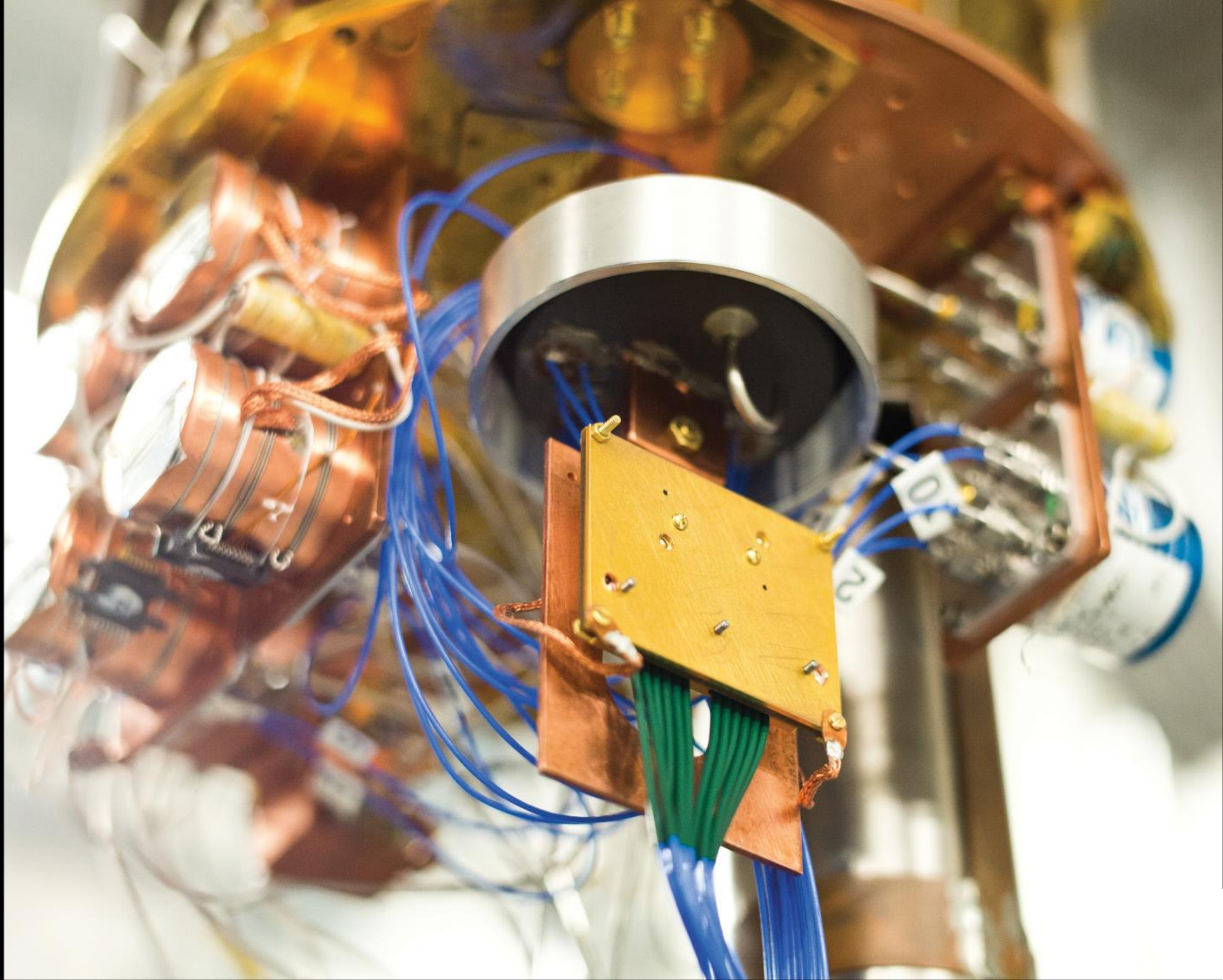
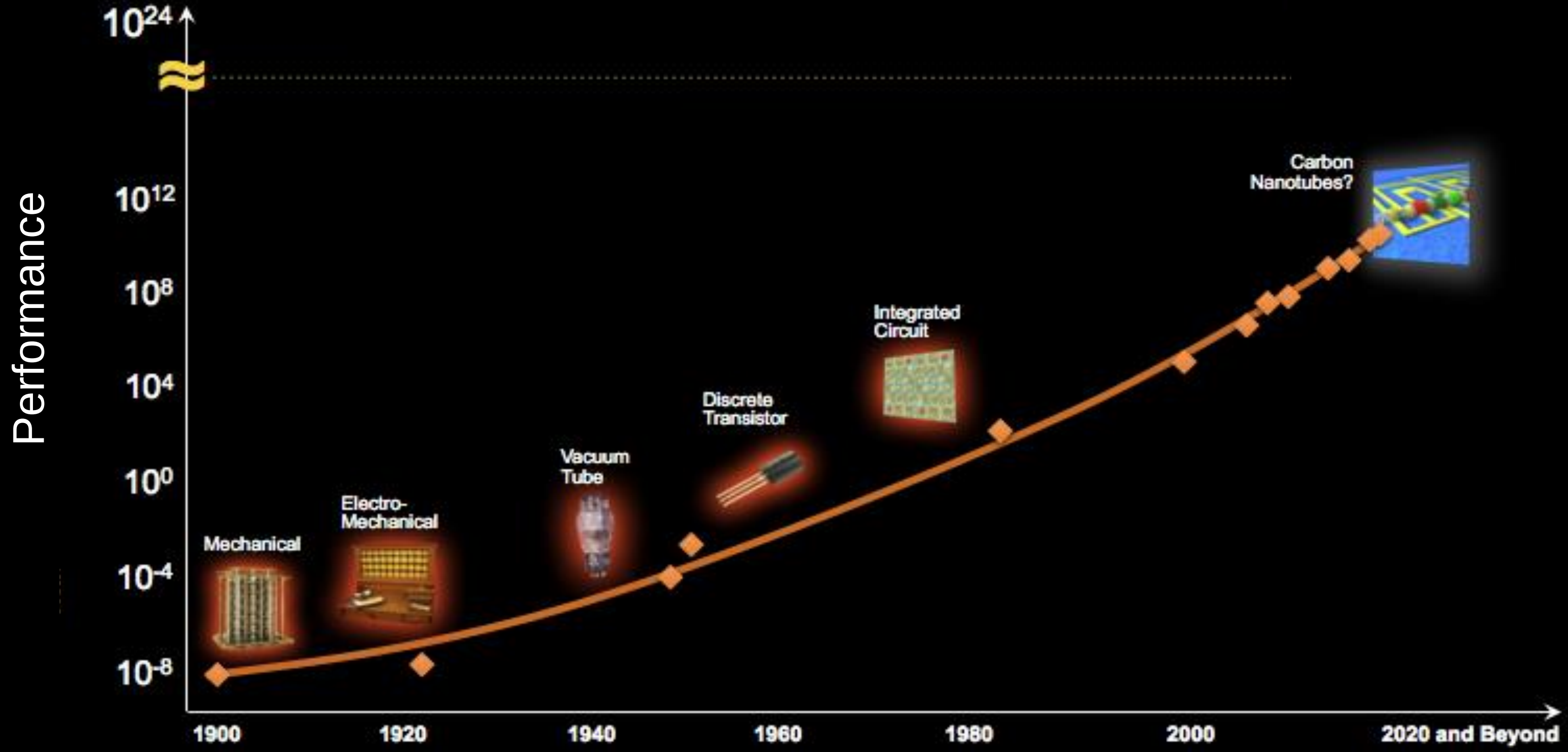
IBM Q

Arwed Tschoeke

IBM Client Center Böblingen



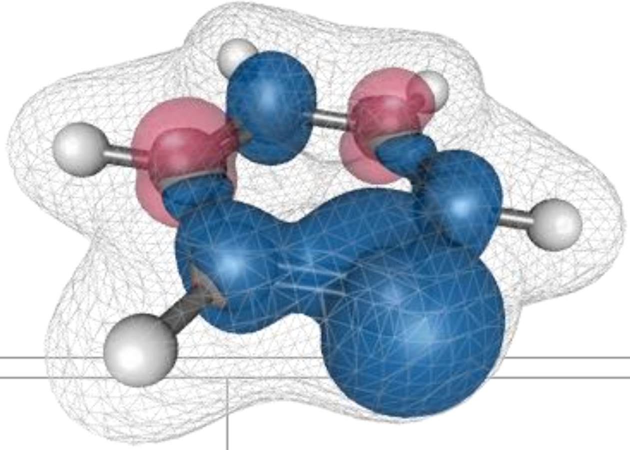
Moore’s Law



Performance
10^24
10^12
10^8
10^4
10^0
10^-4
10^-8
Mechanical
Electro-Mechanical
Vacuum Tube
Discrete Transistor
Integrated Circuit
Carbon Nanotubes?
1900
1920
1940
1960
1980
2000
2020 and Beyond

