley, Calif., plans to **build a 128-qubit quantum computer over the next 12 months** based on an equivalent quantum processor that leverages emerging hybrid computing algorithms used to test programs and potential applications.
- Rigetti Computing launched on Sep. 7, 2018 **Rigetti Quantum Cloud Services (QCS)** – a complete platform for developing and running quantum algorithms that leverages Rigetti's hybrid quantum-classical approach. The company also announced a $1 million prize for the first conclusive demonstration of so-called "**quantum advantage**" by a user on QCS.





The new 128-qubit chip is based on a scalable 16-qubit form factor.

Quantum advantage with shallow circuits

Science 362, 308–311 (2018)
19 October 2018

Sergey Bravyi[1], David Gosset[1*], Robert König[2†]

Quantum effects can enhance information-processing capabilities and speed up the solution of certain computational problems. Whether a quantum advantage can be rigorously proven in some setting or demonstrated experimentally using near-term devices is the subject of active debate. We show that parallel quantum algorithms running in a constant time period are strictly more powerful than their classical counterparts; they are provably better at solving certain linear algebra problems associated with binary quadratic forms. Our work gives an unconditional proof of a computational quantum advantage and simultaneously pinpoints its origin: It is a consequence of quantum nonlocality. The proposed quantum algorithm is a suitable candidate for near-future experimental realizations, as it requires only constant-depth quantum circuits with nearest-neighbor gates on a two-dimensional grid of qubits (quantum bits).

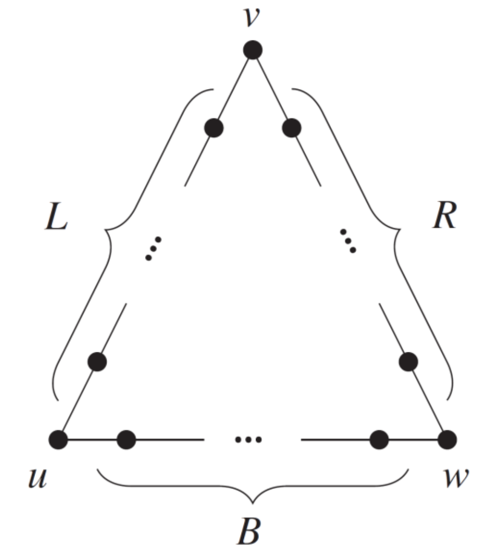


Fig. 1. Cycle graph Γ. Shown is a cycle Γ of even length *M* and three vertices *u*, *v*, *w* such that all pairwise distances are even. The sides *L*, *R*, *B* may have unequal lengths.

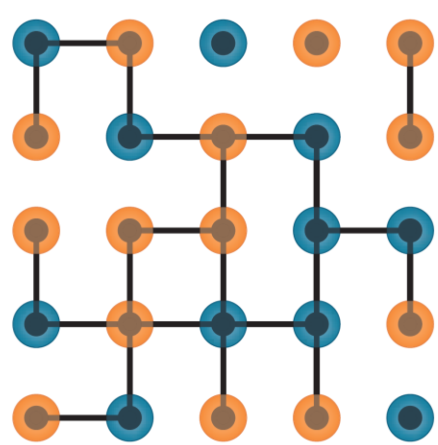
Bravyi *et al.* describe an explicit family of problems that can be solved with a quantum circuit of constant depth, whereas any classical circuit must have depth that scales logarithmically with the size of the problem.

Qubits for linear algebra

To solve the hidden linear function problem for a matrix A corresponding to a subgraph G(A) of a square lattice, a graph state can be prepared using entangling operations, indicated by black edges, across qubits.

Touching bases

Each qubit is measured in one of two measurement bases, indicated by orange or blue circles.



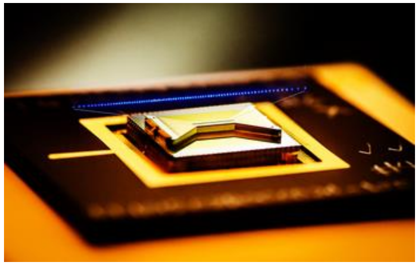
Intel's New Path to Quantum Computing

IEEE SPECTRUM

8 Jun 2018 | 20:00 GMT

- Despite a comparatively late start, Intel is progressing quickly along the road to a useful quantum computer.
- Intel's director of quantum hardware, Jim Clarke, explains the company's two quantum computing technologies
- The first was a Tangle Lake, a specially packaged chip containing 49-superconducting qubits that Intel CEO Brian Krzanich, showed off at CES in January.
- The other was something new: a full silicon wafer of test chips, each containing 3, 7, 11, or 26 qubits that rely on the spins of individual electrons. There are thousands and thousands of these little sub-arrays in a wafer.
- The first of these wafers arrived at **Delft University of Technology**, in The Netherlands, on May 9, 2018 for testing. Clarke's group can make 5 such wafers per week, meaning that Intel has probably now made more qubit "devices than have ever been made in the world of quantum computing."

NSF Awards $15 Million Grant for Development of a Practical Quantum Computer



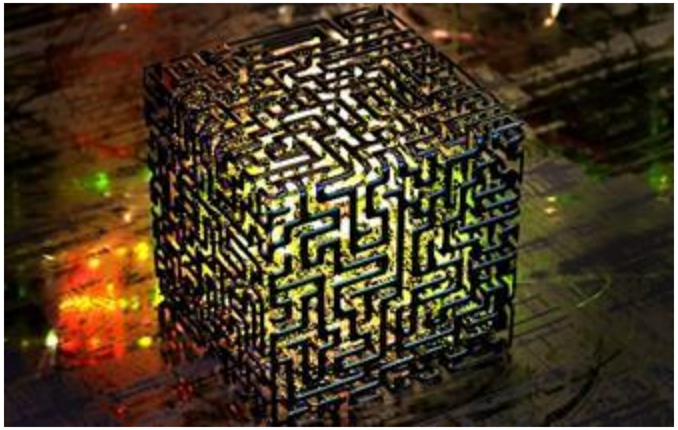
August 7, 2018

- The U.S. National Science Foundation (NSF) has awarded $15 million over five years **for the Software-Tailored Architecture for Quantum Co-design (STAQ) project.** This is a multi-institution project that will involve researchers from Duke University, the Massachusetts Institute of Technology, Tufts University, University of California-Berkeley, University of Chicago, University of Maryland and University of New Mexico.
- The project has **a goal of producing a working quantum computer of 64 qubits or more based upon the ion trap technology** while simultaneously developing software tools that optimally map quantum algorithms to the ion trap device. The ion trap technology apparently leverages previous research performed at Duke University and the University of Maryland and used by IonQ for their quantum computer. **One important feature of this proposed machine is that it will offer all-to-all qubit connectivity which provides certain problem solving advantages over the more restricted connectivity of the superconducting based designs being pursued by IBM, Google, Rigetti, and others.**

