

Professional education

Technical workshop in

Quantum Computing

Instructor: Bruno Fedrici, PhD



FRESNEL

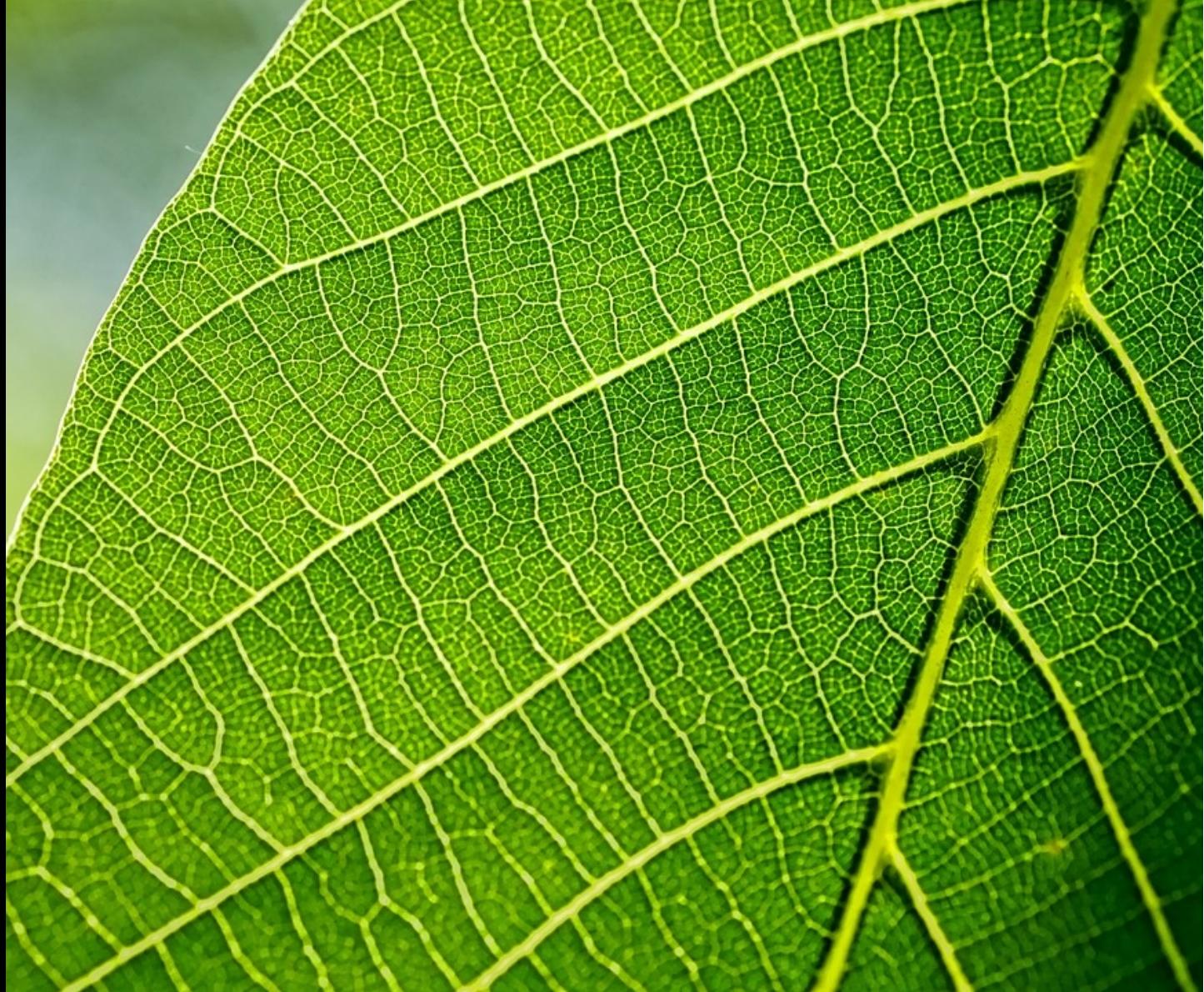
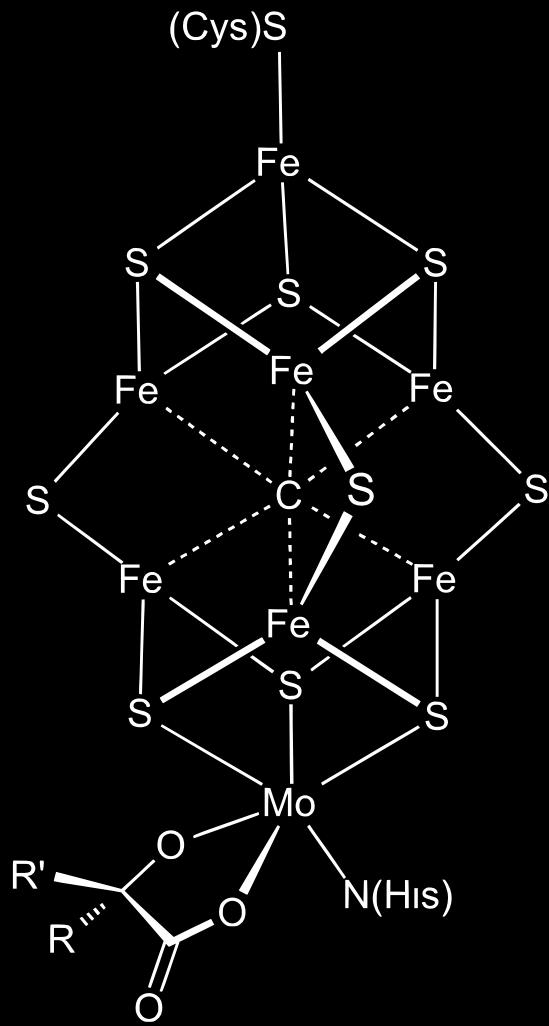


Quantum Computing: overview and prospects



- Applications
- Quantum software and algorithms
- Quantum hardware
- Industry landscape





Character

Bits

7

111

A

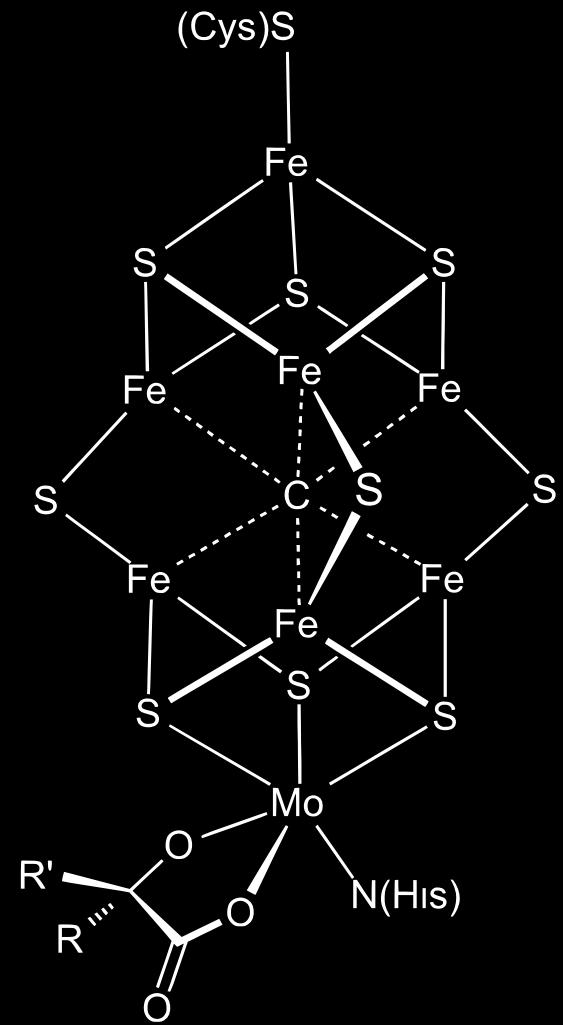
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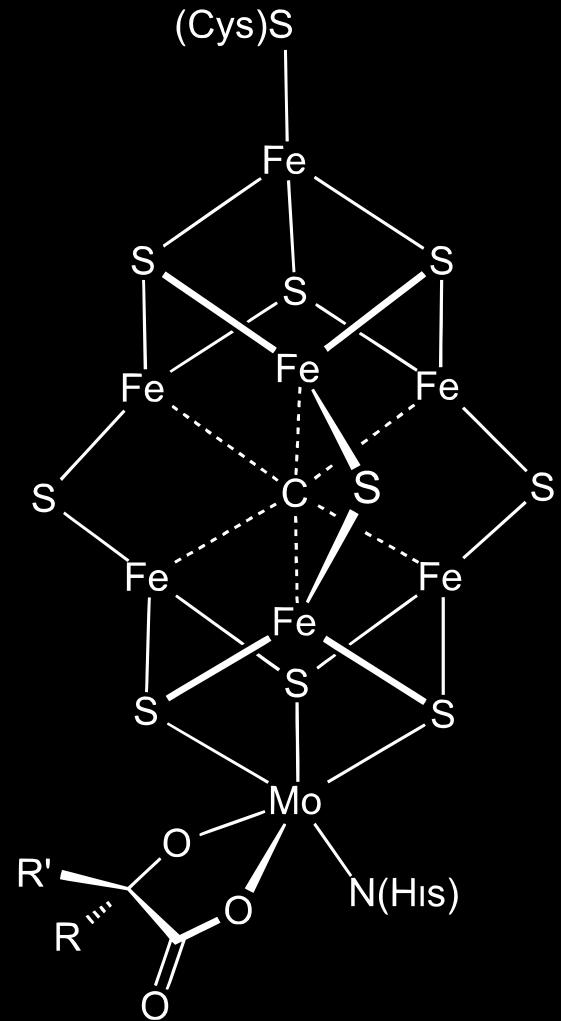
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Classical
 $\sim 10^{32}$
bits



Classical

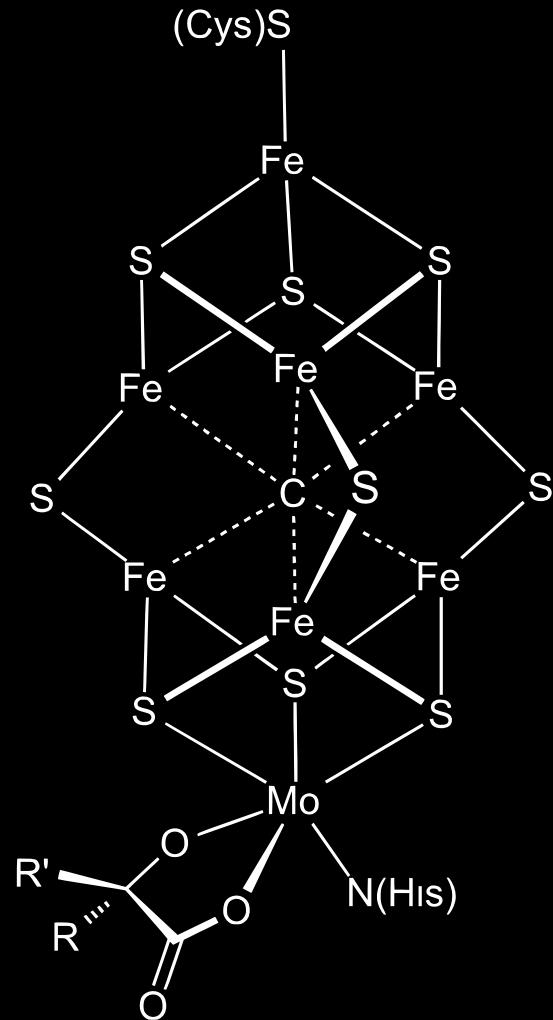
$\sim 10^{32}$

bits

Quantum

$\sim 10^8$

quantum bits



N bits → $2N$ bits

Doubling classical computers memory

N qubits → $N+1$ qubits

Doubling quantum computers memory*

Quantum computing's potential is enormous !

*We will be more precise on this point later in talk

Applications

Quantum Speedup

Quantum Bits

Quantum Algorithms

Hardware

Industry Landscape

Applications

Quantum Speedup

Quantum Bits

Quantum Algorithms

Hardware

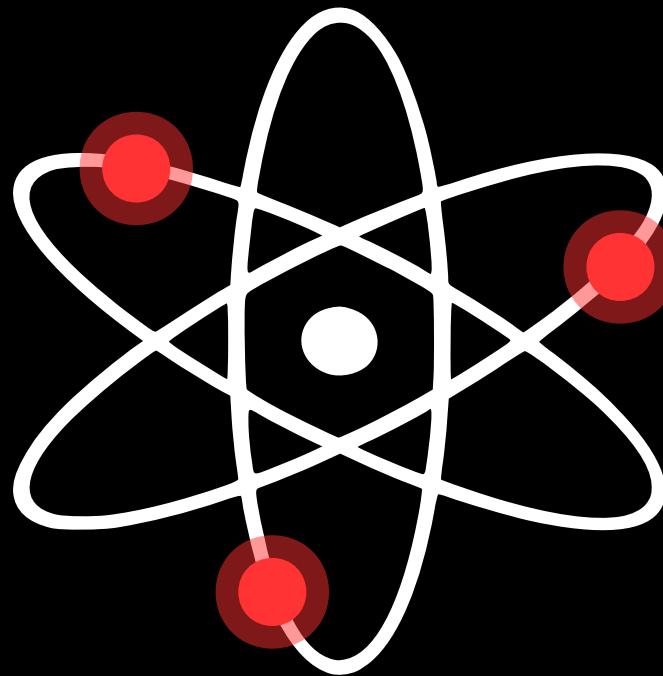
Industry Landscape

Prediction

Extracting information from data and using it to predict trends and behaviour patterns

Simulation

The imitation of the operation of a real-world process or system over time



Optimization

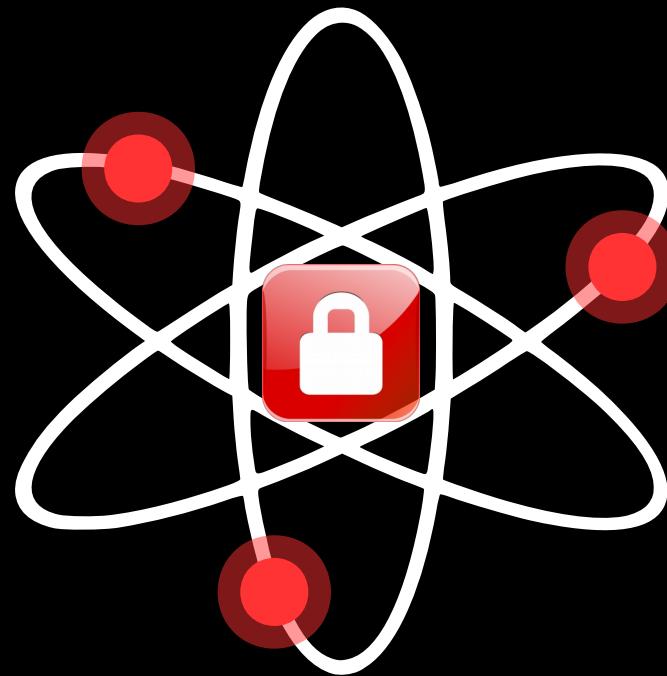
Finding the best solution with the least error from a multitude of possible solutions

Prediction

Extracting information from data and using it to predict trends and behaviour patterns

Simulation

The imitation of the operation of a real-world process or system over time

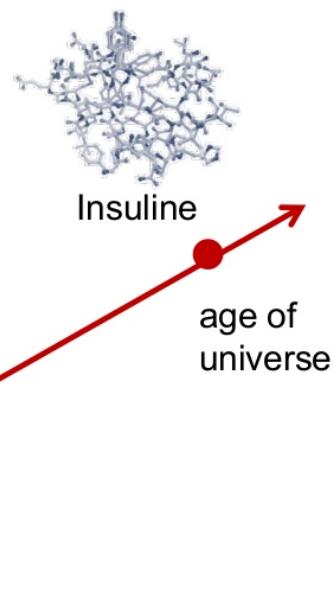


Optimization

Finding the best solution with the least error from a multitude of possible solutions

Computational-chemistry can be a highly valuable tool, but scales very poorly on classical computers; which is why in the 1980s the concept of quantum-computing was proposed.

Timescale to simulate molecules to chemical accuracy on a classical (super-) computer



Catalyst and enzyme design, such as nitrogenase

Pharmaceutical R&D, such as faster drug discovery

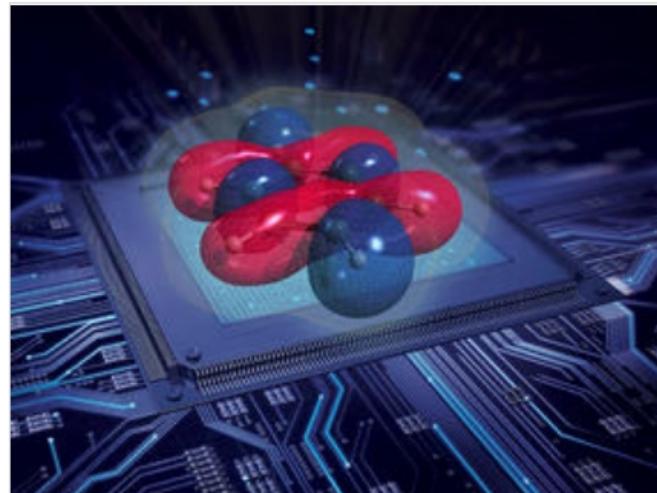
Bio-informatics, such as genomics

Patient diagnostic for health care

Merck cooperates with start-up HQS Quantum Simulations

Unique approach to quantum chemistry on near-term quantum computers

06-Jun-2019



Merck announced a three-year cooperation with HQS Quantum Simulations, a start-up based in Karlsruhe, Germany. The cooperation between the startup and the Chief Digital Organisation of Merck will focus on applying and commercializing software for quantum chemical applications on quantum computers. Merck has the option for a distribution license.

“Quantum computing is poised to disrupt classical computing and enable a variety of unprecedented opportunities. The applications touch upon many fields with direct relevance to Merck and to our customers, for example materials research, drug discovery, artificial intelligence, and e-commerce,” said Philipp Harbach, Head of In Silico Research at the Chief Digital Organisation of Merck.

Merck KGaA
Merck and HQS Quantum Simulations Cooperate in Quantum Computing

BASF invests in quantum computing startup Zapata Computing

- Zapata's technology platform is an innovative approach to leverage the potential of this novel technology
- Applications of quantum computing offer opportunities to meet the challenges of the chemical industry

Ludwigshafen, Germany, April 17, 2019 – BASF Venture Capital is joining a group of prominent investors in the Series A investment round of Zapata Computing, Inc. Headquartered in Cambridge, Massachusetts, Zapata is developing both a powerful software platform as well as specific applications for Global 1000 companies to effectively utilize a range of emerging quantum computing hardware. By investing in Zapata, BASF Venture Capital supports BASF's strategic goal to take advantage of the opportunities that digitalization offers along the entire value chain. Quantum computing will enable BASF experts to very efficiently investigate complex questions and it will further shorten the time it takes to launch new products. Zapata, which was spun-out of Harvard University in 2017, will use the



Christian Müller
Communications

+49 152 54913724

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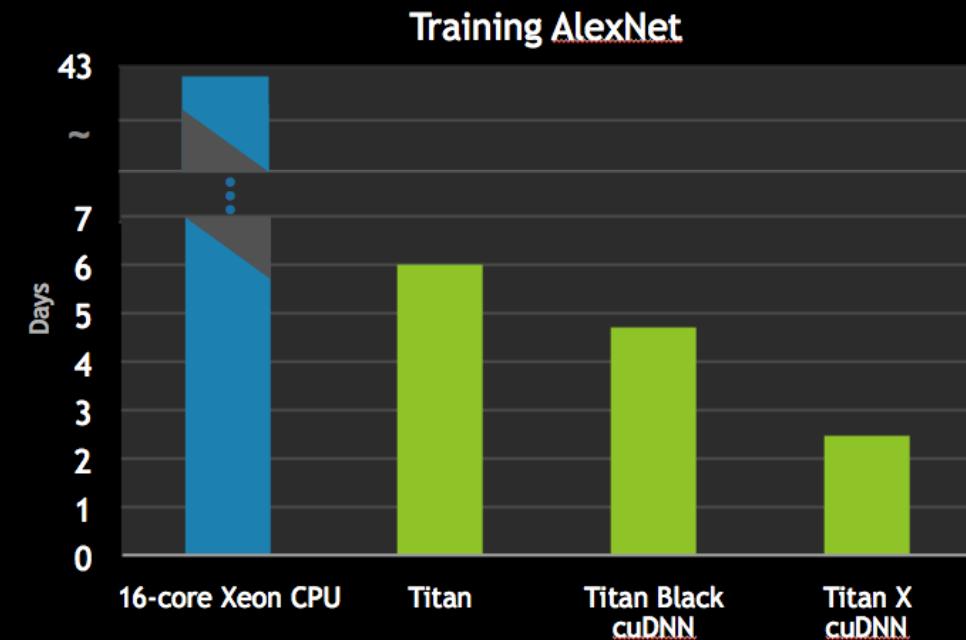
While artificial intelligence is a natural test bed for quantum computing, large scale quantum computers are expected to be threats for cybersecurity.

Machine learning and artificial intelligence

Search

Cybersecurity

Software verification and validation



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Quantum [Recherche](#) [Français](#) [GitHub](#) [Connexion](#)

Aperçu Guide et tutoriels API

TensorFlow Quantum is a library for hybrid quantum-classical machine learning.

TensorFlow Quantum (TFQ) is a [quantum machine learning](#) library for rapid prototyping of hybrid quantum-classical ML models. Research in quantum algorithms and applications can leverage Google's quantum computing frameworks, all from within TensorFlow.

TensorFlow Quantum focuses on *quantum data* and building *hybrid quantum-classical models*. It integrates quantum computing algorithms and logic designed in [Cirq](#), and provides quantum computing primitives compatible with existing TensorFlow APIs, along with high-performance quantum circuit simulators. Read more in the [TensorFlow Quantum white paper](#).

Start with the [overview](#), then run the [notebook tutorials](#).

```
# A hybrid quantum-classical model.
model = tf.keras.Sequential([
    # Quantum circuit data comes in inside of tensors.
    tf.keras.Input(shape=(), dtype=tf.dtypes.string),

    # Parametrized Quantum Circuit (PQC) provides output
    # data from the input circuits run on a quantum computer.
    tfq.layers.PQC(my_circuit, [cirq.Z(q1), cirq.X(q0)]),

    # Output data from quantum computer passed through model.
    tf.keras.layers.Dense(50)
])
```



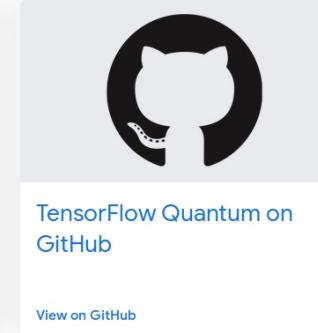
Announcing TensorFlow Quantum
[Read on the Google AI blog](#)



TensorFlow Quantum (TF Dev Summit '20)
[Watch the video](#)



Programming a quantum computer with Cirq
[Watch the video](#)



TensorFlow Quantum on GitHub
[View on GitHub](#)

The screenshot shows the homepage of the PennyLane website. At the top, there's a navigation bar with links for 'PENNY LANE' (highlighted in red), 'Quantum machine learning', 'Install', 'Plugins', 'Documentation', 'FAQ', 'Support', and 'GitHub'. The main title 'PENNY LANE' is prominently displayed in large, light blue letters. Below it, a subtitle reads: 'A cross-platform Python library for quantum machine learning, automatic differentiation, and optimization of hybrid quantum-classical computations'. There are three main sections: 'Learn' (with a video thumbnail), 'Play' (with a code snippet from Strawberryfields), and 'Code' (with a code snippet from PennyLane). A dark banner at the bottom features logos for Xanadu, IBM, Google, Rigetti, Microsoft, TensorFlow, and PyTorch.

PENNY LANE

A cross-platform Python library for quantum machine learning, automatic differentiation, and optimization of hybrid quantum-classical computations

Learn

Play

Code

PennyLane supports a growing ecosystem, including a wide range of quantum hardware and machine learning libraries

XANADU IBM Google rigetti

Microsoft TensorFlow PyTorch



Information Technology Laboratory

COMPUTER SECURITY RESOURCE CENTER

[PROJECTS](#)

Post-Quantum Cryptography

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Project Overview

NIST has initiated a process to solicit, evaluate, and standardize one or more quantum-resistant public-key cryptographic algorithms. [Full details can be found in the Post-Quantum Cryptography Standardization page.](#)

The Round 2 candidates were announced January 30, 2019. [NISTIR 8240, Status Report on the First Round of the NIST Post-Quantum Cryptography Standardization Process](#) is now available.

Background

In recent years, there has been a substantial amount of research on quantum computers – machines that exploit quantum mechanical phenomena to solve mathematical problems that are difficult or intractable for conventional computers. If large-scale quantum computers are ever built, they will be able to break many of the public-key cryptosystems currently in use. This would seriously compromise the confidentiality and integrity of digital communications on the Internet and elsewhere. The goal of *post-quantum cryptography* (also called quantum-resistant cryptography) is to develop cryptographic systems that are secure against both quantum and classical computers, and can interoperate with existing communications protocols and networks.