Our intuition about what we can compute is wrong

Molecular Dynamics, Drug Design, Materials …

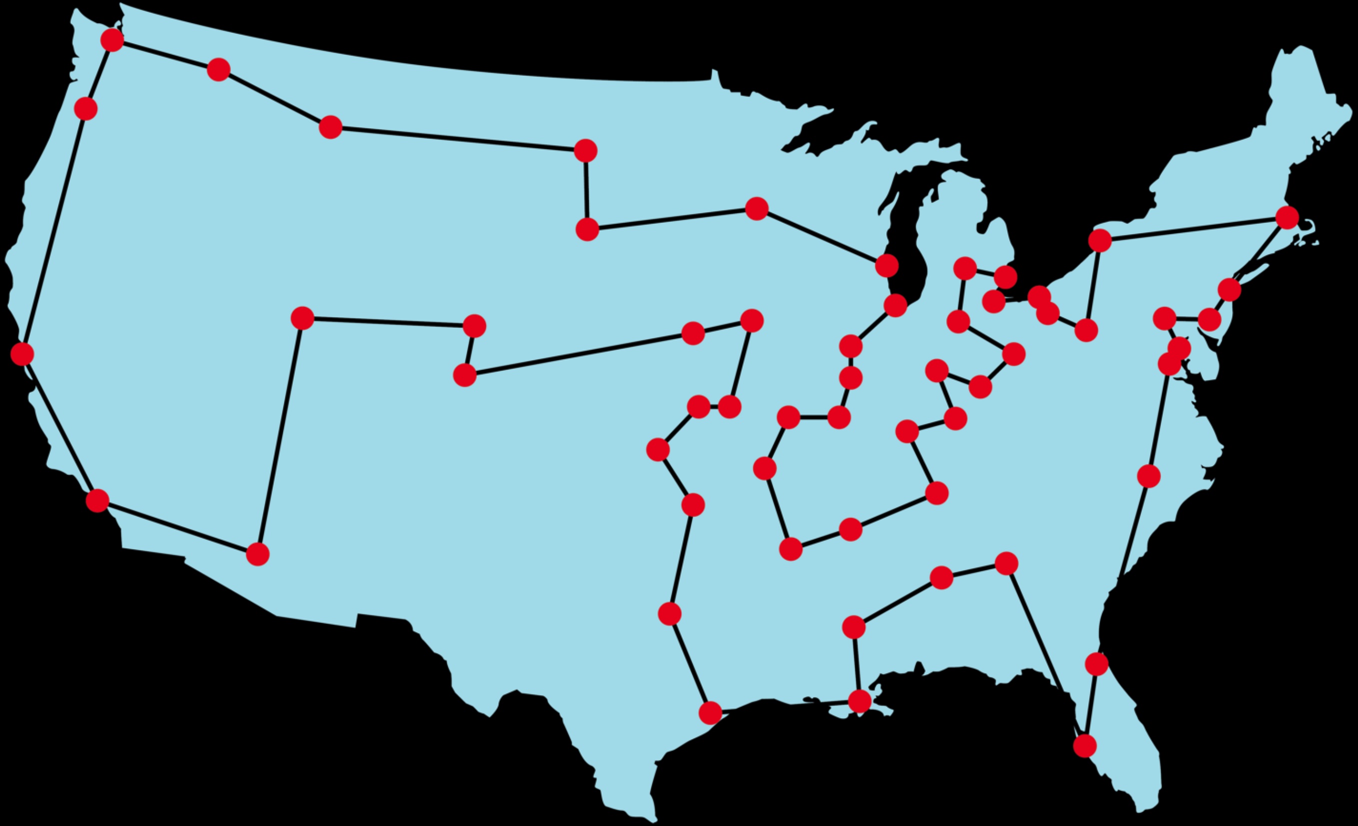


The best supercomputer in the world can accurately simulate a 40-50 electron system

Species	Name	Bond Length (Å)		
		Experimental	Calculated	Difference
CaF	Calcium monofluoride	1.967	4.079	2.112
Na_2	Sodium diatomic	3.079	2.379	-0.700

Source: http://cccbdb.nist.gov

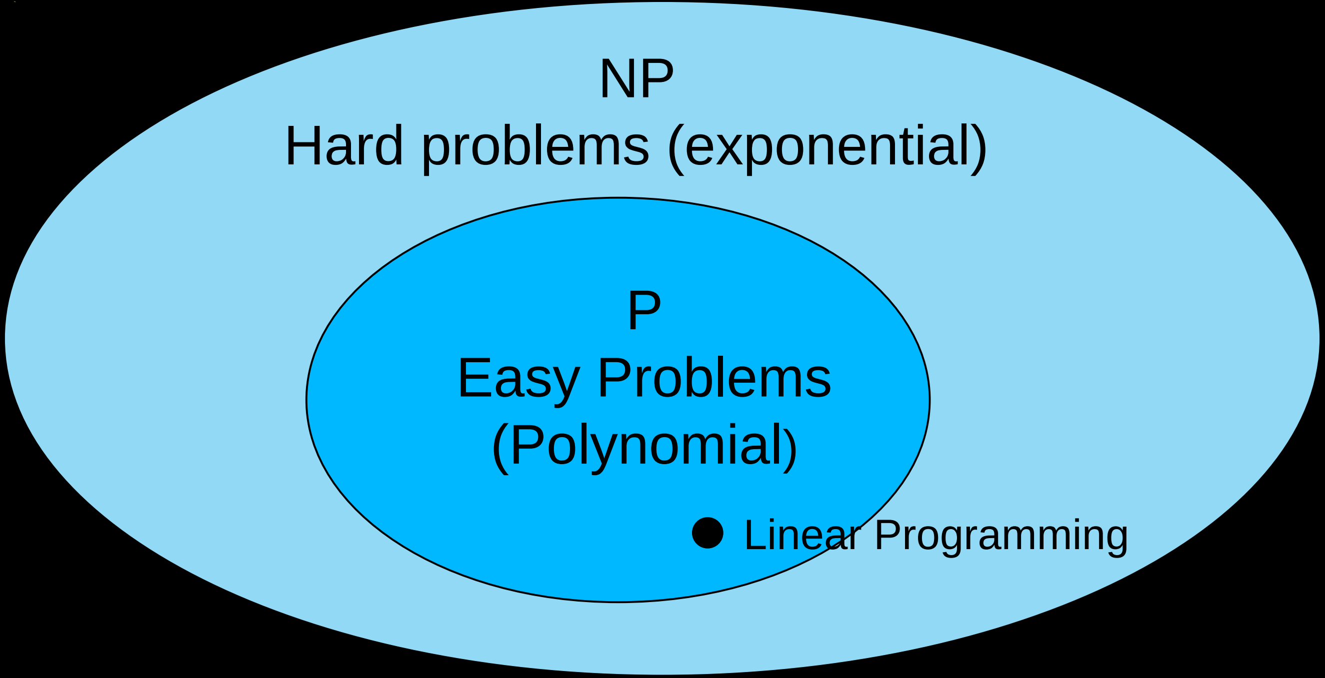
The “Traveling Salesman” Problem



New York Times

Limitations of conventional computers

There are many intractable problems where the best known algorithm has runtime that scales exponentially with input size