Silicon quantum computer: millions for the QuCube project in Grenoble

October 23, 2018

- A grant of up to € 14 millions over six years by the European Research Council (ERC Synergy Grant) has been awarded to the QuCube project to develop a quantum processor **with at least 100 physical qubits**. Conducted in three **Grenoble** research institutes (CEA-Leti, Inac and Institut Néel) and involving scientists from CEA, CNRS and UGA, this project studied within the framework of the multidisciplinary program Quantum Engineering has the task of continuing to explore the concept of quantum processor but with qubits carried by silicon chips similar to those already known to manufacture on a large scale. This, under the direction of the three research managers, laureates of this funding with their teams, Silvano De Franceschi (Inac, CEA), Tristan Meunier (Néel Institute, CNRS) and Maud Vinet (CEA-Leti).

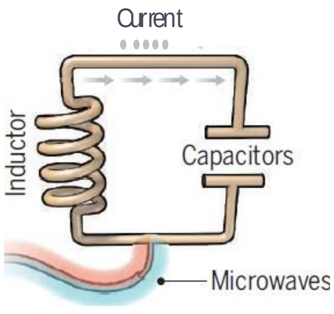


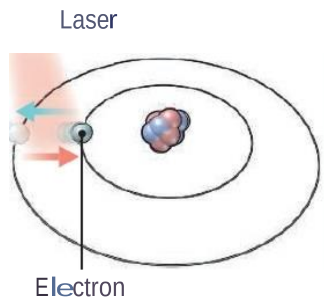
- The project is named QuCube and will utilize 3D integration technology of silicon spin qubits.
- A collaborative project was signed between the first Australian company dedicated to quantum computing, Silicon Quantum Computing Pty Ltd (SQC) and the CEA.

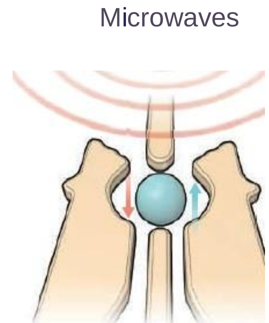
Science (Dec. 1, 2016) DOI: 10.1126/science.aal0442

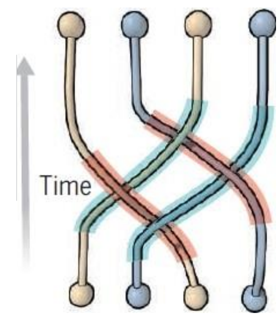
A bit of the action

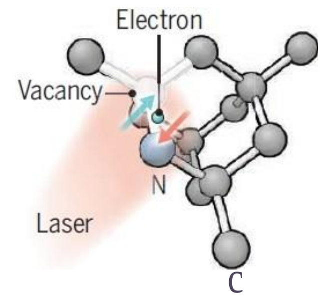
In the race to build a quantum computer, companies are pursuing many types of quantum bits, or qubits, each with its own strengths and weaknesses.











	Superconducting loops	Trapped ions	Silicon quantum dots	Topological qubits	Diamond vacancies
	A resistance-free current oscillates back and forth around a circuit loop. An injected microwave signal excites the current into superposition states.	Electrically charged atoms. or ions.have quantum energies that depend on the location of electrons. Tuned lasers cool and trap the ions.and put them in superposition states.	These "artificial atoms" are made by adding an electron to a small piece of pure silicon. Microwaves control the electron's quantum state.	Quasiparticles can be seen in the behavior of electrons channeled through semi-conductor structures.Their braided paths can encode quantum information.	A nitrogen atom and a vacancy add an electron to a diamond lattice. Its quantum spin state. along with those of nearby carbon nuclei. can be controlled with light.
Longevity (seconds)	**0.00005**	**>1000**	**0.03**	**N/A**	**10**
Logic success rate	**99.4%**	**99.9%**	**–99%**	**N/A**	**99.2%**
Number entangled	50-72; 128	10 -- 64	10 – 26; 100	**N/A**	**6**
Company support	Google, IBM. Quantum Circuits	ionQ	Intel	Microsoft. Bell Labs	Quantum Diamond Technologies
Pros	Fast working. Build on existing semiconductor industry.	*Very* stable. Highest achieved gate fidelities.	Stable. Build on existing semiconductor industry.	Greatly reduce errors.	Can operate at room temperature.
Cons	Collapse easily and must be kept cold.	Slow operation. Many lasers are needed.	Only a few entangled. Must be kept cold.	Existence not yet confirmed.	Difficult to entangle.

