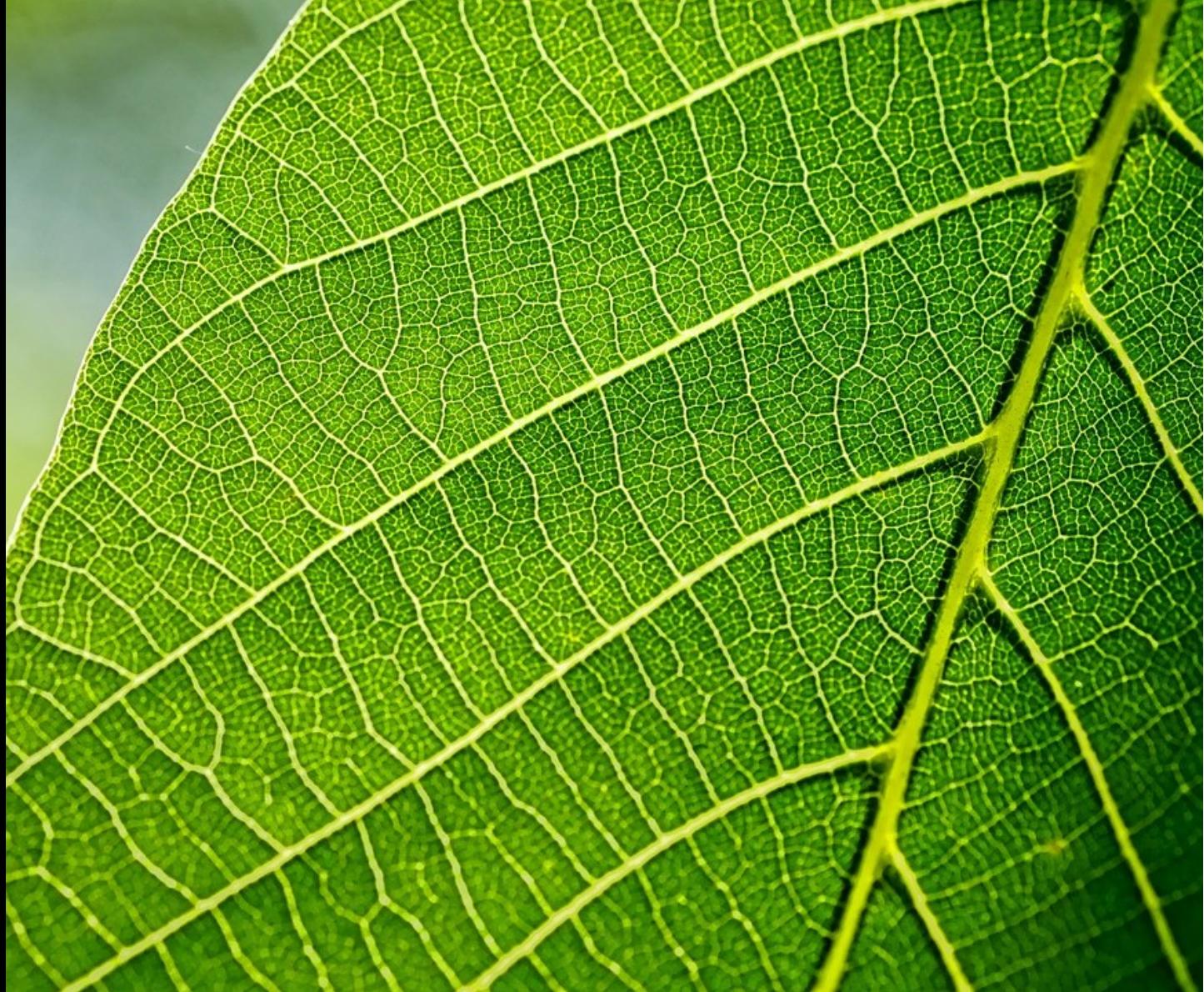
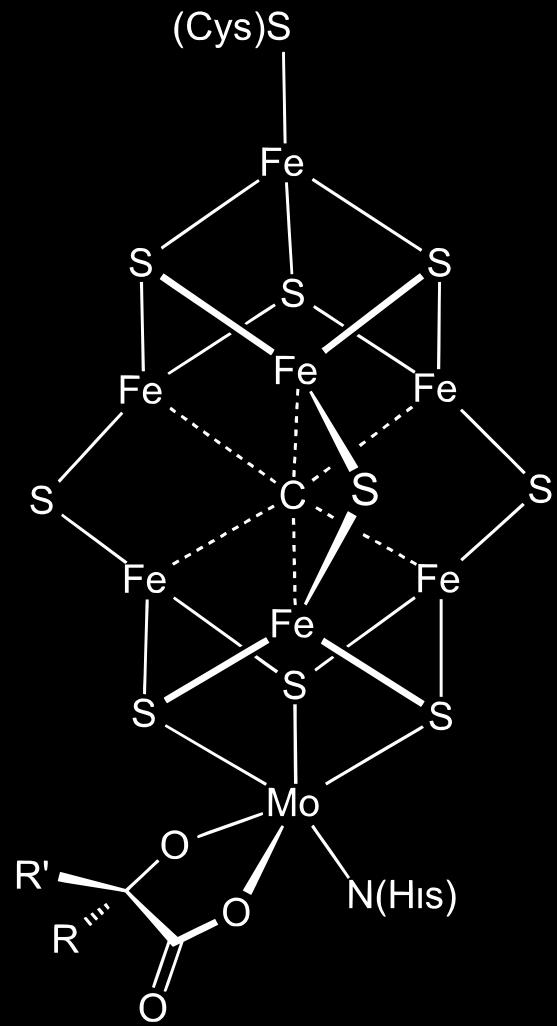




Ch1: Quantum Computing in a Nutshell



Character

Bits

7

111

A

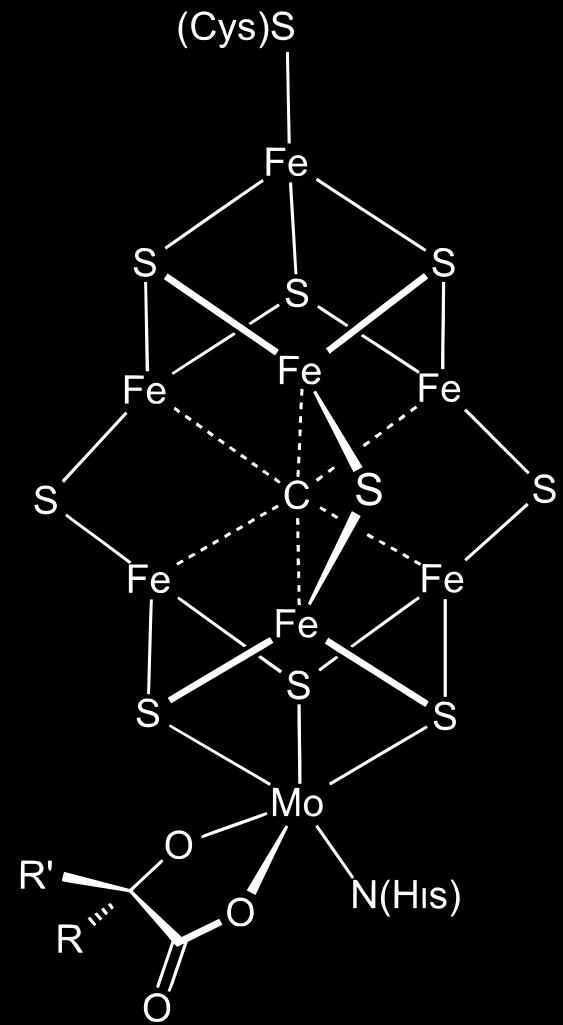
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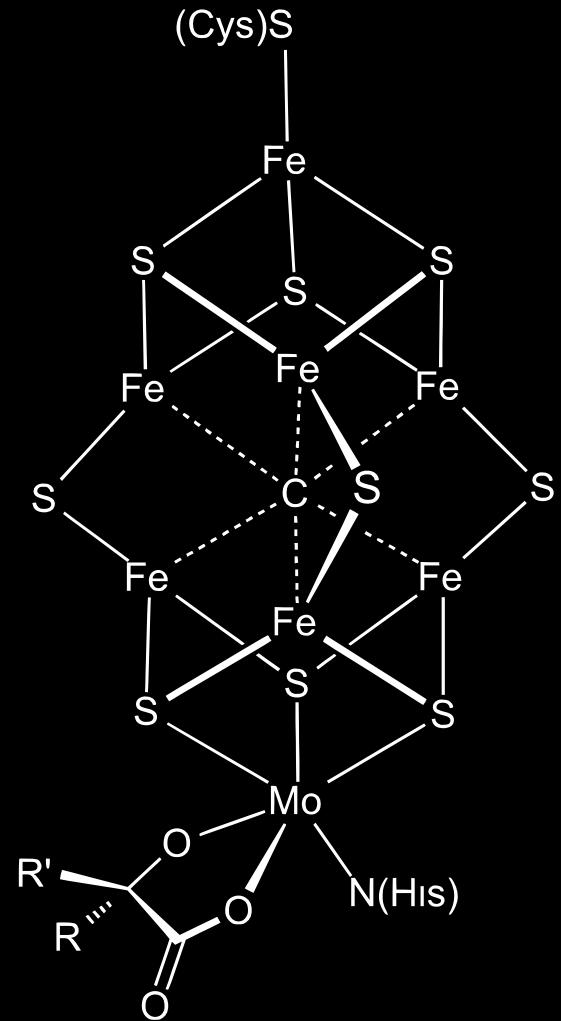
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Classical
 $\sim 10^{32}$
bits



Classical

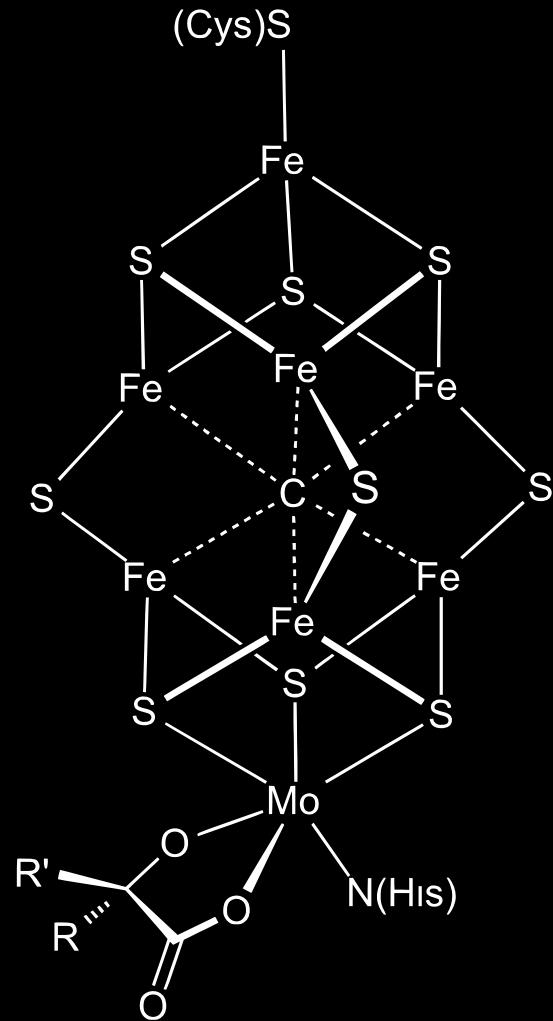
$\sim 10^{32}$

bits

Quantum

$\sim 10^8$

quantum bits



N bits \rightarrow $2N$ bits

Doubling classical computers power

N qubits \rightarrow $N+1$ qubits

Doubling quantum computers power*

Quantum computing's potential is enormous !

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

Applications

Quantum Algorithms

Quantum Bits

Quantum Circuits

Hardware

Industry Landscape

Applications

Quantum Algorithms

Quantum Bits

Quantum Circuits

Hardware

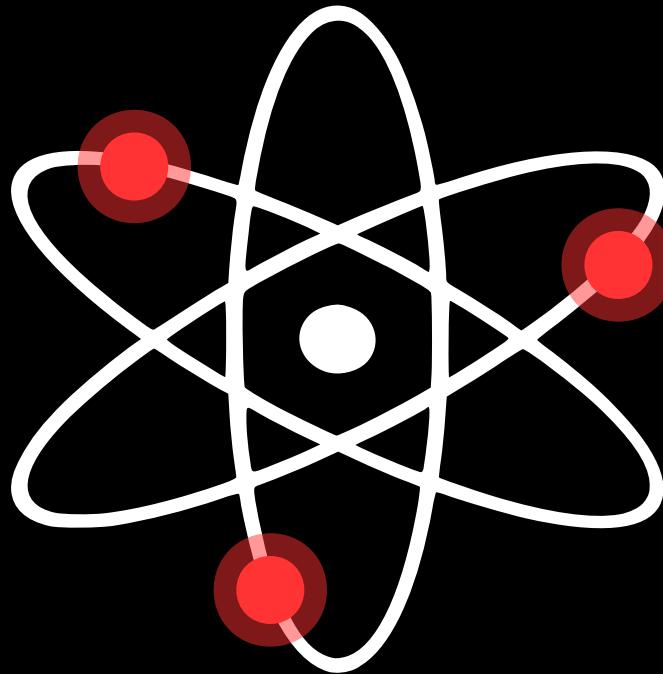
Industry Landscape

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

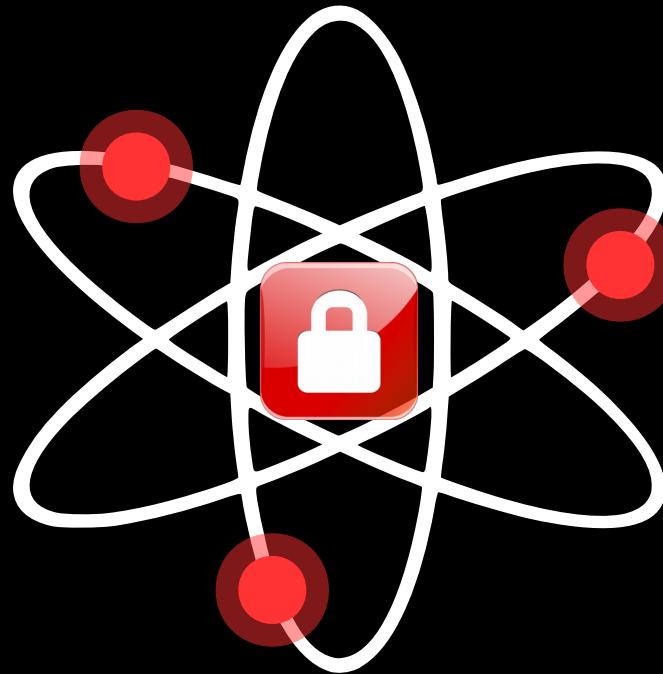
Finding the best solution with the least error from a multitude of possible solutions