Exponential Scaling

On the first day…

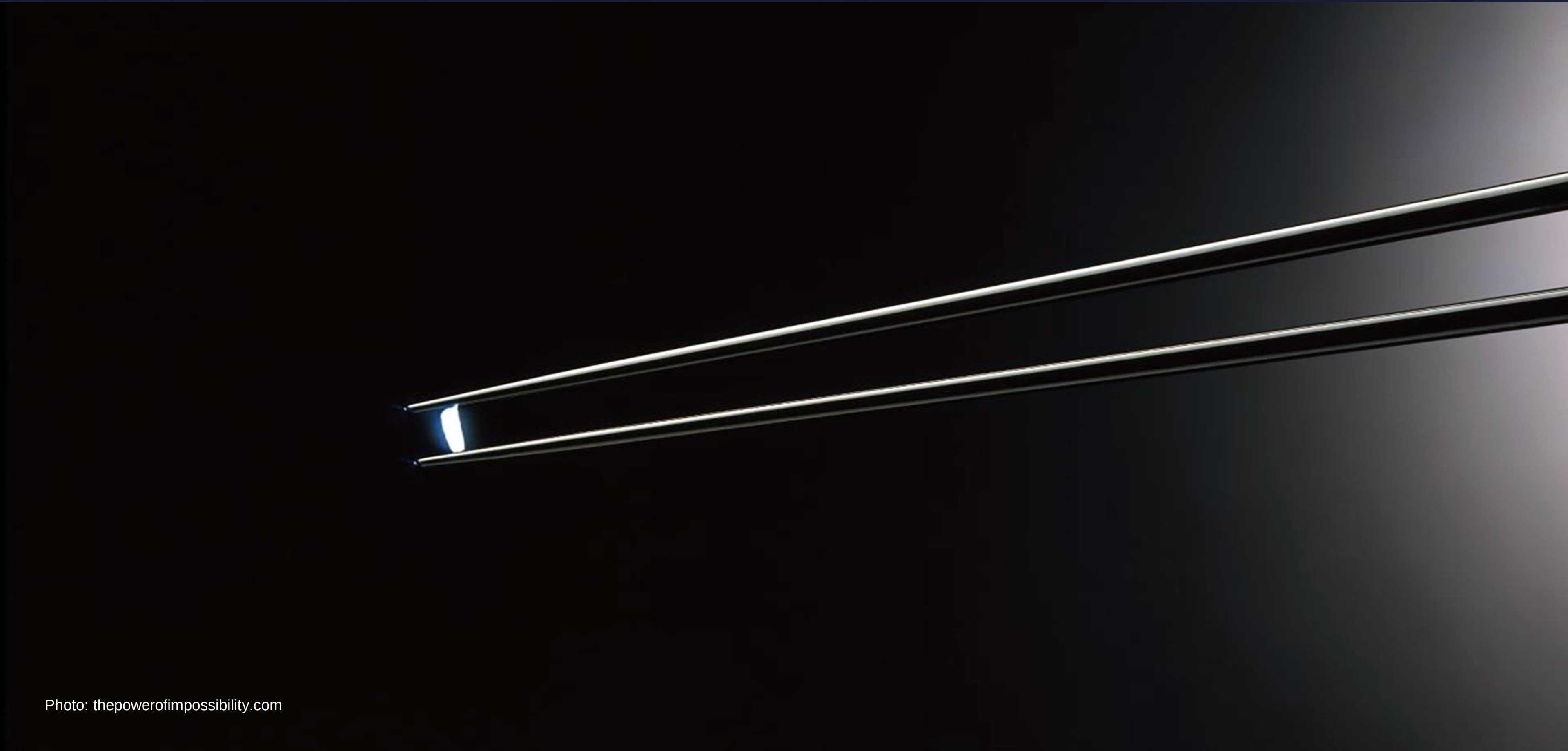


Photo: thepowerofimpossibility.com

After one week…127 grains of rice

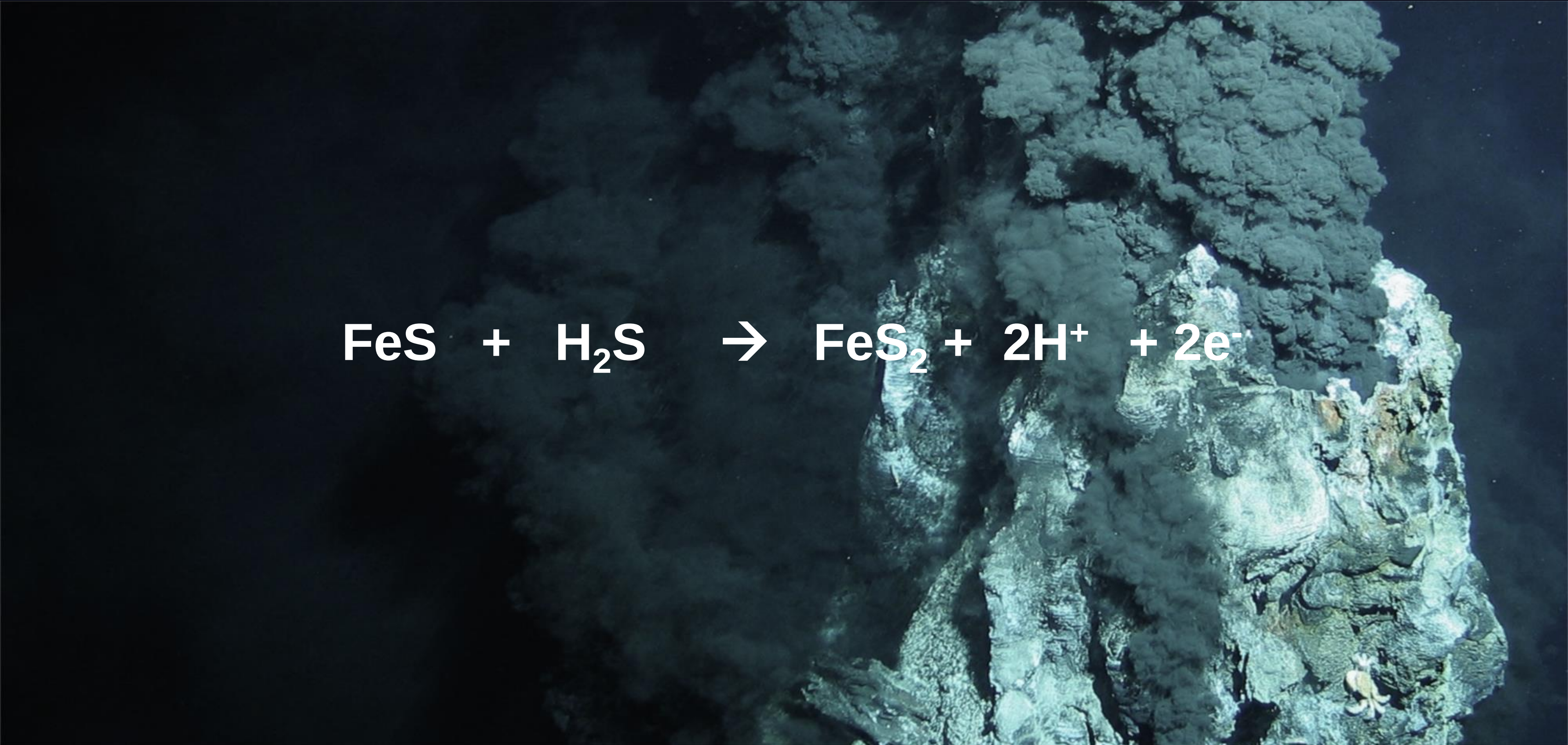
Photo: wikimedia

After one month… 5,368 1kg bags of rice

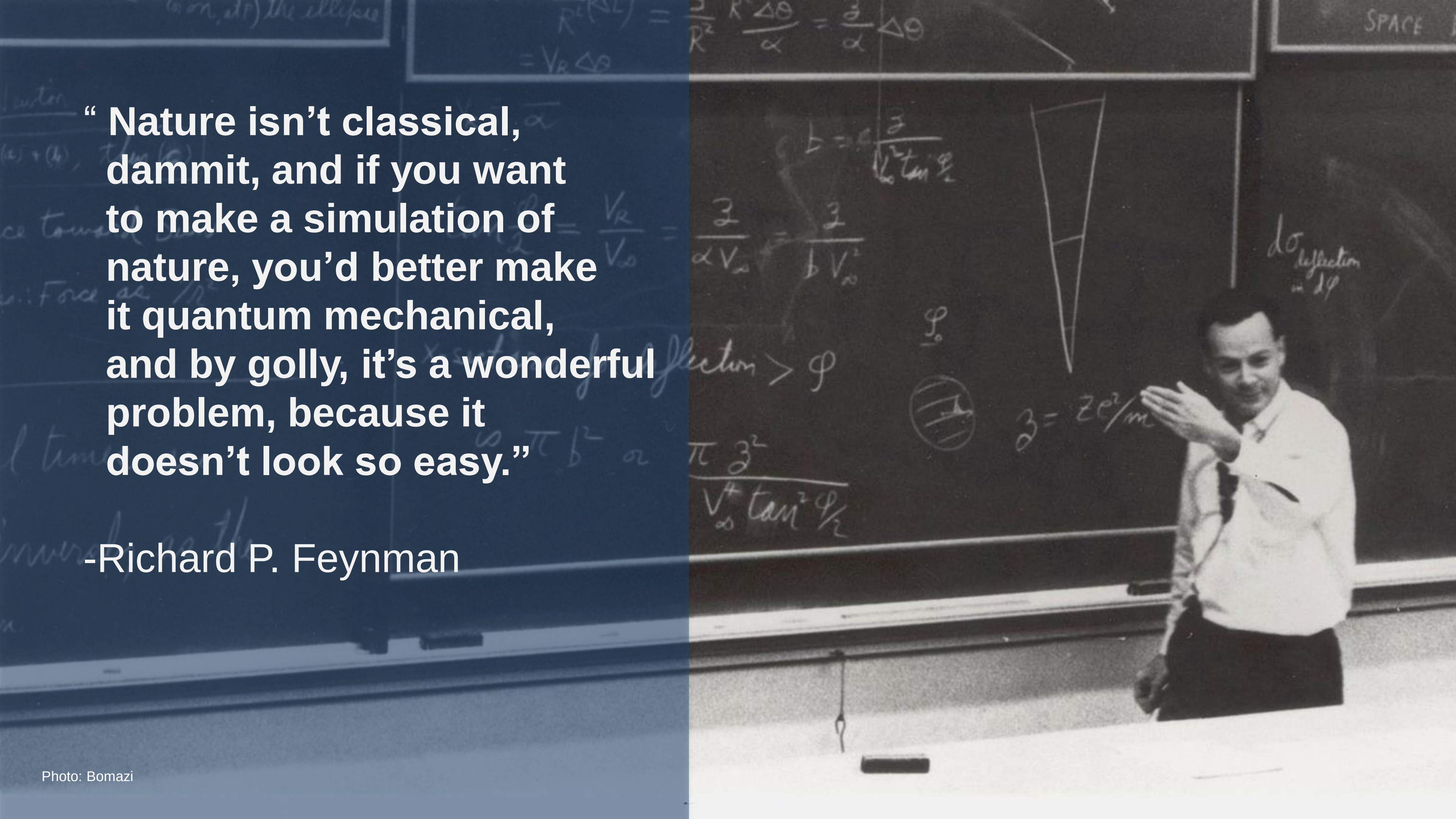
After 64 days … 461 billion metric tons of rice

