Futuro quantistico, tecnologia e società

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Seeds from Ceeds, 4 maggio 2022
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In the news
Hillary Clinton wants “Manhattan-like project” to break encryption

US should be able to bypass encryption—but only for terrorists, candidate says.

JON BROOKIN - 12/21/2015, 5:15 PM

Presidential candidate Hillary Clinton has called for a “Manhattan-like project” to help law enforcement break into encrypted communications. This is in reference to the Manhattan Project, the top-secret concentrated research effort which resulted in the US developing nuclear weapons during World War II.

At Saturday’s Democratic debate (transcript here), moderator Martha Raddatz asked Clinton about Apple CEO Tim Cook’s statements that any effort to break encryption would harm law-abiding citizens.
Europe Will Spend €1 Billion to Turn Quantum Physics Into Quantum Technology

A 10-year-long megaproject will go beyond quantum computing and cryptography to advance other emerging technologies.
China will open a $10 billion quantum computer center and others also investing in quantum computing

October 10, 2017 by Brian Wang

On 37 hectares (nearly 4 million square feet) in Hefei, Anhui Province, China is building a $10 billion research center for quantum applications. This news comes on the heels of the world’s first video call made via quantum-encrypted communications and the completion of a quantum-encrypted fiber optic trunk cable.

China Builds the World’s First Integrated Quantum Communication Network

TOPICS: Popular Quantum Information Science Telecommunications
University Of Science And Technology Of China
By UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA January 4, 2021

Chinese scientists have established the world’s first integrated quantum communication network, combining over 700 optical fibers on the ground with two ground-to-satellite links to achieve quantum key distribution over a total distance of 4,600 kilometers for users across the country. Credit: University of Science and Technology of China
What’s going on?
The Quantum Disruption

- 1930: Church, Turing
- 1946: ENIAC
- 1950: Shannon
- 1970: NP vs P
- 2010: Deep Learning
The Quantum Disruption

1900 Quantum Mechanics

1926 Postulates

1930 Church, Turing

1946 ENIAC

1947 Transistor

1950 Shannon

1960 Laser

1970 NP vs P

1978 GPS

1984 Quantum gates

1991 WWW

1994 Factorization

1994 Quantum Advantage

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2005 Quantum gates

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- 1991 WWW
- 1994 Factorization
- 1994 NP vs P
- 1994 Advanced AI
- 2005 Quantum gates
- 2010 Deep Learning
- 2019 Quantum Advantage

Advanced AI
Quantum Information
Acquiring control of nature at quantum level

First Quantum Revolution

Postulates and first applications:

- Transistors, computers
- Laser, communication
- Atomic clocks, GPS
- MRI, healthcare

Second Quantum Revolution

Quantum control of quantum elements

- Quantum computation
- Quantum communication
- Quantum sensing
- Quantum simulation
Acquiring control of nature at quantum level

**First Quantum Revolution**

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- Transistors, computers
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- Atomic clocks, GPS
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**Second Quantum Revolution**

Quantum control of quantum elements
- Quantum computation
- Quantum communication
- Quantum sensing
- Quantum simulation
Towards **Quantum Information** and Computing

↓

Manipulate **information** with quantum mechanics
Classical Computation

Classical Physics

Computing = Physics: Church, Turing, ...
Information and Quantum Mechanics

Classical Physics
Classical Computation
Quantum Mechanics
Quantum Device

Feynman: Computing with Quantum Mechanics
Physical implementation

(a) Superconducting device assembled by IBM

(b) Chip based on trapped ions technology
Physical implementation
Physical implementation

Transmon (qubit)

Platform design

Cryostat (Fridge)

Lab Devices
The big players
Quantum Technologies

Superconducting loops
A resistance-free current oscillates back and forth around a circuit loop. An injected microwave signal excites the current into superposition states.

Trapped ions
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.

Silicon quantum dots
These “artificial atoms” are made by adding an electron to a small piece of pure silicon. Microwaves control the electron’s quantum state.

Topological qubits
Quasiparticles can be seen in the behavior of electrons channeled through semiconductor structures. Their braided paths can encode quantum information.

Diamond vacancies
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.