Prediction

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

Simulation

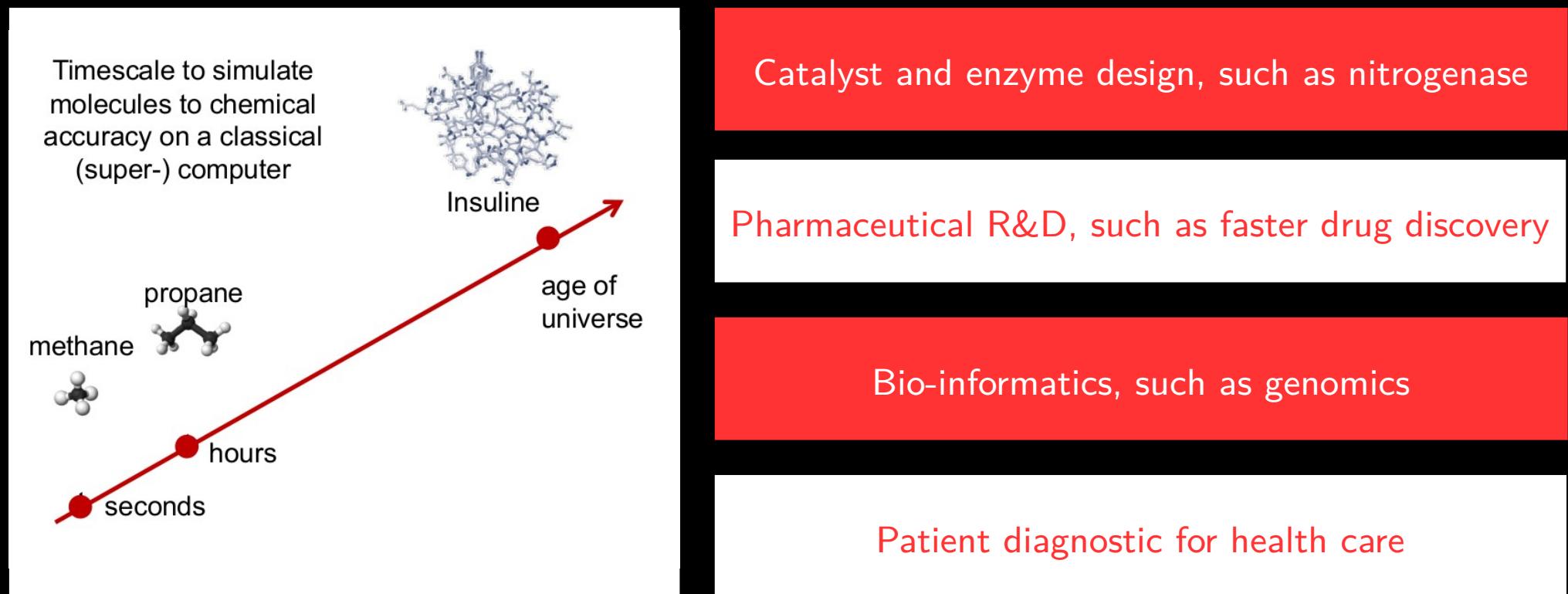
The imitation of the operation of a real-world process or system over time



Optimization

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

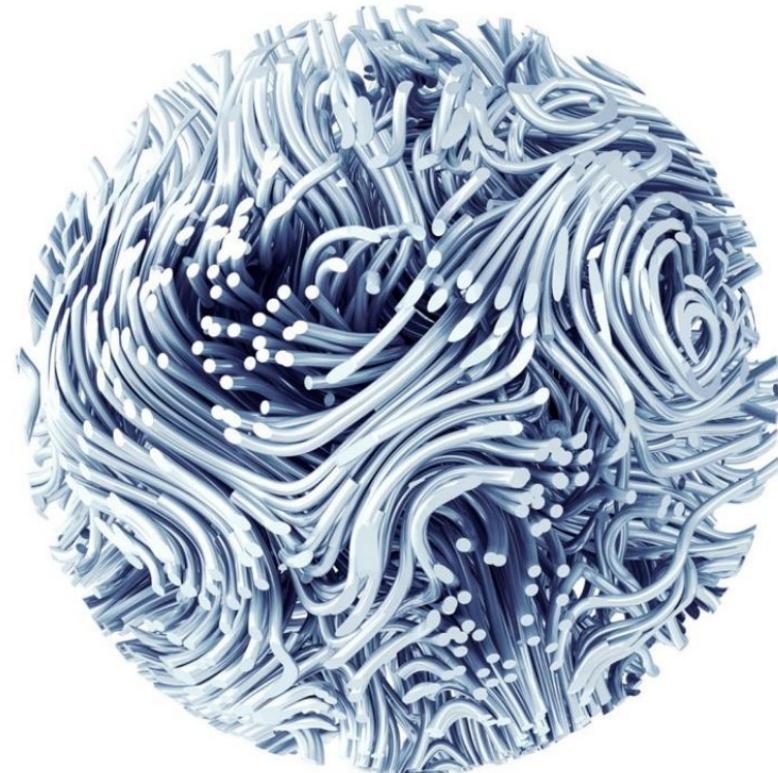
Computational-chemistry can be a highly valuable tool, but scales very poorly on classical computers; which is why in the 1980s the concept of quantum-computing was proposed.



McKinsey & Company report on Quantum Computing (2019)

The next big thing? Quantum computing's potential impact on chemicals

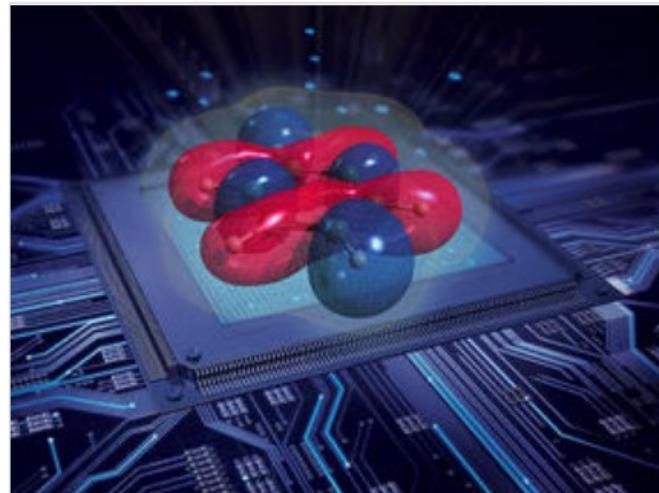
July 2019 | Article



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

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Atos, Bayer and RWTH Aachen University use Atos Quantum Learning Machine to study human disease patterns

Quantum computing to accelerate research in the Health sector

Paris, Leverkusen, Aachen, November 7, 2018

Atos, a global leader in digital transformation, Bayer, an international life science company, and RWTH Aachen University announce that they are working together to evaluate the use of Quantum Computing in research and analysis of human disease patterns. Computing and life science experts from these three institutions will use the Atos Quantum Learning Machine, the world's highest-performing quantum simulator, to research the evolution of multi-morbidity human diseases from large data repositories.

*"Quantum Computing is one of the up and coming technologies that will have a game-changing impact on the life science industry, healthcare providers and of course treatment options for patients. While we consider it being early days for QC we want to make sure to learn how and in which areas it can best be used.", says **Dirk Schapeler, VP G4A Digital Innovation from Bayer**.*

The project is based on anonymized real-world data of intensive care patients, to analyze and identify correlations between comorbidities and relevant patterns of disease evolution. This concept complements the approach of clinical trial studies that usually focuses on a limited number of patients and well-structured data to analyze disease criteria.

*"We need to better understand the health state of patients with more than one disease. The Atos Quantum Learning machine will help us analyze the evolution of a disease and the interaction with comorbidities.", says **Dr. Ulf Hengstmann, G4A Digital Health Innovation Manager from Bayer**. "We already know that patients with specific diseases like heart failure can have several typical comorbidities. Now we need to understand why this is happening and how it affects therapy".*

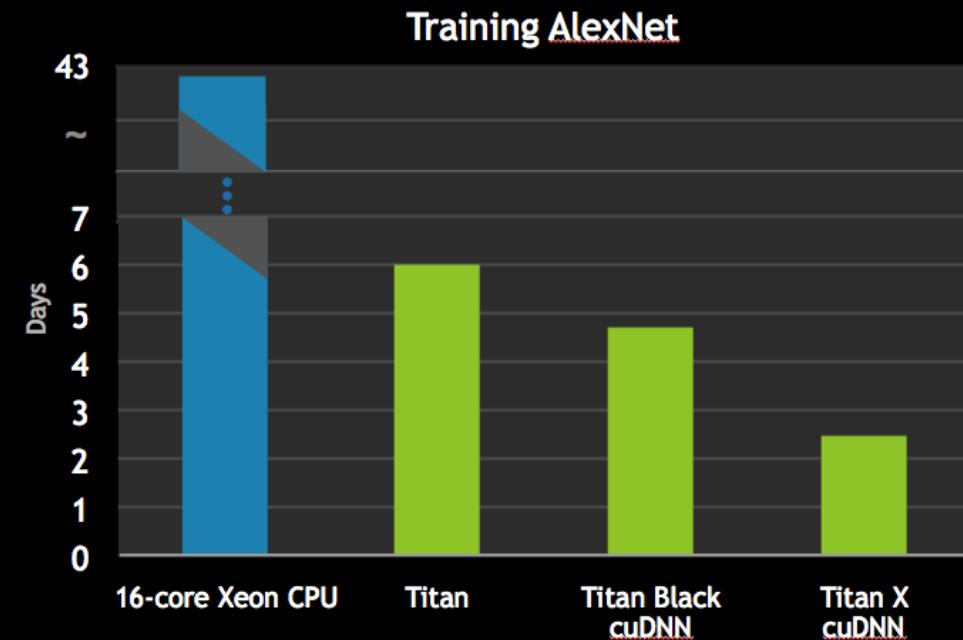
While artificial intelligence is a natural test bed for quantum computing, large scale quantum computers are expected to be threats for cybersecurity.

Machine learning and artificial intelligence

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Software verification and validation