The cradle of life cannot be solved with today's HPC…

IBM Q



$$FeS + H_2S \rightarrow FeS_2 + 2H^+ + 2e^-$$



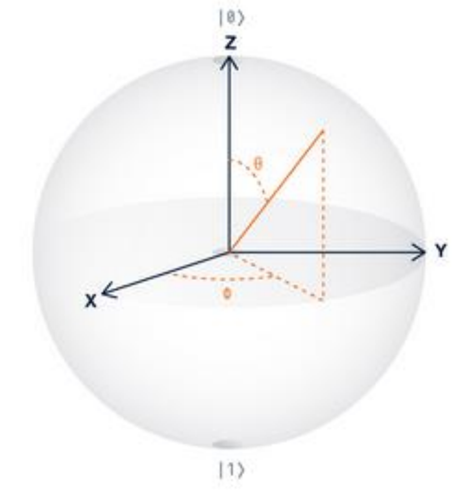
> **“ Nature isn’t classical, dammit, and if you want to make a simulation of nature, you’d better make it quantum mechanical, and by golly, it’s a wonderful problem, because it doesn’t look so easy.”**

-Richard P. Feynman

Photo: Bomazi

A new model of computation

Quantum Applications is about working out how to use two principles, superposition and entanglement in a new model of computation

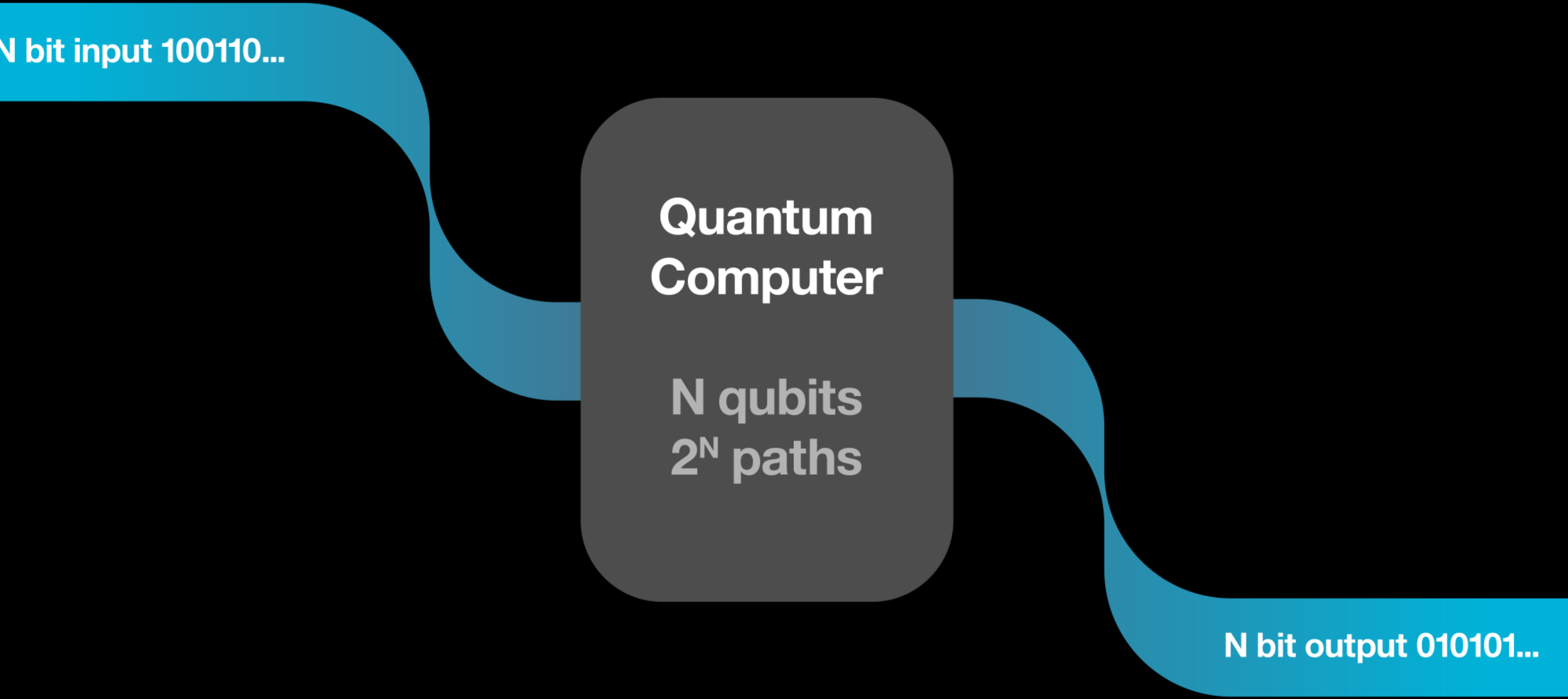


Superposition

A single quantum bit (qubit) can exist in a superposition of 0 and 1, and n qubits allow for a superposition all possible 2n combinations

Entanglement

The states of entangled qubits cannot be described independently of each other



N bit input 100110...

Quantum Computer

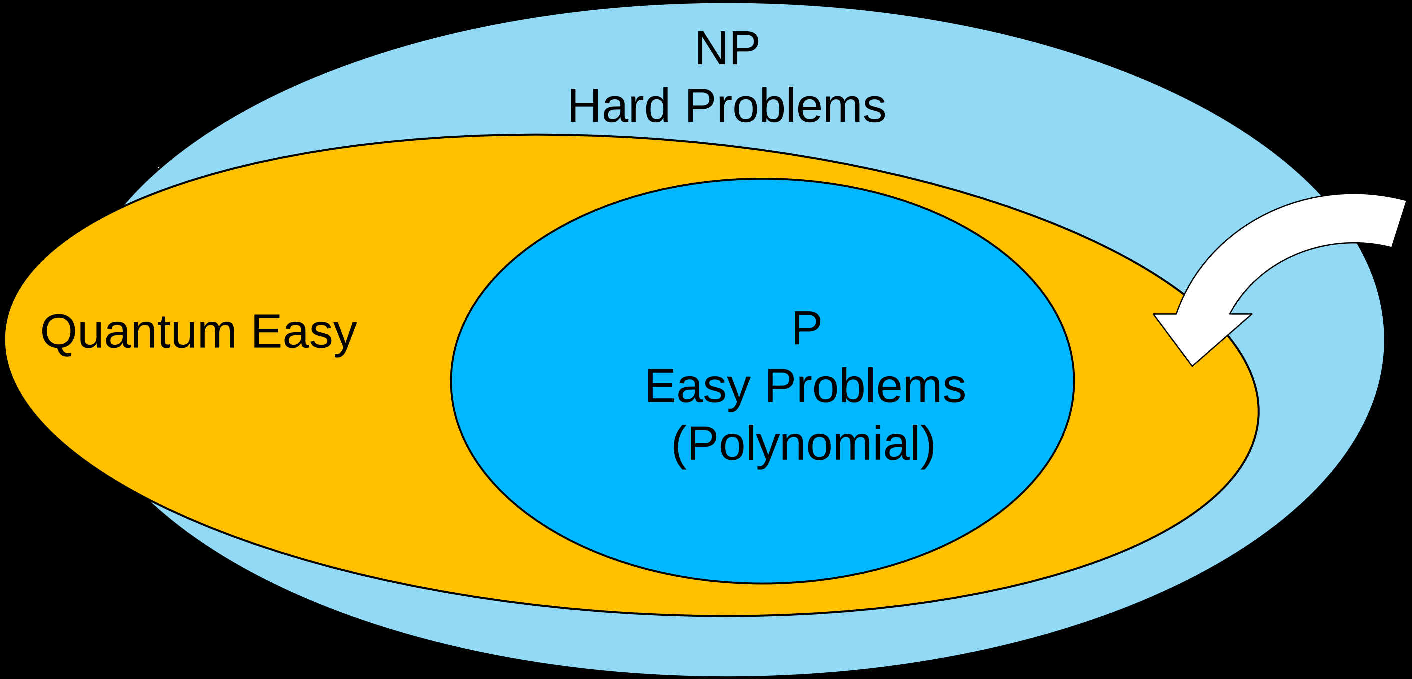
N qubits
2^N paths

N bit output 010101...