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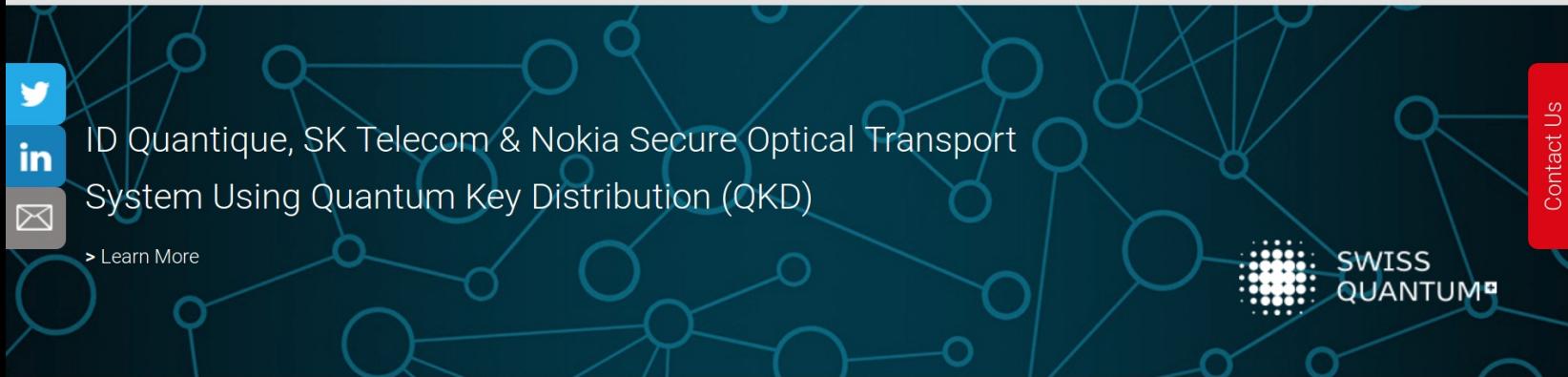
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ID Quantique, SK Telecom & Nokia Secure Optical Transport System Using Quantum Key Distribution (QKD)

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ID Quantique (IDQ) is the world leader in quantum-safe crypto solutions, designed to protect data for the long-term future. The company provides quantum-safe network encryption, secure quantum key generation and quantum key distribution solutions and services to the financial industry, enterprises and government organisations globally.

IDQ also commercializes a quantum random number generator, which is the reference in the security, simulation and gaming industries.

Product development and process optimization are among the manufacturing areas likely to witness major innovations with quantum computing.



Logistics: scheduling, planning, product distribution, routing

Automotive: traffic simulation, e-charging station
and parking search, autonomous driving

Material science: effective catalytic converters for cars,
battery cell research, more efficient material for solar cells,
and property engineering uses such as OLEDs

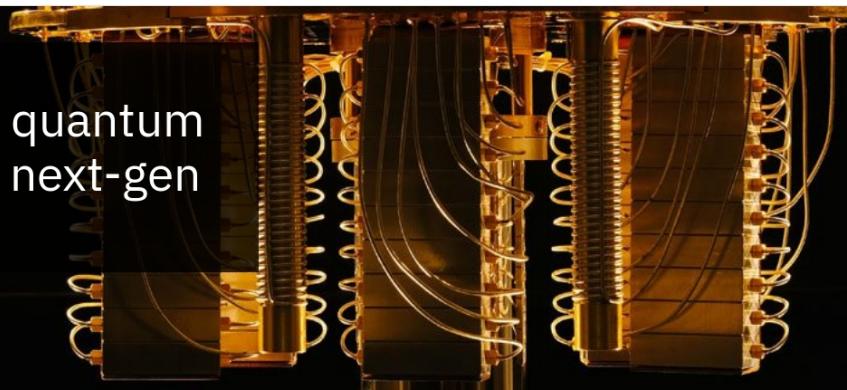
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Quantum Computing

IBM and Daimler use quantum computer to develop next-gen batteries



January 8, 2020 | Written by: Jeannette Garcia

Categorized: [Quantum Computing](#)

Share this post:



Electric vehicles have an Achilles heel: the capacity and speed-of-charging of their batteries. A quantum computing breakthrough by researchers at IBM and Daimler AG, the parent company of Mercedes-Benz, could help tackle this challenge. We used a quantum computer to model the dipole moment of three lithium-containing molecules, which brings us one step closer the next-generation lithium sulfur (Li-S) batteries that would be more powerful, longer lasting and cheaper than today's widely used lithium ion batteries.

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Minimal Waiting Time

Route Optimization

Intelligent traffic control with quantum computers

Traffic control is one of the many areas where quantum computers could be used. An innovative project by Volkswagen: Avoiding traffic jams and shortening waiting times using quantum algorithms.

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Home > News > Mass Navigation: How Ford Is Exploring The Quantum World With Microsoft To Help Reduce Congestion

MASS NAVIGATION: HOW FORD IS EXPLORING THE QUANTUM WORLD WITH MICROSOFT TO HELP REDUCE CONGESTION

DEC 10, 2019 | DEARBORN, MICH.



Balanced routing suggestions resulted in a 73 percent improvement in total congestion when compared to "selfish" routing. The average commuting time, meanwhile, was also reduced by 8 percent — an annual reduction of more than 55,000 hours saved in congestion across the simulated fleet.

Related Videos



Quantum Computi...

Dec 10, 2019

Media Contact

Traditionally, financial players have relied on the power of computing to reduce the risk. This has led to a computing arms race among them, where bigger profits result from analyzing a situation faster and in more detail.

Trading strategies

Portfolio optimization

Asset pricing

Fraud detection

Risk analysis

Market simulation



AMERICAN BANKER

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Why banks like Barclays are testing quantum computing

By
Penny CrosmanPublished
July 16 2018, 4:12pm EDTMore in
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Quantum computing — technology based on the principles of quantum theory — is increasingly attracting the interest of financial services firms that are seeking to process transactions, trades and other types of data as fast as possible.

Barclays and JPMorgan Chase have been experimenting with IBM's quantum computing technology since December, [when they joined the tech company's Q network](#). Salvatore Cucchiara at Morgan Stanley last week articulated the bank's hope of speeding up portfolio optimizations like Monte Carlo simulations with the help of quantum computing.

Trending

Does it really matter where Wells Fargo's CEO is based?

The Most Powerful Women in Banking

A battle royal for online deposits

Energy optimization, for example, requires far too much traditional computing power to identify the ideal balance of resources from different energy sources to meet ever-changing consumption needs in real time.



Network design

Energy distribution

Oil well optimization

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Pasqal and EDF partner to study smart-charging challenges with Quantum Computing

Palaiseau, June 25th 2020 – Quantum Computing startup Pasqal collaborates with the R&D department of electric utility EDF to bring fast solutions to hard optimization problems.

Quantum computers have the potential to solve hard computational problems more efficiently than their classical counterparts. Applications notably encompass computational drug design, materials science, machine learning, and optimization problems. With the rapid developments of quantum hardware, practical quantum advantage is within reach.

With many cities turning to e-mobility to tackle environmental challenges, electric utilities have to account for a growing and more complex load to manage for their production facilities and the grid. One example is the need to schedule resource allocation for shared electric vehicles while taking into considerations their expected and real time availability as well as charging constraints. This class of problem is computationally hard to solve even with large supercomputers and it is expected that a quantum algorithm called Quantum Approximate Optimization Algorithm (QAOA) could improve its resolution



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Jan 8, 2019 - 12:01 a.m. EST

ExxonMobil and IBM to Advance Energy Sector Application of Quantum Computing

- Strategic commitment to advance joint research into quantum computing for energy
- ExxonMobil becomes first energy company to join the IBM Q Network
- Technology could further enhance ExxonMobil's own research and development capabilities

Applications

Quantum Speedup

Quantum Bits

Quantum Algorithms

Hardware

Industry Landscape

Applications

Quantum Speedup

Quantum Bits

Quantum Algorithms

Hardware

Industry Landscape

Task:

Integer Factorization

Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

15

3 x 5

Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Applications

Q-Speedup

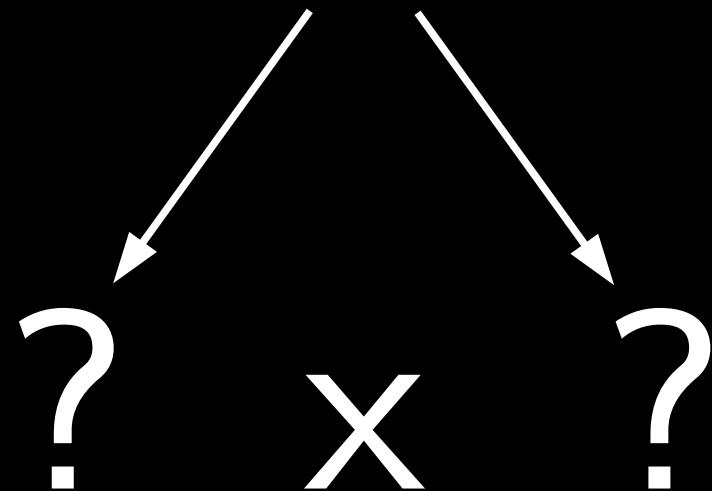
Q-Bits

Q-Algorithms

Hardware

Industry

7110379909909823469971673725424473064353882489427176741102057973000889379665565049610836498148428158908772246304866860943192
0907344516262190407768933383377381407878353760499455979319960700906894699032445175759904798500685134300942629461309714010525
8451183638689370751031611701475016230049806026342053176134099092008619376369645670455584888994220854383100330689198272181971
464627398981966424692315074087395450462661785555515740733919354799058011416327121389973469757674185303667619128805768897233
3216854588089690421544040301537811000428377757537533165315590643914173011914509168646819605343438902256216469789162186128



Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

Classical

$\sim 10^{14}$

years

Quantum*

~ 10

seconds

*assuming a quantum computer with 4096 perfectly stable qubits

Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Task:

Integer Factorization

Quantum algorithm:

Shor's Algorithm

Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

1 digit

Enter Passcode



Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

Number of digits

Number of tries

1



10

Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

4 digits

Enter Passcode

0 0 0 0

1

2

3

4

5

6

7

8

9

0

Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Number of digits

1



10

4



10,000

Applications

Q-Speedup

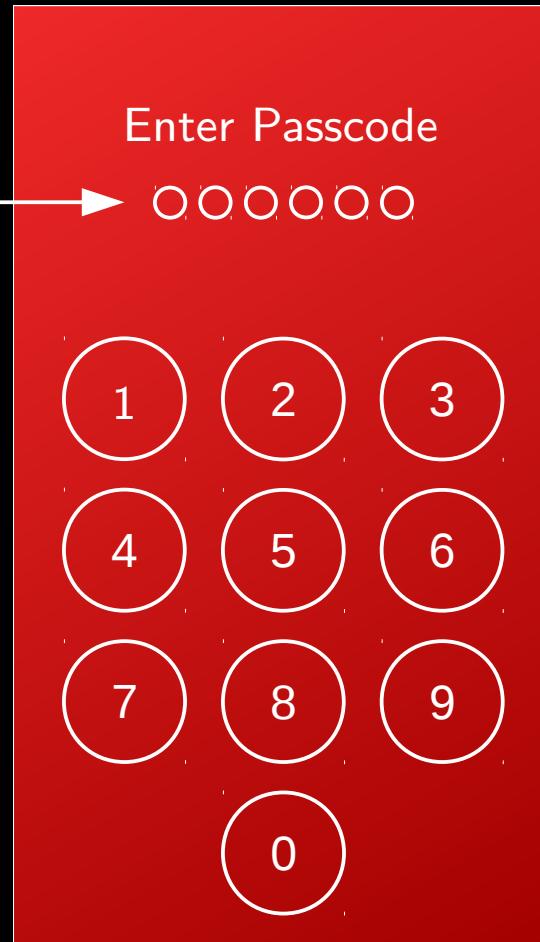
Q-Bits

Q-Algorithms

Hardware

Industry

6 digits



Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Number of digits

Number of tries

1



10

4

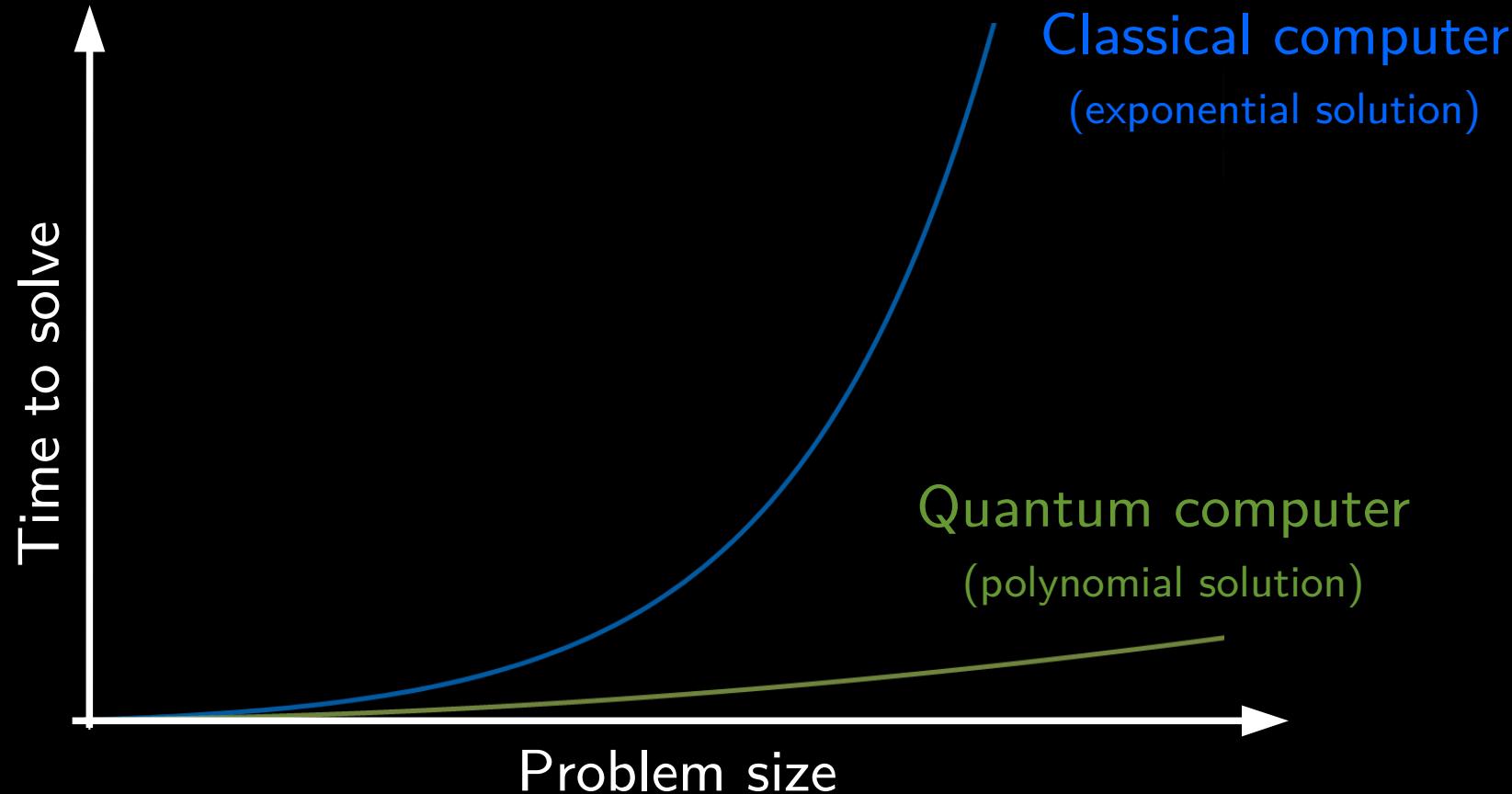


10,000

6



1,000,000



Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Applications

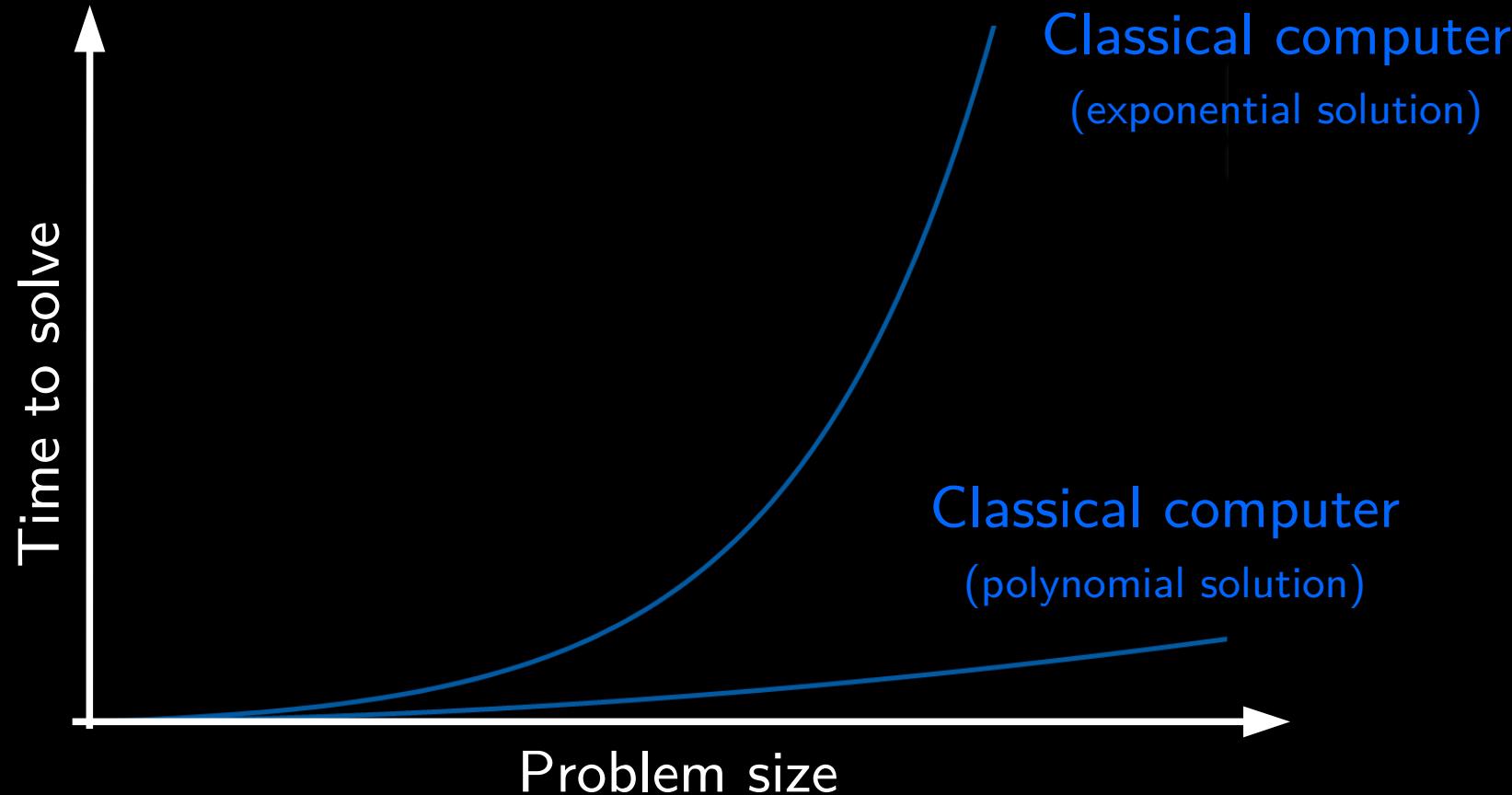
Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