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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)  
])
```



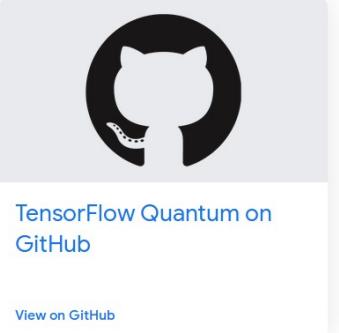
Announcing TensorFlow Quantum [Read on the Google AI blog](#)



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](#)



PENNY LANE

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

Learn

Sit back and learn about the field of quantum machine learning, explore key concepts, and view our selection of curated videos.

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Tutorials to introduce core QML concepts, including quantum nodes, optimization, and devices, via easy-to-follow examples.

[Demos »](#) [bob = q\[s\]](#)

Code

Get started with PennyLane using our quickstart guides, learn how to develop a plugin, and browse the full API.

[Documentation »](#)

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





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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.

PROJECT LINKS

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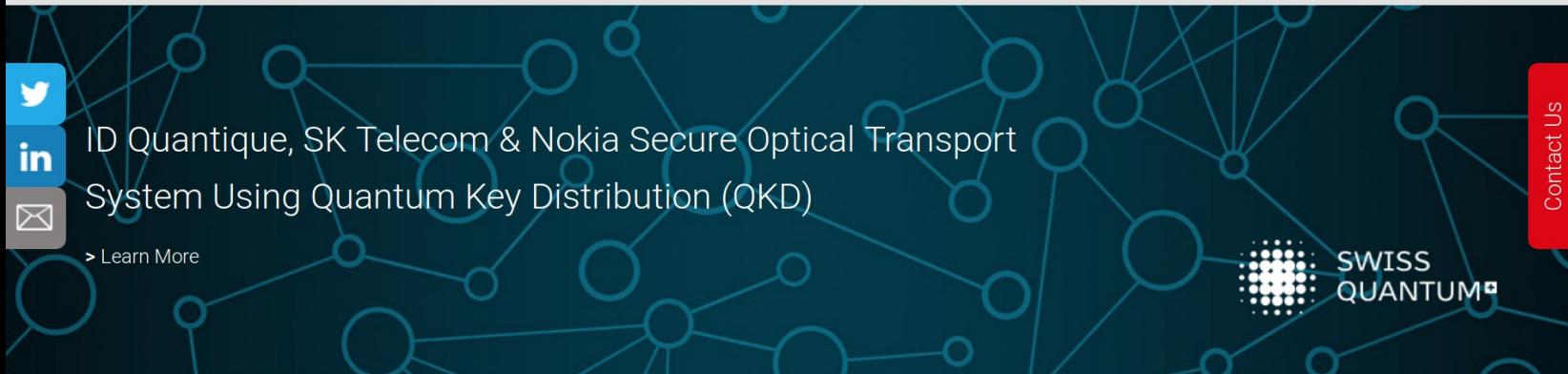
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ID Quantique, SK Telecom & Nokia Secure Optical Transport System Using Quantum Key Distribution (QKD)

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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

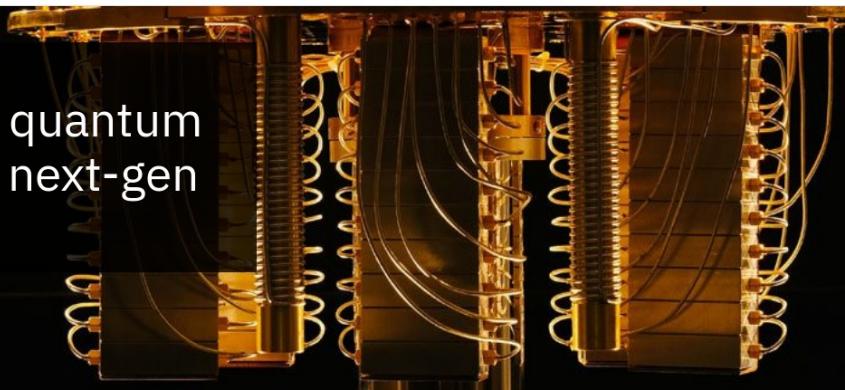
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Quantum Computing

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 Comput...
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

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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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Print Reprint

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

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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

Atos fournit à Total le simulateur quantique le plus performant au monde

Paris, le 16 mai 2019

Atos, leader international de la transformation digitale, annonce aujourd'hui la livraison au groupe Total de son Atos Quantum Learning Machine (QLM), le **simulateur quantique le plus performant au monde**. Dans le cadre d'un projet de recherche transverse ambitieux, le groupe Total compte ainsi mettre l'Atos QLM au service de l'ensemble de ses métiers.