Quantum heuristic algorithms

IBM **Q**

…Quantum computers are the only known game-changer



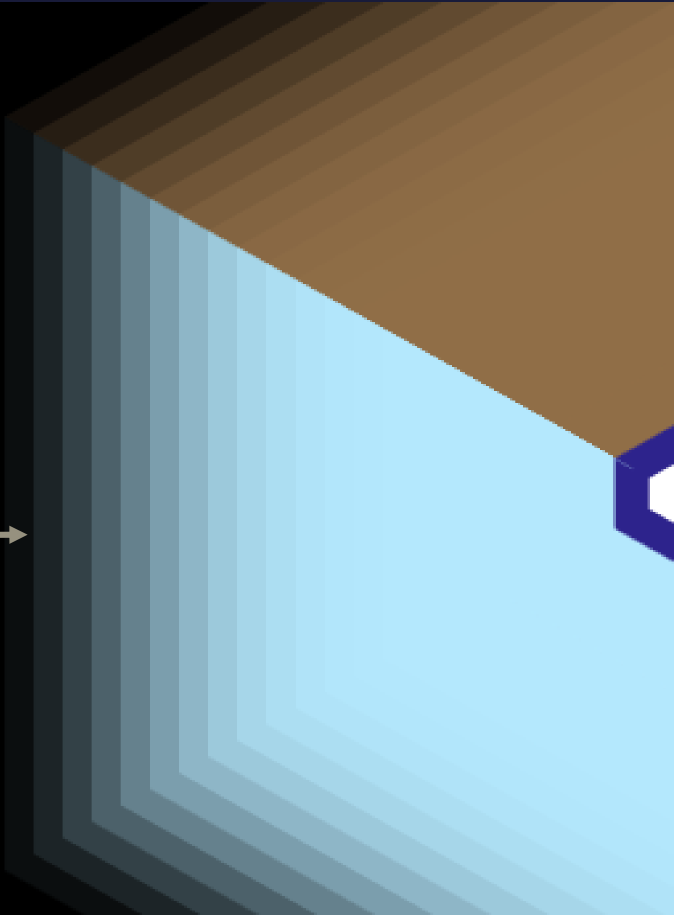
Factoring is in this set, but in practice quantum systems that can do this are decades away!

What else is there in here that we can do with systems in the next few years?

Three types of quantum computing

Quantum Annealing
Limited use, equivalent power to classical

Approximate Universal Quantum Computer
Partial use, high power



Fault-Tolerant Universal Quantum Computer
Complete use cases, holy grail

How powerful is my quantum computer?

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Number of qubits (more is better)

Errors (less is better)

Connectivity (more is better)

Gate set (more is better)

Quantum Volume

Keyword search for Quantum Volume on our IBM Quantum Experience community forum: https://quantumexperience.ng.bluemix.net/qstage/#/community

How powerful is a quantum computer

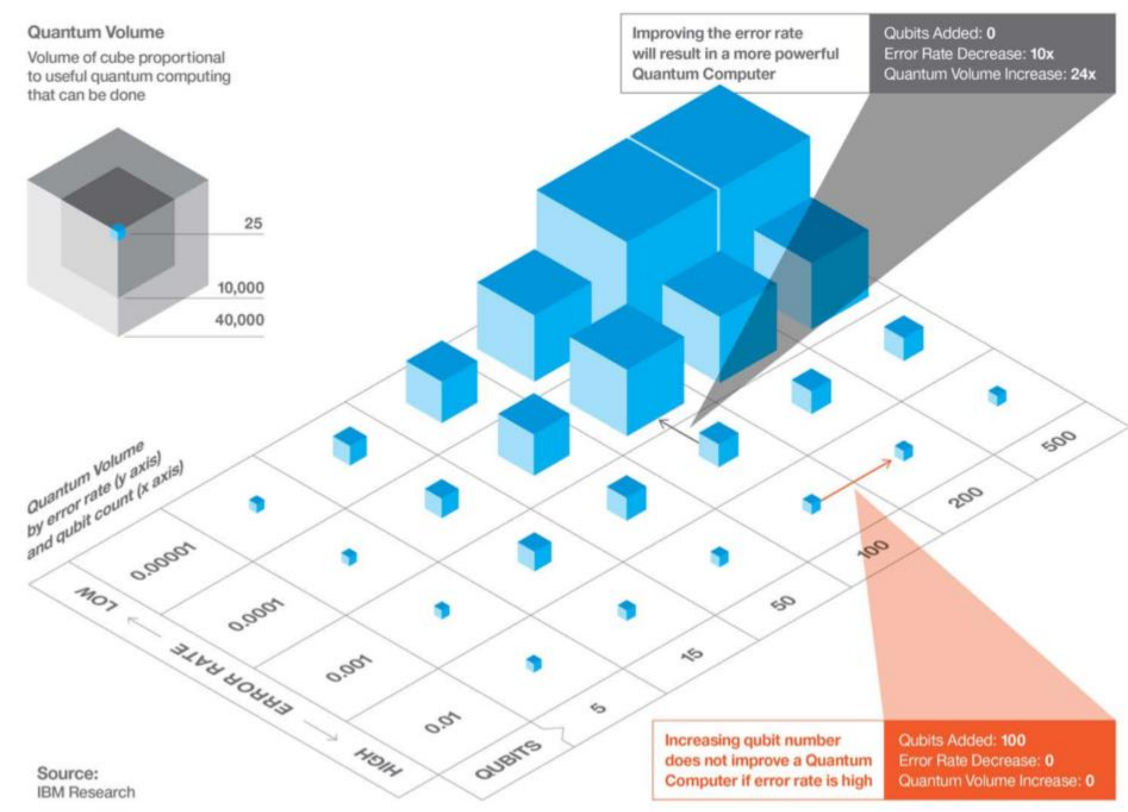
Quantum Volume

Number of **qubits** (more is better)

Errors (less is better)

Connectivity (more is better)

Gate set (more is better)



Quantum Volume

Volume of cube proportional to useful quantum computing that can be done

Improving the error rate will result in a more powerful Quantum Computer

Qubits Added: **0**
Error Rate Decrease: **10x**
Quantum Volume Increase: **24x**

Increasing qubit number does not improve a Quantum Computer if error rate is high

Qubits Added: **100**
Error Rate Decrease: **0**
Quantum Volume Increase: **0**

Quantum Volume by error rate (y axis) and qubit count (x axis)

Source:
IBM Research

The Road to Quantum Advantage

Quantum Science

Fundamentals of quantum information science

Create and scale qubits with increasing coherence

Create error detection and mitgation schemes

~1900

Launch of **IBM Q** Experience

Quantum Ready

Core algorithm development

Increase quantum volume

Standardize performance benchmarks

System infrastructure and software enablement

2016

~2020

Quantum Advantage

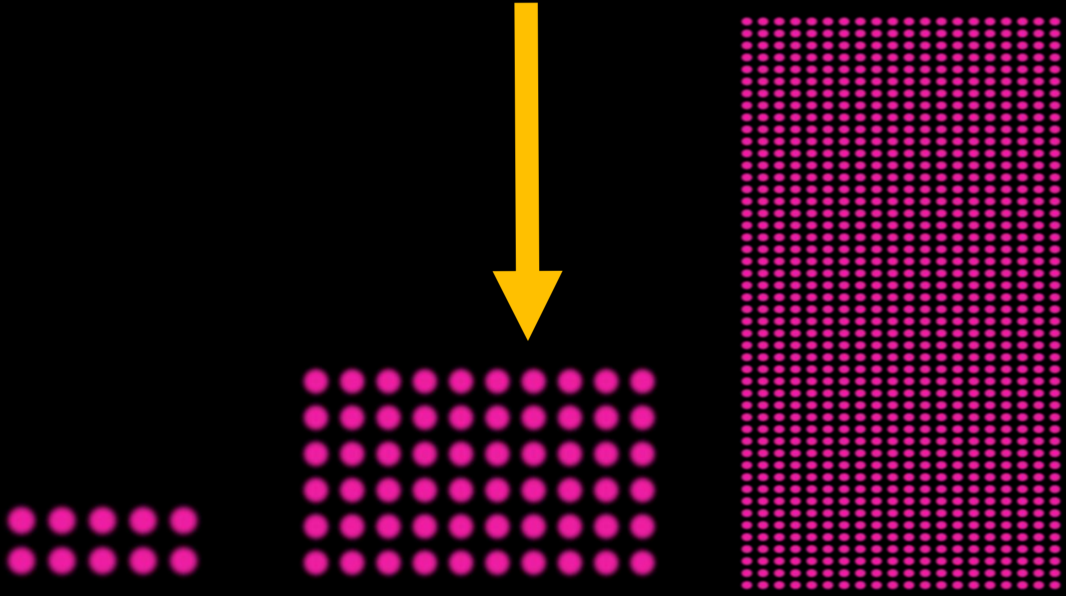
Demonstrate an advantage to using QC for real problems of interest

Extract commercial value

Enable scientific discovery

What applications can we use in the near-term with a handful of qubits and without using error correction?