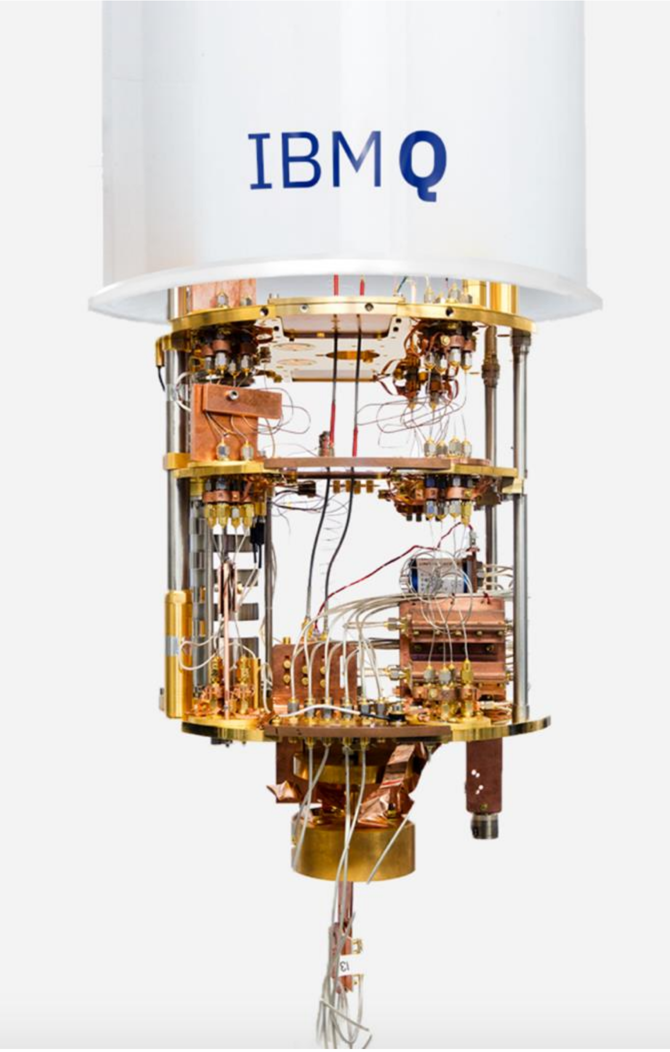
Quantum Computing

- **Quantum computing is an entirely new paradigm of computation that promises to solve some of the most difficult problems in business and science – even problems that are currently intractable.**
- Quantum computing utilizes the fundamental properties of quantum mechanics to process data in ways that offer significant speed-ups – in some cases exponential speedups – for a variety of problems.
- Although it is still early days for the technology, progress over the last few years has been rapid, and the first commercial use cases in the physical sciences, optimization, and machine learning are in sight.
- Yet, quantum computers are so different from the "classical" computers we use today, it will likely take several years for organizations to acquire the talent and expertise needed to develop new applications that utilize quantum computers and incorporate them into new business processes, products, and services in a way that provides commercial value to the organization. **The time to start this is now.**

IBM Q Network

- **IBM Q is a new business initiative** – **a startup within IBM** composed of a diverse set of talented staff from IBM's research, product, and consulting divisions - intended to engage organizations to help them get quantum ready.
- **IBM's partner organizations form the IBM Q Network**, a collaboration of industrial, academic, and government organizations with the mission of advancing quantum computing and launching the first commercial applications.
- The IBM Q Network offers access to the most advanced quantum computers and software available, along with training, consulting, technical support, and opportunities for deep collaboration to develop new uses cases.

IBM Q Network: Mission



Accelerate Research
Collaborate with the most advanced academic and research organizations to advance quantum computing technology.

Launch Commercial Applications
Engage industry leaders to combine IBM's quantum computing expertise with industry specific expertise to accelerate development of the first commercial use cases.

Educate and Prepare
Expand and train the ecosystem of users, developers, and application specialists that will be essential to the adoption and scaling of quantum computing.

IBM reveals first clients of commercial quantum computing initiative Q Network

14 December, 2017 16:00

- IBM today revealed the names of the 12 clients to be given early access to its 20 qubit quantum computer. **JPMorgan Chase, Daimler AG, Samsung, JSR Corporation, Barclays, Hitachi Metals, Honda, Nagase**, Keio University, Oak Ridge National Lab, Oxford University, and the University of Melbourne will be the first organizations to experiment with IBM's most advanced quantum system, as members of Big Blue's commercial quantum computing program – Q Network.
- "IBM sees the next few years as the dawn of the commercial quantum era – a formative period when quantum computing technology and its early use cases develop rapidly," said Dario Gil, vice president of AI and IBM Q, IBM Research. "**The Q Network will serve as a vehicle to make quantum computing more accessible to businesses and organisations through access to the most advanced IBM Q systems and quantum ecosystem**."
- **The Q Network provides organisations with quantum expertise and resources, and cloud-based access to the "most advanced and scalable universal quantum computing systems available" starting with the 20 qubit machine and 50 qubit machine next year.**

Keio University launched IBM Q Network Hub

17 May 2018

Members of the Keio University IBM Q Network Hub are able to access IBM Q's commercial 20 qubit cloud system, and will in future also be able to access a 50-qubit IBM Q system.

The Keio University IBM Q Hub is part of a network of **seven IBM Q Hubs across the world**. The others are located at IBM Research (USA), Oak Ridge National Laboratory (USA), The University of Oxford (UK), North Carolina State University (USA), The University of Melbourne (Australia) and The University of the Bundeswehr Munich (Germany). **The hubs provide access to IBM Q systems, technical support, educational resources, and networking for collaborative research**.