L'Atos Quantum Learning Machine associe une machine ultra compacte et puissante à un langage de programmation universel, permettant aux chercheurs et ingénieurs de développer et tester des algorithmes quantiques. Elle simule les lois de la physique qui sont au cœur même de l'informatique quantique pour calculer l'exécution exacte d'un programme quantique avec une précision à la double décimale.

Le calcul quantique trouvera des applications concrètes au sein du Groupe Total, pour la chimie moléculaire et des matériaux, l'optimisation de réseaux énergétiques, de flottes de véhicules, ou encore d'outils industriels et à plus long terme, l'imagerie sismique ou bien la mécanique des fluides.

« Monter en compétence sur le calcul quantique, avec cette solution d'Atos, l'un des leaders du secteur, c'est démontrer une fois encore notre esprit pionnier. Nous allons développer une approche quantique sur différentes problématiques de recherche couvrant l'ensemble de nos métiers pour explorer de nouvelles voies de résolution et gagner en performance et en efficacité », a déclaré Marie-Noëlle Semeria, directrice recherche & développement groupe de Total.

Microsoft and DEWA bringing quantum computing to Dubai

June 28, 2018 | Microsoft News Center



DEWA will work with Microsoft and access new quantum Microsoft Azure services to create quantum-inspired solutions to power energy optimization and improve sustainability efforts in Dubai and the United Arab Emirates

DUBAI, United Arab Emirates — June 28, 2018 — The Dubai Electricity and Water Authority (DEWA) on Thursday announced plans to work with Microsoft Corp. to develop new quantum-based solutions to address energy optimization and other challenges where classical computers have serious limitations, making it the first organization outside the U.S. to participate in the Microsoft Quantum program.

Applications

Quantum Algorithms

Quantum Bits

Quantum Circuits

Hardware

Industry Landscape

Applications

Quantum Algorithms

Quantum Bits

Quantum Circuits

Hardware

Industry Landscape

Task:

Integer Factorization

Applications

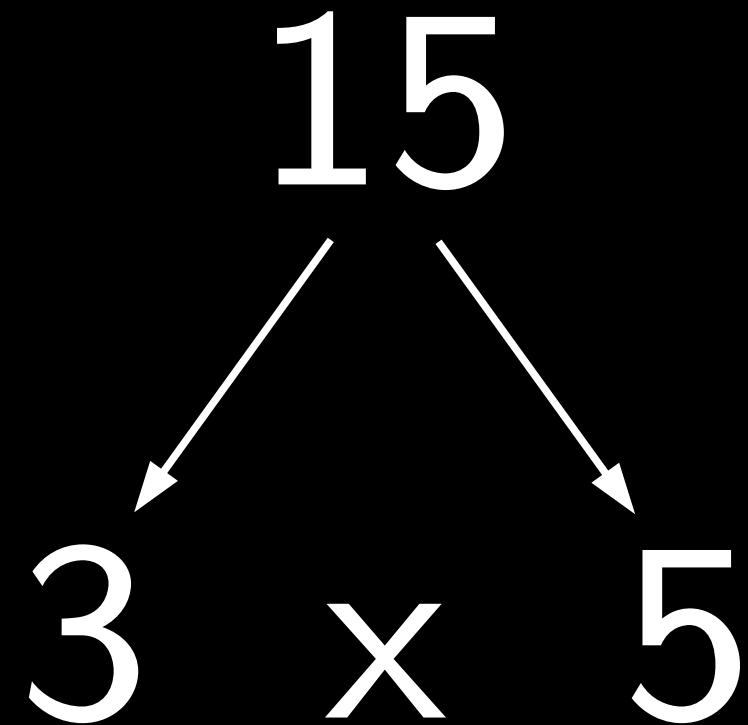
Q-Algorithms

Q-Bits

Q-Circuits

Hardware

Industry



Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Applications

Q-Algorithms

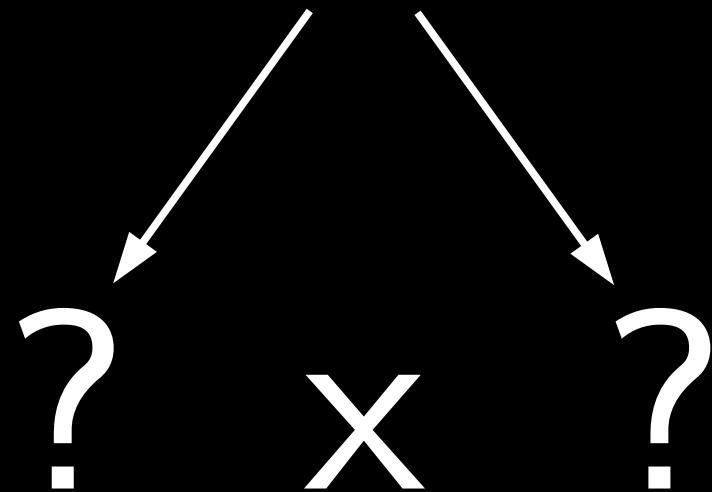
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Q-Circuits

Hardware

Industry

7110379909909823469971673725424473064353882489427176741102057973000889379665565049610836498148428158908772246304866860943192
0907344516262190407768933383377381407878353760499455979319960700906894699032445175759904798500685134300942629461309714010525
8451183638689370751031611701475016230049806026342053176134099092008619376369645670455584888994220854383100330689198272181971