IBM Q



Today
~10^1 qubits

Near future
50-100 qubits
Too big to simulate

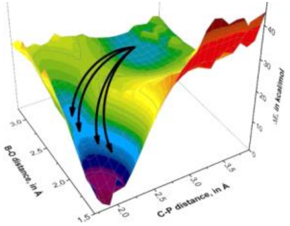
Future
Millions of qubits
Fully fault-tolerant

Example first applications and use cases

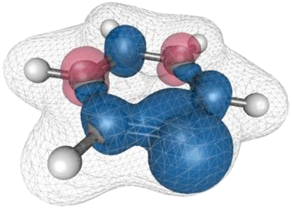
Initial applications will leverage algorithms that can tolerate or mitigate errors found in approximate quantum computers. Research & development for commercial use cases must be focused on selecting algorithms and determining how to best map problems to them.

Quantum Chemistry

Reaction pathways

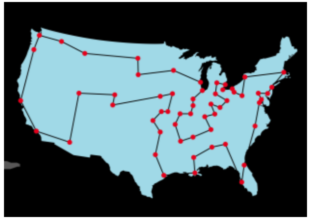


Molecule geometry

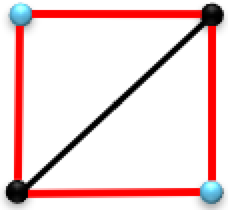


Optimization

Traveling Salesman

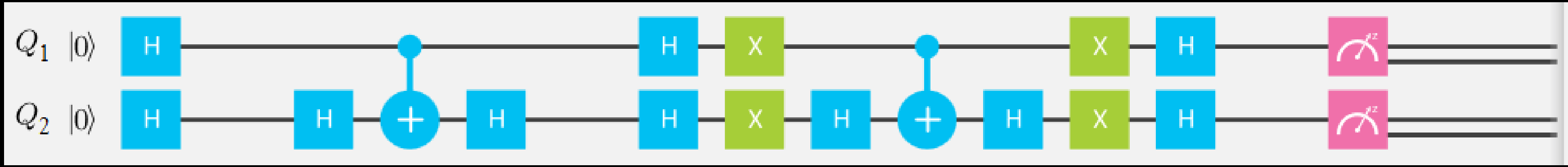


Max Cut



quantum algorithm

IBM Q



1. **initialization** of all qubits in $|0\rangle$
2. sequence of **operations** on single or multiple qubits
3. **measurement** (read-out) concludes algorithm

- many repetitions for **statistical claims** necessary

qubits

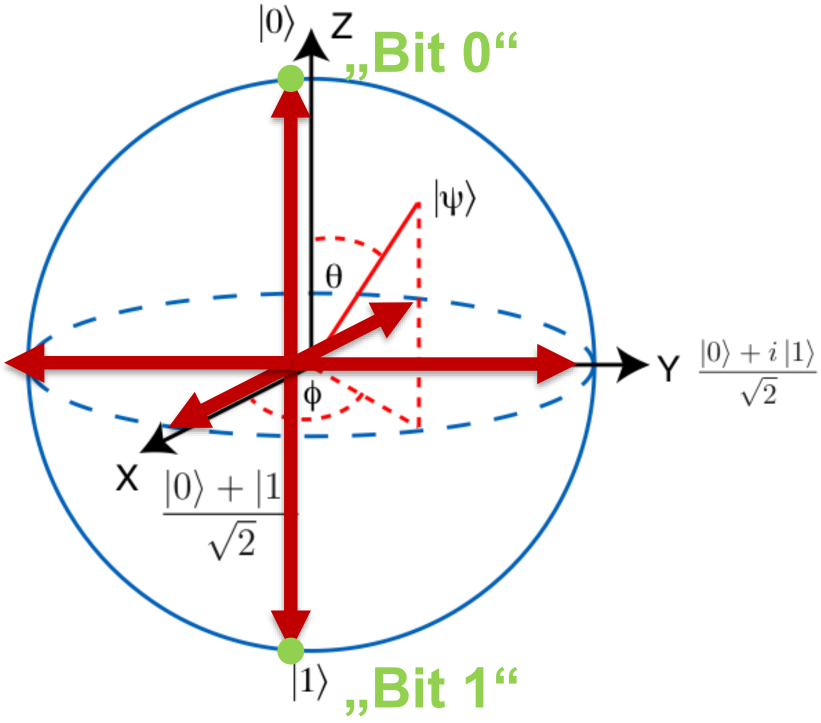
$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \qquad |1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle \qquad |\alpha|^2 + |\beta|^2 = 1$$

$$|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle) \qquad |-\rangle = \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle)$$

$$|\circlearrowright\rangle = \frac{1}{\sqrt{2}}(|0\rangle + i|1\rangle) \qquad |\circlearrowleft\rangle = \frac{1}{\sqrt{2}}(|0\rangle - i|1\rangle)$$

Bloch sphere



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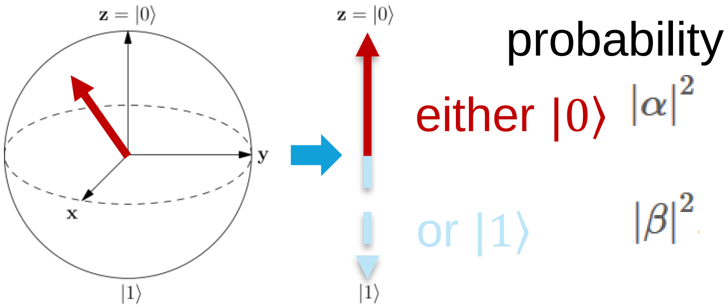
measurement and quantum gates

measurement

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



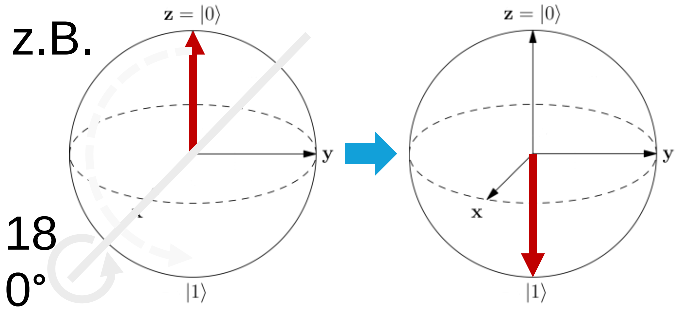
probability

either $|0\rangle$ $|\alpha|^2$

or $|1\rangle$ $|\beta|^2$

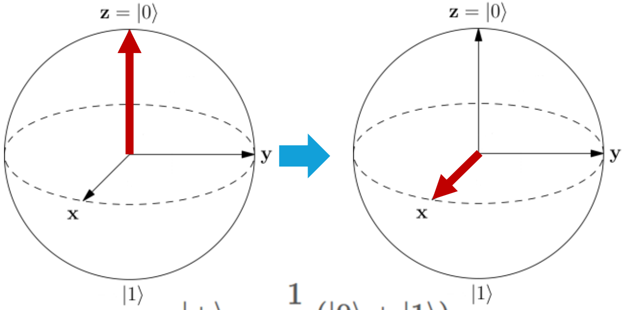
X Z Y rotations

z.B.



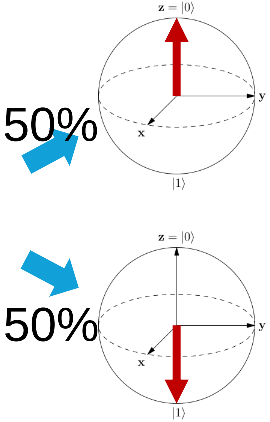
180°

H Hadamard creates superposition



$$|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$$

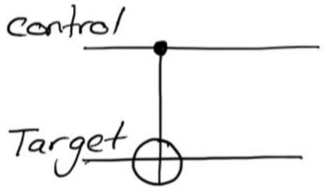
measurement



50%

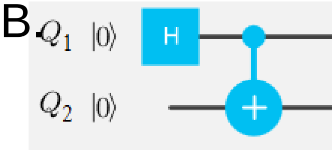
50%

controlled-NOT



for entanglement

z.B.