IBM Collaborating With Top Startups to Accelerate Quantum Computing

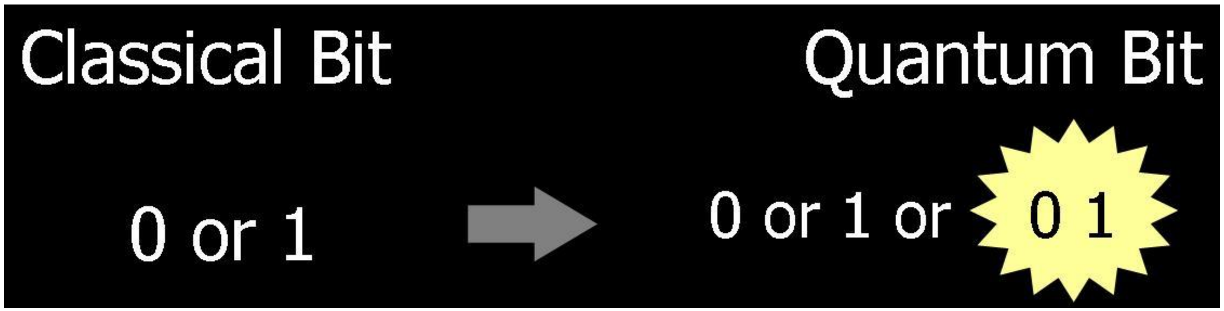
April 5, 2018

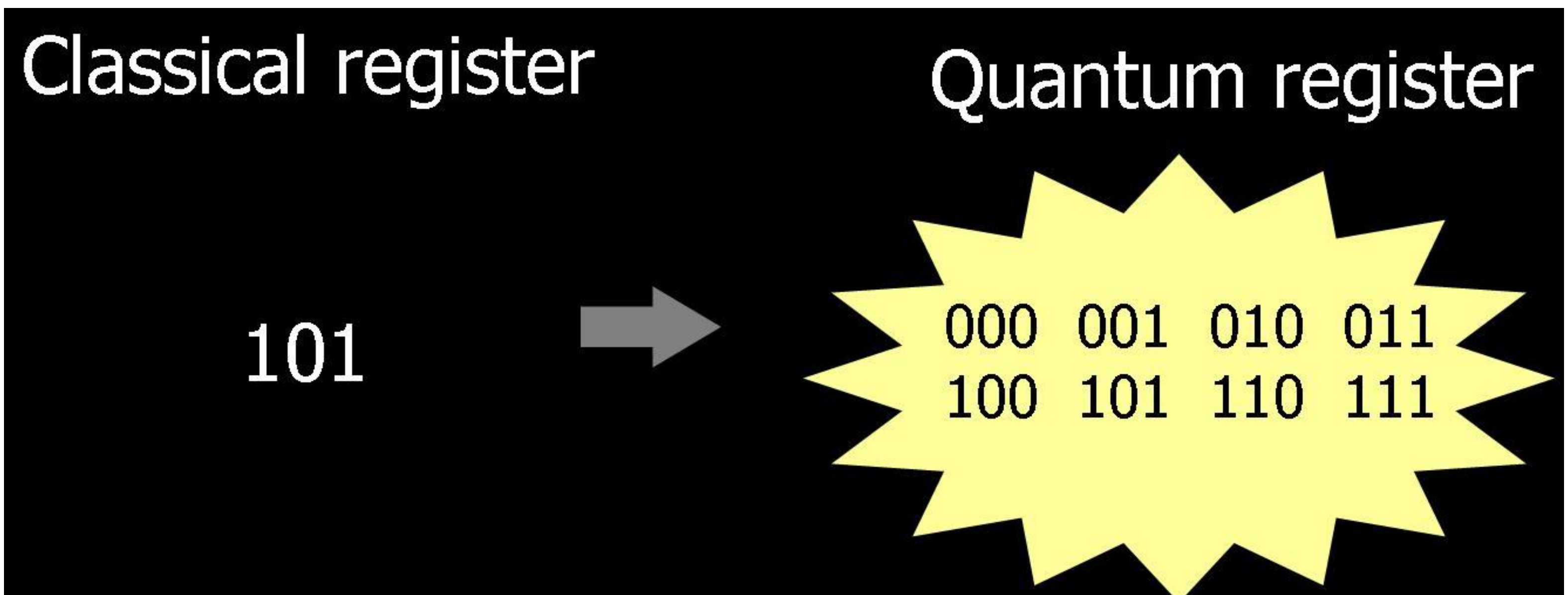
- **Zapata Computing –** Based in Cambridge, MA, a quantum software, applications and services company developing algorithms for chemistry, machine learning, security, and error correction.
- **Strangeworks –** Based in Austin, TX and founded by William Hurley, a quantum computing software company designing and delivering tools for software developers and systems management for IT Administrators and CIOs.
- **QxBranch** – Headquartered in Washington, D.C., delivering advanced data analytics for finance, insurance, energy, and security customers worldwide. QxBranch is developing tools and applications enabled by quantum computing with a focus on machine learning and risk analytics.
- **Quantum Benchmark** – a venture-backed software company with headquarters in Kitchener-Waterloo, Canada. providing solutions that enable error characterization, error mitigation, error correction and performance validation for quantum computing hardware.
- **QC Ware –** Based in Palo Alto, CA, developing hardware-agnostic enterprise software solutions running on quantum computers. QC Ware won a NSF grant, and its customers include Fortune 500 industrial and technology companies.
- **Q-CTRL –** Our hardware agnostic platform – Black Opal – gives you the ability to design and deploy the most effective controls to suppress errors in your quantum hardware before they accumulate, accelerating your roadmap to functional systems. Based in Sydney, Australia.
- **Cambridge Quantum Computing (CQC) –** Established in 2014, a leading independent quantum computing company combining expertise in Quantum Information Processing, Quantum Technologies, Artificial Intelligence, Quantum Chemistry, Optimization and Pattern Recognition. CQC designs solutions such as a proprietary platform agnostic compiler that will allow developers and users to benefit from Quantum Computing even in its earliest forms. CQC also has a growing focus in Quantum Technologies that relate to encryption and security.
- **1QBit** – Headquartered in Vancouver, Canada, building quantum and quantum-inspired software designed to solve the world's most demanding computational challenges. The company's hardware-agnostic platforms and services are designed to enable the development of applications which scale alongside the advances in both classical and quantum computers.

Hilbert space is a big place!

- Carlton Caves

Multiple bits





Hilbert space is a big place!

- Carlton Caves

Multiple qubits

- Two bits with states 0 and 1 form four definite states 00, 01, 10, and 11.
- Two qubits: can be in superposition of four computational basis set states.

$$|\psi\rangle = \alpha|00\rangle + \beta|01\rangle + \gamma|10\rangle + \delta|11\rangle$$

2 qubits	4 states
3 qubits	8 states
10 qubits	1024 states
20 qubits	1 048 576 states
30 qubits	1 073 741 824 states
500 qubits	**More states than our estimate of number of atoms in the Universe!!!**

Exponential growth of basis states

- Due to exponential growth of the number of basis states in Hilbert space with the quantum bit (qubit) number *n*, the computational capabilities of a 50-qubit quantum computing system for some problems are already beyond those of today's classical computing systems, achieving "**quantum supremacy**".
- Problems that are intractable in classical computers due to extremely large number of scenarios or/and involving with many variables, many possible states or possibilities, many possible random influences, etc. may be able to take the quantum advantages of computational state space being exponential in the physical size of the system (2^n) and the randomness that lies at the heart of the quantum theory.

Applications for quantum computer

Medicine & Materials

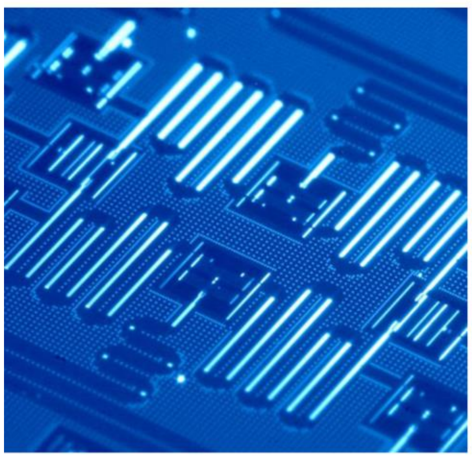
Untangling the complexity of molecular and chemical interactions leading to the discovery of new medicines and materials.

Supply Chain & Logistics

Finding the optimal path for ultra-efficient logistics and global supply chains, such as optimizing fleet operations for deliveries during the holiday season.

Financial Services

Finding new ways to model financial data and isolating key global risk factors to make better investments.



Artificial Intelligence

Making facets of artificial intelligence such as machine learning much more powerful when data sets are very large, such as in searching images or video.

Cloud Security

Making cloud computing more secure by using the laws of quantum physics to keep private data safe no matter where it is stored or processed.

Weather forecasting, Traffic flow and control, …

Quantum **I**nformation **S**oftware **Kit (QISKit)**:

is an open source software development kit for writing quantum computing experiments, programs, and applications.