464627398981966424692315074087395450462661785555515740733919354799058011416327121389973469757674185303667619128805768897233
3216854588089690421544040301537811000428377757537533165315590643914173011914509168646819605343438902256216469789162186128



Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Classical

$\sim 10^{14}$

years

Quantum*

~ 10

seconds

*assuming a quantum computer with 4096 perfectly stable qubits

Task:

Integer Factorization

Quantum algorithm:

Shor's Algorithm

Applications

Q-Algorithms

Q-Bits

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Hardware

Industry

1 digit

Enter Passcode



Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Applications

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Q-Bits

Q-Circuits

Hardware

Industry

Number of digits

Number of tries

1



10

Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Applications

Q-Algorithms

Q-Bits

Q-Circuits

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-Algorithms

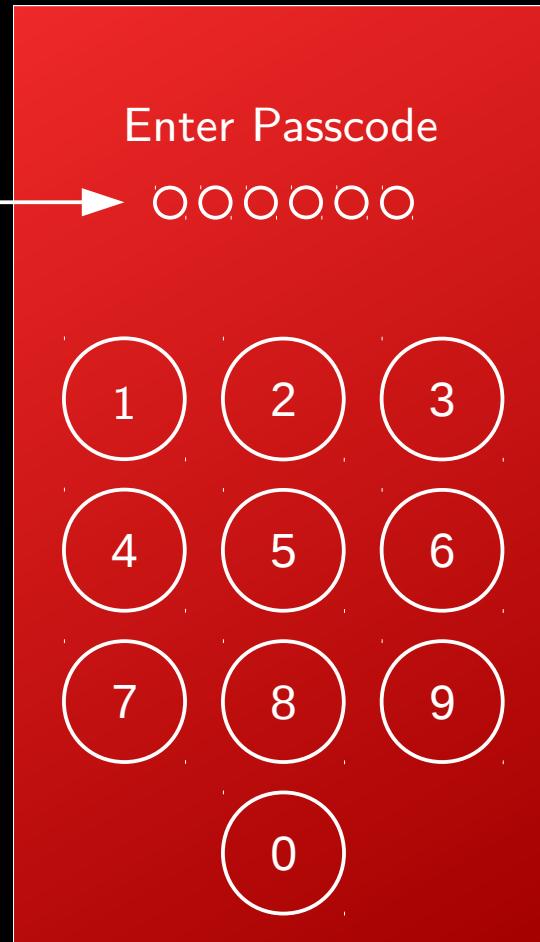
Q-Bits

Q-Circuits

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

Applications

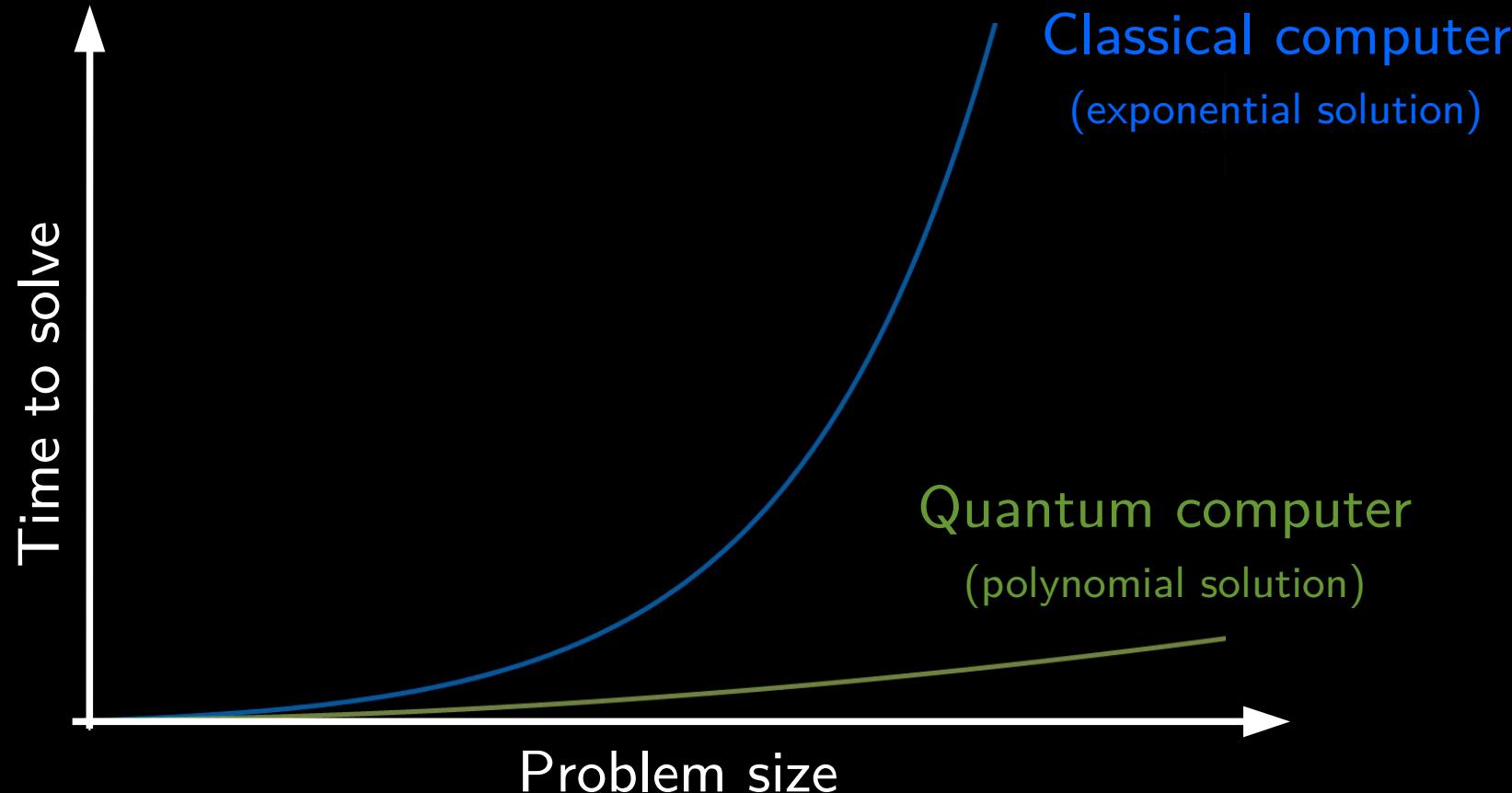
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Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Applications

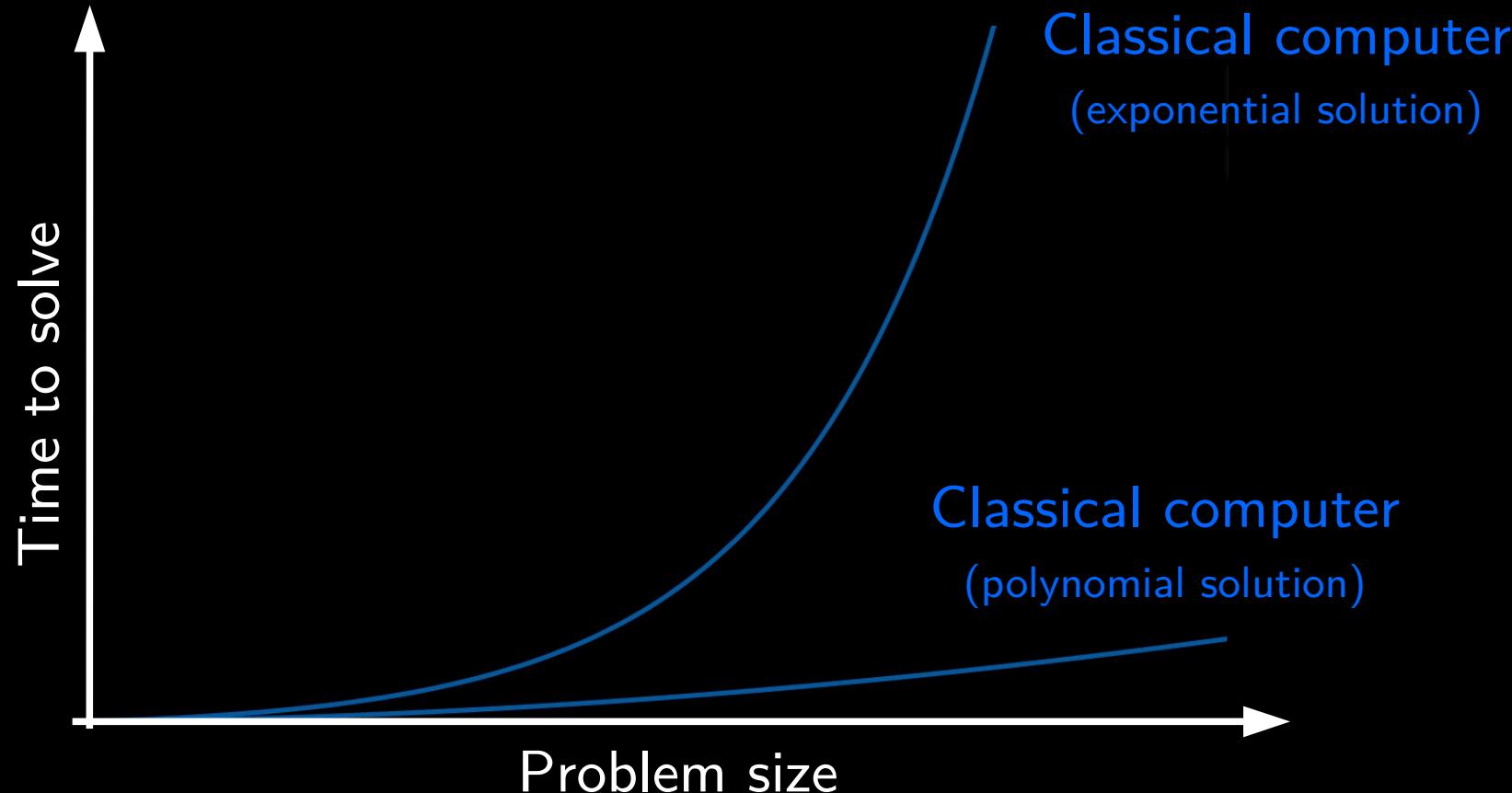
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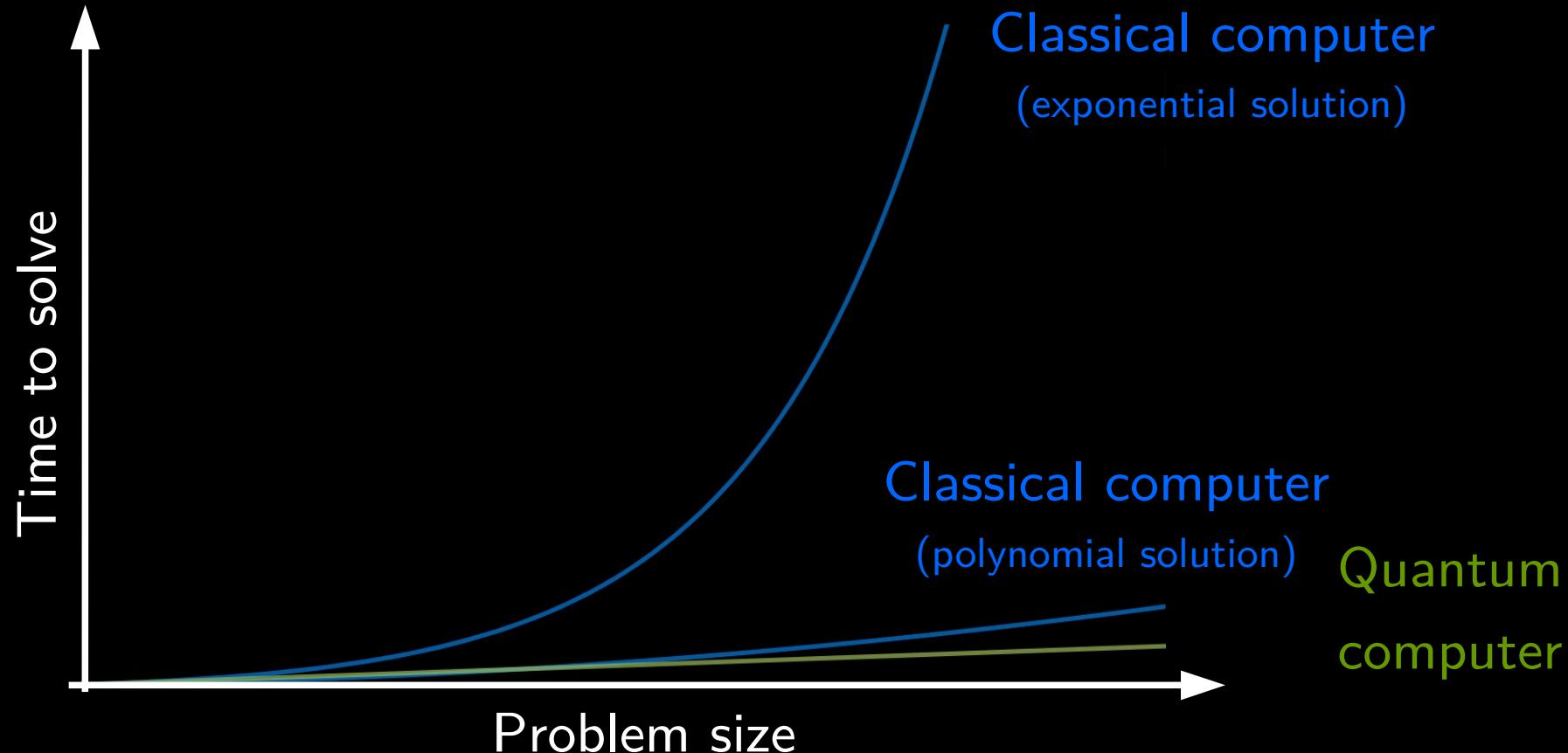
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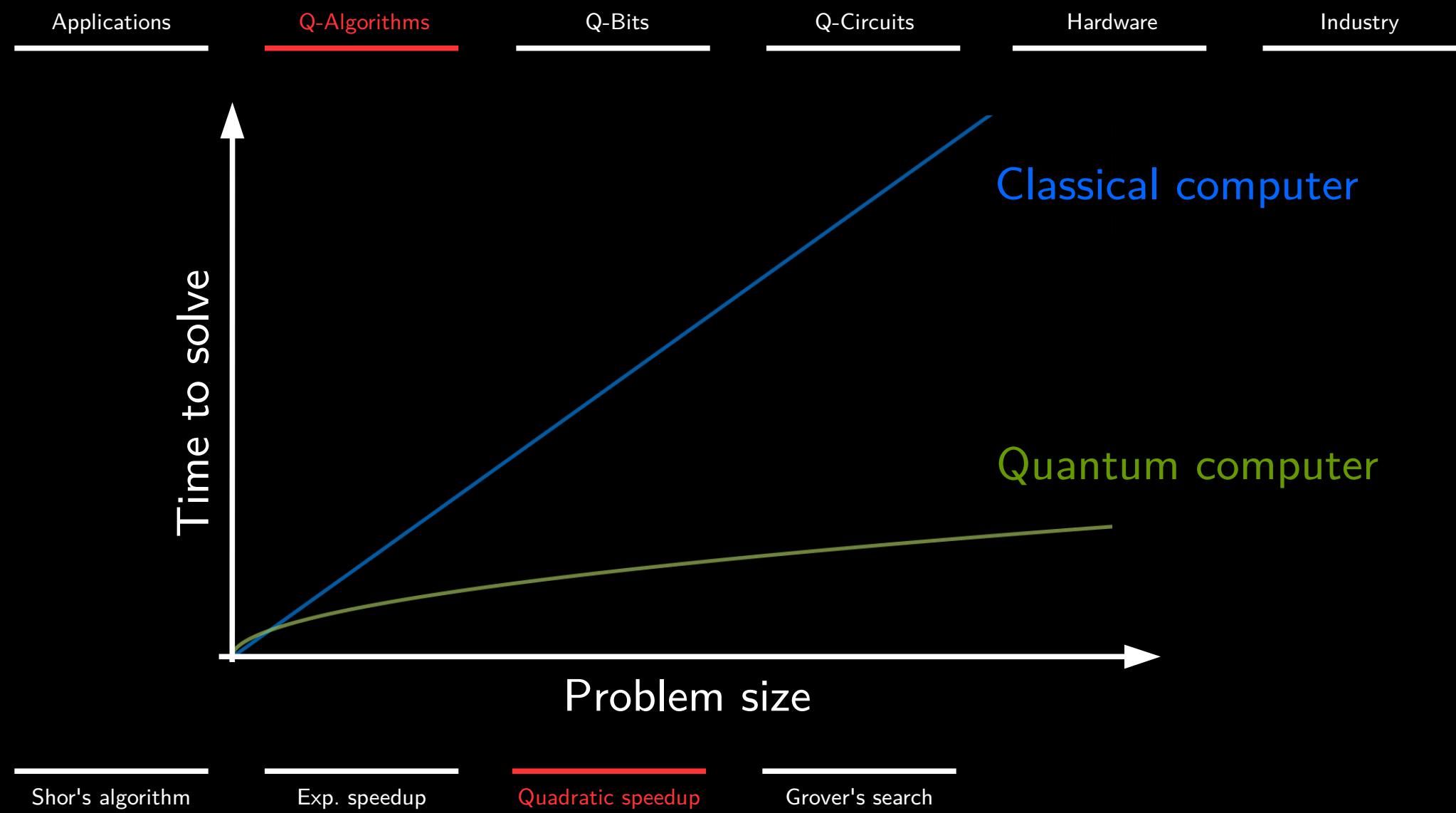


Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search



Applications

Q-Algorithms

Q-Bits

Q-Circuits

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Industry

1 digit

1 number

Enter Passcode

1

Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Applications

Q-Algorithms

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Q-Circuits

Hardware

Industry

1 digit

4 numbers

Enter Passcode



1

2

3

4

Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

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1 digit

6 numbers

Enter Passcode



1

2

3

4

5

6

Shor's algorithm

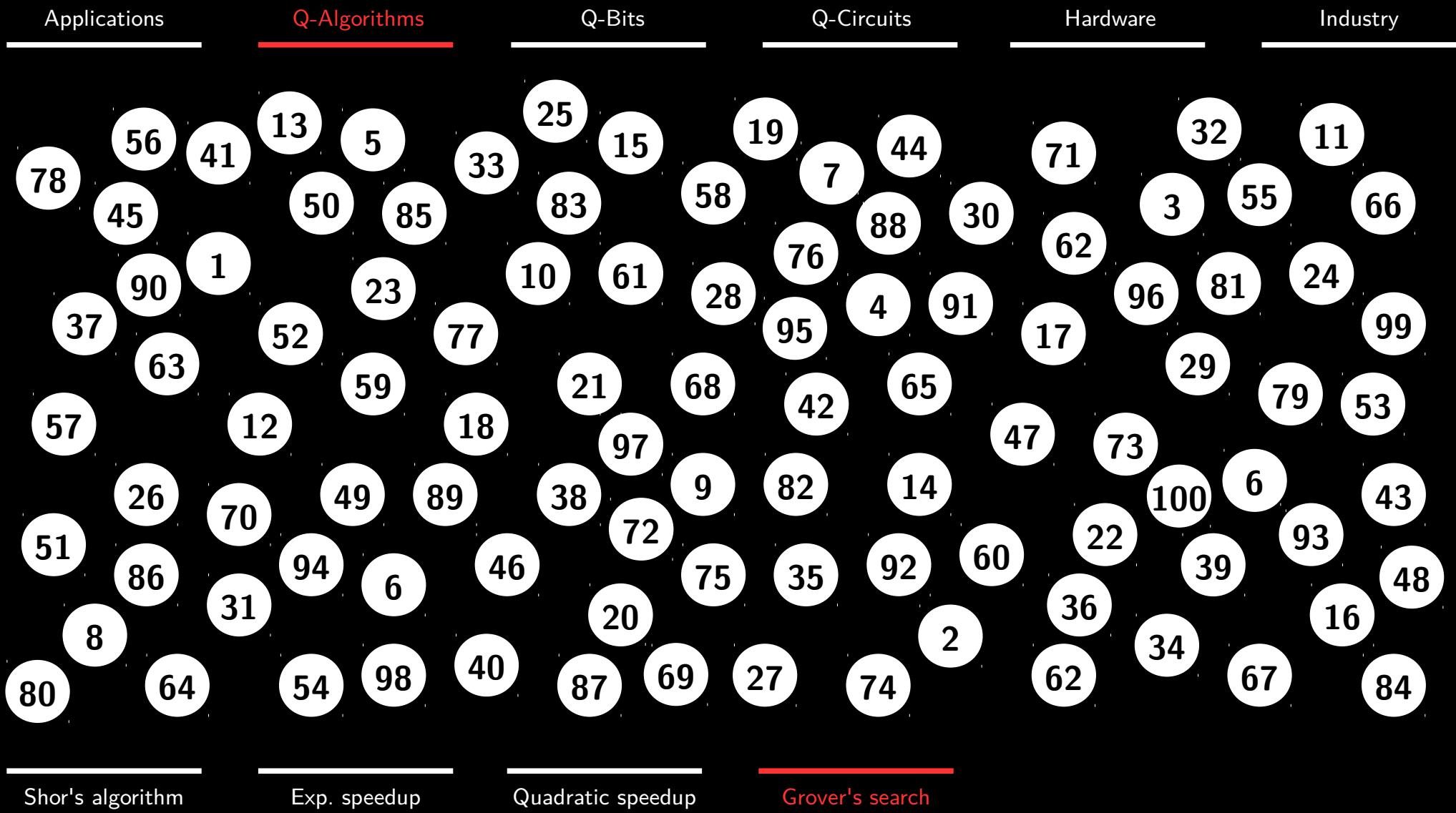
Exp. speedup

Quadratic speedup

Grover's search

Task:

Searching unsorted database



Applications

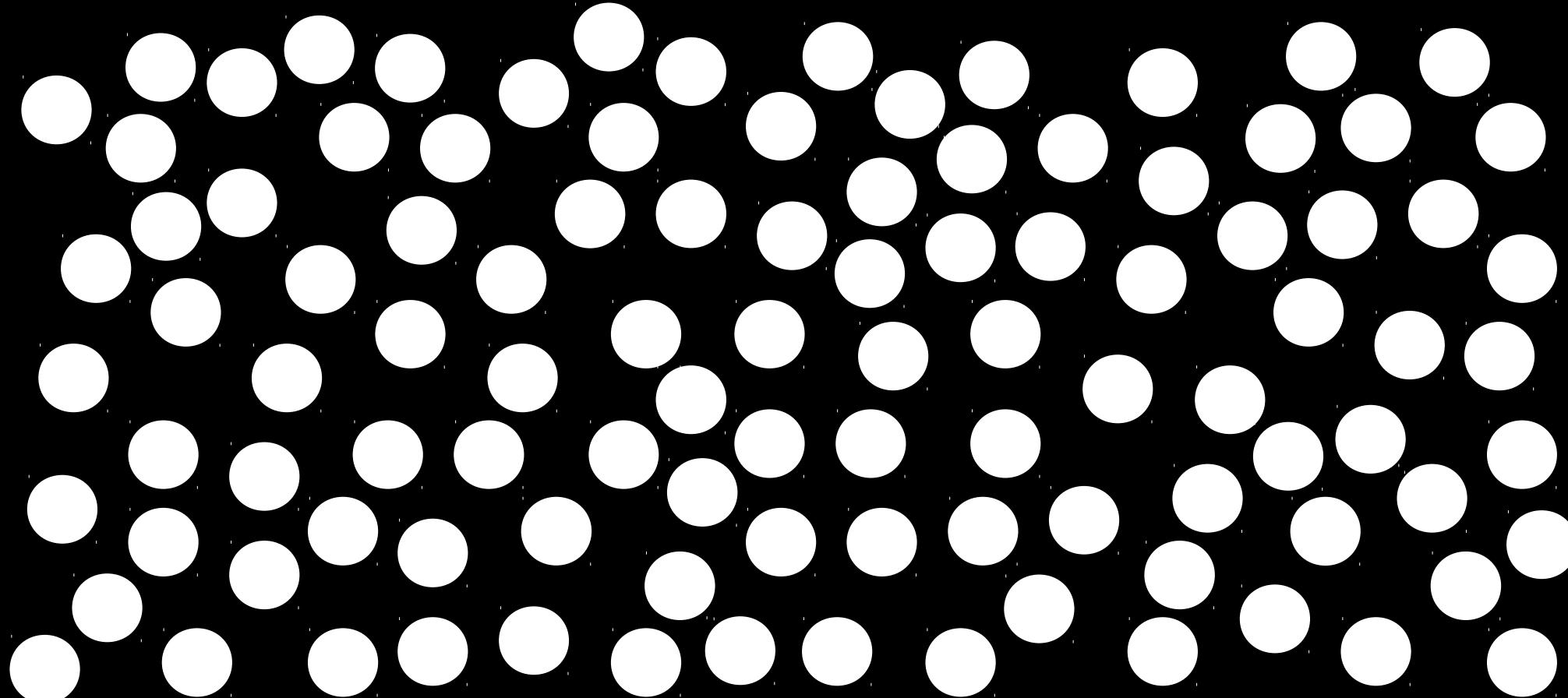
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Q-Bits

Q-Circuits

Hardware

Industry



Shor's algorithm

Exp. speedup

Quadratic speedup

Grover's search

Classical

100

tries

Quantum

8

tries

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 Algorithms