→ no classical equivalent exists

- IBM Quantum Experience - quantumexperience.ng.bluemix.net/

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research.ibm.com/ibm-qx

IBM Q experience

Launched May 2016

Program 5 qubit quantum processor from any web browser

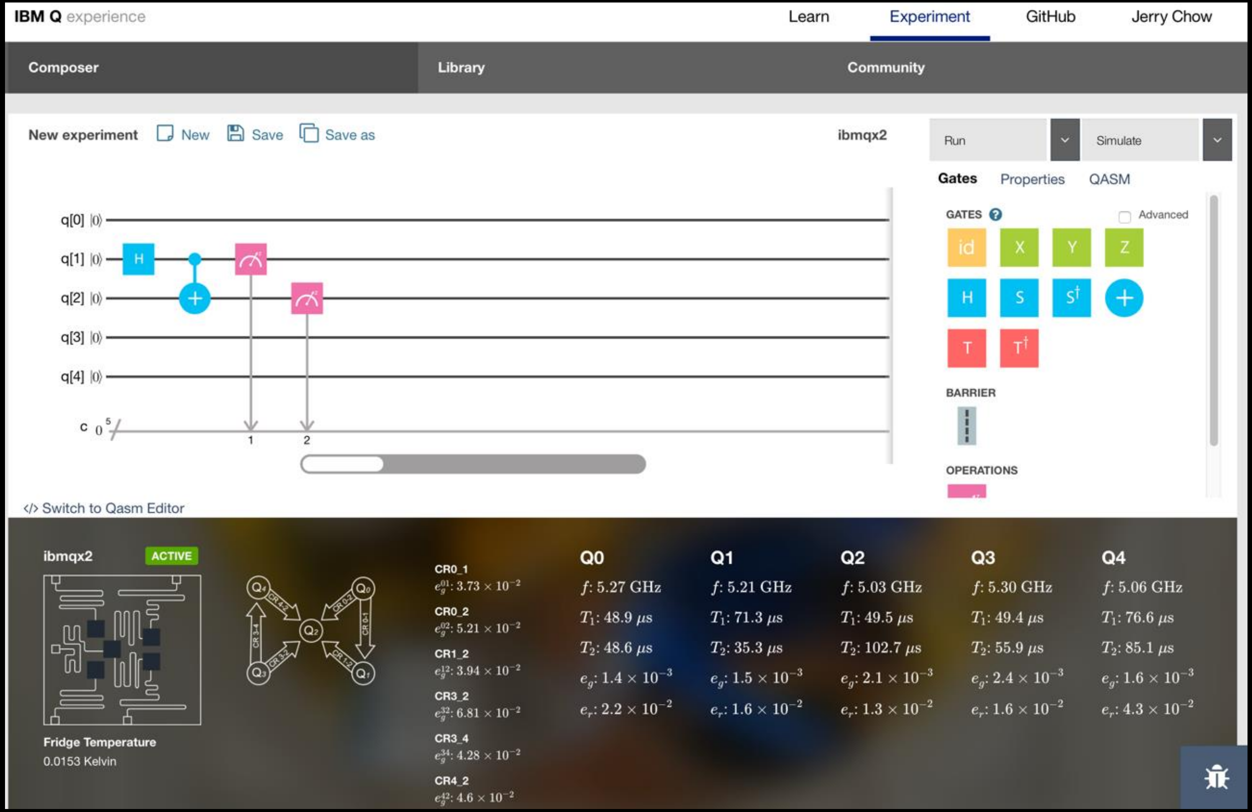
Upgraded Mar 2017

API access

SDK launched

Upgraded May 2017

16 qubit beta program



Fridge Temperature
0.0153 Kelvin

CR0_1
e_g^{01}: 3.73×10^{-2}

CR0_2
e_g^{02}: 5.21×10^{-2}

CR1_2
e_g^{12}: 3.94×10^{-2}

CR3_2
e_g^{32}: 6.81×10^{-2}

CR3_4
e_g^{34}: 4.28×10^{-2}

CR4_2
e_g^{42}: 4.6×10^{-2}

Q0	Q1	Q2	Q3	Q4
f: 5.27 GHz	f: 5.21 GHz	f: 5.03 GHz	f: 5.30 GHz	f: 5.06 GHz
T_1: 48.9 μs	T_1: 71.3 μs	T_1: 49.5 μs	T_1: 49.4 μs	T_1: 76.6 μs
T_2: 48.6 μs	T_2: 35.3 μs	T_2: 102.7 μs	T_2: 55.9 μs	T_2: 85.1 μs
e_g: 1.4×10^{-3}	e_g: 1.5×10^{-3}	e_g: 2.1×10^{-3}	e_g: 2.4×10^{-3}	e_g: 1.6×10^{-3}
e_r: 2.2×10^{-2}	e_r: 1.6×10^{-2}	e_r: 1.3×10^{-2}	e_r: 1.6×10^{-2}	e_r: 4.3×10^{-2}

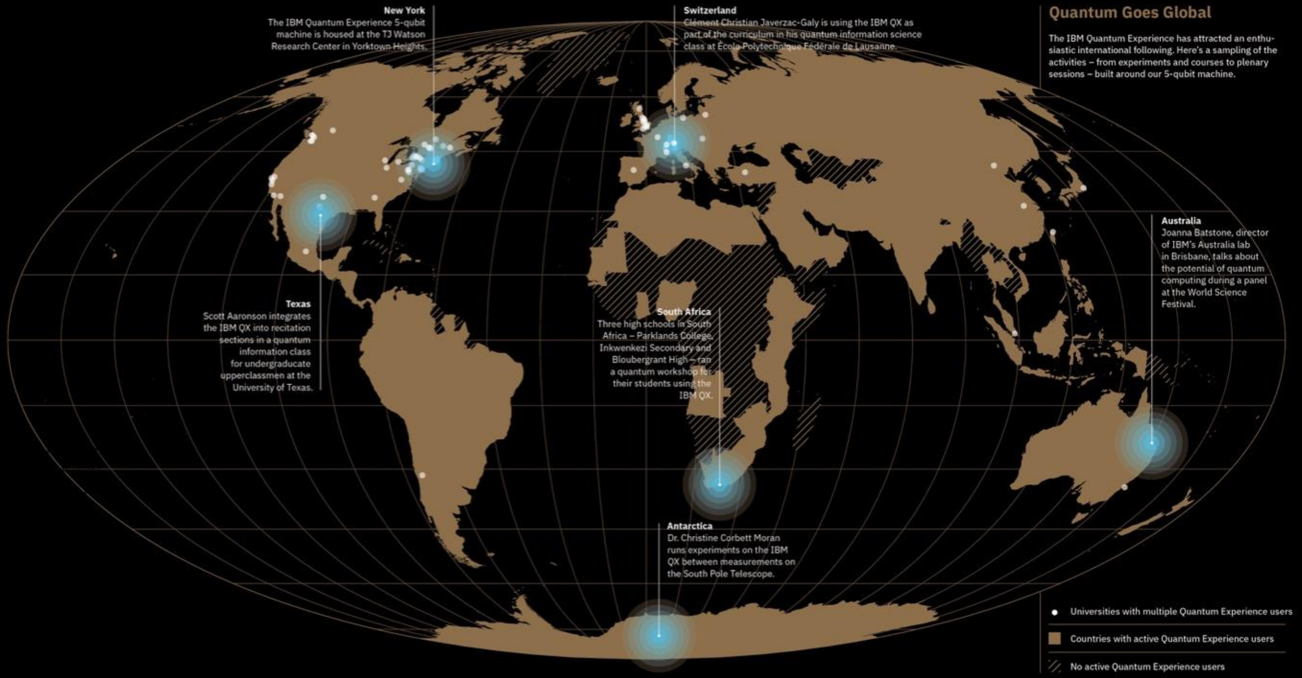
IBM Q experience

50,000 users

All 7 continents

>150 colleges and universities

Over 1 Million experiments



Quantum Goes Global

The IBM Quantum Experience has attracted an enthusiastic international following. Here's a sampling of the activities – from experiments and courses to plenary sessions – built around our 5-qubit machine.

New York
The IBM Quantum Experience 5-qubit machine is housed at the TJ Watson Research Center in Yorktown Heights.

Switzerland
Clément Christian Javerzac-Galy is using the IBM QX as part of the curriculum in his quantum information science class at École Polytechnique Fédérale de Lausanne.

Australia
Joanna Batstone, director of IBM's Australia lab in Brisbane, talks about the potential of quantum computing during a panel at the World Science Festival.

Texas
Scott Aaronson integrates the IBM QX into recitation sections in a quantum information class for undergraduate upperclassmen at the University of Texas.

South Africa
Three high schools in South Africa – Parklands College, Inkwenkezi Secondary and Bloubergrant High – ran a quantum workshop for their students using the IBM QX.

Antarctica
Dr. Christine Corbett Moran runs experiments on the IBM QX between measurements on the South Pole Telescope.