Download qiskit-tutorial from https://github.com/QISKit/qiskit-tutorial

Install qiskit (optionally download SDK from https://github.com/QISKit/qiskit-sdk-py)

Navigate to qiskit-tutorial folder and launch Jupyter notebook

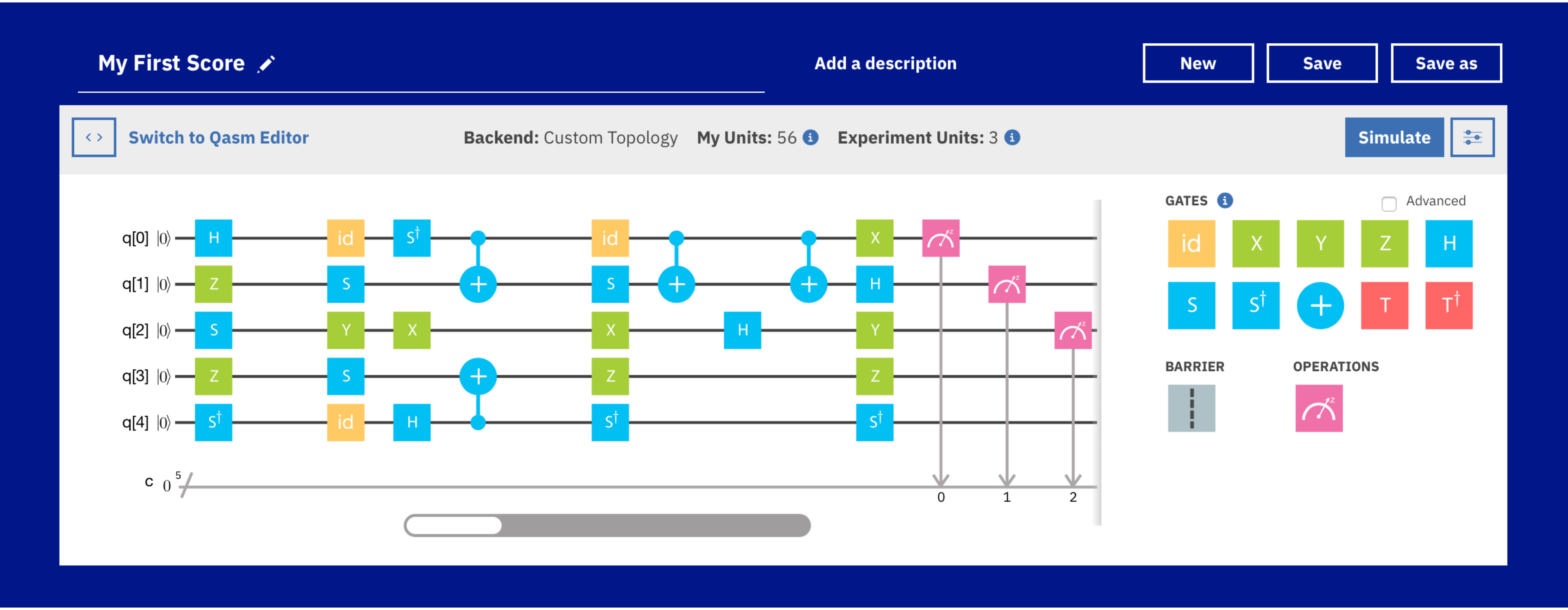
```
1. cjwood@christophers-MacBook-Pro: ~/Documents/IBM-Git/qiskit-tutorial
➜ qiskit-tutorial git:(master) ✗ pip install qiskit; jupyter notebook
```

Create a new Python 3 notebook and import qiskit

```
In [1]: # Import QISKit
        import qiskit
        from qiskit import QuantumProgram  # basic QISKit object

        # Add IBMQX API token and URL. Needed for online access
        API_TOKEN = "your_quantum_experience_api_token_here"
        API_URL = 'https://quantumexperience.ng.bluemix.net/api'
```