Quantum Bits

Quantum Circuits

Hardware

Industry Landscape

Applications

Quantum Algorithms

Quantum Bits

Quantum Circuits

Hardware

Industry Landscape

1. Superposition

2. Entanglement

Applications

Q-Algorithms

Q-Bits

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Hardware

Industry

1. Superposition

2. Entanglement

Superposition

Entanglement

Applications

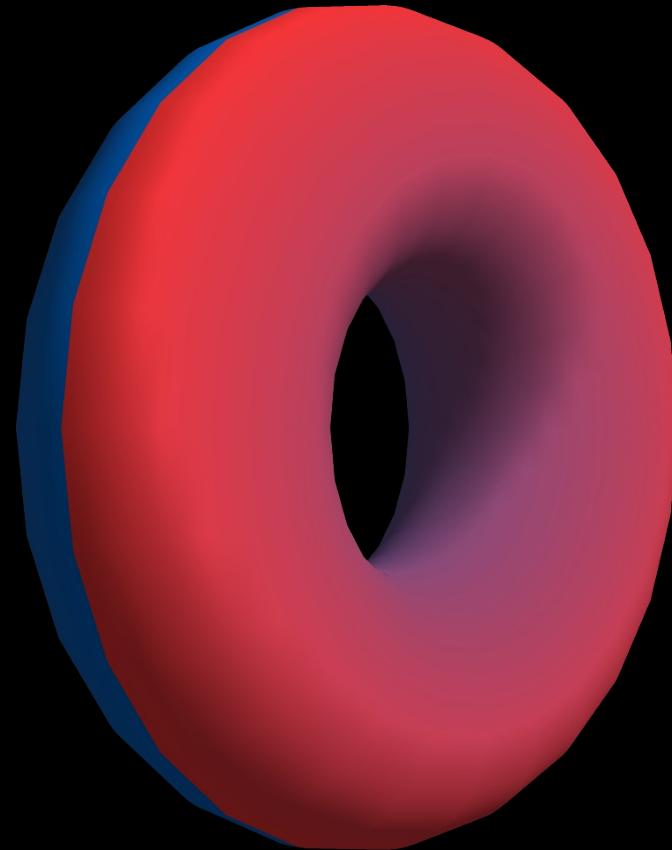
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Q-Bits

Q-Circuits

Hardware

Industry



Superposition

Entanglement

Applications

Q-Algorithms

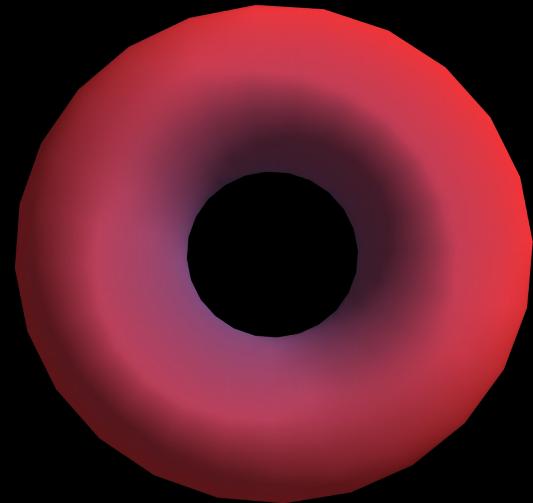
Q-Bits

Q-Circuits

Hardware

Industry

Classical bit:



0

Superposition

Entanglement

Applications

Q-Algorithms

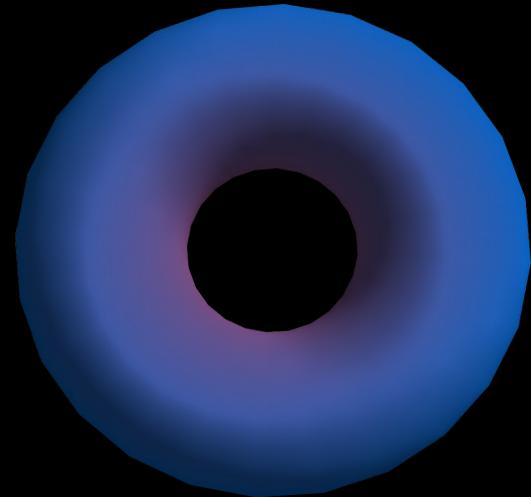
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Q-Circuits

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Industry

Classical bit:

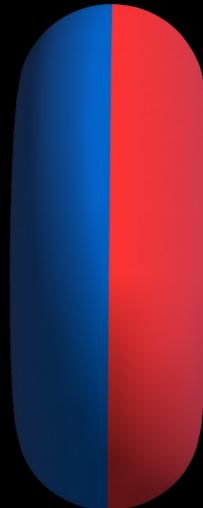
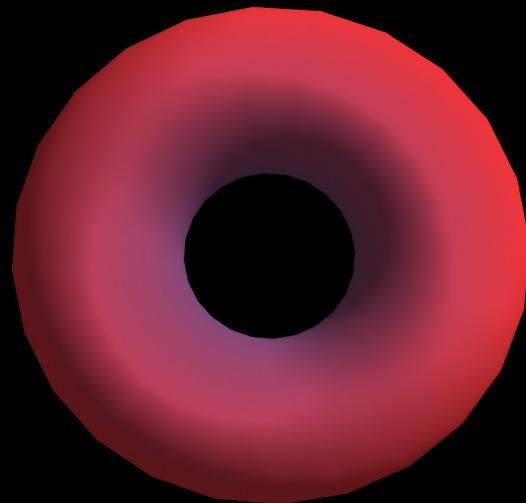
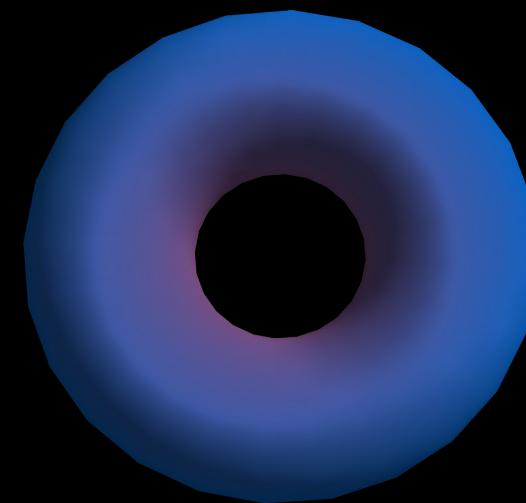


1

Superposition

Entanglement

Superposition:

 $=$  $+$ 

50%

50%

Applications

Q-Algorithms

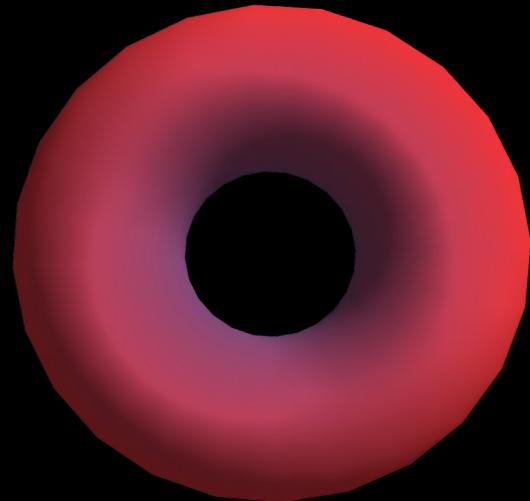
Q-Bits

Q-Circuits

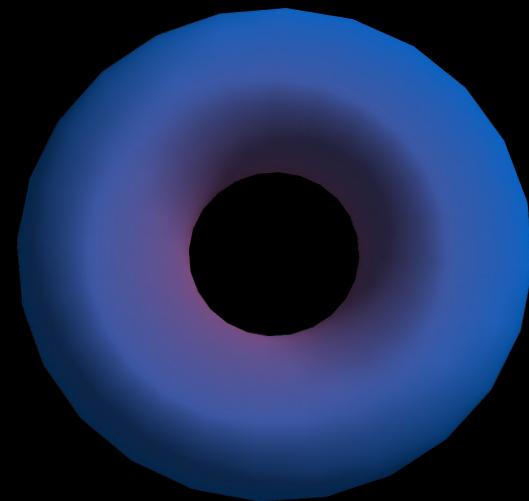
Hardware

Industry

Measurement:



50%

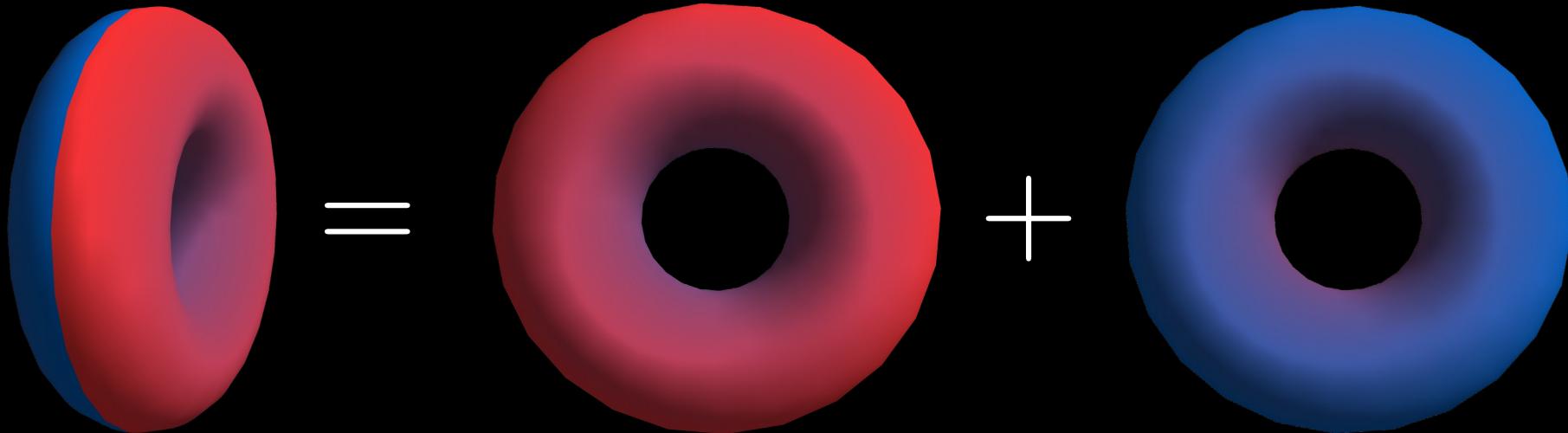


50%

Superposition

Entanglement

Superposition:



70%

30%

Applications

Q-Algorithms

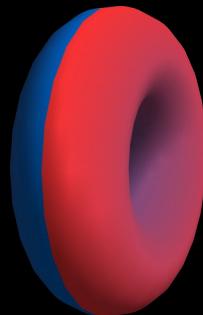
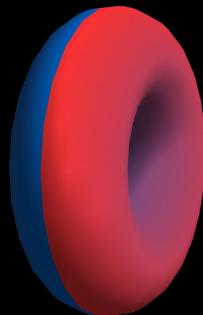
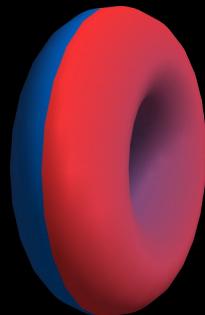
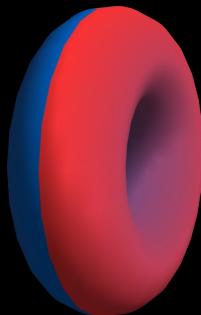
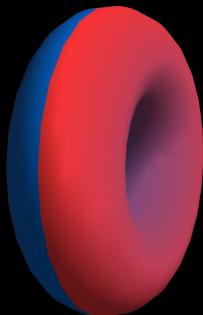
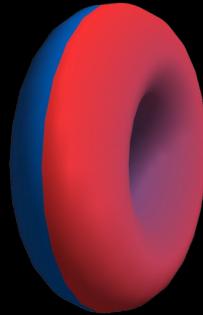
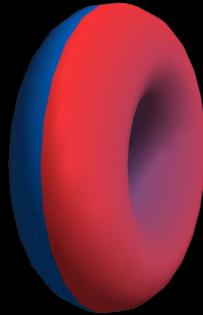
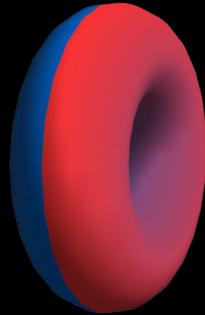
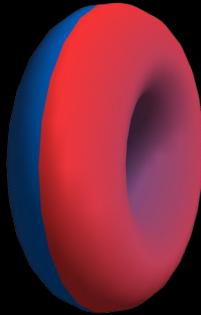
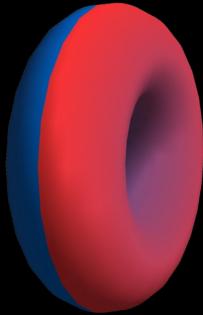
Q-Bits

Q-Circuits

Hardware

Industry

Multiple qubits:



Superposition

Entanglement

Applications

Q-Algorithms

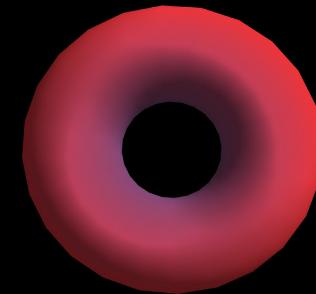
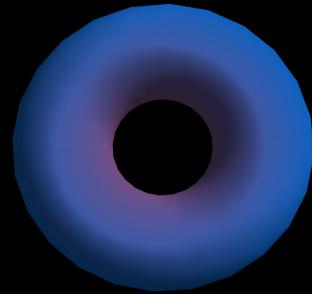
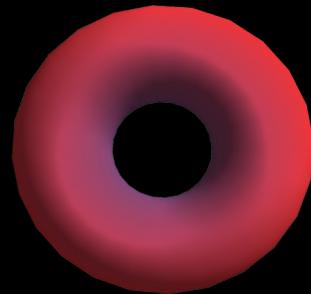
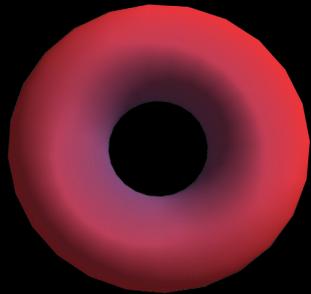
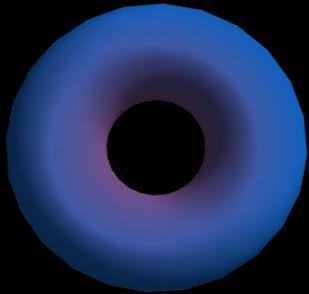
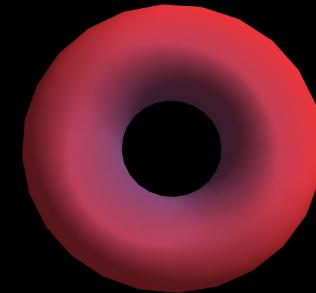
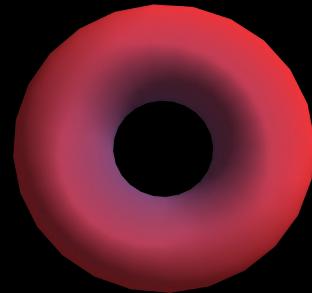
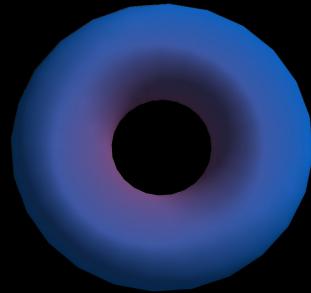
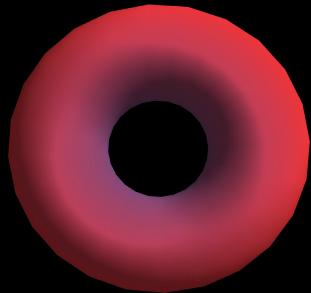
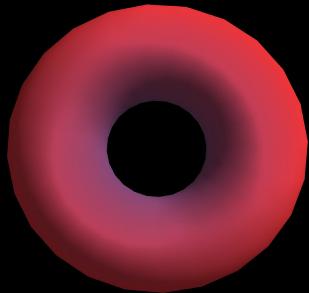
Q-Bits

Q-Circuits

Hardware

Industry

Multiple measurements:



Superposition

Entanglement

Applications

Q-Algorithms

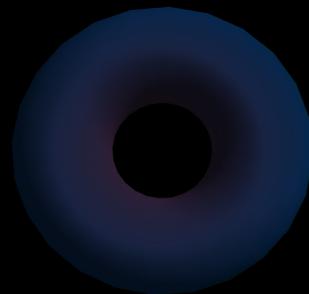
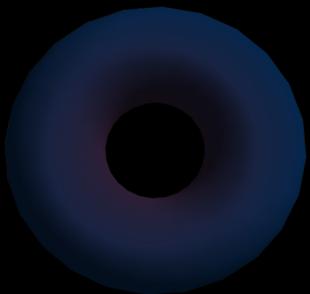