● Universities with multiple Quantum Experience users

■ Countries with active Quantum Experience users

▨ No active Quantum Experience users

20 publications since last May

IBM Q

IOP Publishing

New J. Phys. 18 (2016) 073004

New Journal of Phy

The open access journ

CrossMark

PAPER

Demonstrating non-Abelian braiding of surface code defects in a five qubit

James R. Wootton

of Basel, Klingelbergstrasse 82, CH-4056 Basel,

PHYSICAL REVIEW A

covering atomic, molecular, and optical physics and quantum information

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xperimental test of Mermin inequalities on a five-qubit qu

mputer

l Alsina and José Ignacio Latorre

Rev. A 94, 012314 – Published 11 July 2016

References Citing Articles (1) PDF HTM

ABSTRACT

IBM Quantum Ex

子計算入門

nate

direct method for tomography

Python 5-qubit quantum computer simulator to

computing

Experimental Comparison of Two Quantum Computing Architectu

N. M. Linke,[1] D. Maslov,[2,3] M. Roetteler,[4] S. Debnath,[1] C. Figgatt,[1] K. A. Landsman,[1] K. Wright,[1] and C. Monroe[1,3,5]

[1] Joint Quantum Institute and Department of Physics, University of Maryland, College Park, MD 20742

[2] National Science Foundation, Arlington, VA 22230

[3] Joint Center for Quantum Information and Computer University of Maryland, College Park, MD

[4] Microsoft Research, Redmond,

[5] IonQ, Inc.

onducting qubit addressing the

Homomorphic Encryption Experiments on IBM's Cloud Quantum Comput Platform

He-Liang Huang,[1,2] You-Wei Zhao,[2,3] Tan Li,[1,2] Feng-Guang Li,[1,2] Yu-Tao Du,[1,2] Xiang-Qun Fu,[1,2] Shuo Zhang,[1,2] Xiang Wang,[1,2] and Wan-Su Bao[1,2,*]

[1] Zhengzhou Information Science and Technology Institute, Henan, Zhengzhou 450000,

Centre for Excellence and Synergetic Innovation Centre in Quantum Information and Qu

University of Science and Technology of China, Hefei, Anhui 230026, China

Laboratory for Physical Sciences at Microscale and Department of Mod

University of Science and Technology of China, Hefei, Anhui 230026,

has undergone rapid development in recent years. Owing

computers still seem slightly unrealistic in the near

ordinary users is likely to be on the cloud. Howe

security is ensured. Homomorphic encryptio

performed on encrypted data witho

first applied homomorphic en

we successfully impleme

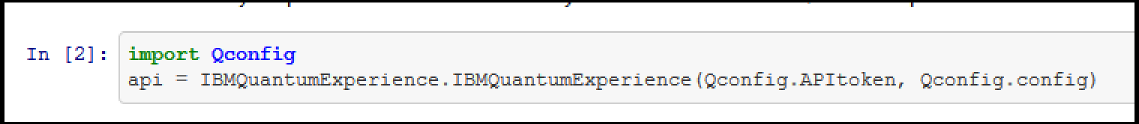
This demonstration

technology. Clou

Python Programming Using OpenQASM with QISkit SDK

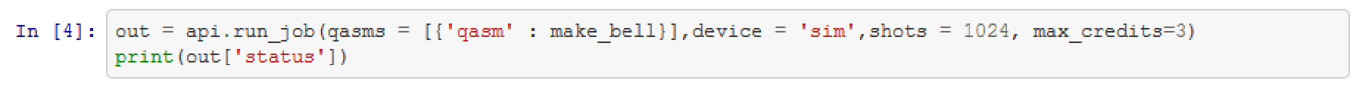
Very simple interface, several Jupyter notebook examples

Set up the API



```
In [2]: import Qconfig
        api = IBMQuantumExperience.IBMQuantumExperience(Qconfig.APItoken, Qconfig.config)
```

Submit a job



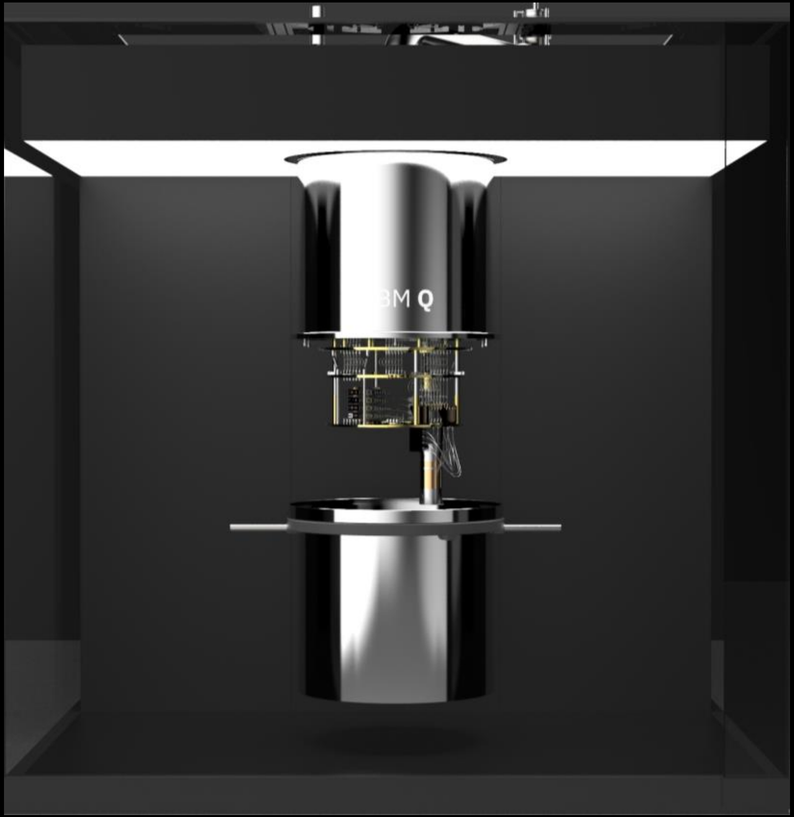
```
In [4]: out = api.run_job(qasms = [{'qasm' : make_bell}],device = 'sim',shots = 1024, max_credits=3)
        print(out['status'])
```

Wait for completion

```
In [5]: import time
        jobids=out['id']
        results = api.get_job(jobids)
        print(results['status'])
        while (results['status'] == 'RUNNING'):
            time.sleep(2)
            results = api.get_job(jobids)
            print(results['status'])

        RUNNING
        RUNNING
        COMPLETED
```

IBM Q commercial initiative



<u>Announced May 2017</u>

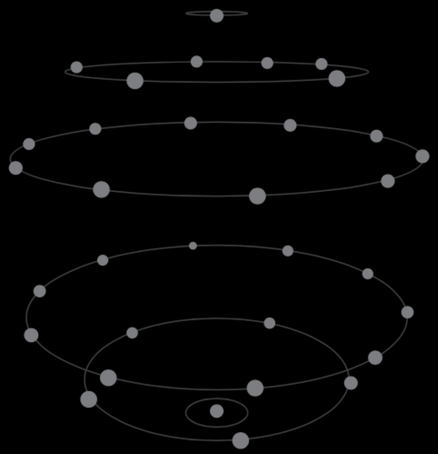
IBM's first prototype commercial processor with 17 qubits

- Most powerful quantum processor created to date - leverages significant materials, device, and architecture improvements
- Engineered to be at least twice as powerful as the experience delivered on IBM Cloud
- Basis for IBM Q commercial systems

IBM

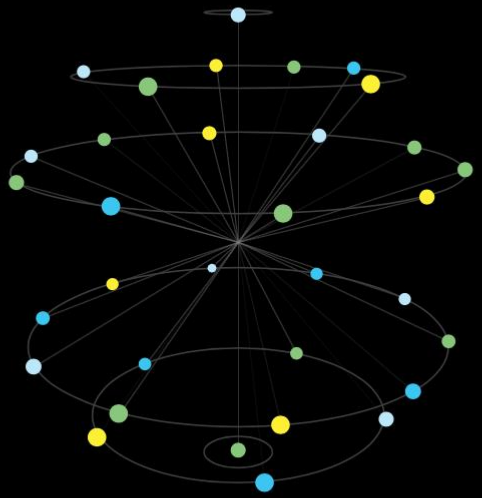
A Quantum Algorithm

IBM Q



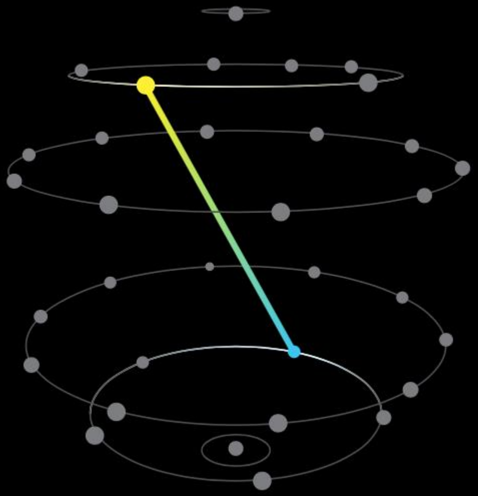
The spread

First part of the algorithm is make a equal superposition of all 2^n states. Apply H gates



The problem

The second part is to encode the problem into this states (phases on the on the all 2^n states.



The magic

The magic of quantum algorithms is to interfere all these states back to a few outcomes containing the solution