Quantum Computing and Quantum Circuits I



Applications: Quantum Chemistry

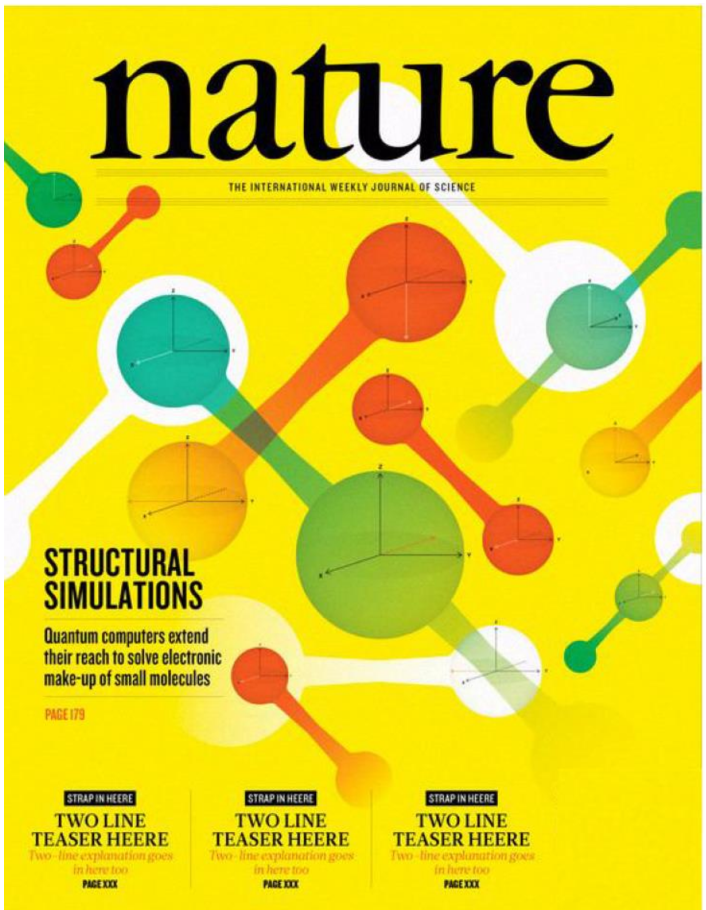
LETTER

doi:10.1038/nature23879

242 | NATURE | VOL 549 | 14 SEPTEMBER 2017

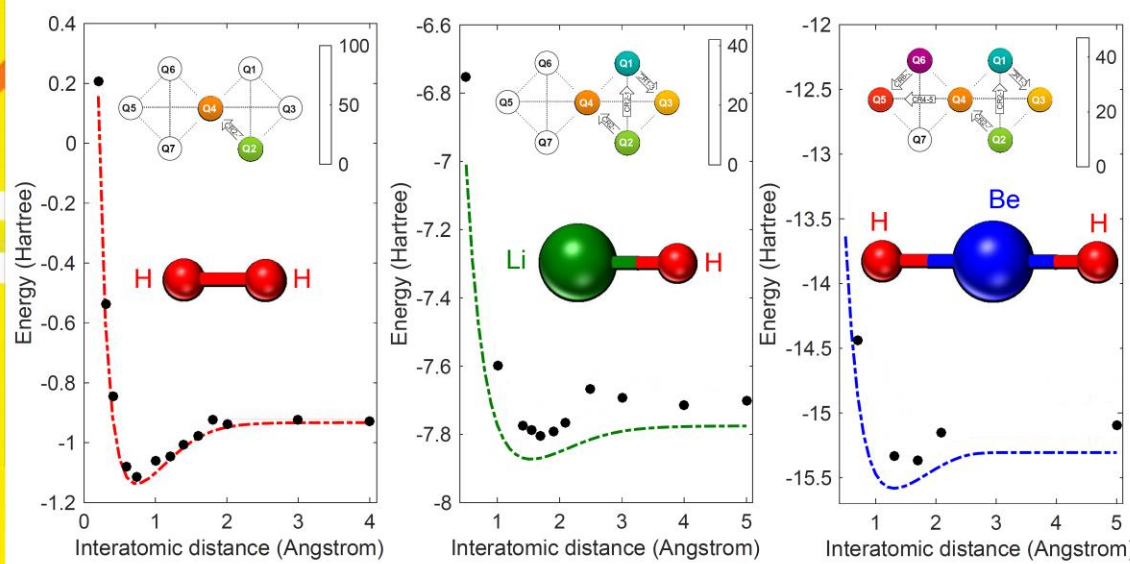
Hardware-efficient variational quantum eigensolver for small molecules and quantum magnets

Abhinav Kandala[1]*, Antonio Mezzacapo[1]*, Kristan Temme[1], Maika Takita[1], Markus Brink[1], Jerry M. Chow[1] & Jay M. Gambetta[1]



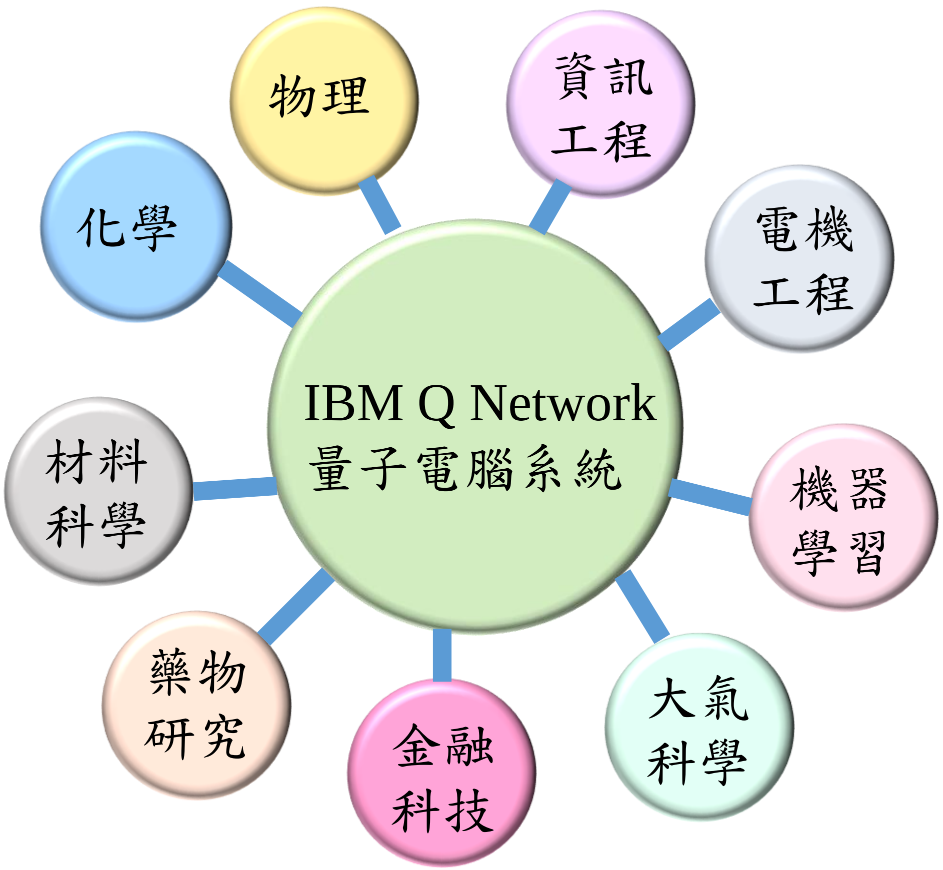
For the first time, we are able to use real, scalable quantum computers that exist today to solve real problems.

Although these problems are still solvable on classical systems, it should only be a few years before we can solve problems that can't be solved classically.



Applications

- 50~100-qubit quantum processors, available in the next 5~10 years, may be able to solve problems that cannot be solved by today's most powerful supercomputers.
- The focus at this stage is not on the great speedup advantage of quantum computers over their classical counterparts through, e.g., Shor's quantum factoring algorithm, but rather on the capability of dealing with a huge number of possible states (situations) that are beyond the capacity and capability of classical computers.



Quantum Support Vector Machine for Big Data Classification

Patrick Rebentrost,[1,*] Masoud Mohseni,[2] and Seth Lloyd[1,3,†]
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(Received 12 February 2014; published 25 September 2014)

Supervised machine learning is the classification of new data based on already classified training examples. In this work, we show that the support vector machine, an optimized binary classifier, can be implemented on a quantum computer, with complexity logarithmic in the size of the vectors and the number of training examples. In cases where classical sampling algorithms require polynomial time, an exponential speedup is obtained. At the core of this quantum big data algorithm is a nonsparse matrix exponentiation technique for efficiently performing a matrix inversion of the training data inner-product (kernel) matrix.

- Quantum computers of the future will have the potential to give artificial intelligence (AI) a major boost. The team developed a quantum version of 'machine learning', a type of AI in which programs can learn from previous experience to become progressively better at finding patterns in data. The team's invention would take advantage of quantum computations to speed up machine-learning tasks exponentially.
- **QML takes the results of algebraic manipulations and puts them to good use. Data can be split into groups — a task that is at the core of handwriting- and speech-recognition software — or can be searched for patterns. Massive amounts of information could therefore be manipulated with a relatively small number of qubits.**
- **Such quantum AI techniques could dramatically speed up tasks such as image recognition for comparing photos on the web or for enabling cars to drive themselves** — fields in which companies such as Google have invested considerable resources.