<table>
<thead>
<tr>
<th>Number entangled</th>
<th>9</th>
<th>14</th>
<th>2</th>
<th>N/A</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company support</td>
<td>Google, IBM, Quantum Circuits</td>
<td>ionQ</td>
<td>Intel</td>
<td>Microsoft, Bell Labs</td>
<td>Quantum Diamond Technologies</td>
</tr>
<tr>
<td>Cons</td>
<td>Collapse easily and must be kept cold.</td>
<td>Slow operation. Many lasers are needed.</td>
<td>Only a few entangled. Must be kept cold.</td>
<td>Existence not yet confirmed.</td>
<td>Difficult to entangle.</td>
</tr>
</tbody>
</table>
Quantum advantage

First quantum computation that can not be reproduced on a classical supercomputer from Google, *Nature* 574, 505-510(2019):

\[
\begin{array}{c}
\text{53 qubits (86 qubit-couplers)} \rightarrow \text{Task of sampling the output of a pseudo-random quantum circuit (extract probability distribution).}
\end{array}
\]

Classically the probability distribution is \textit{exponentially more difficult}. 
Quantum computers are getting more powerful

Number of qubits achieved by date and organization 1998 – 2020*

2 qubits
IBM, Oxford, Berkeley, Stanford, MIT 1998

5 qubits
Technical University of Munich 2000

12 qubits
Institute for Quantum Computing, Perimeter Institute for Theoretical Physics, and MIT 2006

28 qubits
D-Wave Systems 2009

50 qubits
IBM 2016

72 qubits
Google 2019

128 qubits
Rigetti 2019*

20 Years of Quantum Computing Growth

- IBM, Oxford, Berkeley, Stanford, MIT 1998 2
- Technical University of Munich 2000 5
- Los Alamos National Laboratory 2000 7
- Institute for Quantum Computing, Perimeter Institute for Theoretical Physics, and MIT 2006 12
- D-Wave Systems 2008
- IBM, Oxford, Berkeley, Stanford, MIT 2017 50
- Intel 2018 49
- Google 2019 72
- Rigetti 2019 128

The big players

Full-Stack (End-to-End)
- Google
- IBM
- Microsoft
- Amazon
- Honeywell
- Rigetti
- Alibaba Group
- D-Wave
- Xanadu

Cloud Computing
- Agnostiq
- IQBit
- BraneCell
- Aligo

Quantum Encryption and AI
- ISARA
- Agnostiq
- IQBit
- Sigale
- ZYX

Systems & Firmware
- IQBit
- Q-CTRL
- Aligo
- QM
- Quantum Works

Quantum Hardware
- ColdQuanta
- IQBit
- IONIQ
- ILM

Software Applications
- Riverlane
- Menten AI
- Zapata
- Acware
- Q-Rithm
- QLAB

Start-up activity and investments in quantum computing have skyrocketed since 2015.

Volume¹ of raised funding, $ millions

$1.7 billion

$0.7 billion


Based on public investment data recorded in PitchBook; actual investment is likely higher.¹
Start-ups from 2011 and later are likely still in stealth mode or are not yet recognized as quantum computing companies by relevant platforms and experts.²

¹Source: PitchBook, McKinsey analysis.
²Start-up funding: $1.7 billion; Number of quantum-computing start-ups: 50, 25, 10

Not exhaustive. Commercial activity is opaque in some regions.
Annual spending on quantum technology

No small effort
Estimated annual spending on non-classified quantum-technology research, 2015, €m

- United States: 360
- Canada: 100
- Brazil: 11
- Britain: 105
- France: 52
- Germany: 120
- Netherlands: 27
- Denmark: 22
- Sweden: 15
- Finland: 12
- Poland: 12
- Austria: 35
- Switzerland: 67
- Russia: 30
- China: 220
- Japan: 63
- South Korea: 13
- Singapore: 44
- Australia: 75

World 1,500 (estimate)

*Combined estimated budget of EU countries

Source: McKinsey
Excited states
Patent applications to 2015, in:

Quantum computing
- United States: 295
- Canada: 79
- Japan: 78
- Britain: 36
- China: 29
- Australia: 26
- Germany: 22
- South Korea: 11
- Israel: 9
- Finland: 7

Quantum cryptography
- China: 367
- United States: 233
- Japan: 100
- Britain: 50
- Malaysia: 31
- South Korea: 27
- Germany: 24
- France: 15
- Australia: 14
- Canada: 11
- Italy: 11

Quantum sensors
- United States: 105
- China: 104
- Germany: 25
- Japan: 18
- Britain: 12
- Canada: 6
- Israel: 6
- France: 5
- Australia: 3
- South Korea: 2
- Russia: 2
- Taiwan: 2

Quantum-key distribution
Patent applications by country*

Sources: UK Intellectual Property Office; European Commission
*By location of corporate headquarters
The big players

Foreign entanglements
Authorship of papers on quantum computing by nationality of authors*
Top 6 nations, 2004–13

Excited state
Venture-capital deals in quantum computing
Worldwide

*Collaborations between more than two countries may be counted multiple times

Source: Digital Science; Clarivate
Economist.com

Source: PitchBook
*To September 4th
Summary
Quantum technology is not a fashion or a simple hype!

Funding and interest is large and in continuous growing.

LHC at CERN: 4.5B Euros
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Open questions:

- Which development model is the most sustainable for future technological research?
- How to measure its cost-benefit?
- What’s the impact in our society?