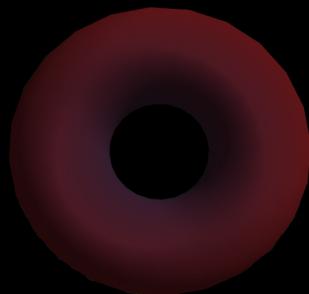
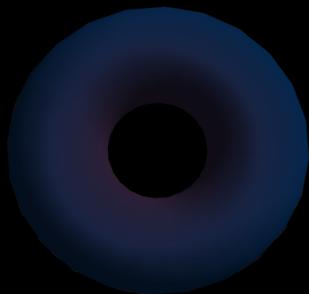
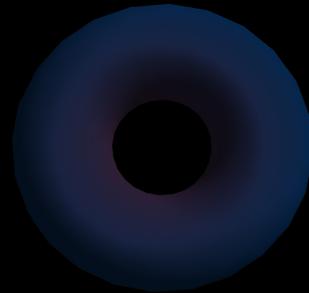
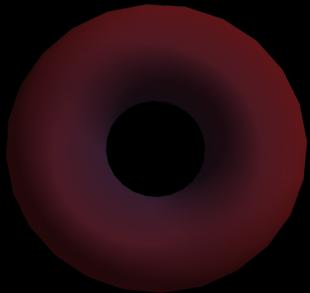
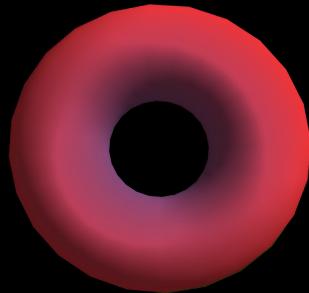
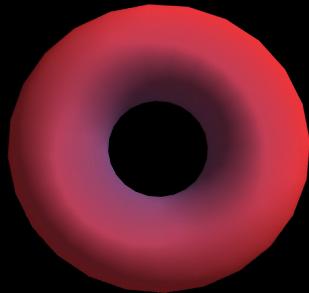
Q-Bits

Q-Circuits

Hardware

Industry

2 (classical) bits:



Superposition

Entanglement

Applications

Q-Algorithms

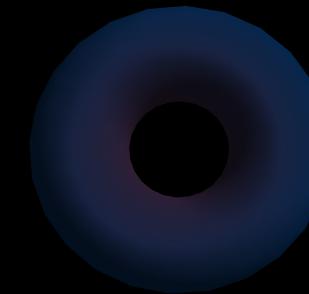
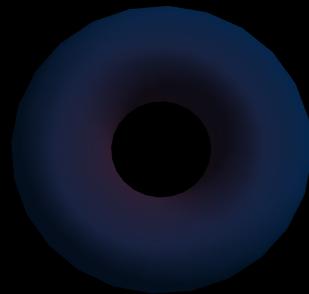
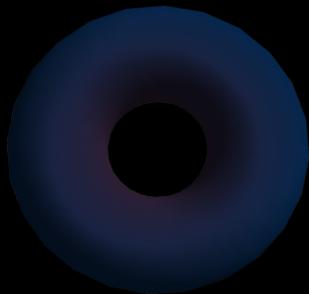
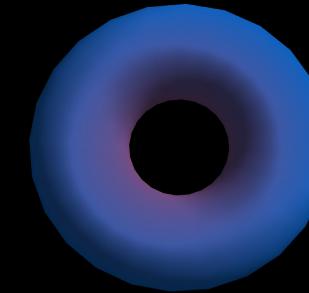
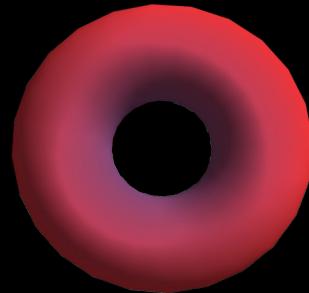
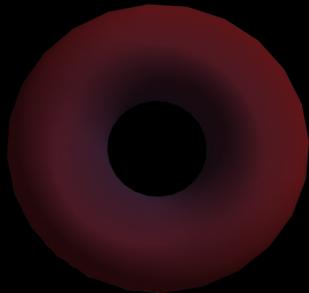
Q-Bits

Q-Circuits

Hardware

Industry

2 (classical) bits:



Superposition

Entanglement

Applications

Q-Algorithms

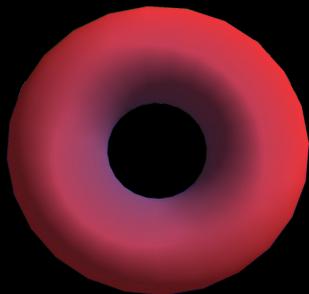
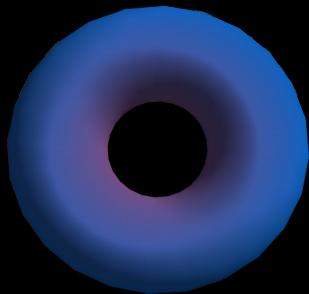
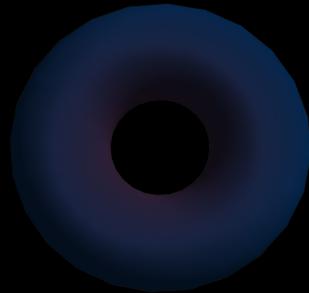
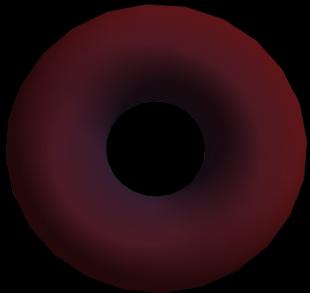
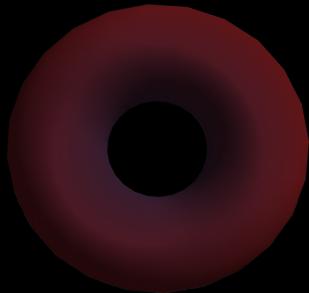
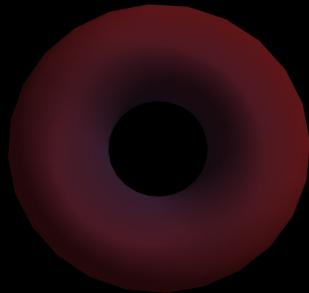
Q-Bits

Q-Circuits

Hardware

Industry

2 (classical) bits:



Superposition

Entanglement

Applications

Q-Algorithms

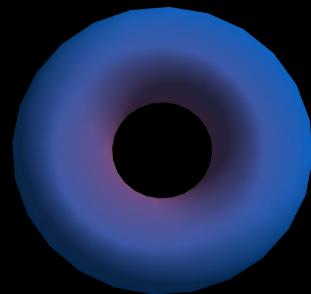
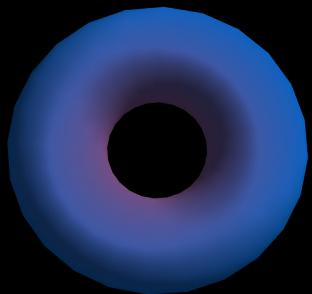
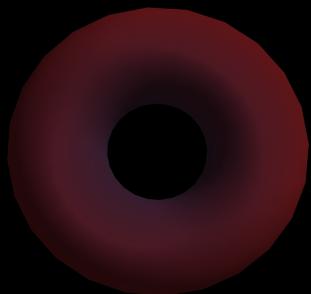
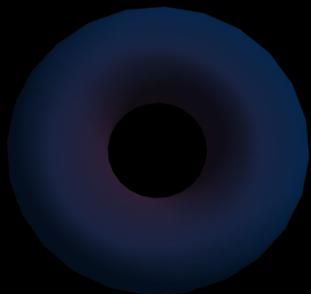
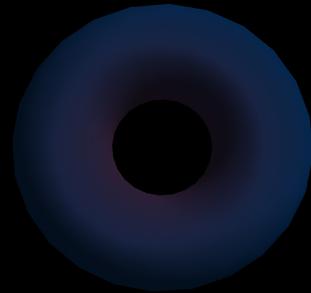
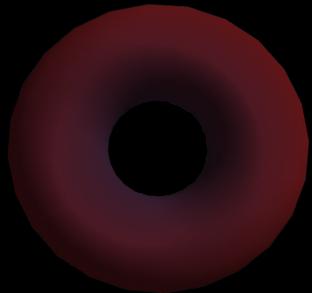
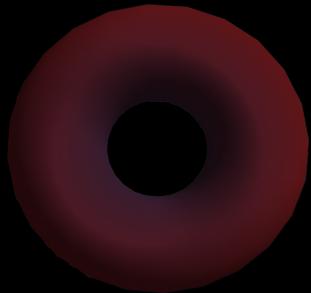
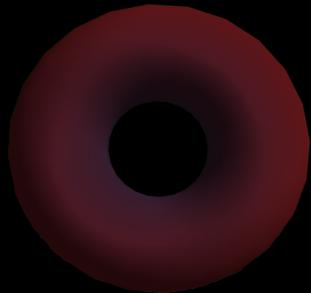
Q-Bits

Q-Circuits

Hardware

Industry

2 (classical) bits:



Superposition

Entanglement

Applications

Q-Algorithms

Q-Bits

Q-Circuits

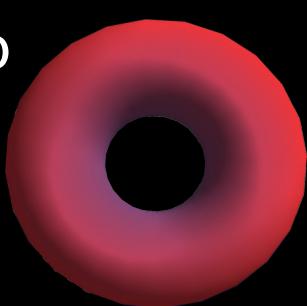
Hardware

Industry

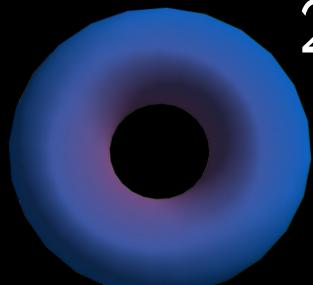
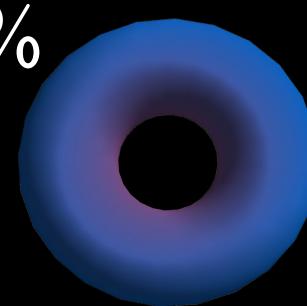
2 qubits:



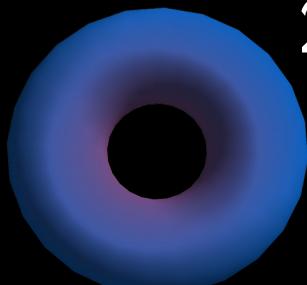
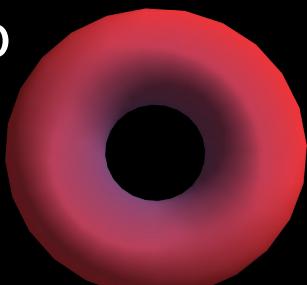
25%



25%



25%



25%

Superposition

Entanglement

Applications

Q-Algorithms

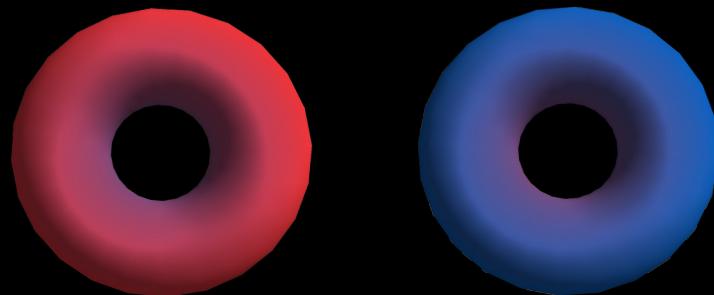
Q-Bits

Q-Circuits

Hardware

Industry

2 (classical) bits:



1st bit
of information



2nd bit
of information

Superposition

Entanglement

Applications

Q-Algorithms

Q-Bits

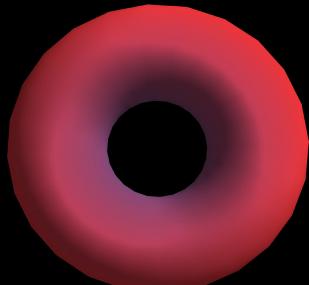
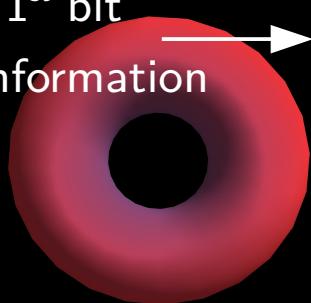
Q-Circuits

Hardware

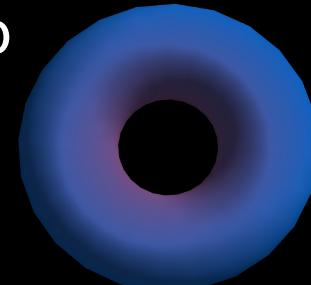
Industry

2 qubits:

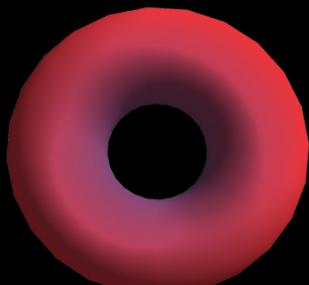
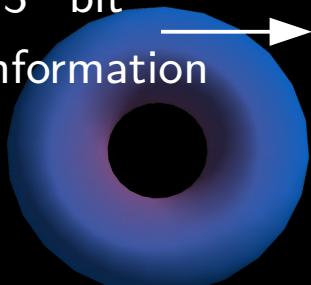
1st bit
of information → ?%



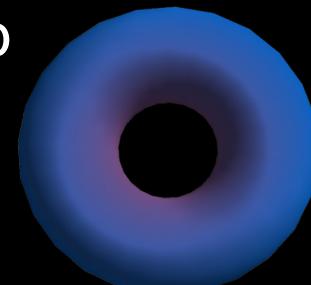
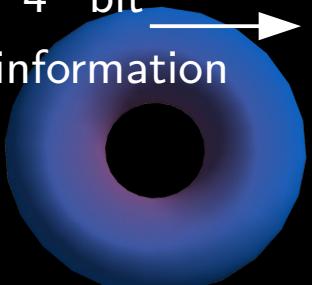
2nd bit
of information → ?%



3rd bit
of information → ?%



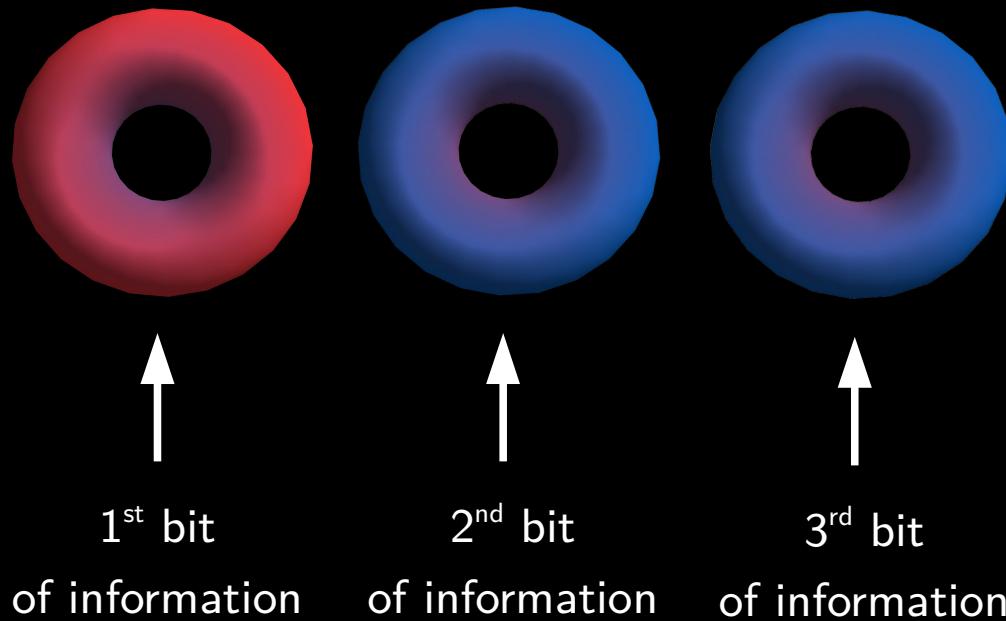
4th bit
of information → ?%