PRL **114,** 140504 (2015) PHYSICAL REVIEW LETTERS week ending 10 APRIL 2015

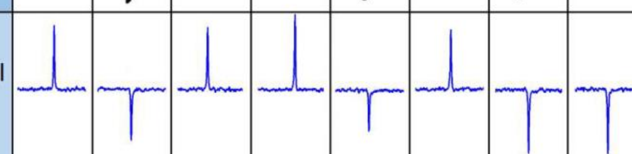
Experimental Realization of a Quantum Support Vector Machine

Zhaokai Li,[1,2] Xiaomei Liu,[1] Nanyang Xu,[1,2,*] and Jiangfeng Du[1,2,†]
[1]*Hefei National Laboratory for Physical Sciences at the Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China*
[2]*Synergetic Innovation Center of Quantum Information and Quantum Physics, University of Science and Technology of China, Hefei 230026, China*
(Received 1 December 2014; revised manuscript received 17 February 2015; published 8 April 2015)

The fundamental principle of artificial intelligence is the ability of machines to learn from previous experience and do future work accordingly. In the age of big data, classical learning machines often require huge computational resources in many practical cases. Quantum machine learning algorithms, on the other hand, could be exponentially faster than their classical counterparts by utilizing quantum parallelism. Here, we demonstrate a quantum machine learning algorithm to implement handwriting recognition on a four-qubit NMR test bench. The quantum machine learns standard character fonts and then recognizes handwritten characters from a set with two candidates. Because of the wide spread importance of artificial intelligence and its tremendous consumption of computational resources, quantum speedup would be extremely attractive against the challenges of big data.

Training data (printed characters)		label
6	$\vec{x}_1 = (0.987, 0.159)$	$y(\vec{x}_1) = +1$
9	$\vec{x}_2 = (0.354, 0.935)$	$y(\vec{x}_2) = -1$

Handwritten characters			
6	(0.997, -0.072)	9	(0.338, 0.941)
9	(0.147, 0.989)	6	(0.999, 0.025)
6	(0.999, -0.030)	9	(0.439, 0.899)
6	(0.987, -0.161)	9	(0.173, 0.985)

Hand-written characters	6	9	6	6	9	6	9	9
Experimental indicators								
Recognition results	6	9	6	6	9	6	9	9

The feature values are chosen as the vertical ratio and the horizontal ratio, calculated from the pixels in the left (upper) half over the right (lower) half.

Quantum-Enhanced Machine Learning

Vedran Dunjko,[1,*] Jacob M. Taylor,[2,3,†] and Hans J. Briegel[1,‡]
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[2]*Joint Quantum Institute, National Institute of Standards and Technology, Gaithersburg, Maryland 20899, USA*
[3]*Joint Center for Quantum Information and Computer Science, University of Maryland, College Park, Maryland 20742, USA*
(Received 15 April 2016; published 20 September 2016)

The emerging field of quantum machine learning has the potential to substantially aid in the problems and scope of artificial intelligence. This is only enhanced by recent successes in the field of classical machine learning. In this work we propose an approach for the systematic treatment of machine learning, from the perspective of quantum information. Our approach is general and covers all three main branches of machine learning: supervised, unsupervised, and reinforcement learning. While quantum improvements in supervised and unsupervised learning have been reported, reinforcement learning has received much less attention. Within our approach, we tackle the problem of quantum enhancements in reinforcement learning as well, and propose a systematic scheme for providing improvements. As an example, we show that quadratic improvements in learning efficiency, and exponential improvements in performance over limited time periods, can be obtained for a broad class of learning problems.

- We are witnessing the emergence of a new field: quantum machine learning (QML), which has a further, profound potential to revolutionize the field of artificial intelligence (AI), much like quantum information processing has influenced its classical counterpart.

REVIEW

1 4 S E P T E M B E R 2 0 1 7 | VO L 5 4 9 | N AT U RE | 1 9 5

doi:10.1038/nature23474

Quantum machine learning

Jacob Biamonte[1,2], Peter Wittek[3], Nicola Pancotti[4], Patrick Rebentrost[5], Nathan Wiebe[6] & Seth Lloyd[7]

Fuelled by increasing computer power and algorithmic advances, machine learning techniques have become powerful tools for finding patterns in data. Quantum systems produce atypical patterns that classical systems are thought not to produce efficiently, so it is reasonable to postulate that quantum computers may outperform classical computers on machine learning tasks. The field of quantum machine learning explores how to devise and implement quantum software that could enable machine learning that is faster than that of classical computers. Recent work has produced quantum algorithms that could act as the building blocks of machine learning programs, but the hardware and software challenges are still considerable.

We are witnessing the emergence of a new field: quantum machine learning (QML), which has a further, profound potential to revolutionize the field of artificial intelligence (AI), much like quantum information processing has influenced its classical counterpart.

Quantum Linear System Algorithm for Dense Matrices

Leonard Wossnig,[1,2] Zhikuan Zhao,[3,4,*] and Anupam Prakash[4]
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[2]*Department of Materials, University of Oxford, Oxford OX1 3PH, United Kingdom*
[3]*Singapore University of Technology and Design, 487372 Singapore*
[4]*Centre for Quantum Technologies, National University of Singapore, 117543 Singapore*

(Received 25 May 2017; revised manuscript received 10 November 2017; published 31 January 2018)

Solving linear systems of equations is a frequently encountered problem in machine learning and optimization. Given a matrix A and a vector $\mathbf{b}$ the task is to find the vector $\mathbf{x}$ such that $A\mathbf{x} = \mathbf{b}$. We describe a quantum algorithm that achieves a sparsity-independent runtime scaling of $\mathcal{O}(\kappa^2 \sqrt{n} \mathrm{polylog}(n)/\epsilon)$ for an $n \times n$ dimensional A with bounded spectral norm, where κ denotes the condition number of A, and ϵ is the desired precision parameter. This amounts to a polynomial improvement over known quantum linear system algorithms when applied to dense matrices, and poses a new state of the art for solving dense linear systems on a quantum computer. Furthermore, an exponential improvement is achievable if the rank of A is polylogarithmic in the matrix dimension. Our algorithm is built upon a singular value estimation subroutine, which makes use of a memory architecture that allows for efficient preparation of quantum states that correspond to the rows of A and the vector of Euclidean norms of the rows of A.