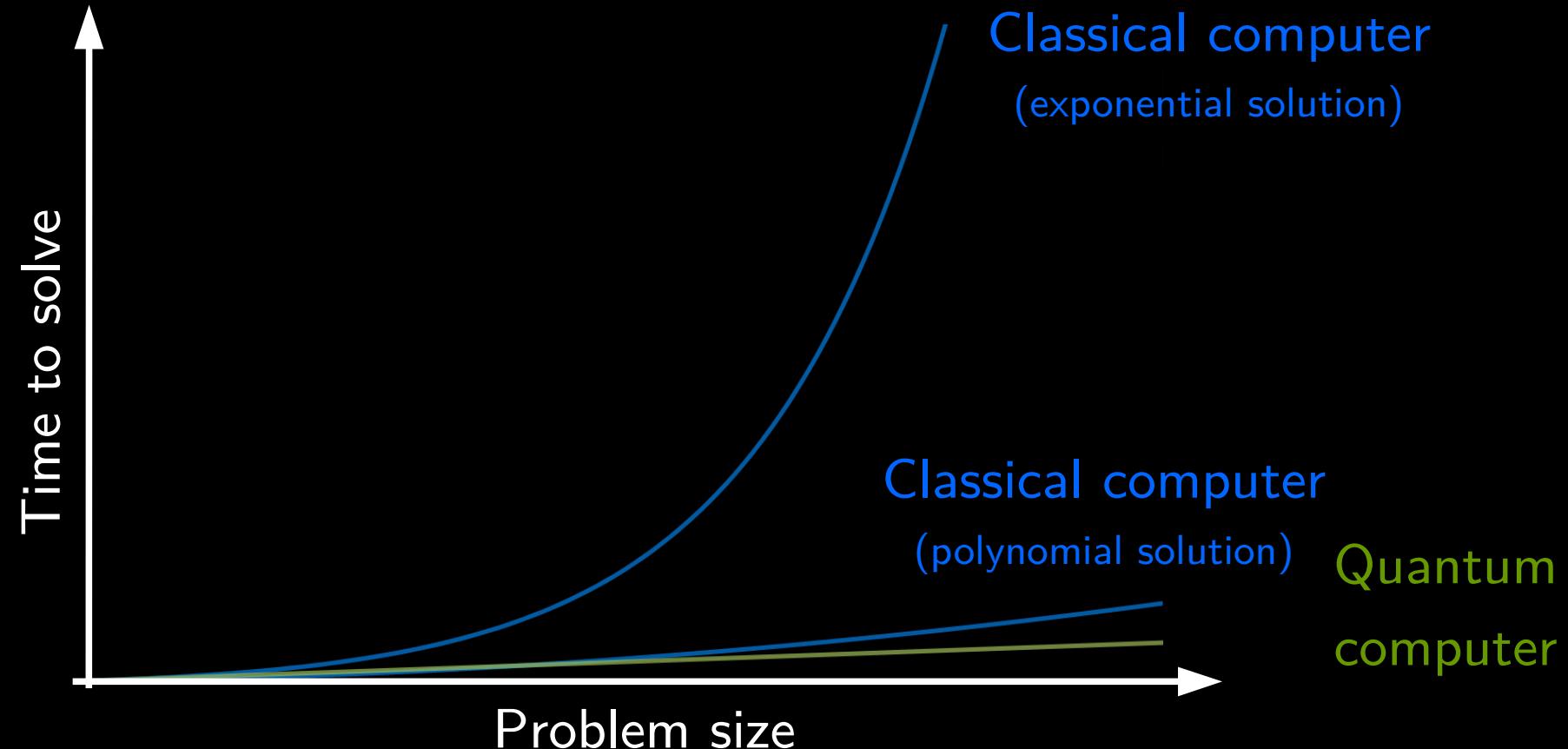


Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search



Applications

Q-Speedup

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Hardware

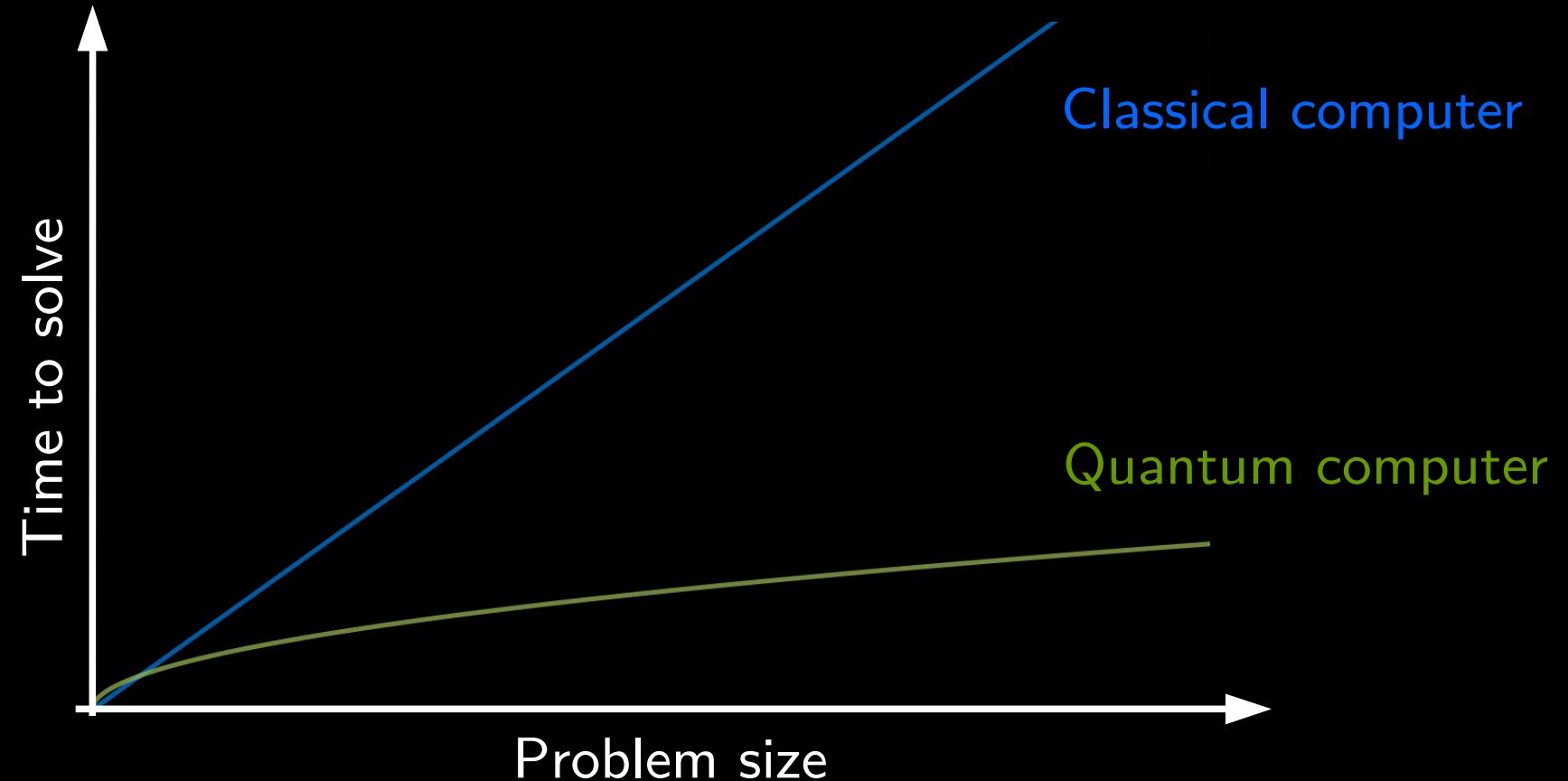
Industry

Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search



Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

1 digit

1 number

Enter Passcode

1

Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Applications

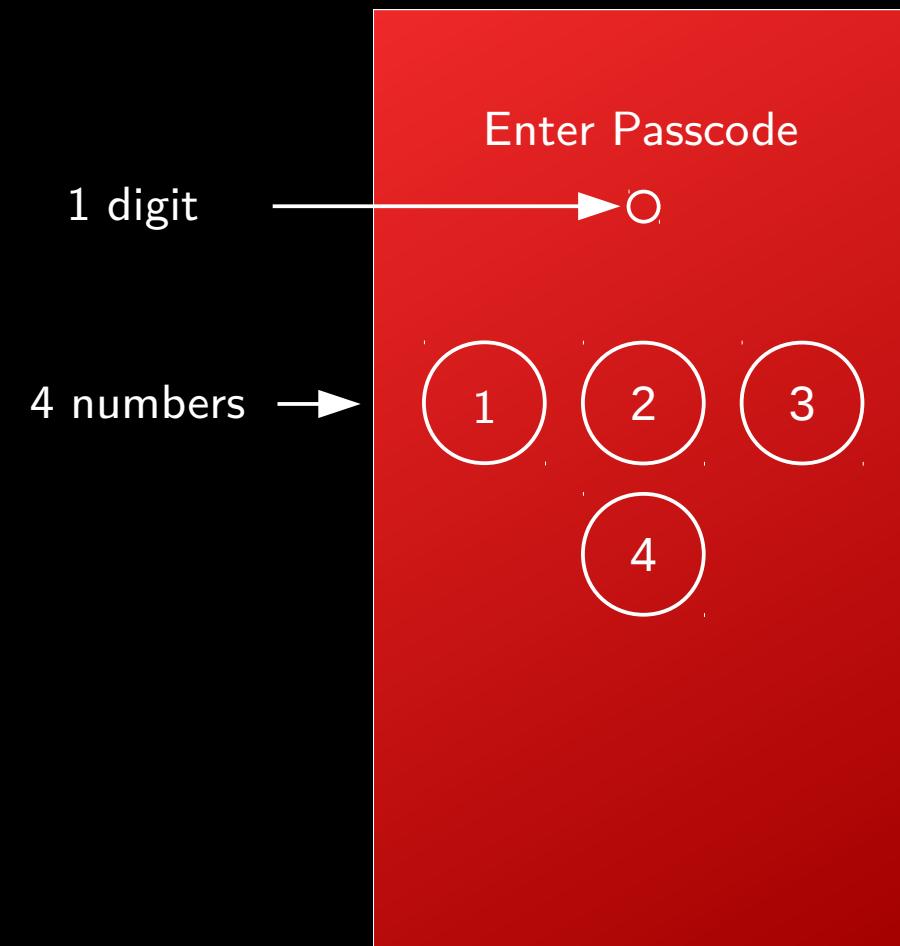
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Q-Bits

Q-Algorithms

Hardware

Industry



Shor's algorithm

Exp. speedup

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Applications

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Hardware

Industry

1 digit

6 numbers

Enter Passcode



1

2

3

4

5

6

Shor's algorithm

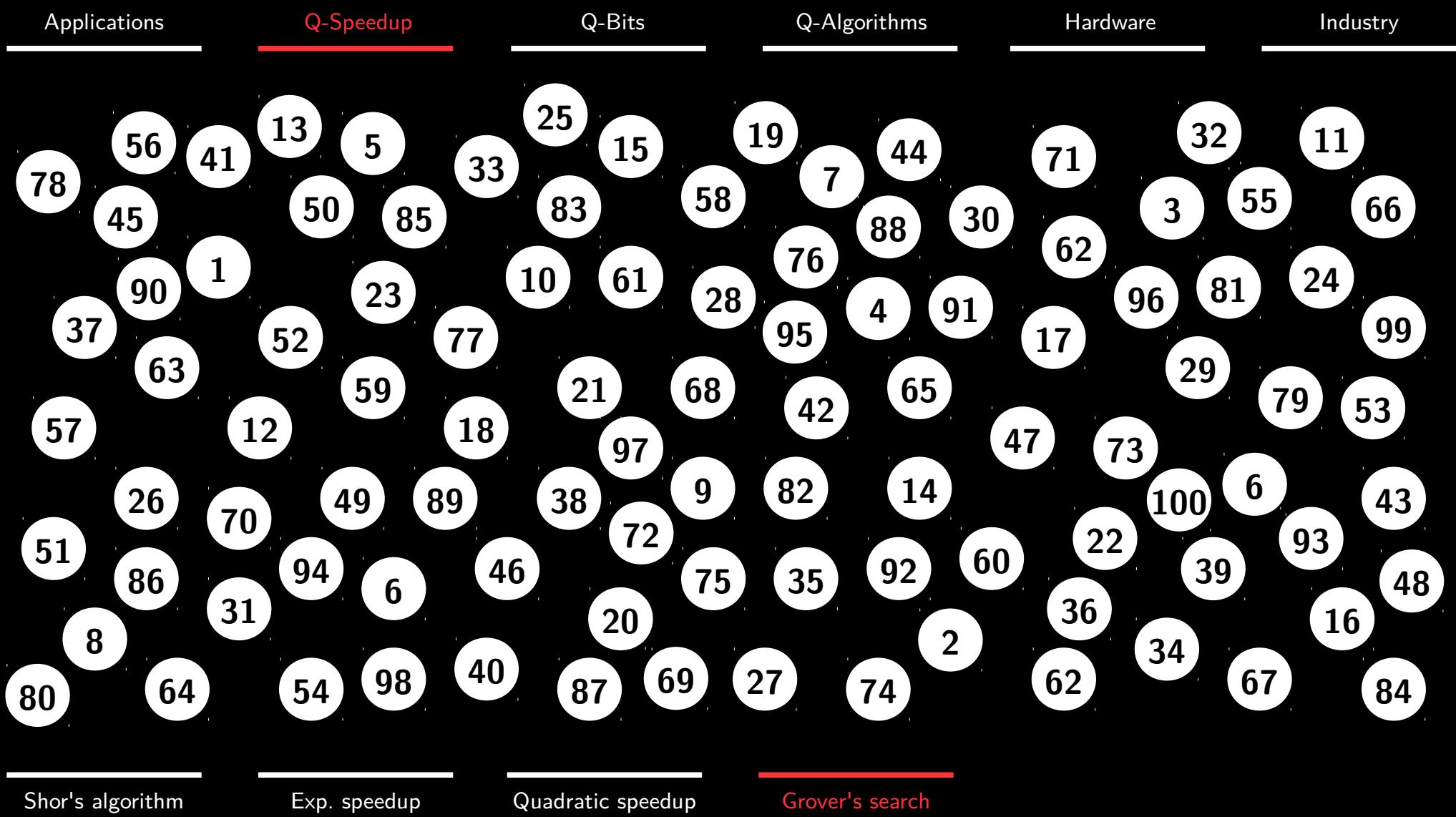
Exp. speedup

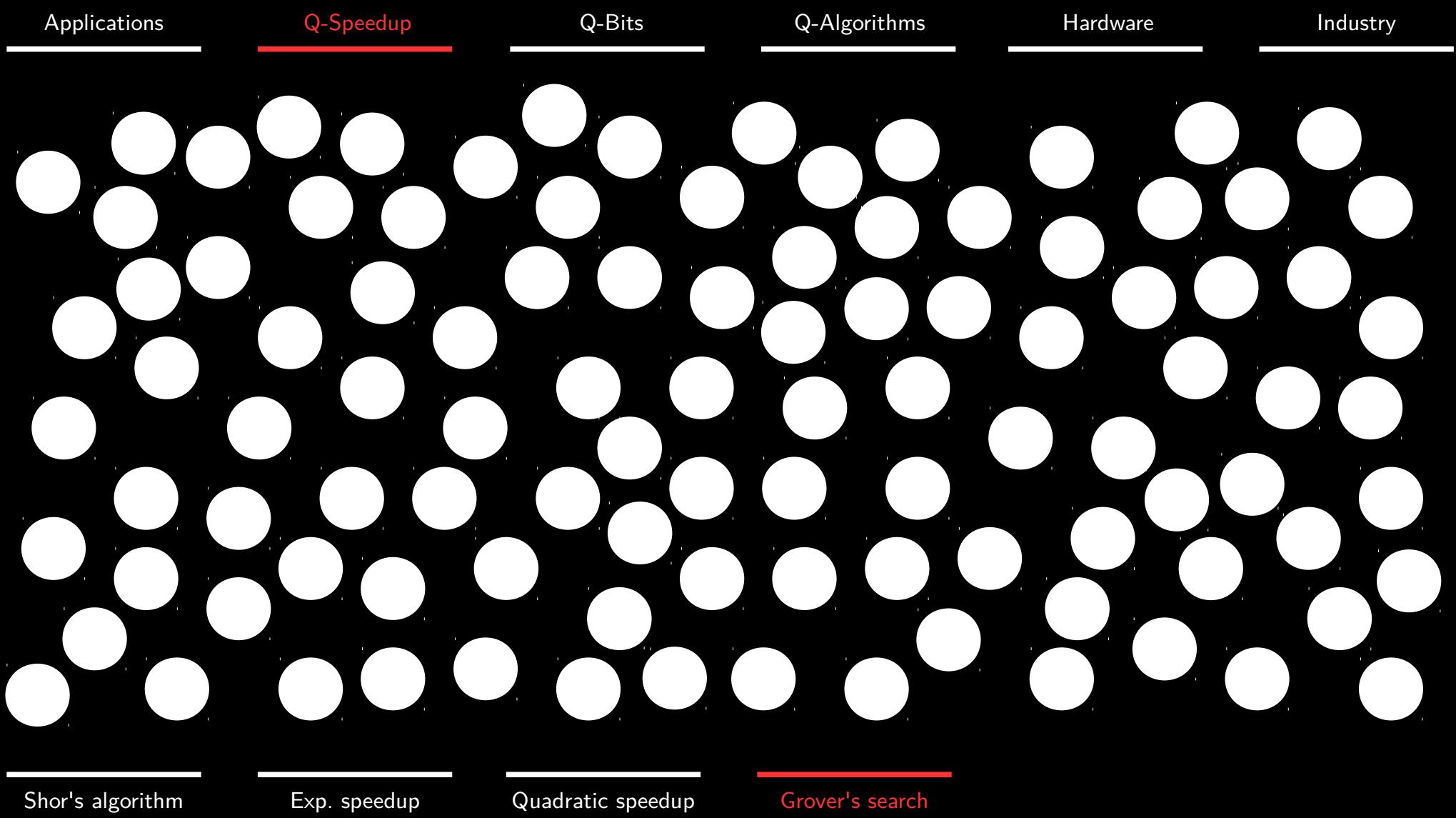
Quadratic speedup

Grover's search

Task:

Searching unsorted database





Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

Classical

100

tries

Quantum

8

tries

Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Classical

n

tries

Quantum

\sqrt{n}

tries

Task:

Searching unsorted database

Quantum algorithm:

Grover's Search

Task:

Searching unsorted database

Quantum algorithm:

Grover's Search



Later in talk

Applications

Quantum Speedup

Quantum Bits

Quantum Algorithms

Hardware

Industry Landscape

Applications

Quantum Speedup

Quantum Bits

Quantum Algorithms

Hardware

Industry Landscape

1. Superposition

2. Entanglement

Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

1. Superposition

2. Entanglement

Superposition

Entanglement

Applications

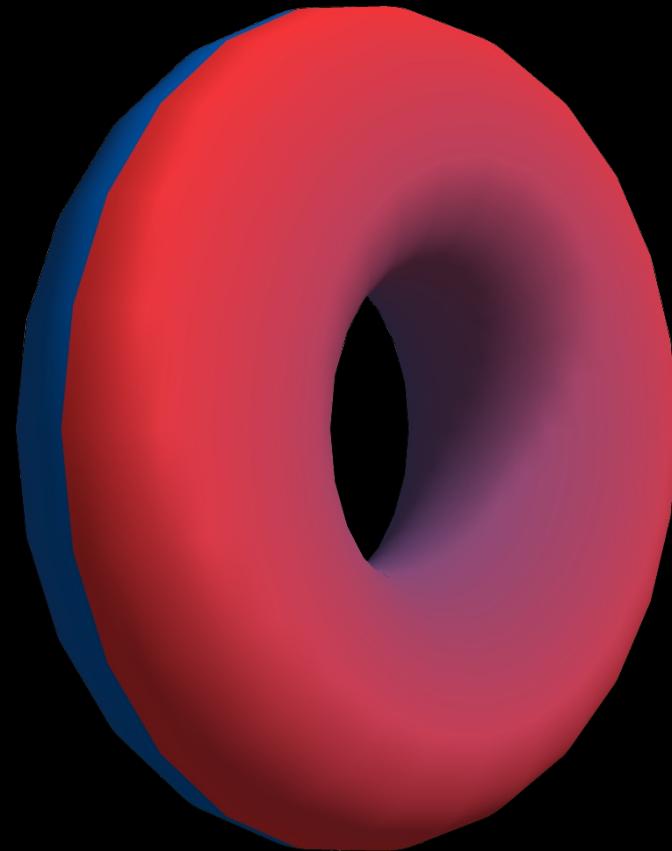
Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry



Superposition

Entanglement

Applications

Q-Speedup

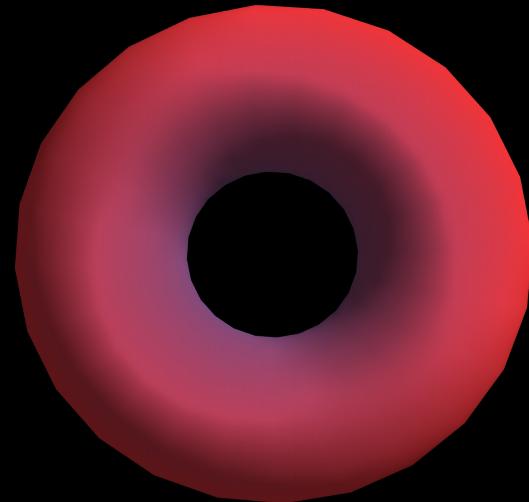
Q-Bits

Q-Algorithms

Hardware

Industry

Classical bit:



0

Superposition

Entanglement

Applications

Q-Speedup

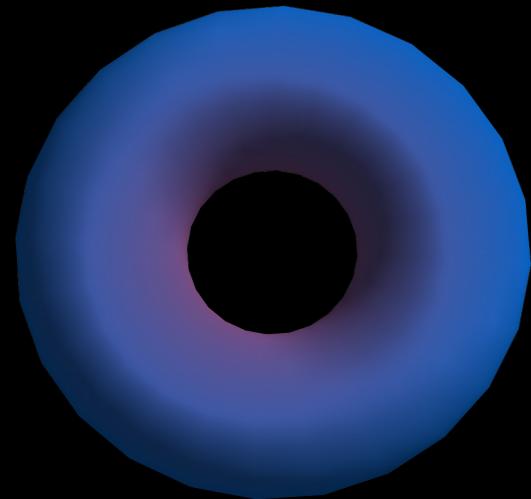
Q-Bits

Q-Algorithms

Hardware

Industry

Classical bit:



1

Superposition

Entanglement

Applications

Q-Speedup

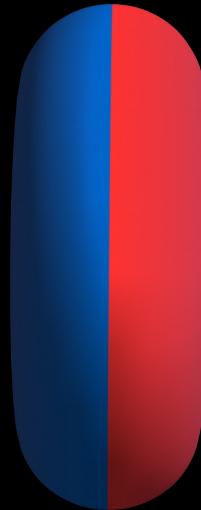
Q-Bits

Q-Algorithms

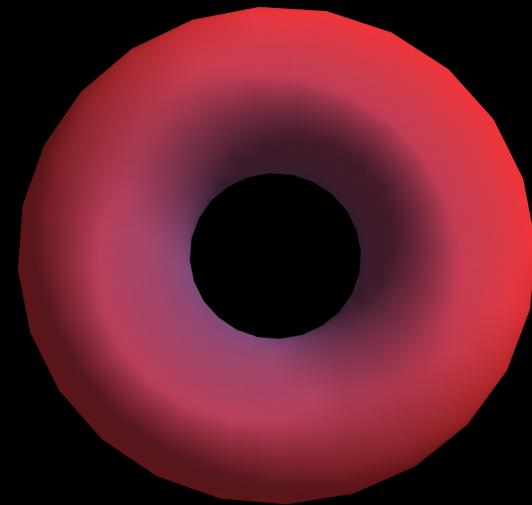
Hardware

Industry

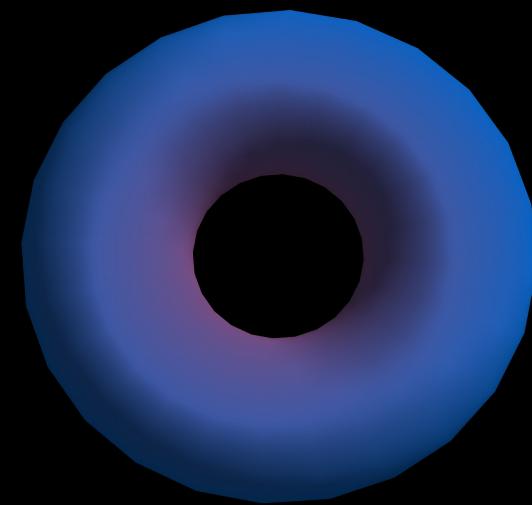
Superposition:



=



+



50%

50%

Superposition

Entanglement

Applications

Q-Speedup

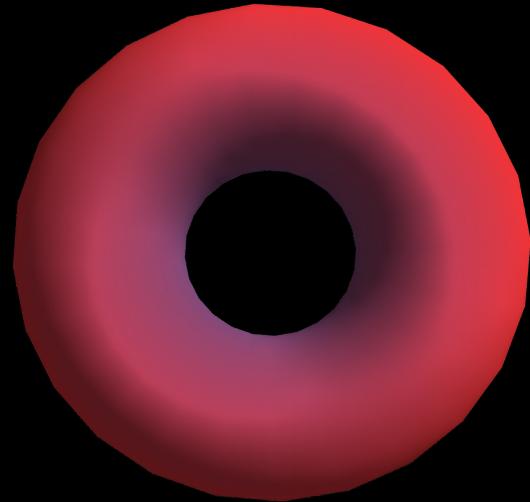
Q-Bits

Q-Algorithms

Hardware

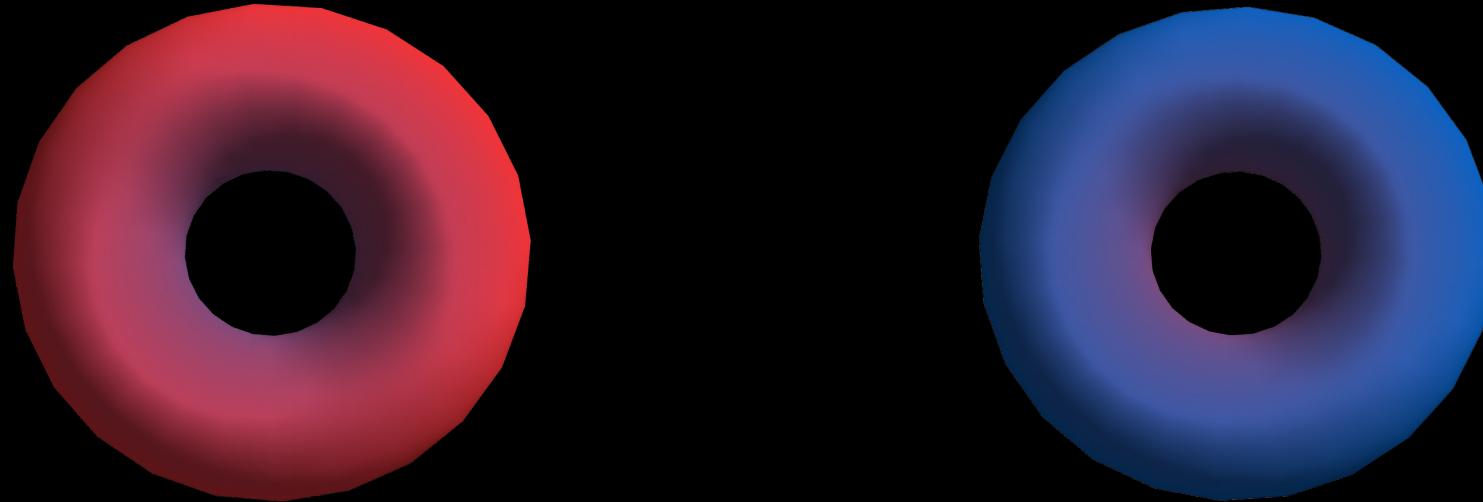
Industry

Measurement:



50%

Superposition



50%

Entanglement

Applications

Q-Speedup

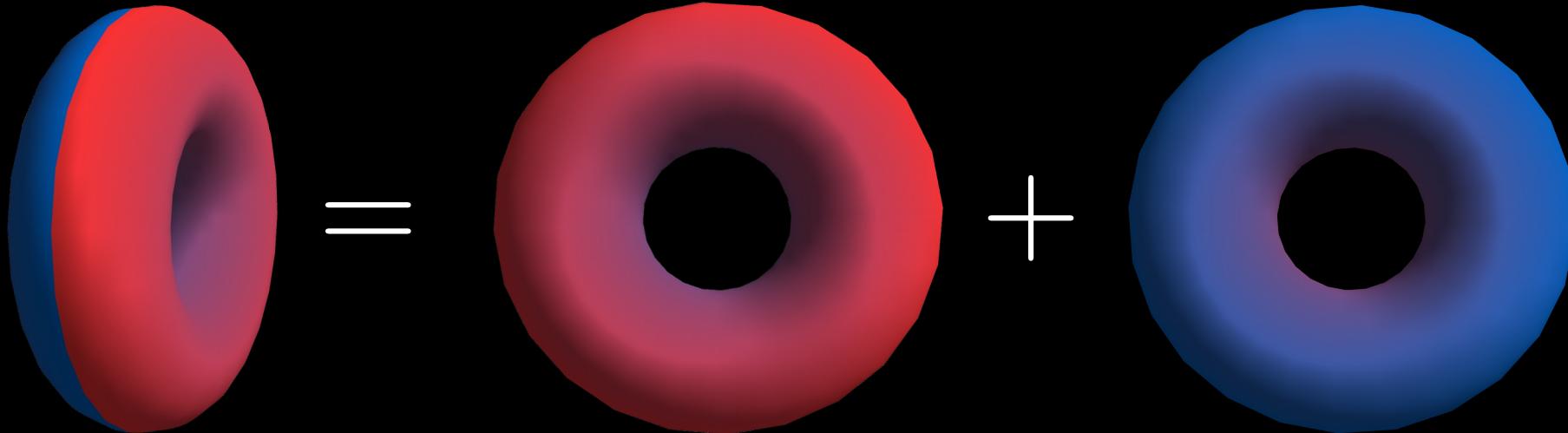
Q-Bits

Q-Algorithms

Hardware

Industry

Superposition:



70%

30%

Superposition

Entanglement

Applications

Q-Speedup

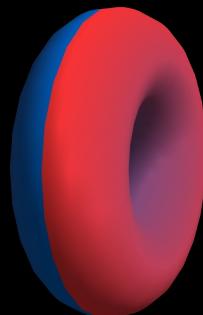
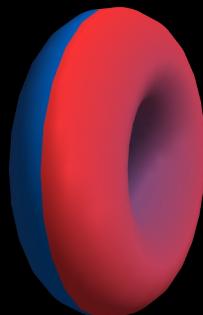
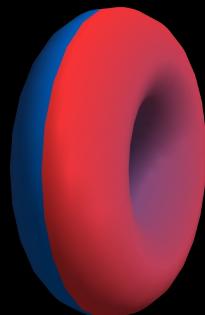
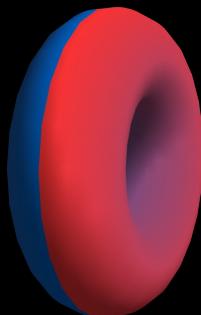
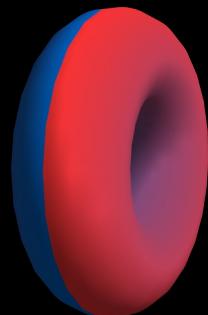
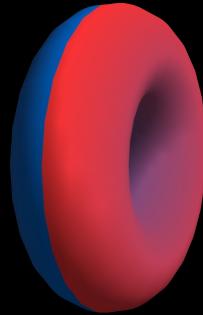
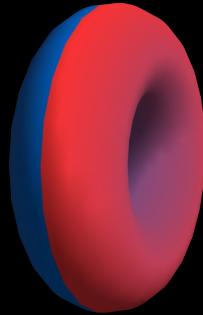
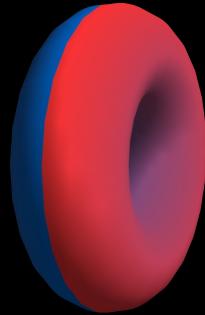
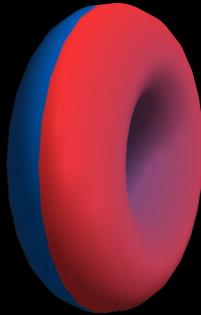
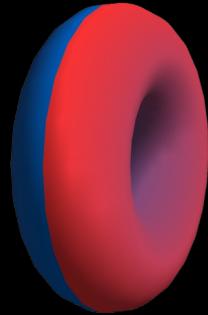
Q-Bits

Q-Algorithms

Hardware

Industry

Multiple qubits:



Superposition

Entanglement

Applications

Q-Speedup

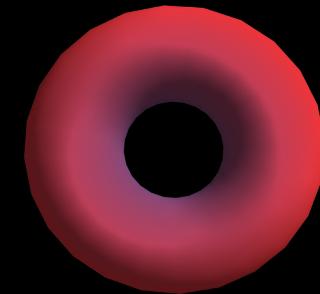
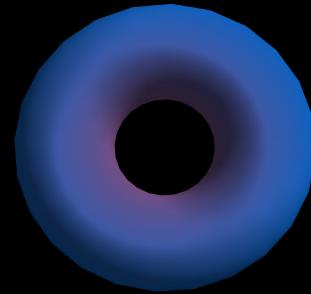
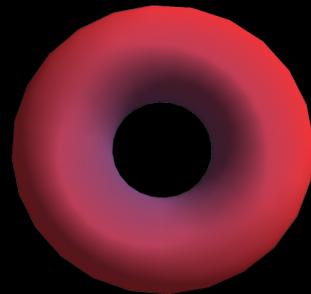
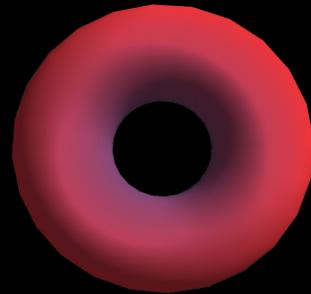
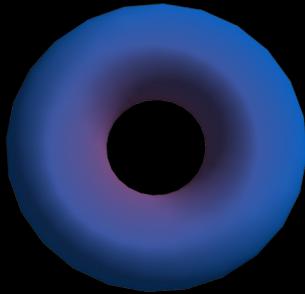
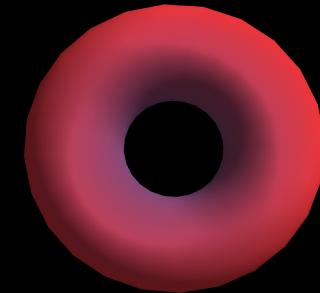
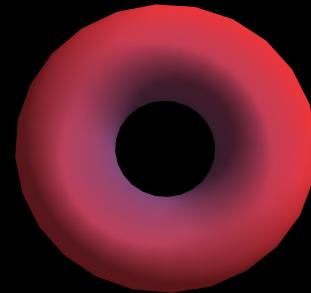
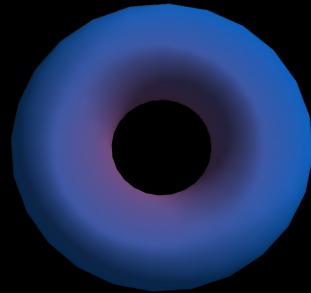
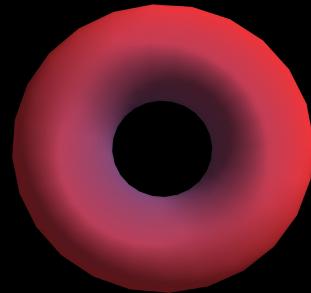
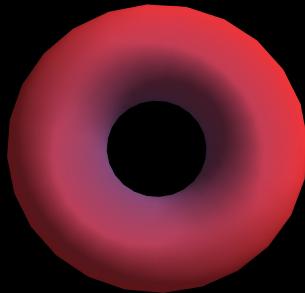
Q-Bits

Q-Algorithms

Hardware

Industry

Multiple measurements:



Superposition

Entanglement

Applications

Q-Speedup

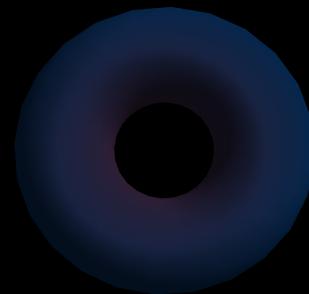
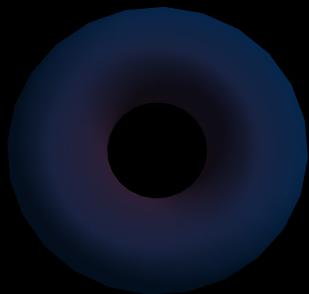
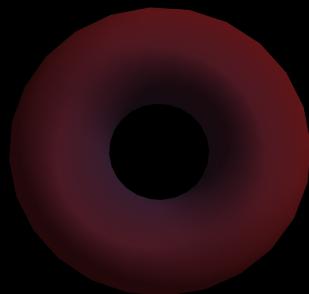
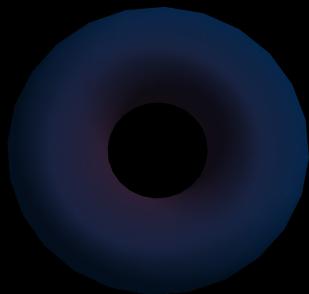
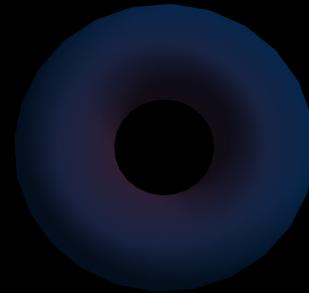
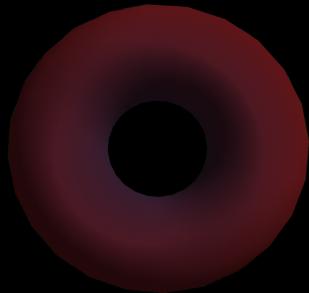
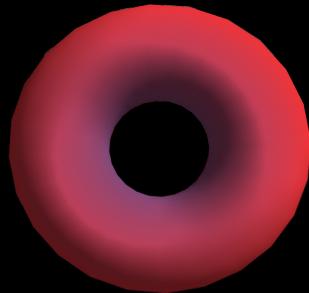
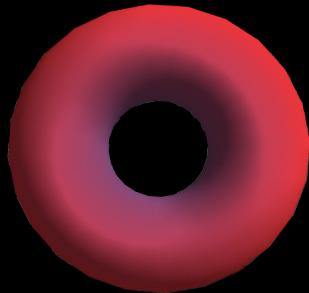
Q-Bits

Q-Algorithms

Hardware

Industry

2 (classical) bits:



Superposition

Entanglement

Applications

Q-Speedup

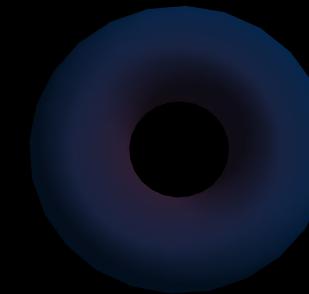
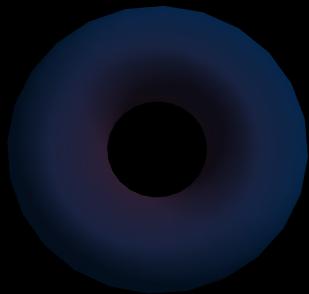
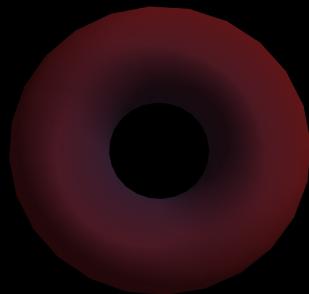
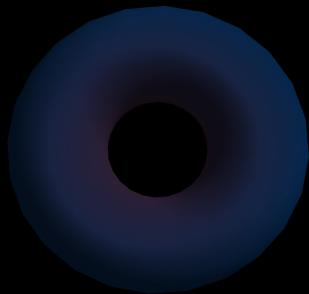
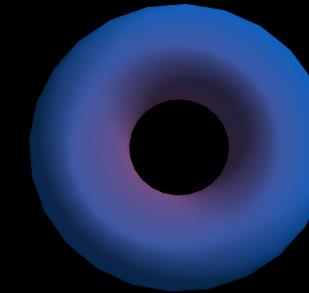
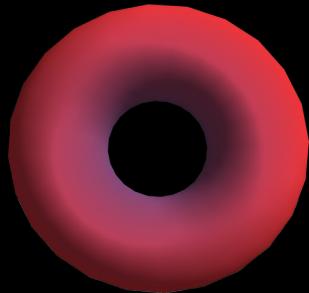
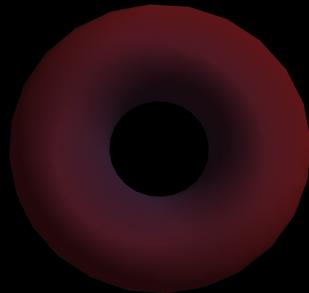
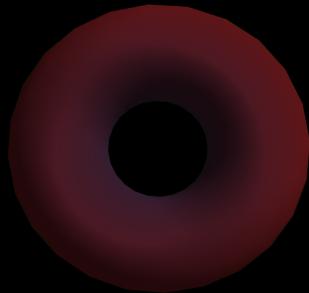
Q-Bits

Q-Algorithms

Hardware

Industry

2 (classical) bits:



Superposition

Entanglement

Applications

Q-Speedup

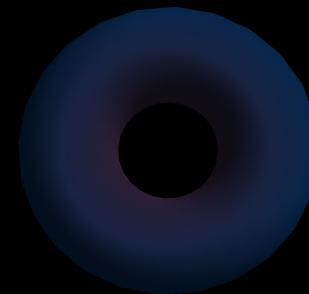
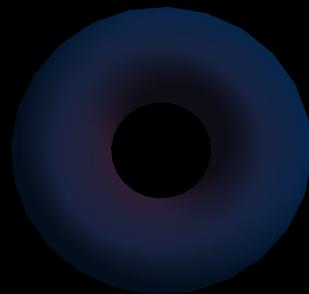
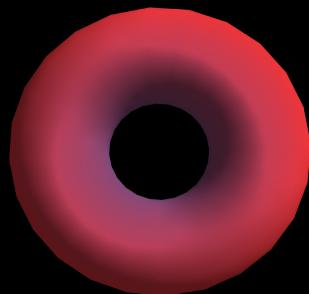
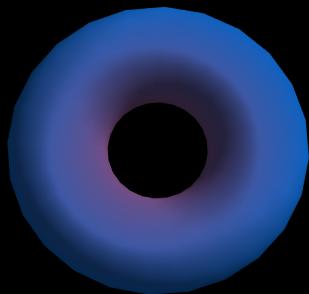
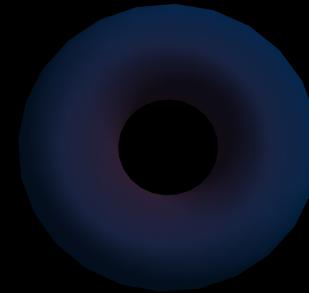
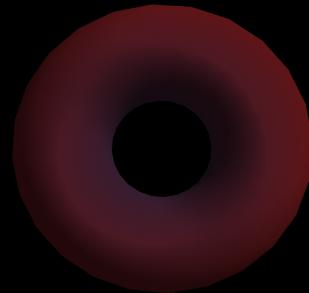
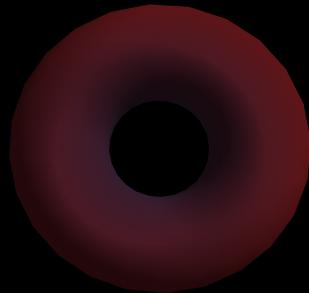
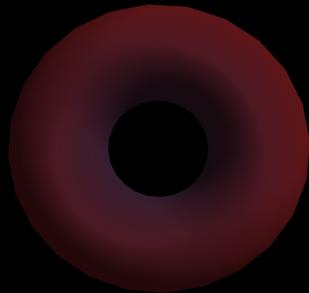
Q-Bits

Q-Algorithms

Hardware

Industry

2 (classical) bits:



Superposition

Entanglement

Applications

Q-Speedup

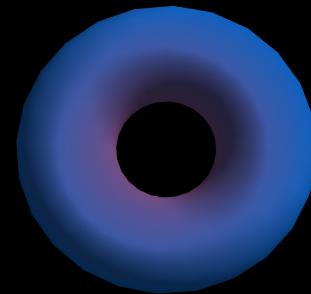
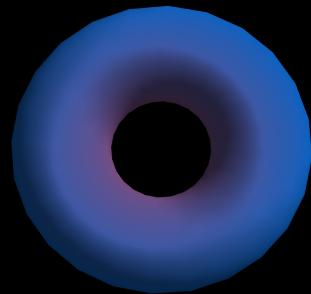
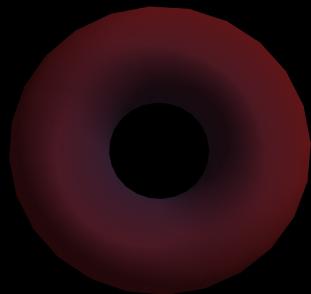
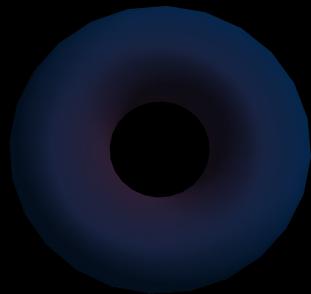
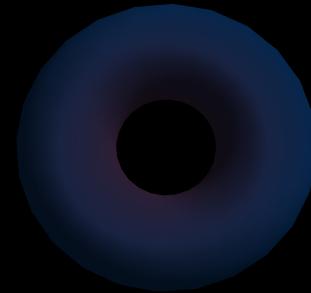
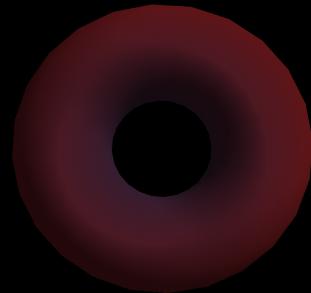
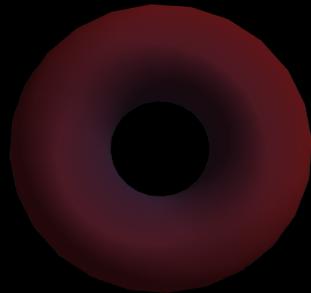
Q-Bits

Q-Algorithms

Hardware

Industry

2 (classical) bits:



Superposition

Entanglement

Applications

Q-Speedup

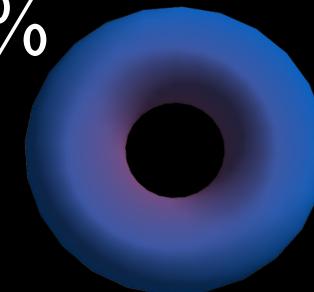
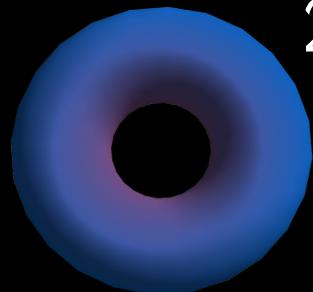
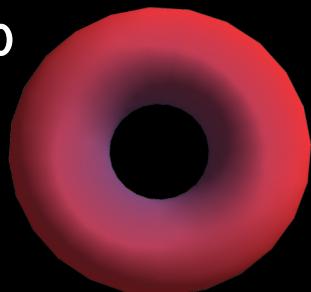
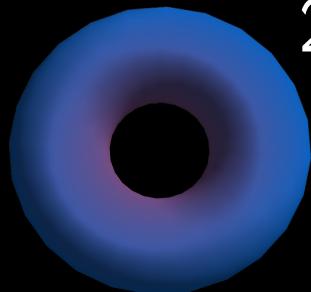
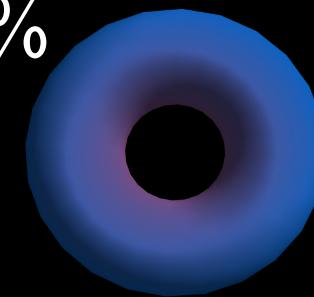
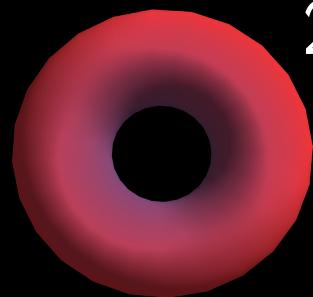
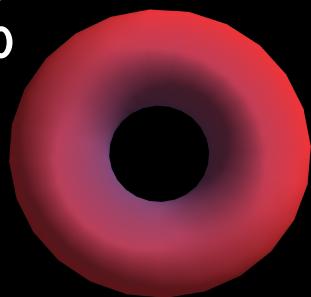
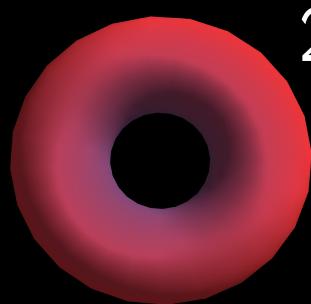
Q-Bits

Q-Algorithms

Hardware

Industry

2 qubits:



Superposition

Entanglement

Applications

Q-Speedup

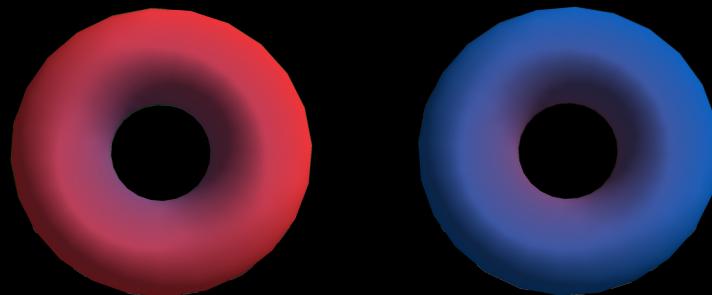
Q-Bits

Q-Algorithms

Hardware

Industry

2 (classical) bits:



1st bit



2nd bit

of information

of information

Superposition

Entanglement

Applications

Q-Speedup

Q-Bits

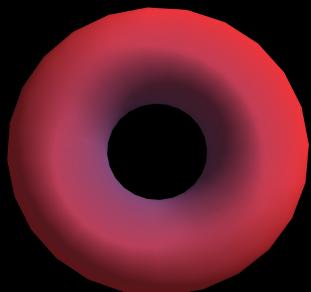
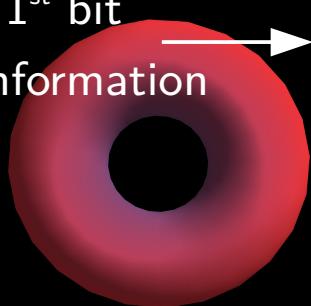
Q-Algorithms

Hardware

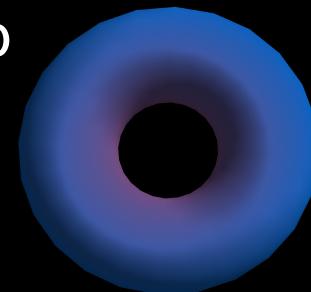
Industry

2 qubits:

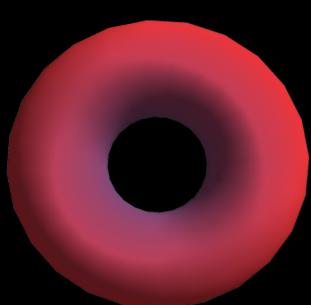
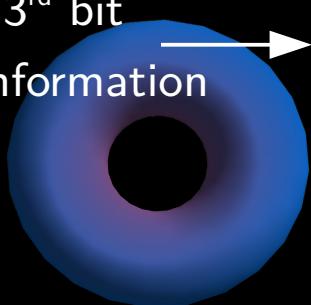
1st bit
of information → ?%



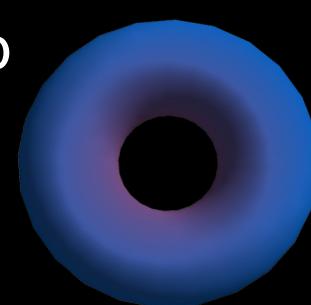
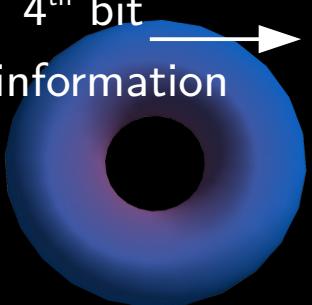
2nd bit
of information → ?%



3rd bit
of information → ?%



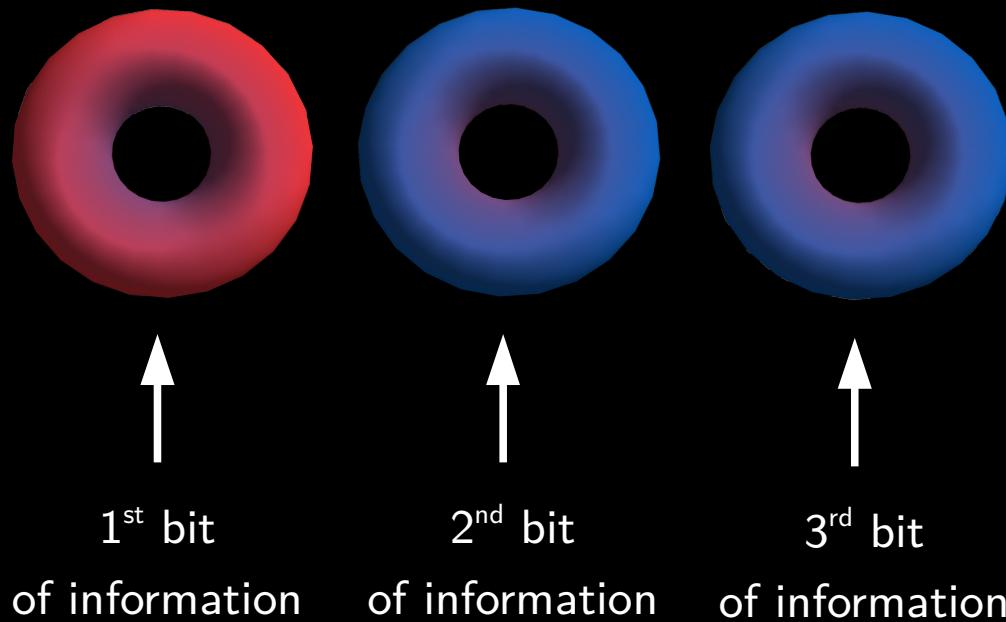
4th bit
of information → ?%



Superposition

Entanglement

3 (classical) bits:



Applications

Q-Speedup

Q-Bits

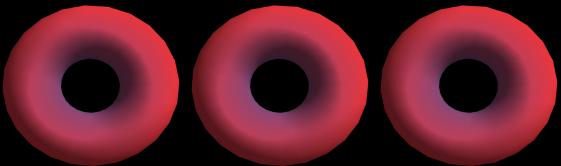
Q-Algorithms

Hardware

Industry

3 qubits:

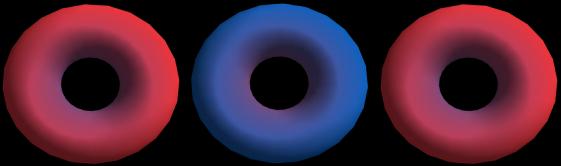
1st bit
of information → ?%



2nd bit
of information → ?%



3rd bit
of information → ?%



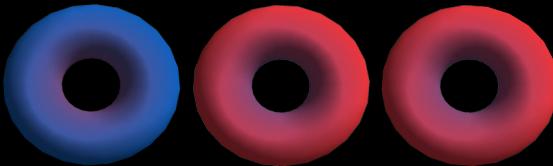
4th bit
of information → ?%



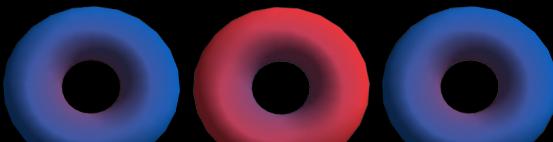
Superposition

Entanglement

5th bit
of information → ?%



6th bit
of information → ?%



7th bit
of information → ?%



8th bit
of information → ?%



Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

n

qubits

2^n

bits

Superposition

Entanglement

Applications

Q-Speedup

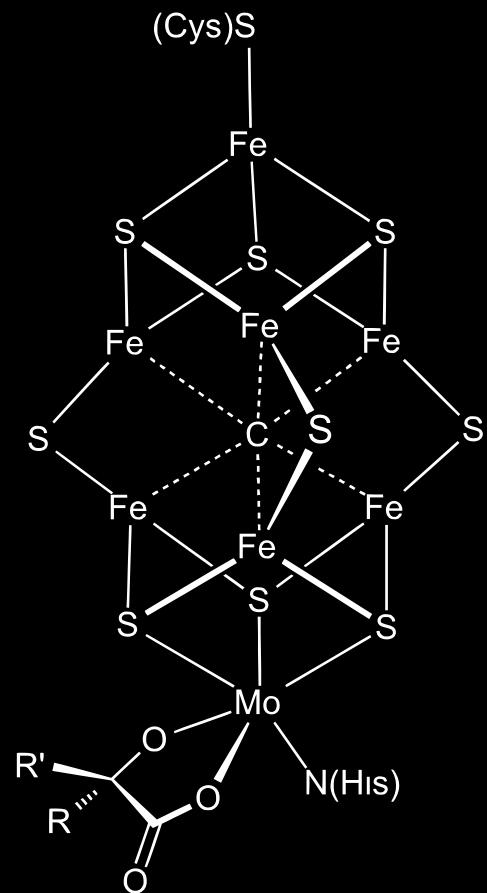
Q-Bits

Q-Algorithms

Hardware

Industry

108
qubits



2^{108}

$\approx 10^{32}$
bits

Superposition

Entanglement

Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

1. Superposition

2. Entanglement

Superposition

Entanglement

Applications

Q-Speedup

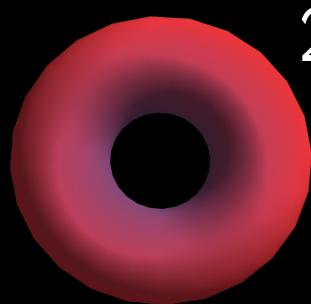
Q-Bits

Q-Algorithms

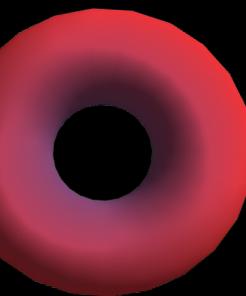
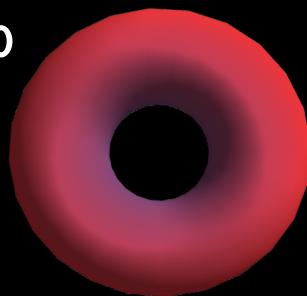
Hardware

Industry

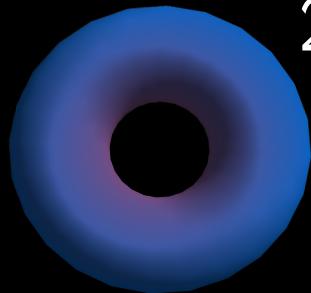
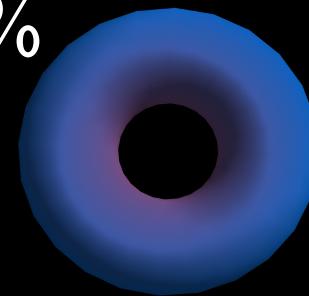
Superposition:



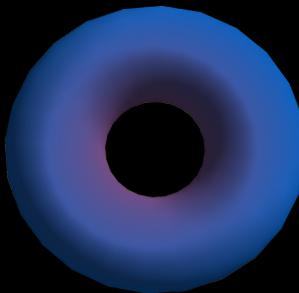
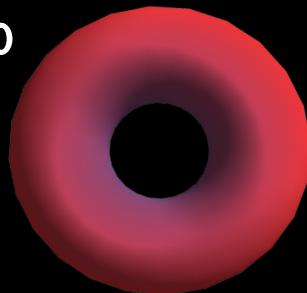
25%



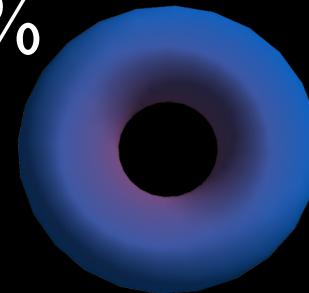
25%



25%



25%



Superposition

Entanglement

Applications

Q-Speedup

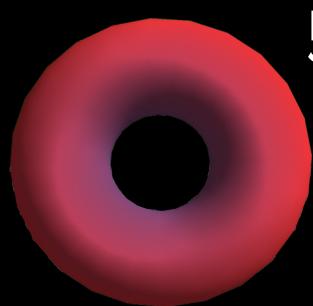
Q-Bits

Q-Algorithms

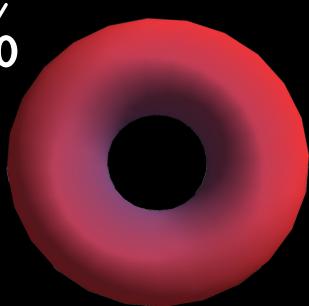
Hardware

Industry

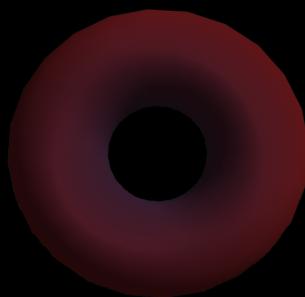
Entanglement:



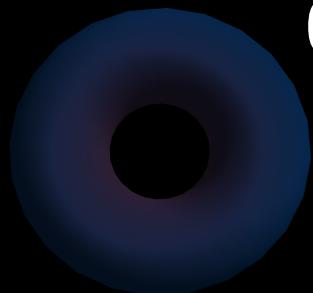
50%



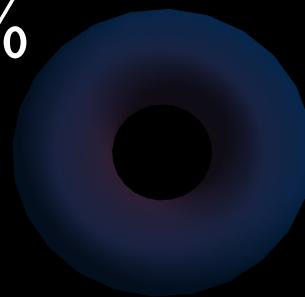
0%



0%



50%



Superposition

Entanglement

Applications

Q-Speedup

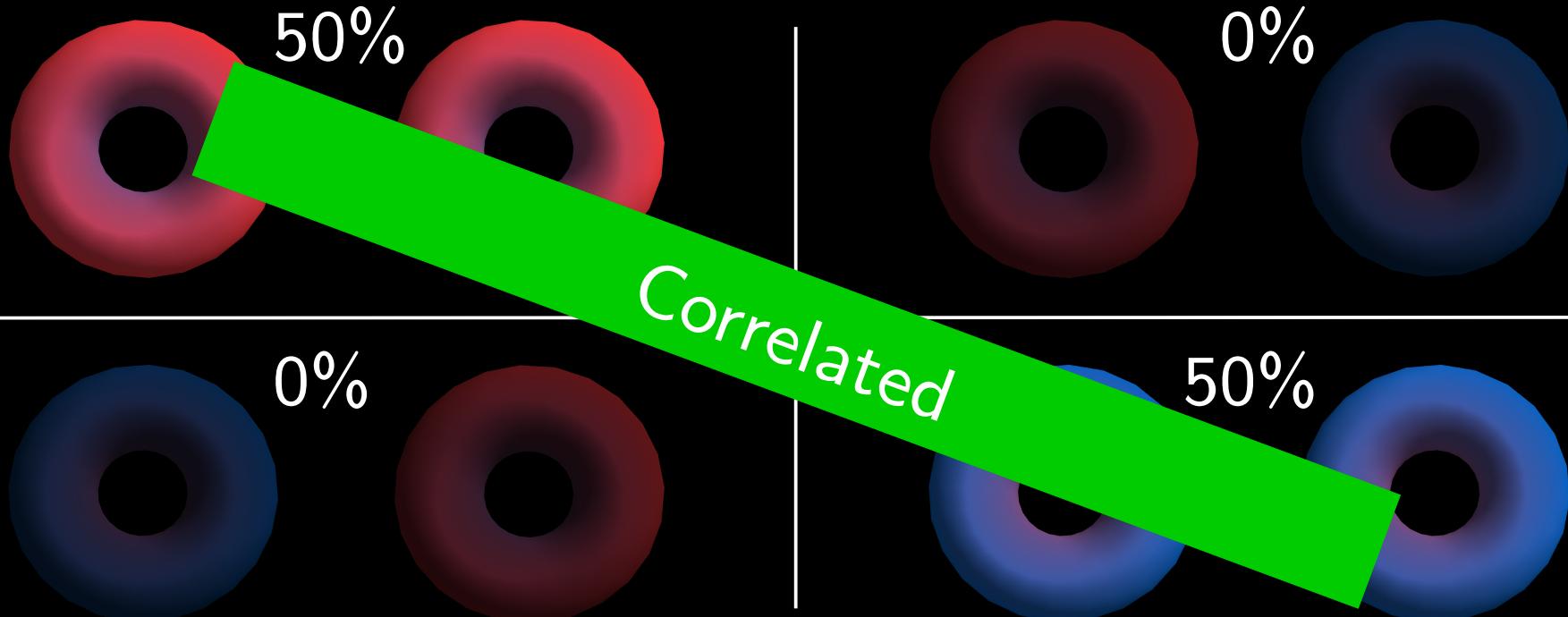
Q-Bits

Q-Algorithms

Hardware

Industry

Entanglement:



Superposition

Entanglement

Applications

Q-Speedup

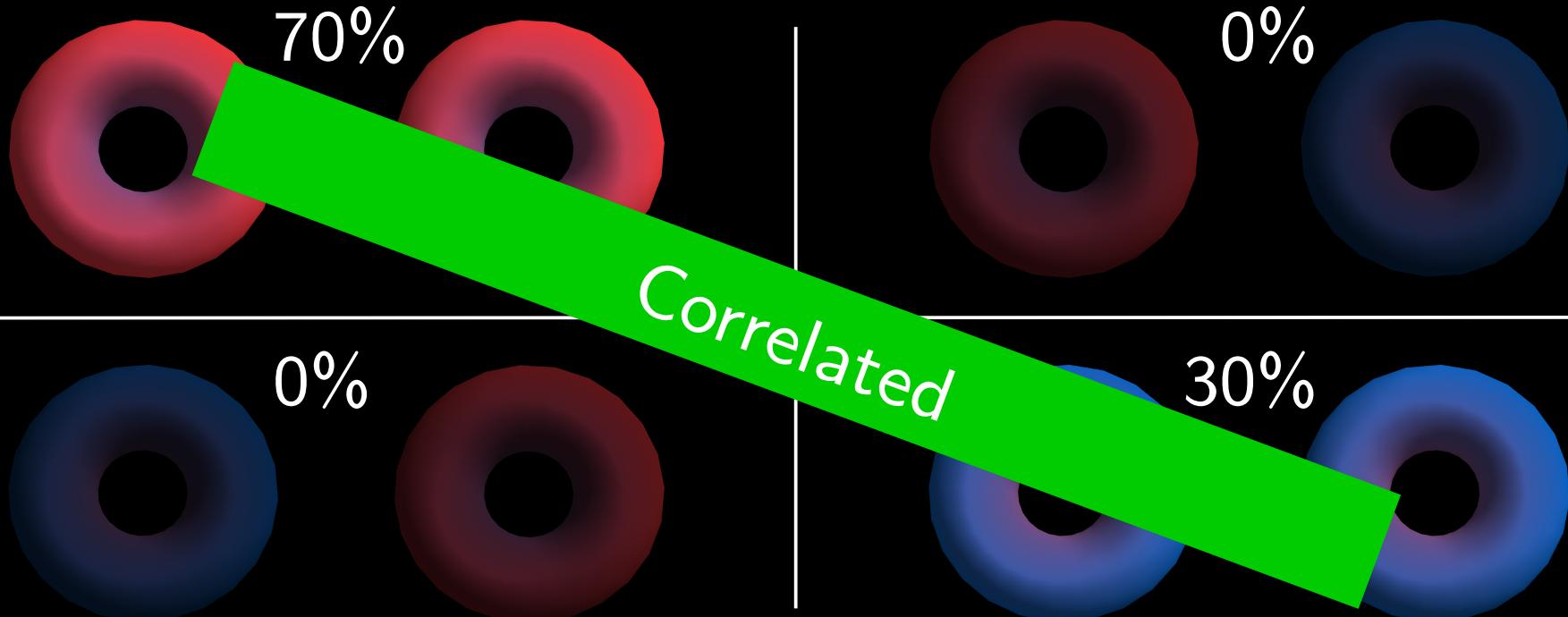
Q-Bits

Q-Algorithms

Hardware

Industry

Entanglement:



Superposition

Entanglement

Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

Entanglement:

0%



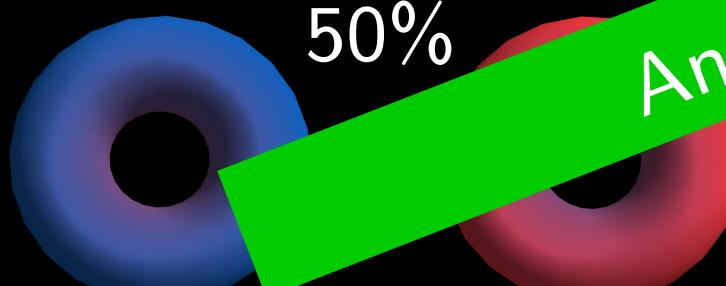
0%



50%

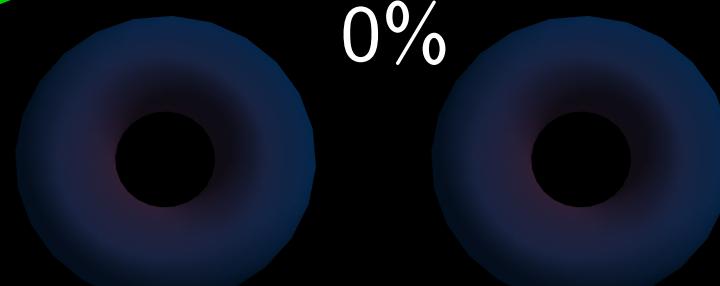


50%



Anti-Correlated

0%



Superposition

Entanglement

Applications

Quantum Speedup

Quantum Bits

Quantum Algorithms

Hardware

Industry Landscape

Applications

Quantum Speedup

Quantum Bits

Quantum Algorithms

Hardware

Industry Landscape

Analog vs Digital quantum computing

Digital: In digital computing, a succession of gates is applied to the qubits to implement a quantum algorithms. Each gate is performed by addressing the qubits individually.

Analog: Some QPUs naturally mimic the behaviour of some problems / other systems, we say they are analog systems. In analog processing all the qubits can be addressed simultaneously through a global evolution.

Analog vs Digital quantum computing

Digital: In digital computing, a succession of gates is applied to the qubits to implement a quantum algorithms. Each gate is performed by addressing the qubits individually.



Universal approach



Requires a large number of gates

Analog: Some QPUs naturally mimic the behaviour of some problems / other systems, we say they are analog systems. In analog processing all the qubits can be addressed simultaneously through a global evolution.



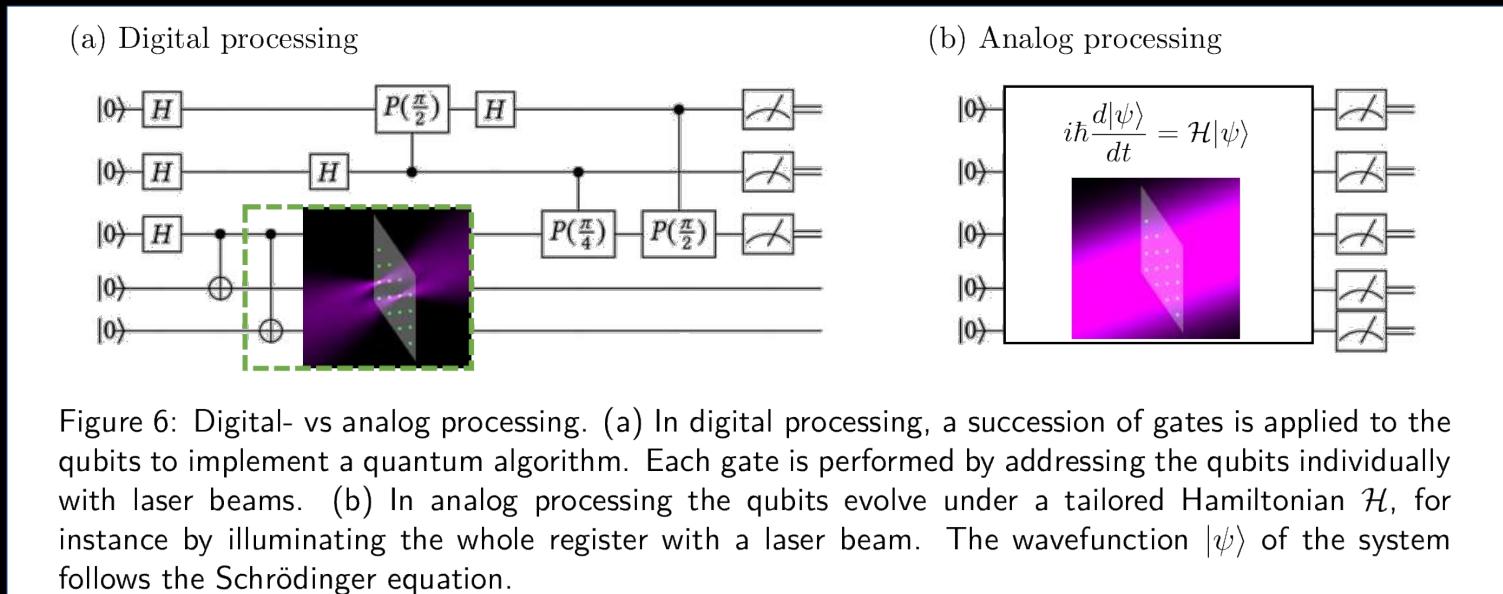
Resource efficient



Restricted to analog problems

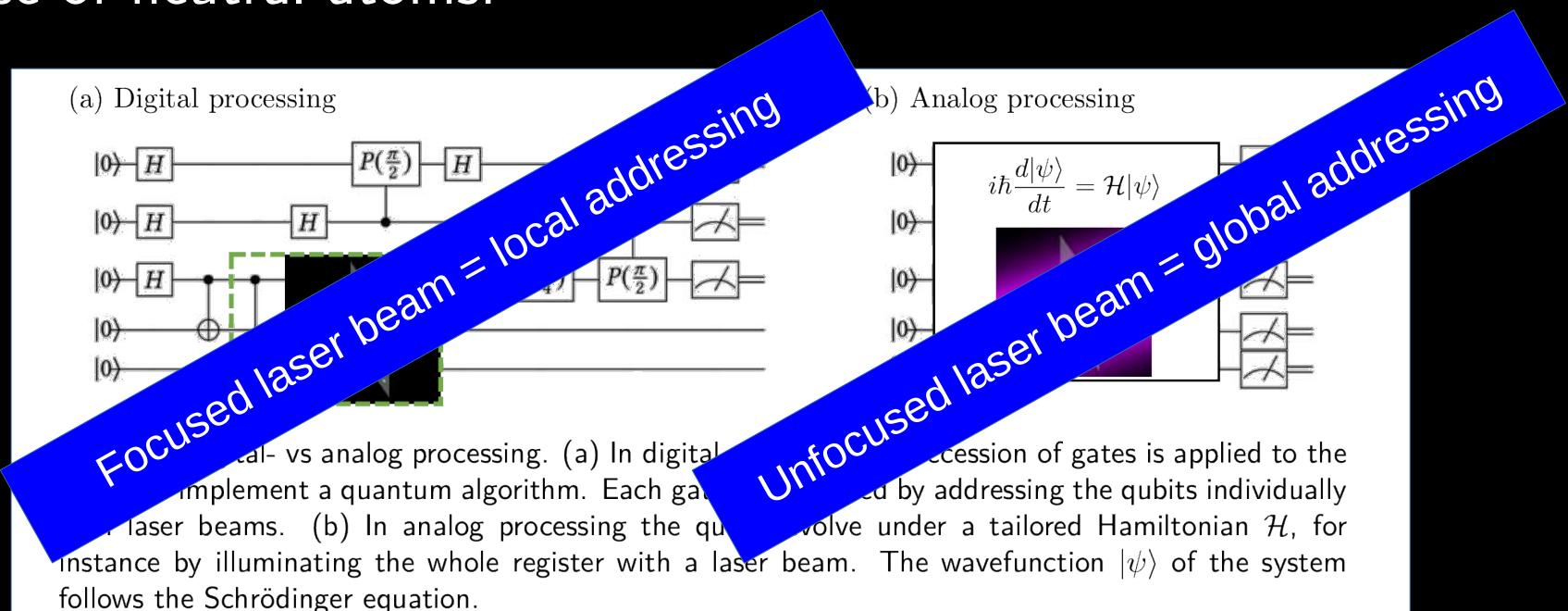
Analog vs Digital quantum computing

The case of neutral atoms:



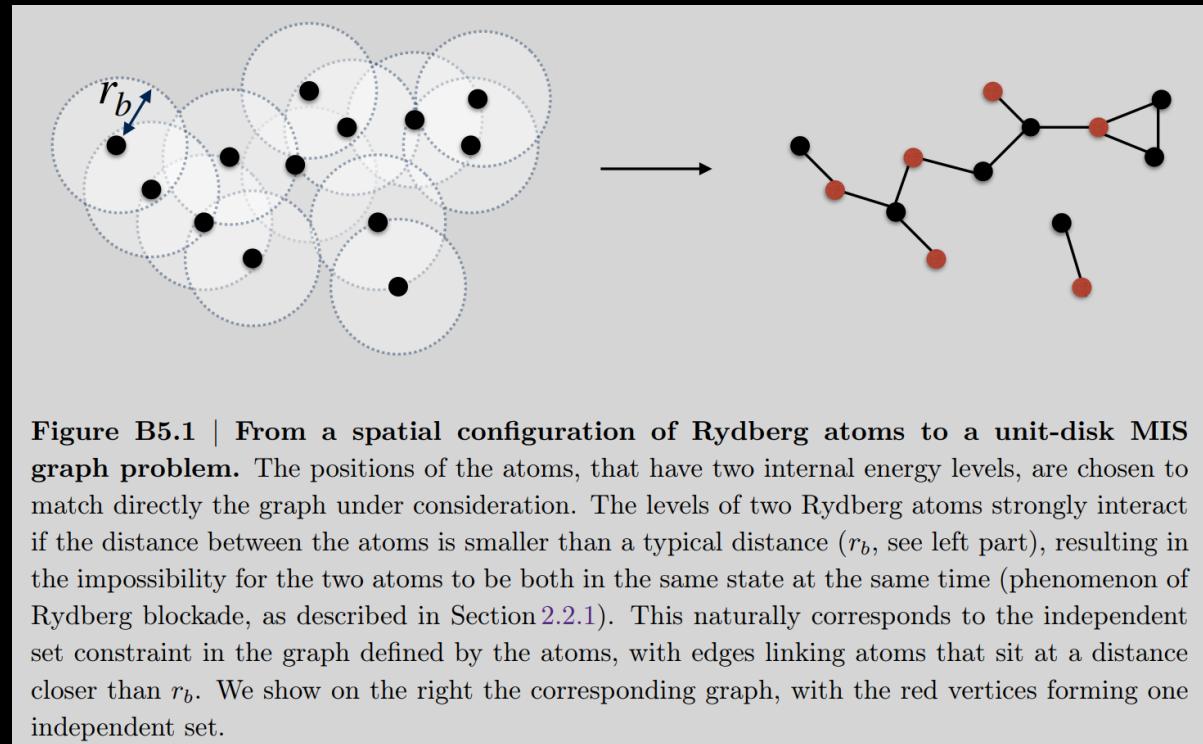
Analog vs Digital quantum computing

The case of neutral atoms:



Example analog problem with neutral atoms

The Maximum Independent Set graph optimization problem:



Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

Quantum gates

Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

Superposition



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Speedup

Q-Bits

Q-Algorithms

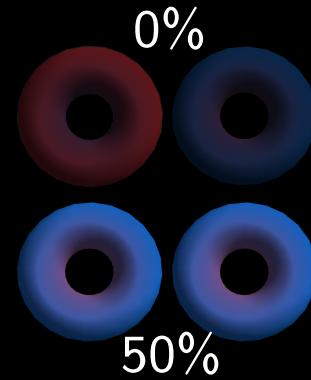
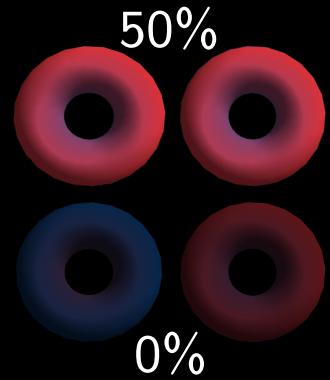
Hardware

Industry

Superposition



Entanglement



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Speedup

Q-Bits

Q-Algorithms

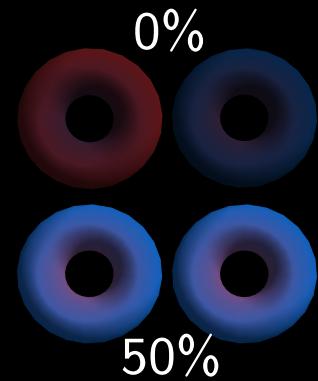
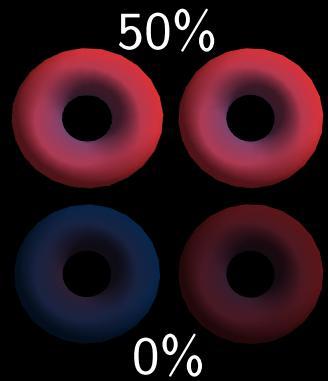
Hardware

Industry

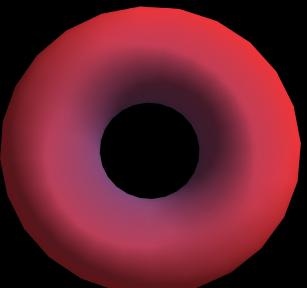
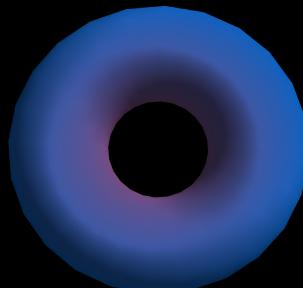
Superposition



Entanglement



Bit flip



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Speedup

Q-Bits

Q-Algorithms

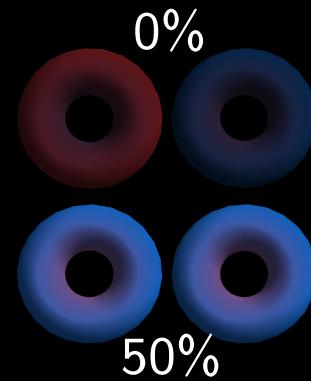
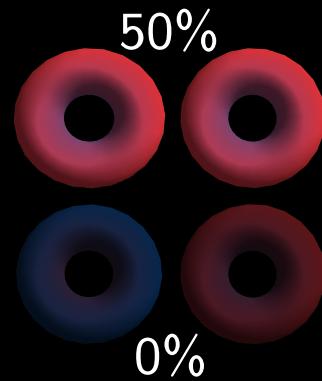
Hardware

Industry

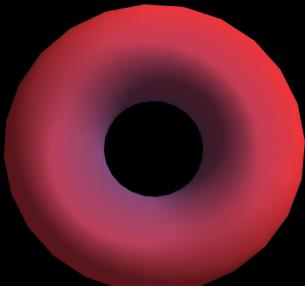
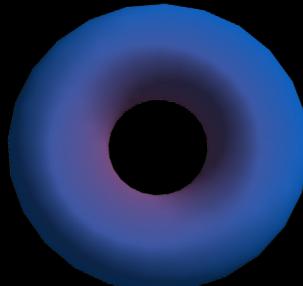
Superposition



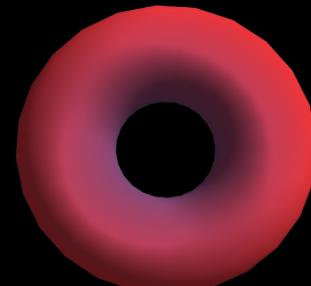
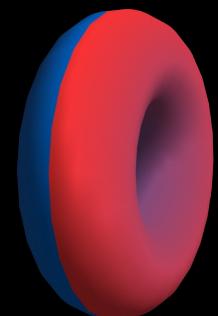
Entanglement



Bit flip



Measurement



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

Hadamard H-gate:



Operations on Q-Bits

Q-Gates

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Applications

Q-Speedup

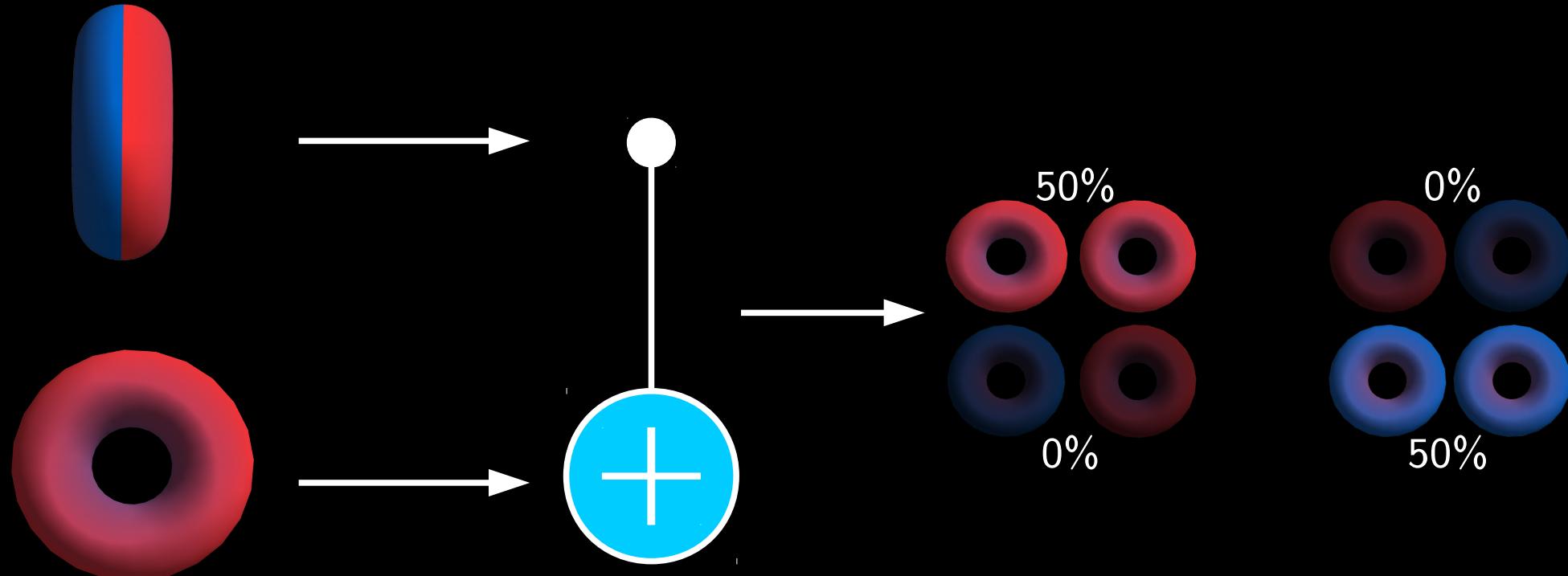
Q-Bits

Q-Algorithms

Hardware

Industry

C-NOT gate:



Operations on Q-Bits

Q-Gates

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Grover's search

Applications

Q-Speedup

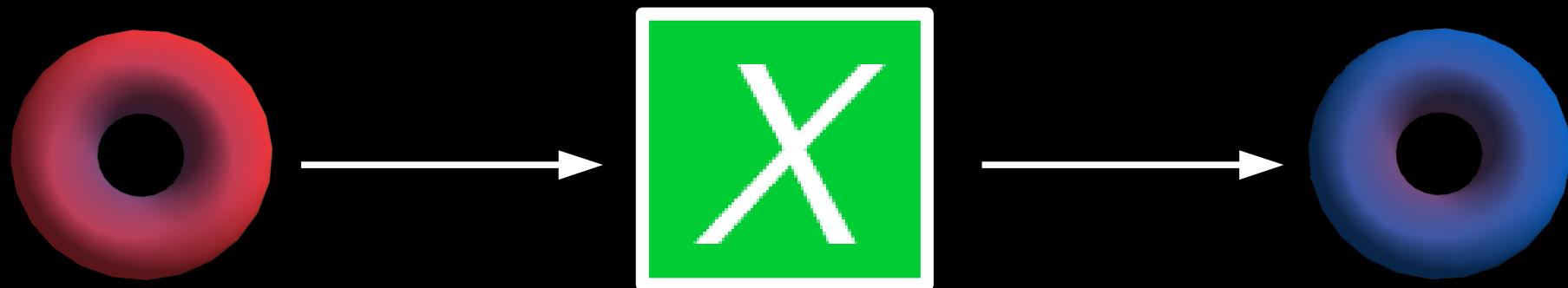
Q-Bits

Q-Algorithms

Hardware

Industry

Bit flip X-gate:



Operations on Q-Bits

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Applications

Q-Speedup

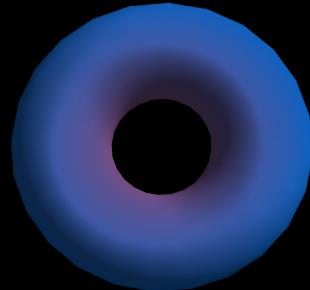
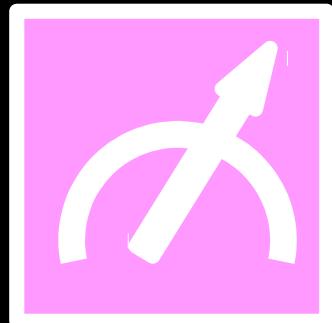
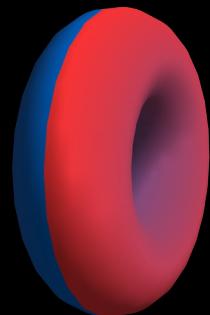
Q-Bits

Q-Algorithms

Hardware

Industry

Measurement:



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Speedup

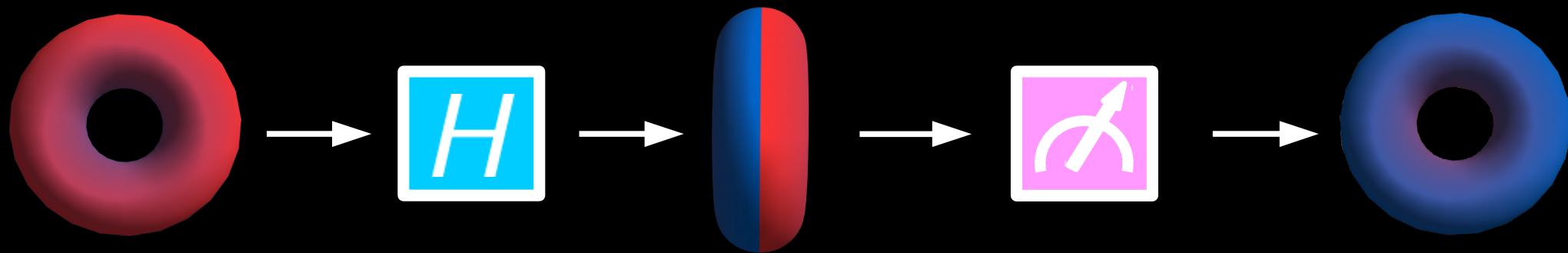
Q-Bits

Q-Algorithms

Hardware

Industry

Quantum circuit:



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Speedup

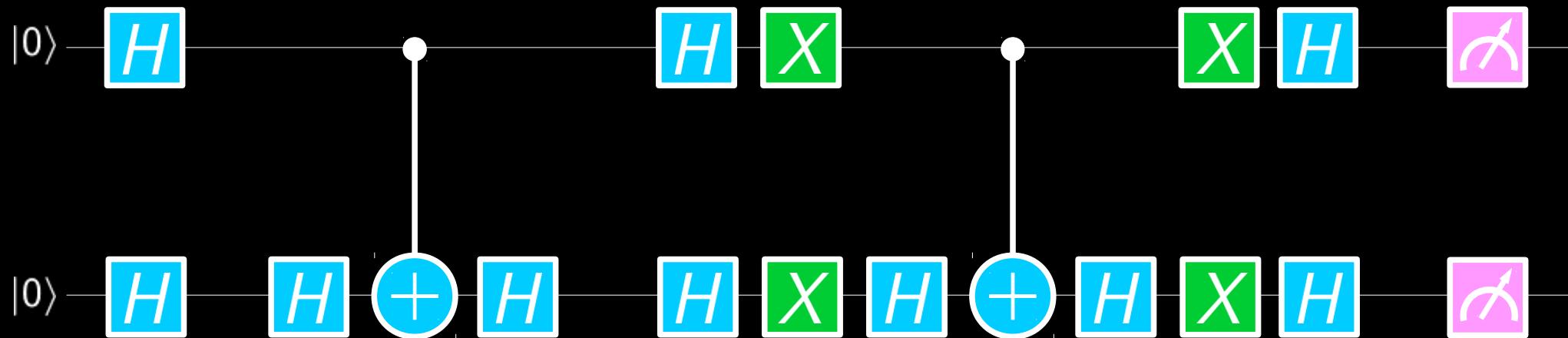
Q-Bits

Q-Algorithms

Hardware

Industry

Grover's search:



Operations on Q-Bits

Q-Gates

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Grover's search

Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

Grover's search:

0

2

3

1

Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Grover's search:

0

2

3

1

Classical

Quantum

4

1

tries

try

Grover's search:

Number Bits

0

00

1

01

2

10

3

11

Grover's search:

Number Bits

0

00

1

01

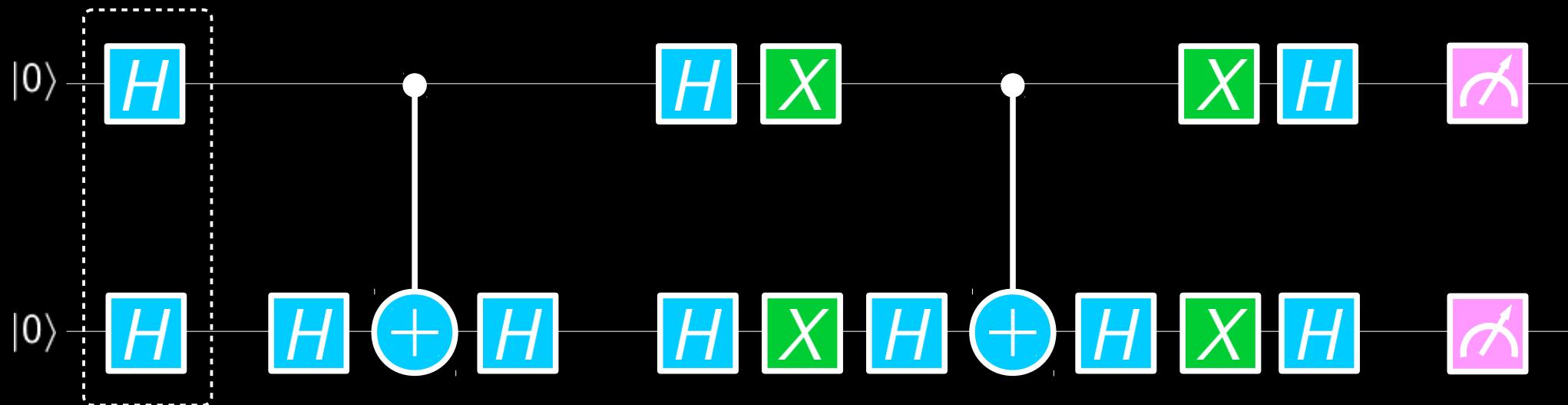
2

10

3

11

Grover's search: Step 1 – Superposition



Applications

Q-Speedup

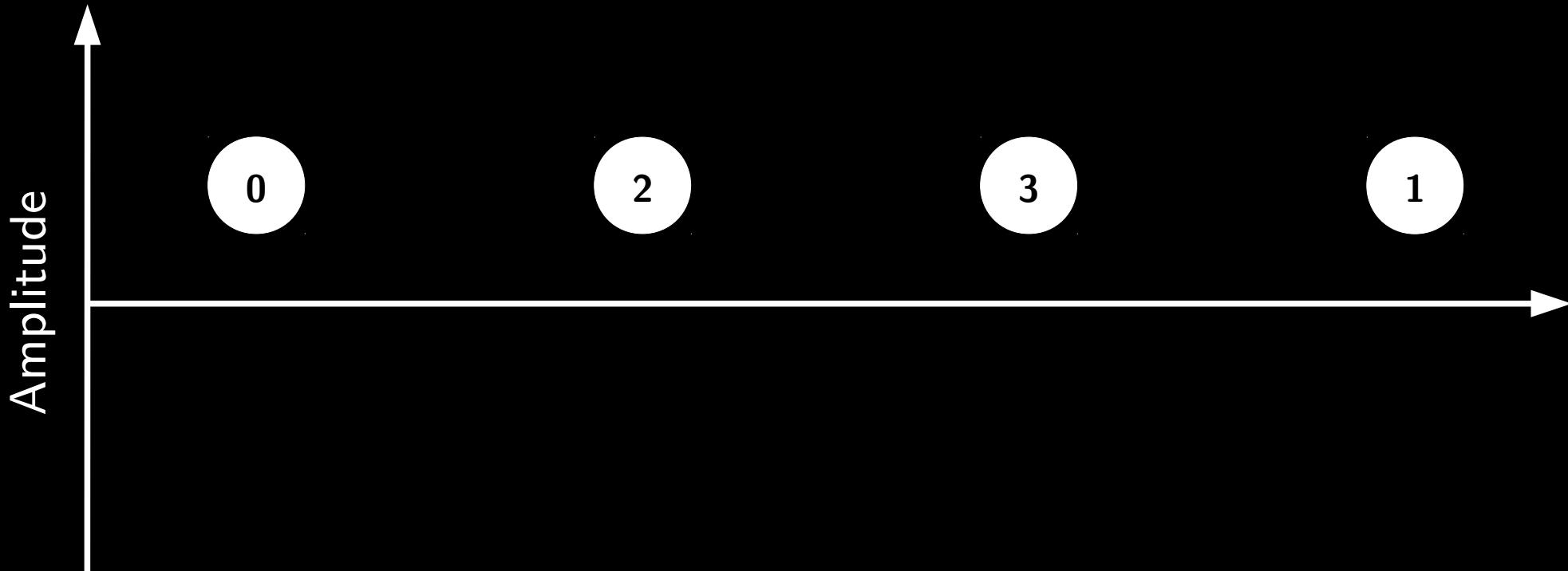
Q-Bits

Q-Algorithms

Hardware

Industry

Grover's search: Step 1 – Superposition



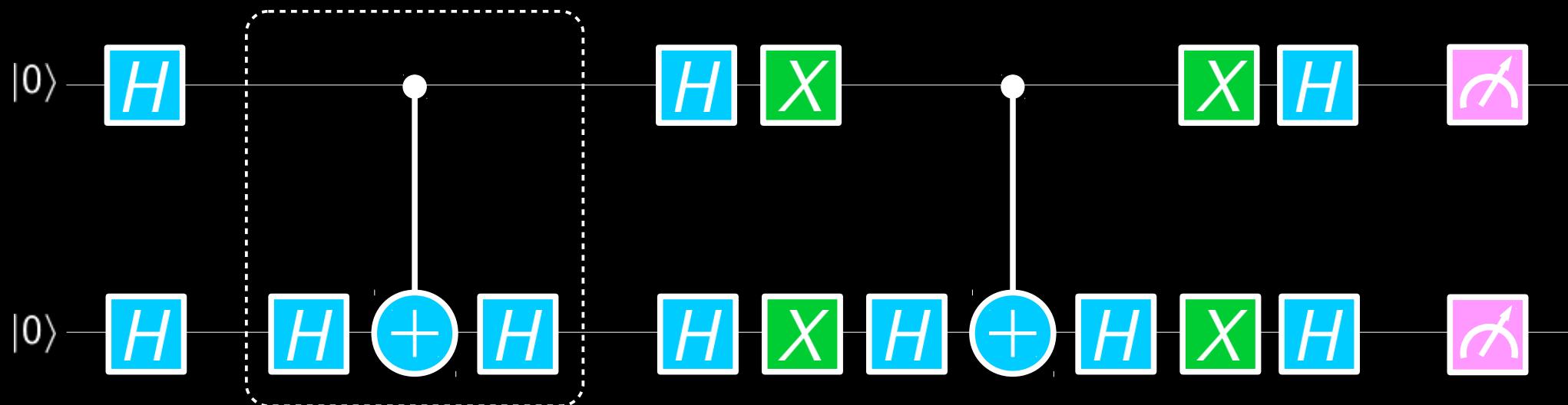
Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Grover's search: Step 2 – Oracle



Applications

Q-Speedup

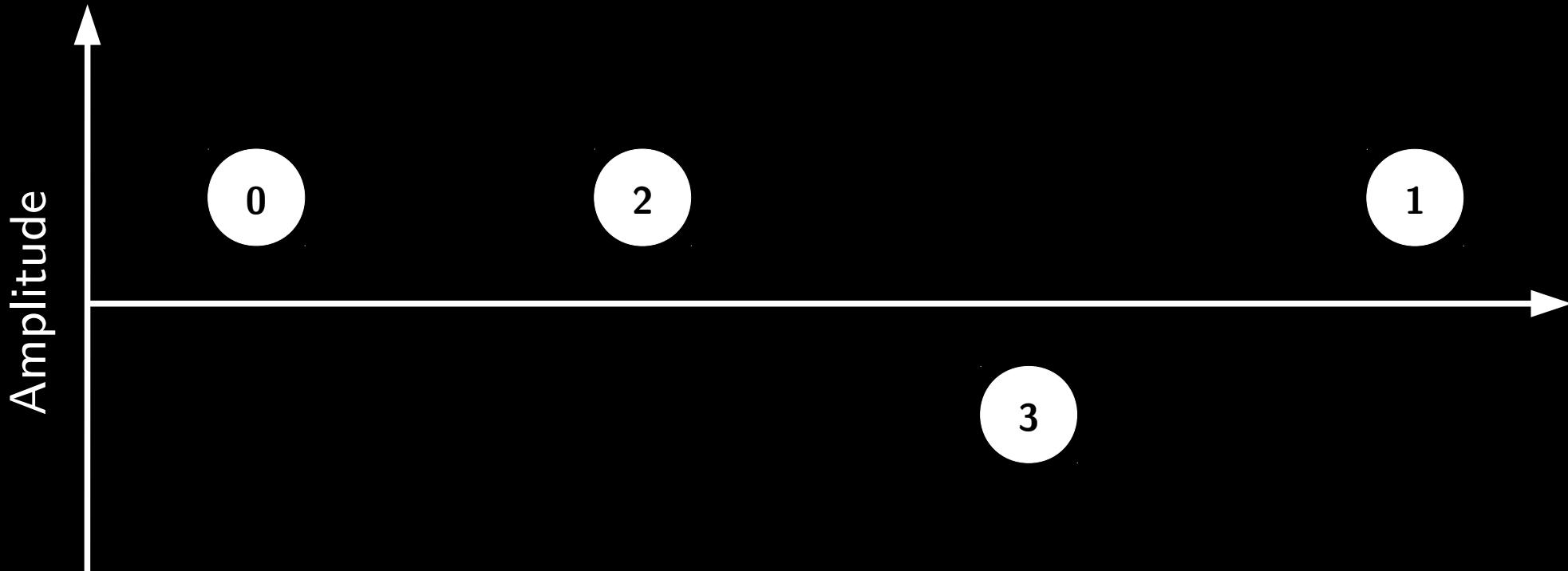
Q-Bits

Q-Algorithms

Hardware

Industry

Grover's search: Step 2 – Oracle



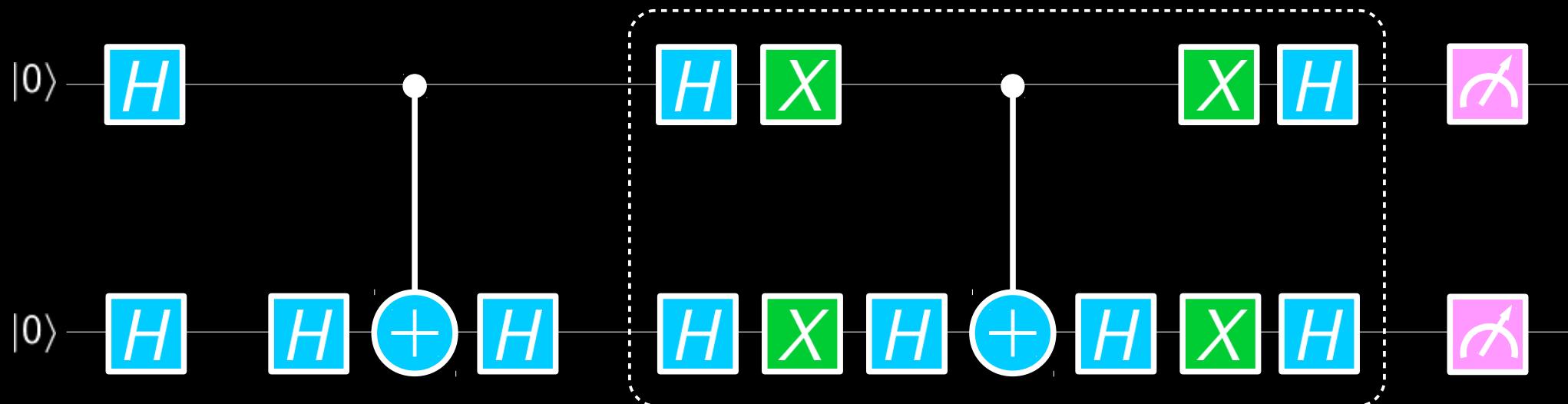
Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Grover's search: Step 3 – Reflection