DOI: 10.1103/PhysRevLett.120.050502

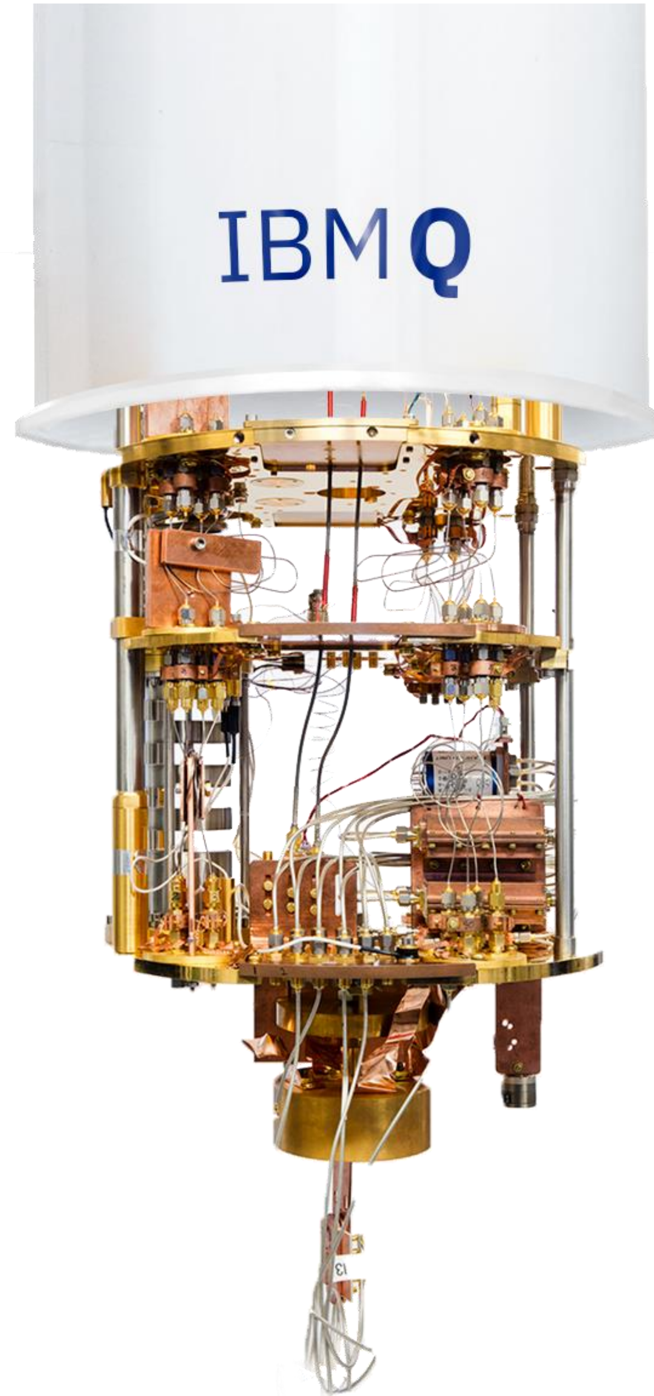
for a sparse and well-conditioned A

A.W. Harrow, A. Hassidim, and S. Lloyd, Phys. Rev. Lett. 103, 150502 (2009).

量子電腦的研究項目與應用場域

- 量子計算應用程式介面編程工具與軟體套件開發
- 可視化（Visualization）量子物理教育與量子計算平台建立
- 研究和測試新物理或涉及量子特性的新理論的實驗平台
- 混合（Hybrid）量子和古典計算方法
- 量子機器學習（QML）與最佳化（Optimization）應用研究
- 人工智慧(AI)
- 新穎材料開發
- 新藥研發和生物醫學應用
- 複雜工程系統設計應用
- 金融科技應用
- 未來交通車流、物流
- 天氣預測
- ．．．．．．

IBM Q Hub at NTU



January 2019

IBM Q Hub at NTU: Mission

- 國立臺灣大學配合科技部 IBM Q 量子電腦中心之策劃，成立「臺灣大學-IBM量子電腦中心」(IBM Q Hub at NTU)
- 提供全臺學術研究界量子計算研究與教育訓練之服務平臺
- 聚焦相關領域之科技人才培育養成
- 推動學界與法人研究機構組成研發團隊投入此新穎科技之研發
- 加速臺灣量子電腦程式設計，軟體開發及前瞻應用之研發能量的建立與提昇
- 作為推動量子計算產、學、研合作之準備。

量子電腦程式設計與軟體應用

- 在 50到100量子位元左右，量子電腦就能達到所謂的「**量子優勢(霸權)**」（quantum supremacy），也就是量子電腦在一些領域(比如在化學和材料科學裡模擬分子的結構)就有傳統超級電腦所不具有的能力。
- **現在正值量子電腦硬體裝置快速發展的階段，也是量子電腦程式設計與軟體開發正在起步發展的時候**。
- **台灣已跟IBM簽約將成立IBM Q Network Hub at NTU，能透過IBM Cloud網路登入使用IBM最先進的量子電腦，因此若能在此時把握機會，教育並培訓年輕人才朝量子電腦程式設計方向發展**，開發、學習和應用軟體程式語言將欲解決問題的演算法映射到量子電腦的硬體上去執行計算。
- **培育養成相關之科技人才，建立和提升台灣在量子電腦程式設計、軟體開發及前瞻應用之研發能力和能量，對未來新的量子電腦與量子計算技術和產業做準備的影響是巨大的，且效益更是難以估算的。**

Quantum Computing Era

- The Era of Quantum Computing Is Here.
- Join the effort and prepare yourself for future industry of quantum computer programming, software development and applications.
- The time to start this is now.
- If you are interested in becoming a user, please leave your contact information to Ms Pai
  - 計畫辦公室白小姐；
  - 電話：02-33669928；
  - E-mail：ntuq2018@gmail.com
- IBM QC Workshops (software):
  - Taipei (NTU); January 16-18, 2019 (Wed.-Fri.)
- MOST Taiwan International Quantum Computer Workshops (hardware):
  - Taipei, January 21-22, 2019 (Mon., Tue.)
  - Hsinchu, January 23-2, 2019 (Wed., Thu.)

量子電腦國際研討會

返回 http://www.etop.org.tw/index.php?d=epp&c=epp12911&m=show&id=1022

分類：中心研討會
發佈日期：2019-01-21
附件： Agenda_v1008(Tapei).docx Agenda_v1071011(HsinChu).docx

Taiwan International Quantum Computer Workshop 2019

The Taiwan Ministry of Science and Technology (MOST) is pleased to announce Taiwan International Quantum Computer Workshop 2019, as the manifestation of Taiwan government's devotion and promise for technology developing program. To strengthen and accelerate the development, MOST invite the prestigious researchers, both international and domestic, to introduce the development of quantum computing technologies in their respective research. The workshop will promote the development of the quantum computer technology in Taiwan academic and between industrial parties. It aims to enhance the multidisciplinary and multinational collaboration in the coming quantum era. The workshop will be held in Taipei (January 21, 22) and Hsinchu (January 23-24) in 2019.