Applications

Q-Speedup

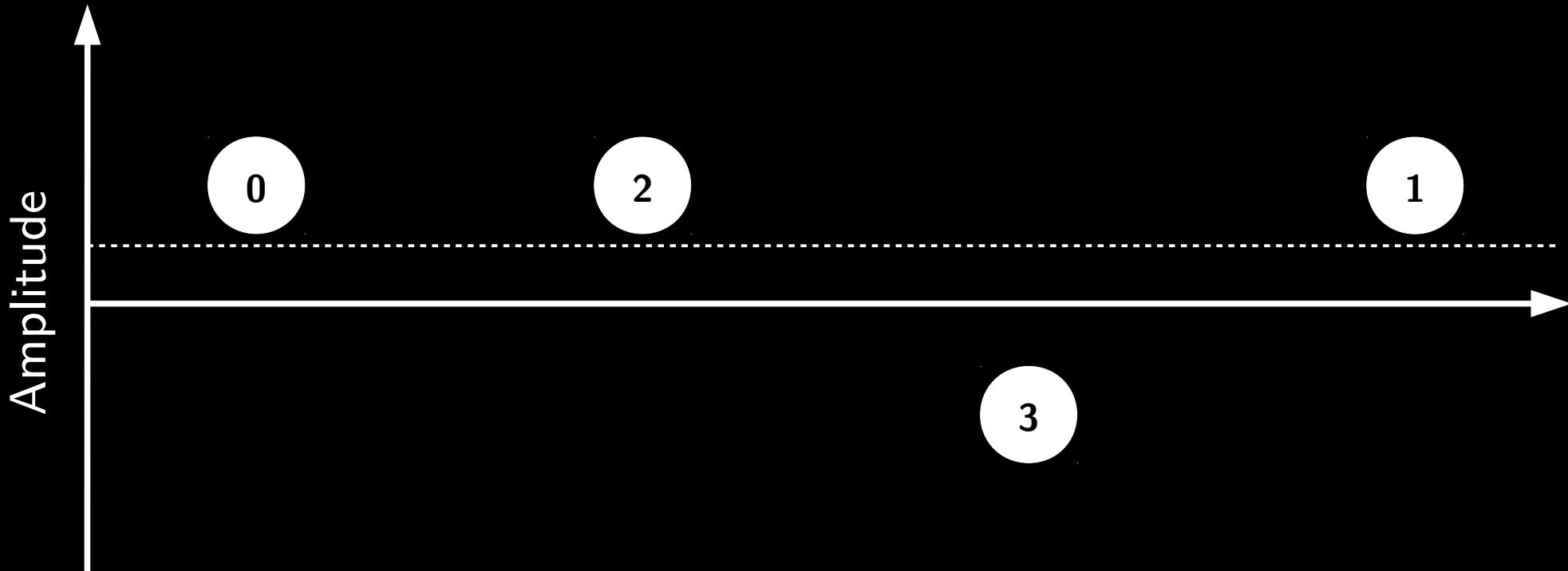
Q-Bits

Q-Algorithms

Hardware

Industry

Grover's search: Step 3 – Reflection



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Speedup

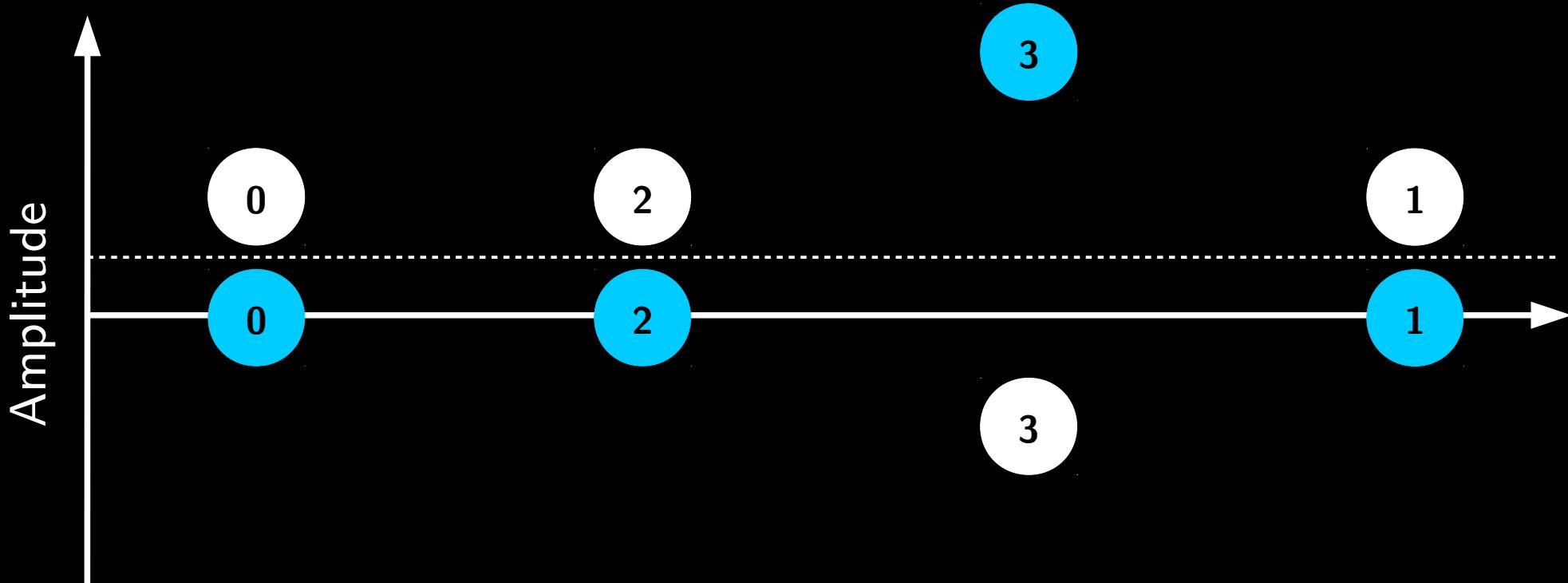
Q-Bits

Q-Algorithms

Hardware

Industry

Grover's search: Step 3 – Reflection



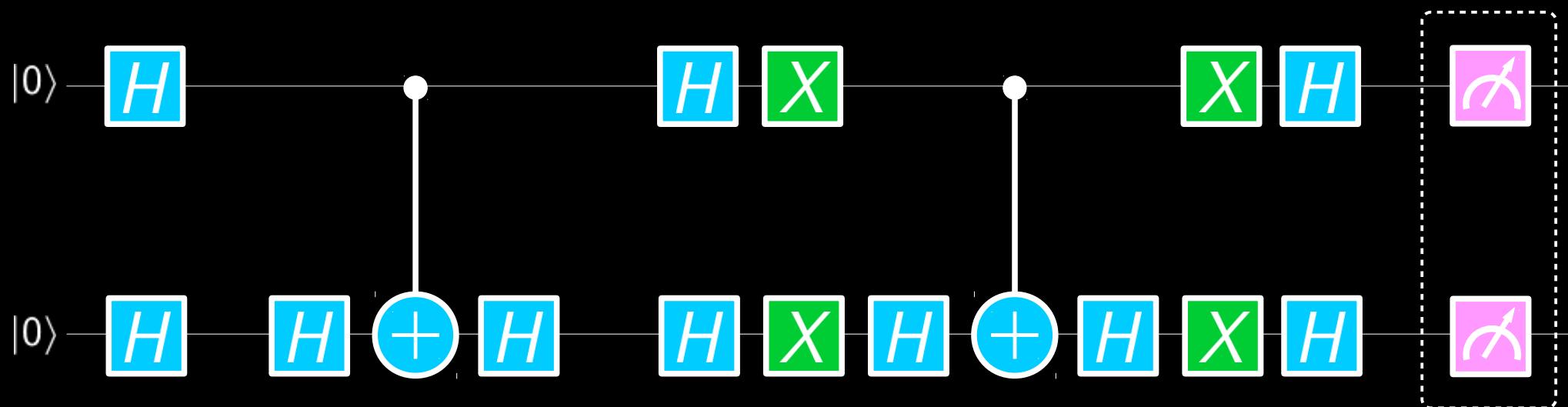
Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Grover's search: Step 4 – Measurement



Applications

Q-Speedup

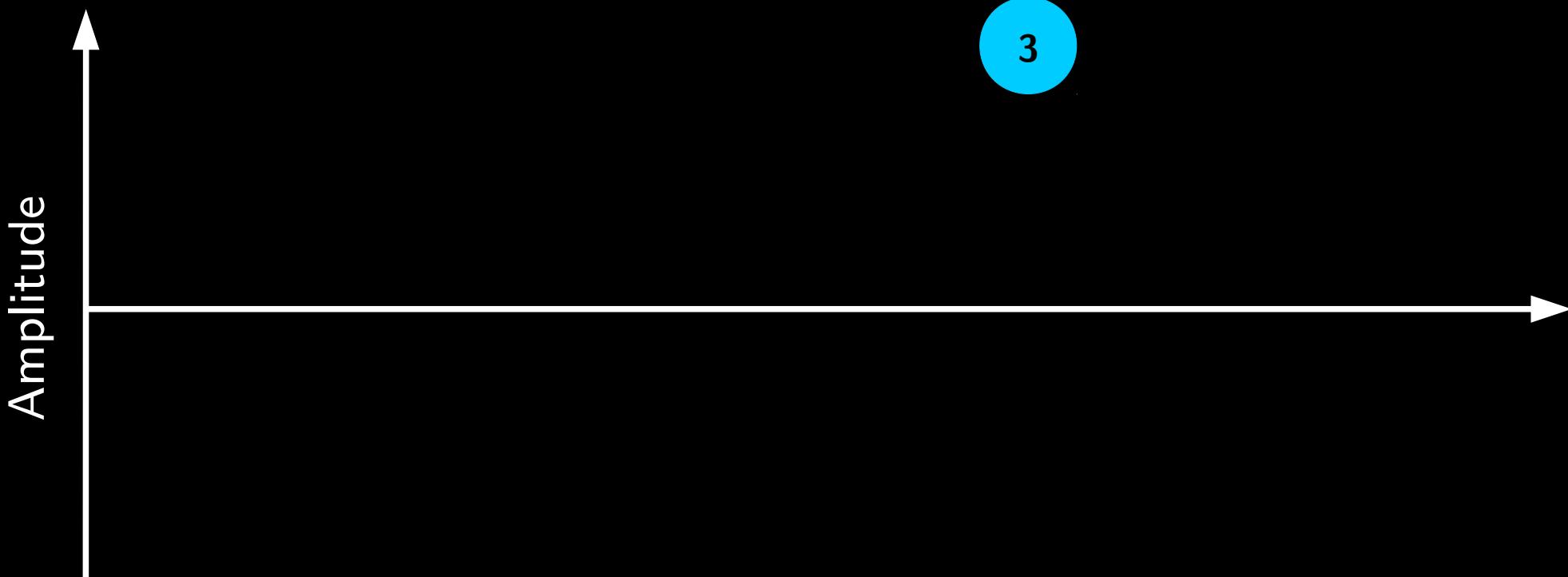
Q-Bits

Q-Algorithms

Hardware

Industry

Grover's search: Step 4 – Measurement



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Quantum Speedup

Quantum Bits

Quantum Algorithms

Hardware

Industry Landscape

Applications

Quantum Speedup

Quantum Bits

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Hardware

Industry Landscape

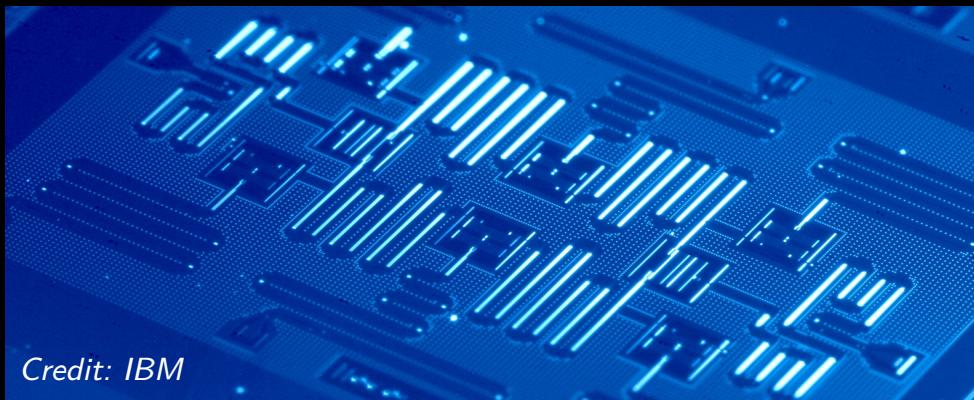
Why is quantum computing (so) hard ?

We want qubits to interact strongly with one another.

We don't want qubits to interact with the environment.

Until we measure them.

Superconducting qubits

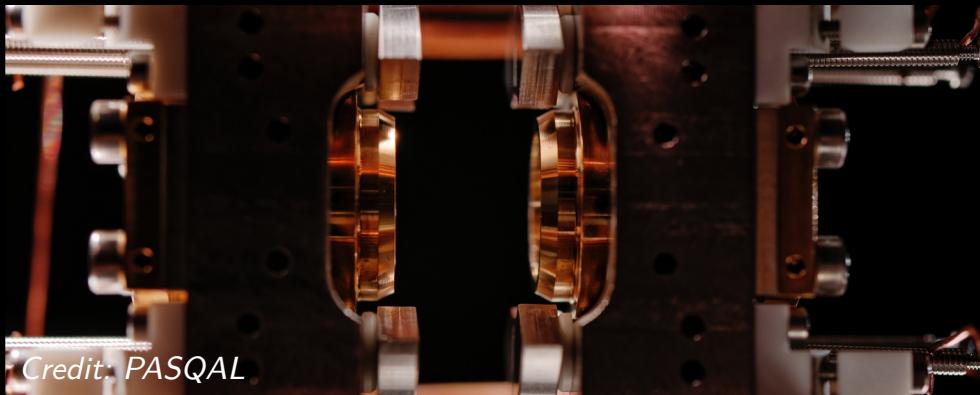


Credit: IBM

IBM, Google and others

- X Coherence time
- X Gate fidelities
- X Nearest neighbours connectivity
- X Artificial systems
- X Digital quantum computing only
- ✓ Clock rate
- X Near absolute zero operation

Neutral atoms



PASQAL and others

- ✓ Coherence time
- ✓ Gate fidelities
- ✓ All-to-all connectivity
- ✓ Natural systems
- ✓ Digital / Analog quantum computing
- ✗ Clock rate
- ✗ Vacuum operation

Applications

Q-Speedup

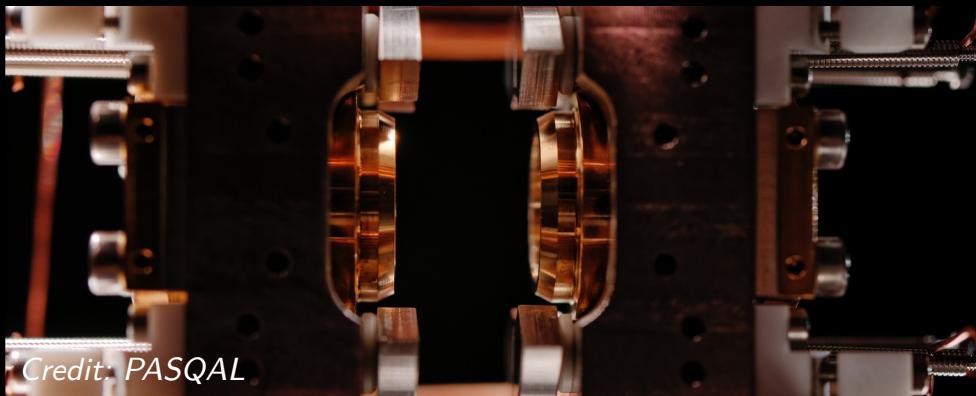
Q-Bits

Q-Algorithms

Hardware

Industry

Neutral atoms



Decoherence

Leading qubit platforms

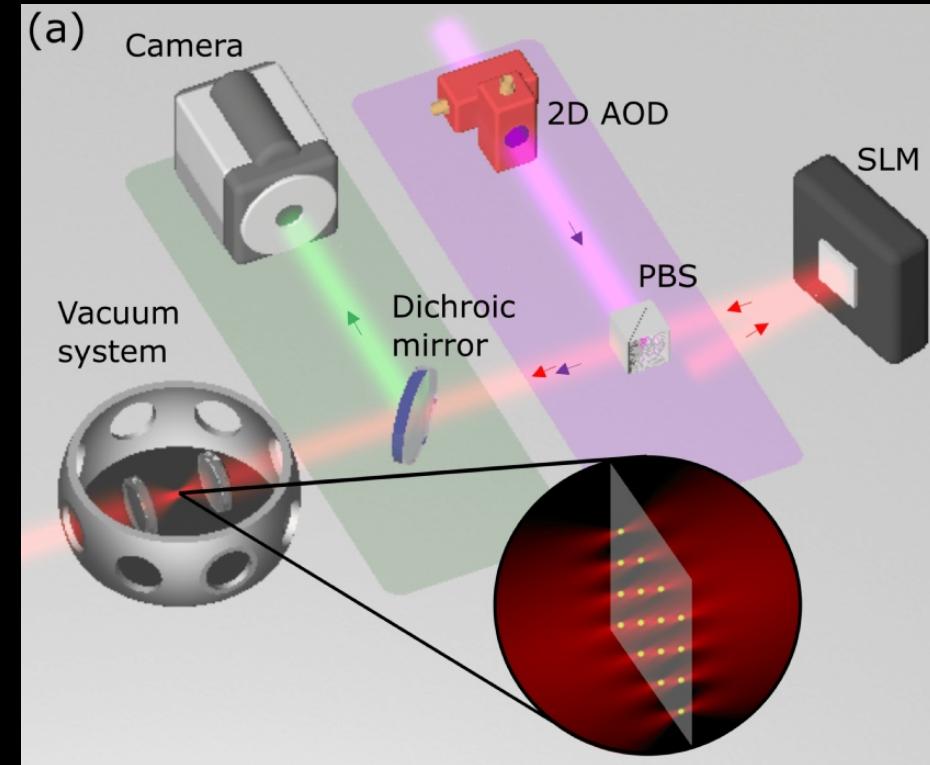
Quantum supremacy

Other platforms

Error correction

NISQ era

PASQAL and others



Volume 574 Issue 7779, 24 October 2019

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Quantum supremacy

In this week's issue, [John Martinis and his colleagues](#) describe a significant step in the development of quantum computing. For the first time, the researchers have demonstrated experimentally that a programmable quantum computer can outperform the world's most powerful conventional processors – a state known as quantum supremacy. The team used a quantum processor made up of 53 functional qubits to tackle a task that involved sampling the output of a... [show more](#)

Applications

Q-Speedup

Q-Bits

Q-Algorithms

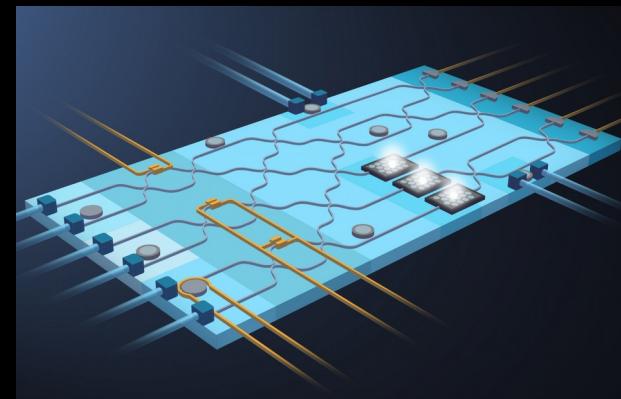
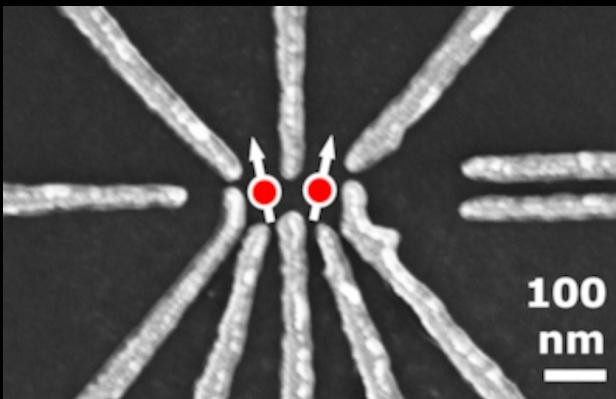
Hardware

Industry

Quantum dots

Photonic

Topological



Decoherence

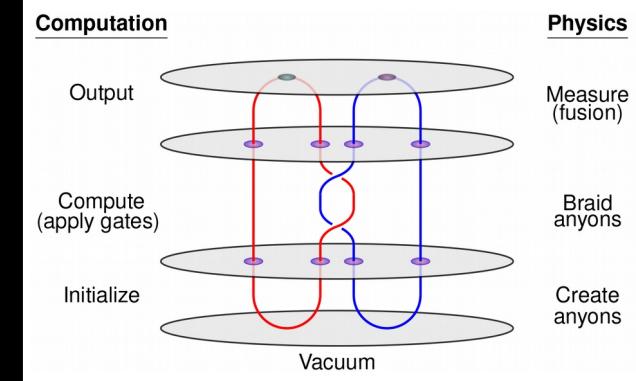
Leading qubit platforms

Quantum supremacy

Other platforms

Error correction

NISQ era



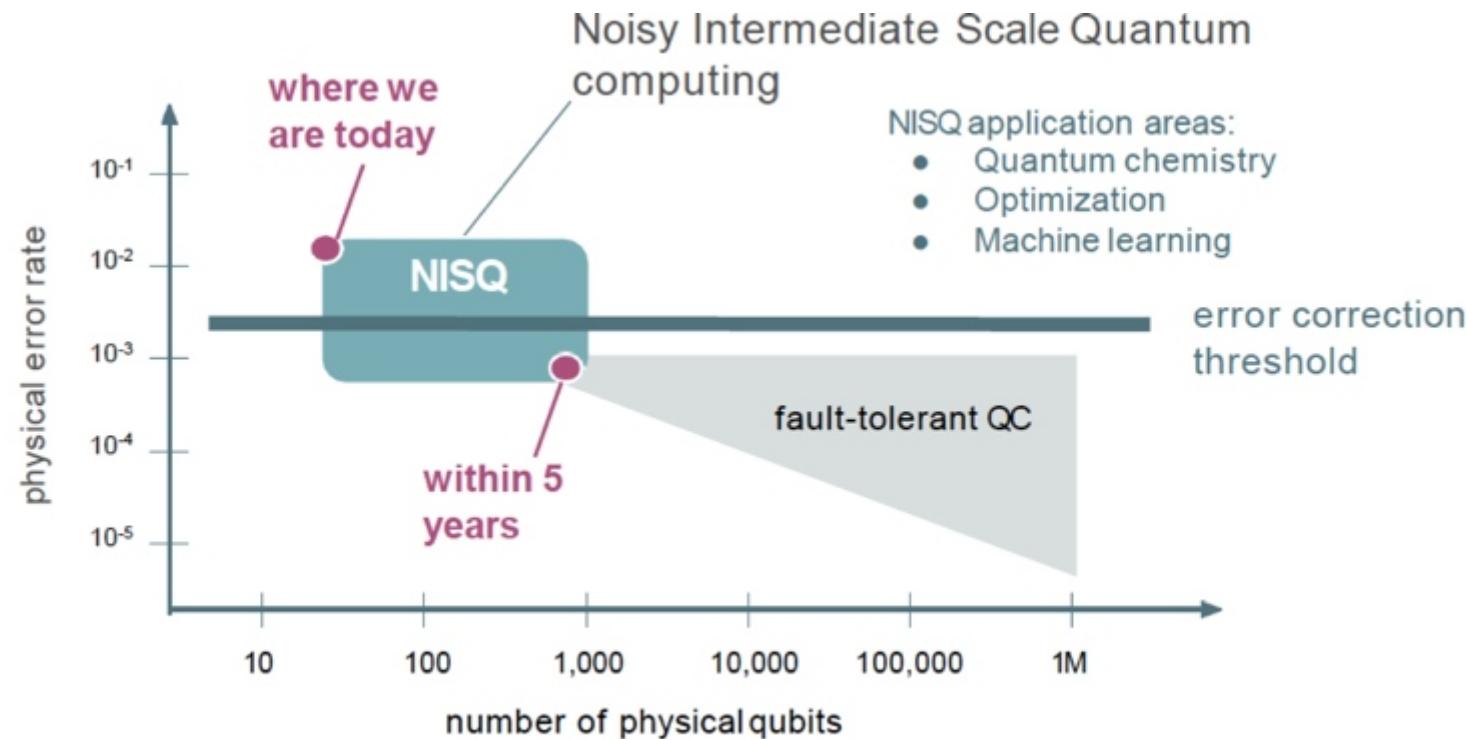
Quantum error correction

Long term goal → Fault-Tolerant QC

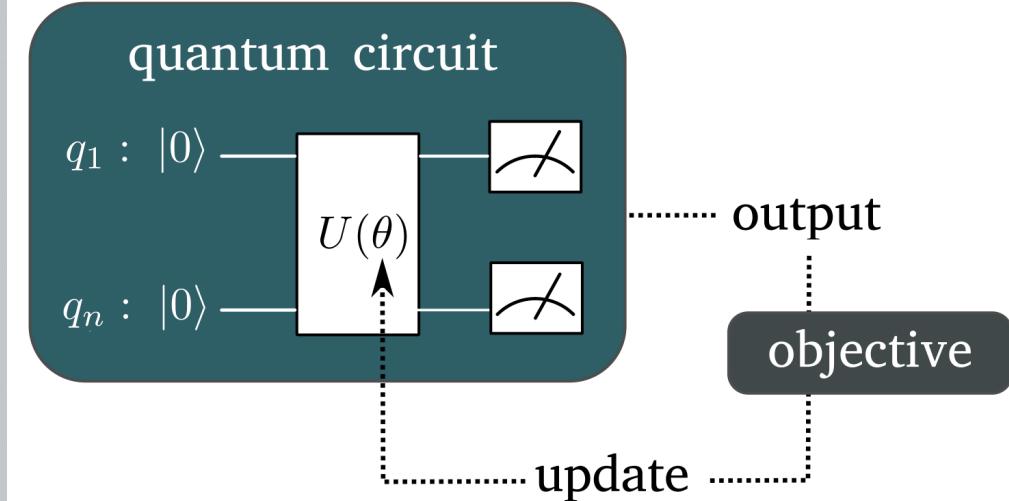
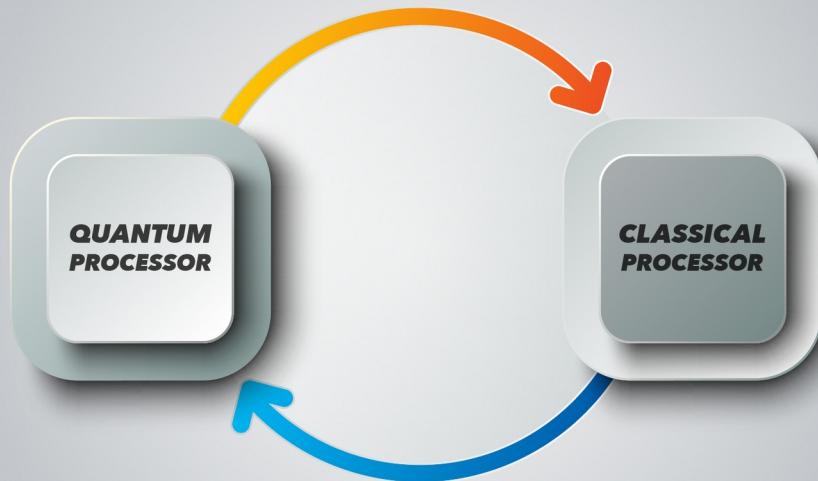
The protected “logical” quantum information is encoded in a highly entangled states of many physical qubits.

The environment can't access this information if it interacts locally with the protected system.

"Quantum computing in the NISQ era and beyond", J. Preskill (2018)



Near term quantum computers (NISQ) will be used as co-processors



Applications

Quantum Speedup

Quantum Bits

Quantum Algorithms

Hardware

Industry Landscape

Applications

Quantum Speedup

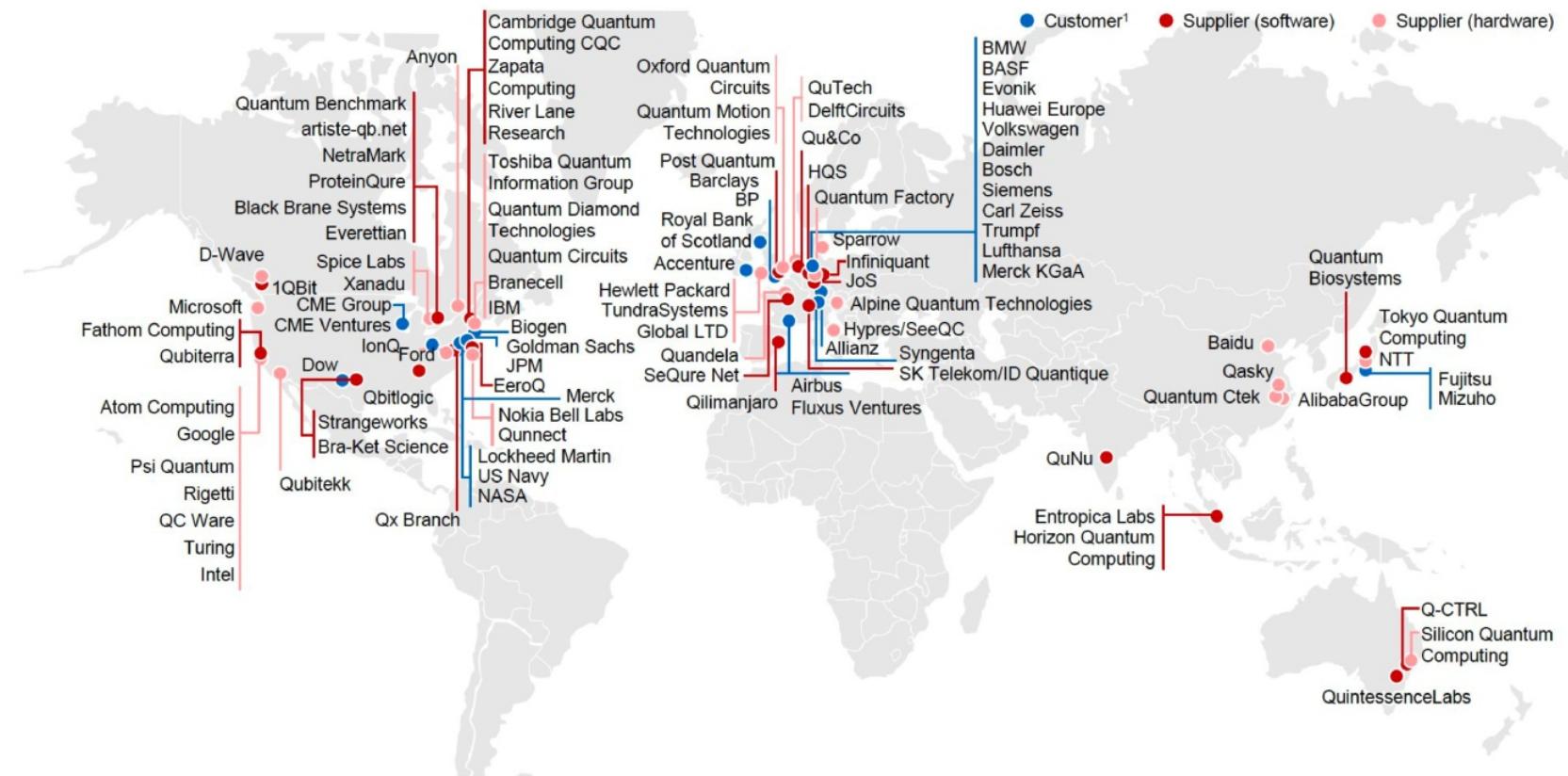
Quantum Bits

Quantum Algorithms

Hardware

Industry Landscape

Non-exhaustive overview of quantum computing players (2019)



Applications

Q-Speedup

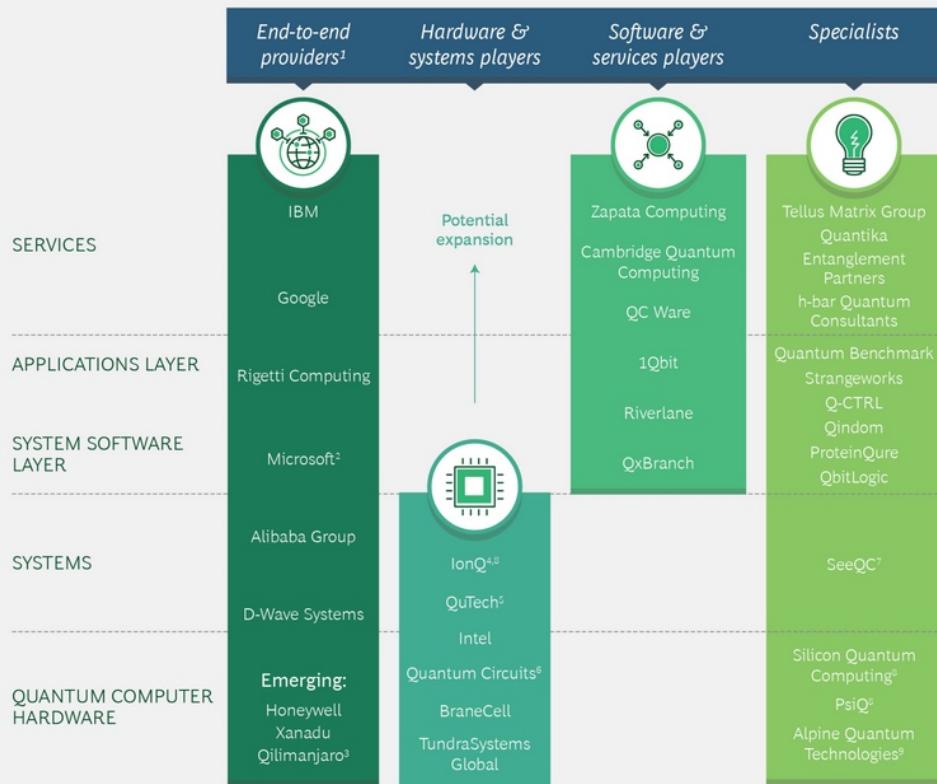
Q-Bits

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Hardware

Industry

BCG report on Quantum Computing (2019)



QC players

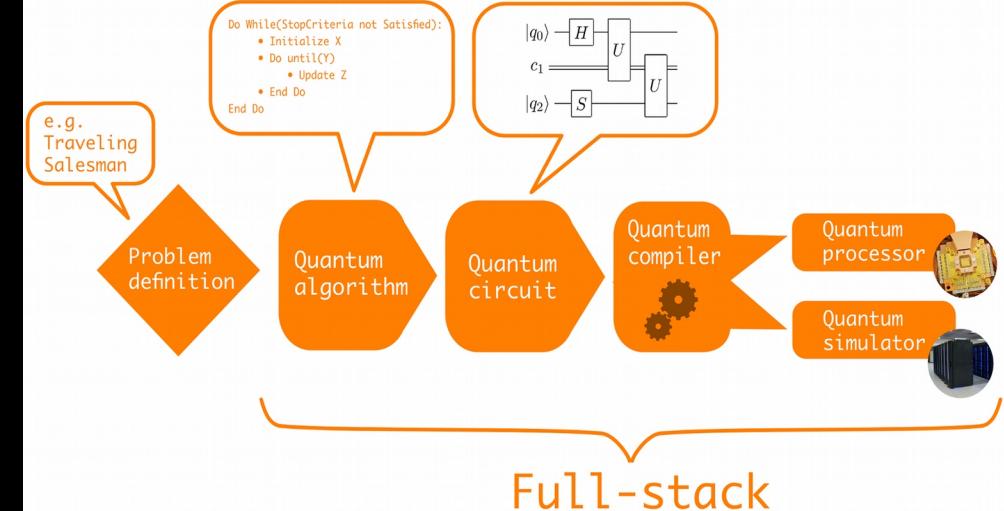
Funding – National initiatives

Funding – VC funds

Short-term plan

Long-term plan

Quantum Computing as a Service



Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

Canada

D-Wave, 1Qbit notable private investment. Creative Destruction Lab in Toronto accelerates market launch of deep tech startups in quantum technologies. Hundreds of millions of government funding invested (IQC, Perimeter Institute).

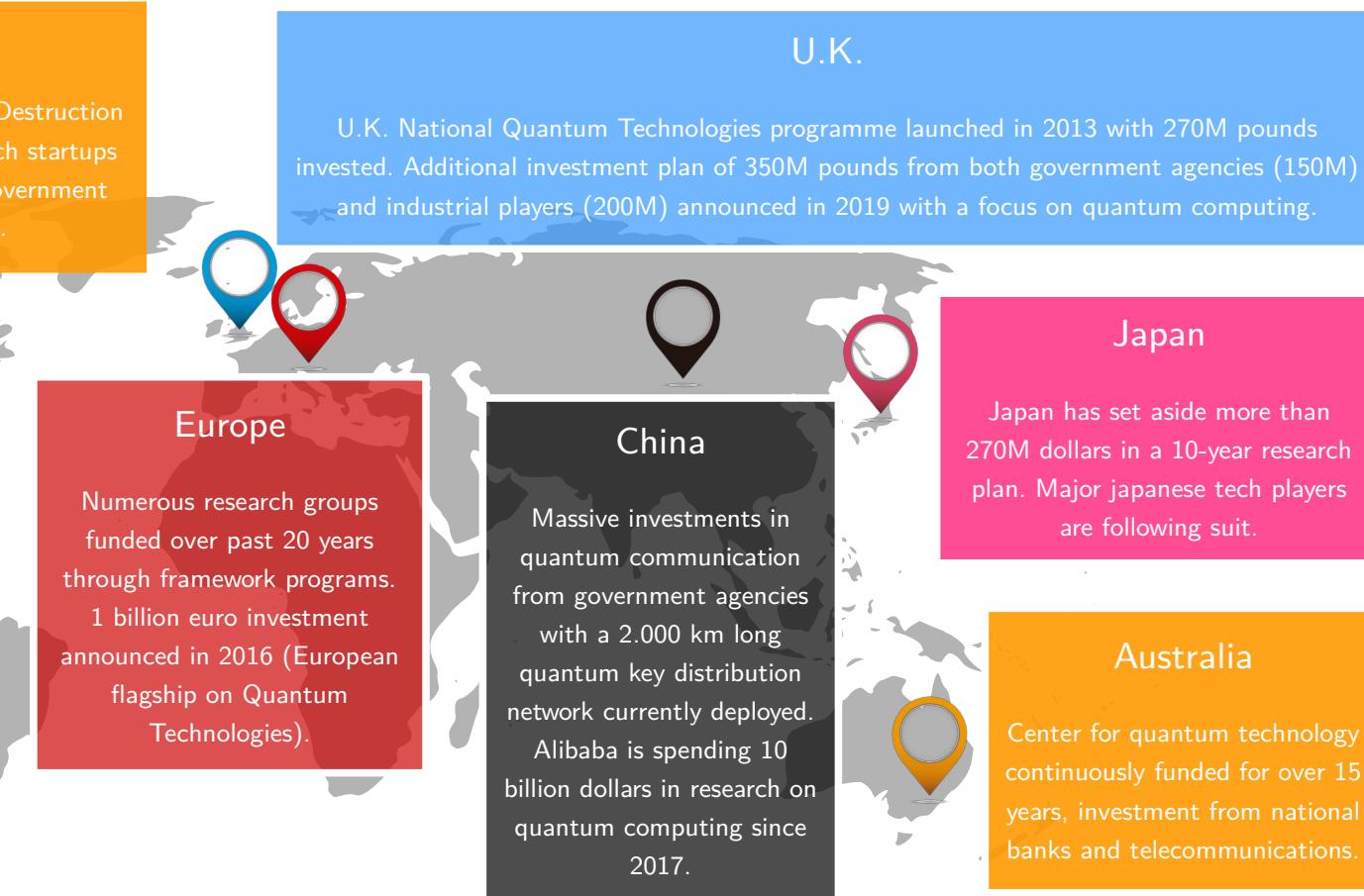


United States

Heavy industrial interests from tech giants such as IBM, Google and Microsoft. End of 2018 president Trump signed the National Quantum Initiative into law, which granted more than a billion dollar in quantum research funding. Most major universities conduct quantum technology research.

Europe

Numerous research groups funded over past 20 years through framework programs. 1 billion euro investment announced in 2016 (European flagship on Quantum Technologies).



China

Massive investments in quantum communication from government agencies with a 2.000 km long quantum key distribution network currently deployed. Alibaba is spending 10 billion dollars in research on quantum computing since 2017.

Australia

Center for quantum technology continuously funded for over 15 years, investment from national banks and telecommunications.

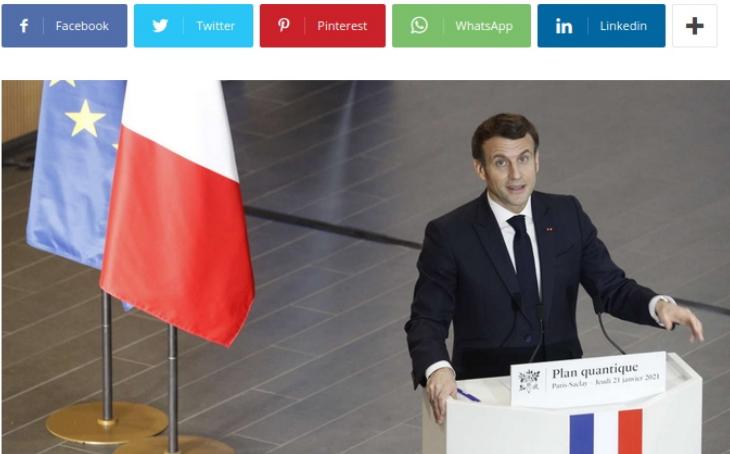
Home > France > Emmanuel Macron presents a "quantum plan" for France of 1.8 billion euros...

France

Emmanuel Macron presents a “quantum plan” for France of 1.8 billion euros over five years

By admin January 21, 2021

54 0



The Head of State, Emmanuel Macron, must present, Thursday, January 21 in the morning, on the Saclay plateau, a national investment plan of 1.8 billion euros in quantum technologies, called to transform the IT and industry, said the Elysee.

Total 2021 – 2025 [M€]		1815
PIA 4		594
Subvention aux organismes de recherche		274
Autres contributions nationales		164
Financements européens		238
Secteur Privé		545

Total 2021 – 2025 [M€]		1815
Recherche (Organismes CNRS, CEA, INRIA, ONERA, CNES; programmes UE, infrastructures)		725
Formation (PhD, Ingénieurs, masters, techniciens)		61
Maturation Technologique		171
Innovation de rupture (ordinateur quantique)		114
Soutien au déploiement industriel (lignes pilotes et cryogénie)		224
Politique d'Achat Public (calcul, défense)		72
Entreprenariat (fonds d'investissement, incubateurs)		439
Intelligence Economique (standardisation, PI)		9

Axes technologiques de la stratégie nationale						Total 2021 – 2025 [M€]
NISQ	LSQ	Capteurs quantique	Communications quantiques	Cryptographie post quantique	Technologies capacitan	
352	432	258	325	156	292	1815

"Nous voulons faire émerger 5 à 6 start-up du quantique en France", annonce Christophe Jurczak, du fonds Quantonation

MANUEL MORAGUES

FRANCE, INVESTISSEMENT, INFORMATIQUE, ELECTRONIQUE, BONNE NOUVELLE

PUBLIÉ LE 16/11/2018 À 10H15

ENTRETIEN Lancé en mai 2018, Quantonation vient de réaliser sa première opération dans le quantique en investissant dans la start-up britannique Kets Quantum Security. Un début pour ce fonds d'investissement dédié aux technologies quantiques et plus généralement à "la physique de rupture". Son dirigeant, Christophe Jurczak, détaille à l'Usine Nouvelle ses ambitions et dresse le portrait d'une France du quantique forte de ses talents, mais encore peu mobilisée pour faire naître une industrie.

pasqal @pasqalio

Belle itw de Georges Reymond le CEO de Pasqal « Nous sommes très contents d'avoir lancé Pasqal en mars dernier, sinon, nous n'aurions pas été dans la course" Non seulement Pasqal est dans la course, mais dans certains domaines elle l'a fait en tête !

Pasqal fait la course en tête dans l'informatique quantique

De quoi demain sera-t-il fait ? Bpifrance s'est lancé le défi de mener une réflexion sur les sujets d'innovation qui révolutionneront notre quotidien dans les années à venir, latribune.fr

07:18 - 24 oct. 2019

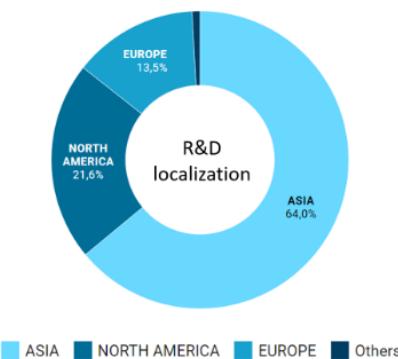
5 J'aime

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Patent landscape (M. Kurek's report 2020)

Priority country	Count of patent families
China	5 161
USA	2 401
International patent WO	1 916
Japan	768
UK	394
Korea (South)	379
European patent EP	288
Germany	239
Australia	104
Russian Federation	82
France	71
India	53
Taiwan	42
Canada	31

- ✓ 9,905 Patents
- ✓ 50 Inventors (R&D) countries
- ✓ 31 Priority countries



R&D Localisation	Count of patent families
1 China	5 164
2 USA	1 990
3 Japan	822
4 Germany	410
5 Korea (South)	390
6 UK	376
7 Canada	235
8 France	126
9 Russia Federation	120
10 Netherlands	84
11 Taiwan	83
12 Switzerland	82
13 Australia	68
14 India	61
15 Finland	31
16 Israel	28
17 Spain	26
18 Malaysia	25
19 Italy	20
20 Austria	18

Assignees	Count of patent families
1 RUBAN QUANTUM TECHNOLOGY	167
2 IBM	163
3 INTEL	150
4 MICROMASS	137
5 THERMO FISHER SCIENTIFIC	125
6 QUANTUMCTEK	117
7 UNIVERSITY OF SCIENCE & TECHNOLOGY OF CHINA	116
8 TSINGHUA UNIVERSITY	112
9 ANHUI ASKY QUANTUM TECHNOLOGY	107
10 BEIJING UNIVERSITY OF POSTS & TELECOMMUNICATIONS	104
Assignees	Count of patent families
11 TOSHIBA	102
12 STATE GRID CORPORATION OF CHINA (SGCC)	98
13 SHIMADZU	83
14 GOOGLE	81
15 MICROSOFT TECHNOLOGY LICENSING	81
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17 ELECTRONIC SCIENCE RESEARCH INSTITUTE CHINA ELECTRONICS TECHNOLOGY	77
18 ZHEJIANG SHENZHOU LIANGZI NETWORK SCIENCE & TECHNOLOGY	71
19 SOUTH CHINA NORMAL UNIVERSITY	67
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Applications

Q-Speedup

Q-Bits

Q-Algorithms

Hardware

Industry

QUANTUMBUSINESS by Xcorp
EUROPE

Digital Expo and Conference
1st Edition • March 16-17, 2021

THE QUANTUM TECHNOLOGIES EVENT FOR BUSINESS

1000 attendees • 20 partners • 50 speakers

www.quantumbusinesseurope.com

FREE SIGN UP

The image shows a dark purple banner for the Quantum Business Europe event. It features the event's name, date, and a large image of a complex quantum computing system with multiple layers of components and glowing lights.

QT
Quantum.Tech

April 12 - 14 2021 | Virtual Event

Commercial applications of quantum computing, communications and sensing

www.quantumtechdigital.co.uk

FREE SIGN UP

The image shows a dark blue banner for Quantum.Tech. It features the event's name, date, and a red "FREE SIGN UP" button. Below the text, there is a stylized network diagram with nodes connected by lines.

Brought to you by:

3DR HOLDINGS | **QuTech**

Inside Quantum Technology Europe Online

The Future of Quantum Computing, Quantum Networking, Quantum Sensors, and Quantum Cryptography.

October 26-30, 2020

The image shows a dark banner for Inside Quantum Technology Europe Online. It features logos for 3DR Holdings and QuTech, followed by the event's name and a brief description. The background is a close-up image of a circuit board.

Q2B

Practical Quantum Computing

December 8-10, 2020 | Virtual Event

SIGN-UP FOR UPDATES

Presented by **QCWARE**

The image shows a dark blue banner for Practical Quantum Computing. It features the event's name, date, and a green "SIGN-UP FOR UPDATES" button. The background has a hexagonal grid pattern.

QC players

Funding – National initiatives

Funding – VC funds

Short-term plan

Long-term plan

Applications

Q-Speedup

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Q-Algorithms

Hardware

Industry

Engage with QC (customer side):

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Long-term plan

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 3. Test initial use cases with hardware specific software.
 4. Create a timeline for how these use cases will scale with quantum computing advancements.
1. - 2. - 3. -4. Collaborate with QC providers throughout these steps.

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Although quantum computers are currently small and noisy, a great way to exploit their non-classical properties is to adopt an hybrid approach which leverage both quantum and classical computation.

Direct collaboration with a software provider or an end-to-end provider allows partners to take early advantage of rising technology maturity. However, at this stage companies should avoid locking into a particular technology or approach.

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This is not the conclusion, it's just the beginning !