Superposition

Entanglement

3 (classical) bits:



Applications

Q-Algorithms

Q-Bits

Q-Circuits

Hardware

Industry

3 qubits:

1st bit
of information → ?%



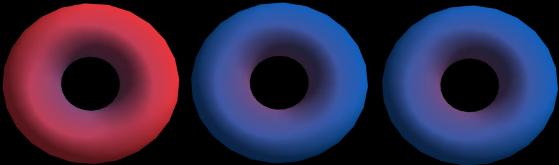
2nd bit
of information → ?%



3rd bit
of information → ?%



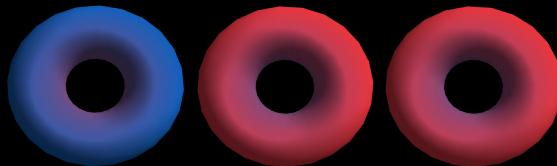
4th bit
of information → ?%



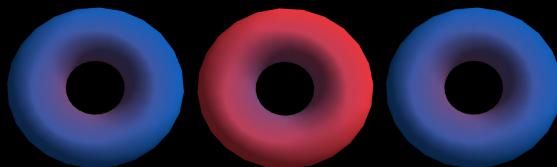
Superposition

Entanglement

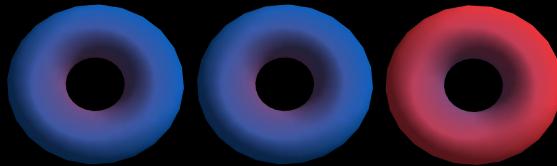
5th bit
of information → ?%



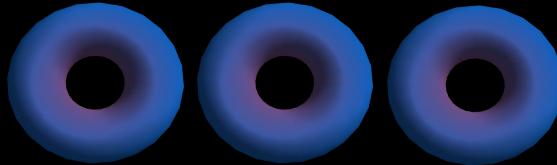
6th bit
of information → ?%



7th bit
of information → ?%



8th bit
of information → ?%



Applications

Q-Algorithms

Q-Bits

Q-Circuits

Hardware

Industry

n

qubits

2^n

bits

Superposition

Entanglement

Applications

Q-Algorithms

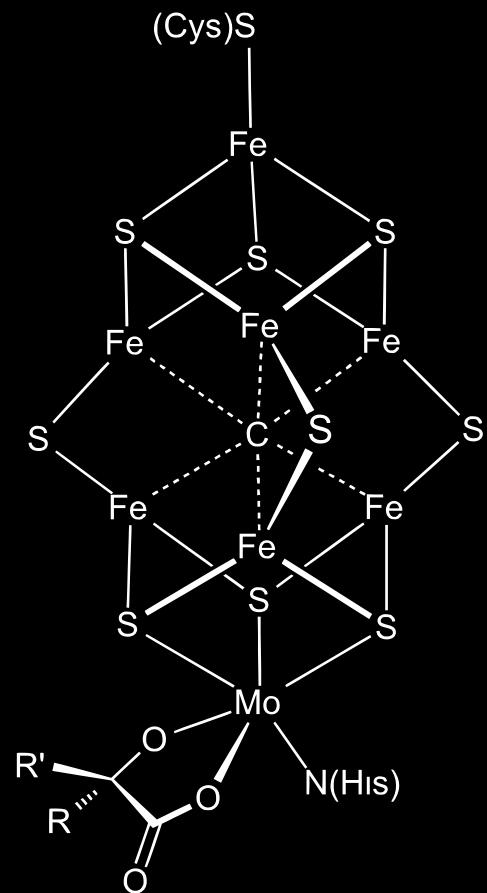
Q-Bits

Q-Circuits

Hardware

Industry

108
qubits



2^{108}

$\approx 10^{32}$
bits

Superposition

Entanglement

Applications

Q-Algorithms

Q-Bits

Q-Circuits

Hardware

Industry

1. Superposition

2. Entanglement

Superposition

Entanglement

Applications

Q-Algorithms

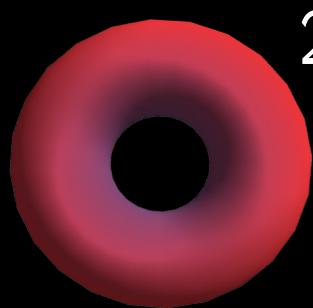
Q-Bits

Q-Circuits

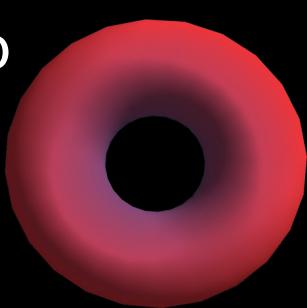
Hardware

Industry

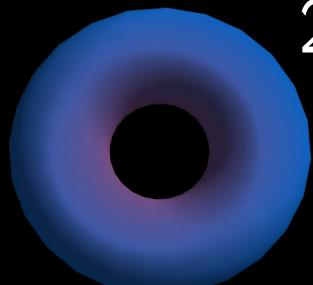
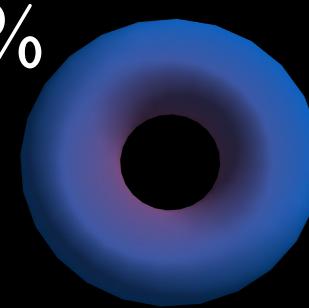
Superposition:



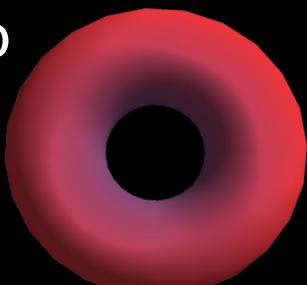
25%



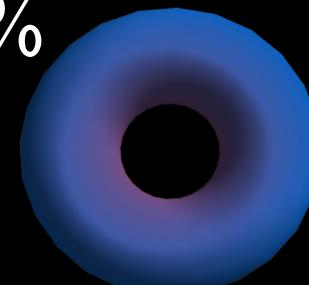
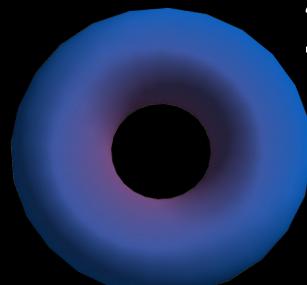
25%



25%



25%



Superposition

Entanglement

Applications

Q-Algorithms

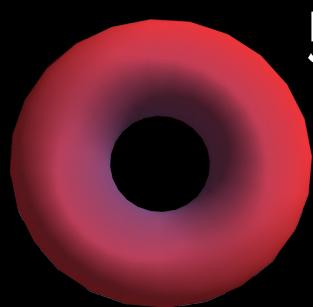
Q-Bits

Q-Circuits

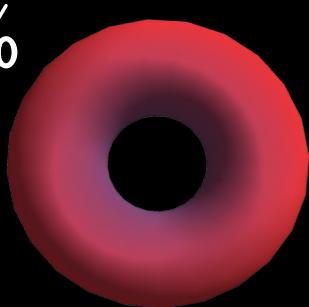
Hardware

Industry

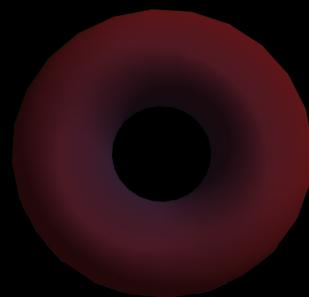
Entanglement:



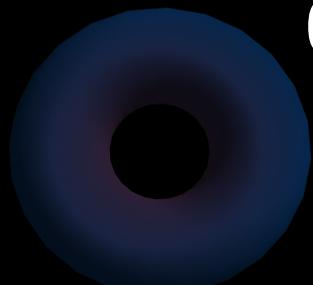
50%



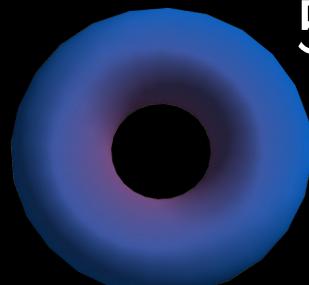
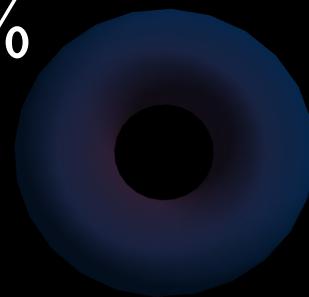
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0%



50%



Superposition

Entanglement

Applications

Q-Algorithms

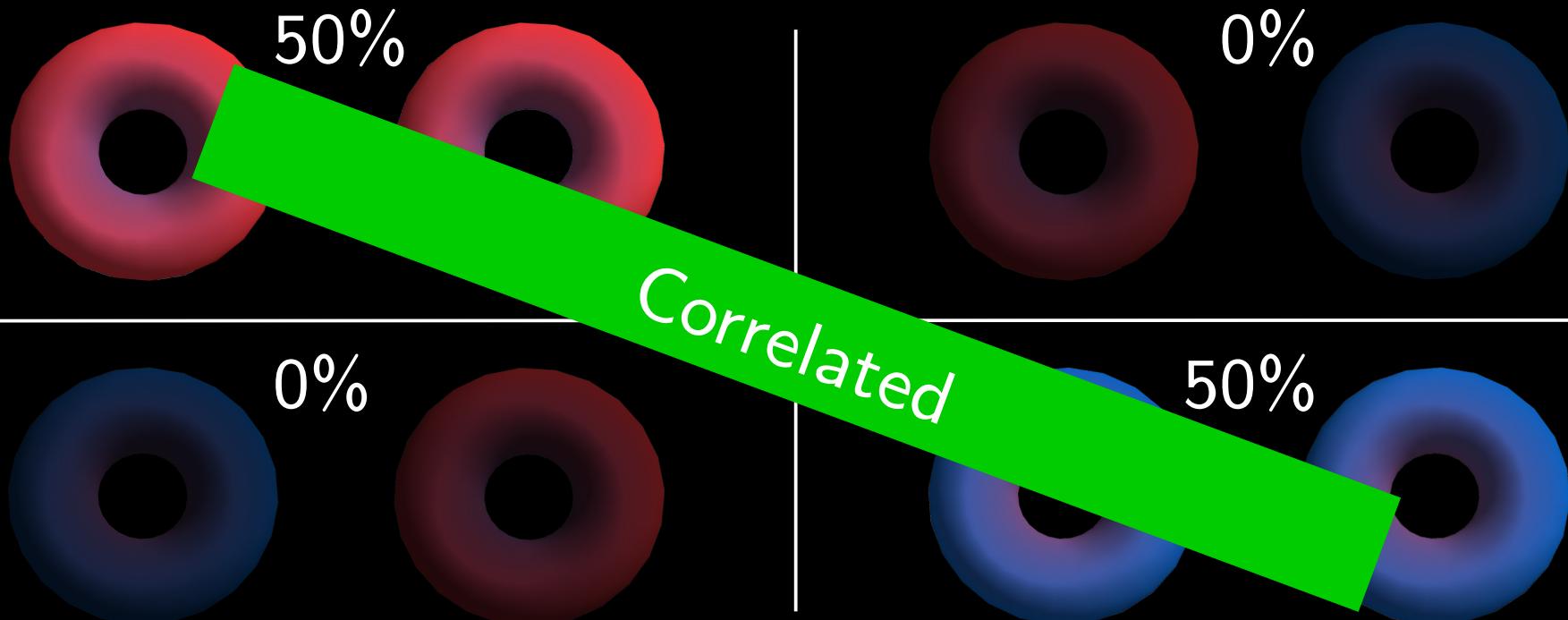
Q-Bits

Q-Circuits

Hardware

Industry

Entanglement:



Superposition

Entanglement

Applications

Q-Algorithms

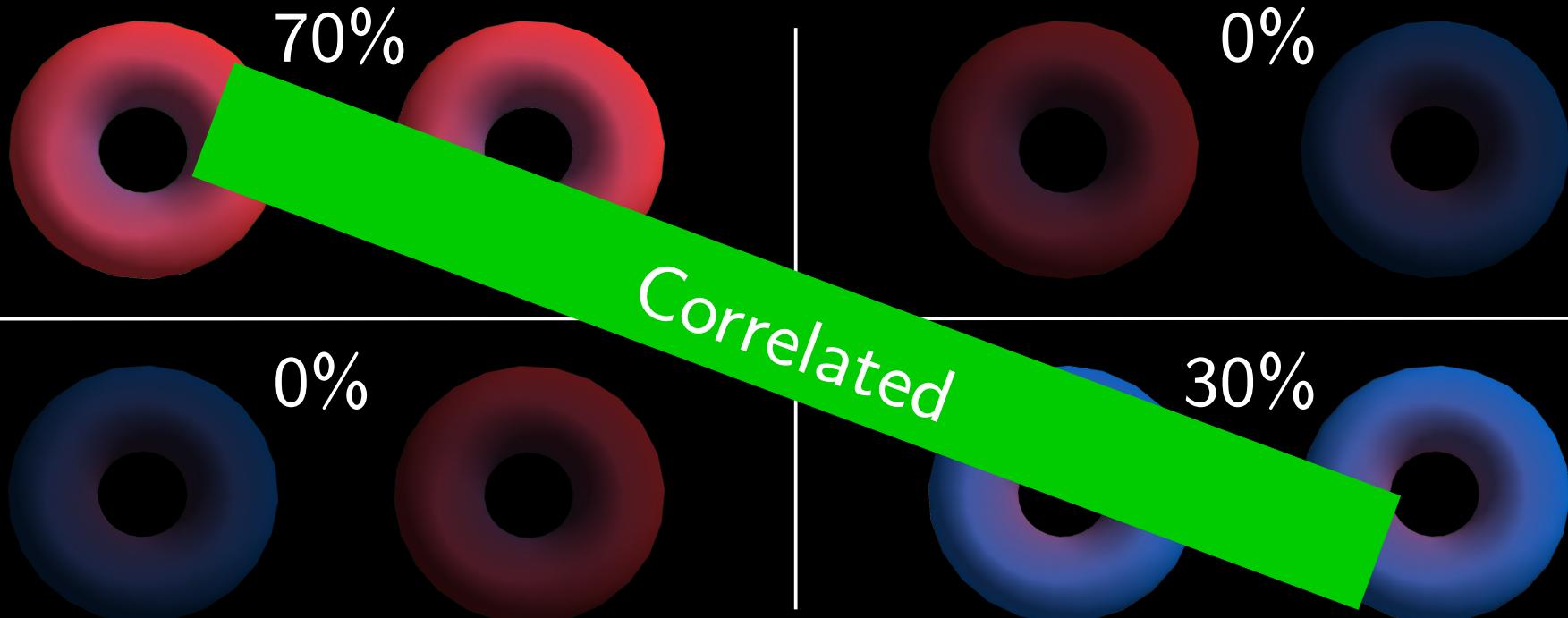
Q-Bits

Q-Circuits

Hardware

Industry

Entanglement:



Superposition

Entanglement

Applications

Q-Algorithms

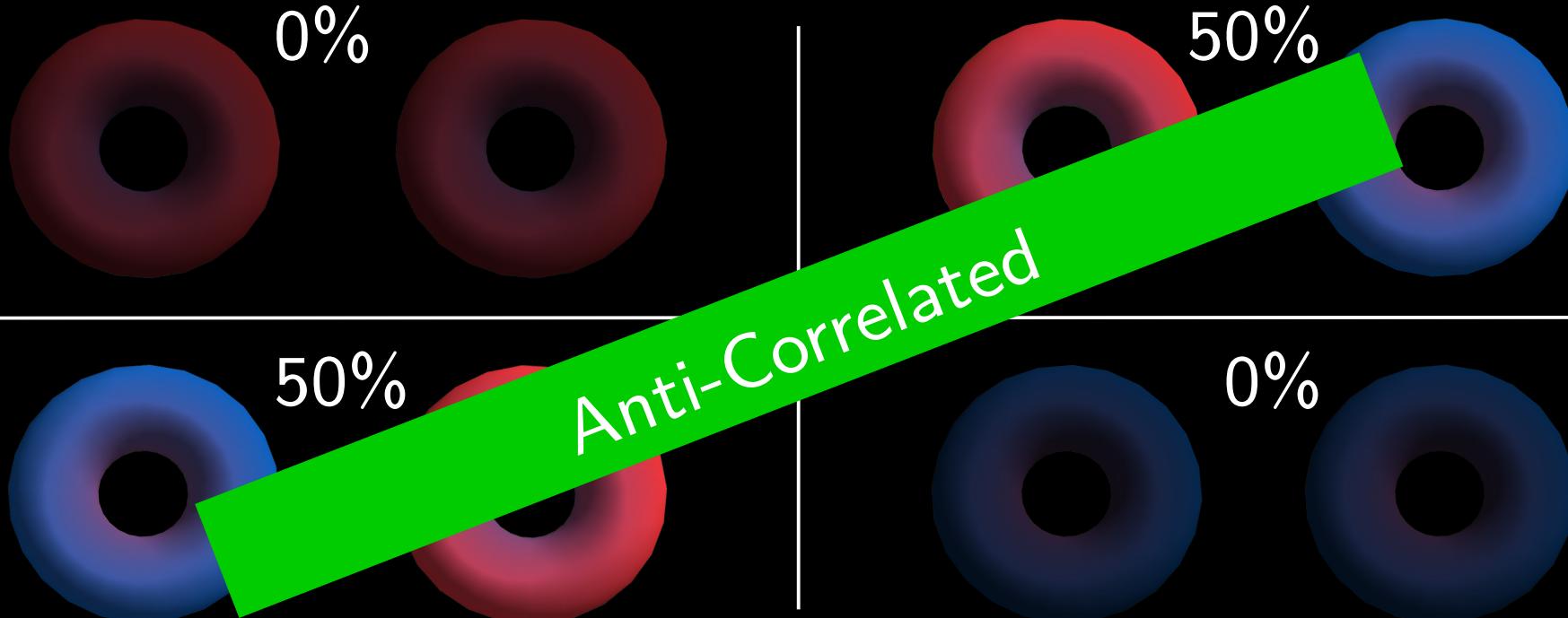
Q-Bits

Q-Circuits

Hardware

Industry

Entanglement:



Superposition

Entanglement

Applications

Quantum Algorithms

Quantum Bits

Quantum Circuits

Hardware

Industry Landscape

Applications

Quantum Algorithms

Quantum Bits

Quantum Circuits

Hardware

Industry Landscape

Applications

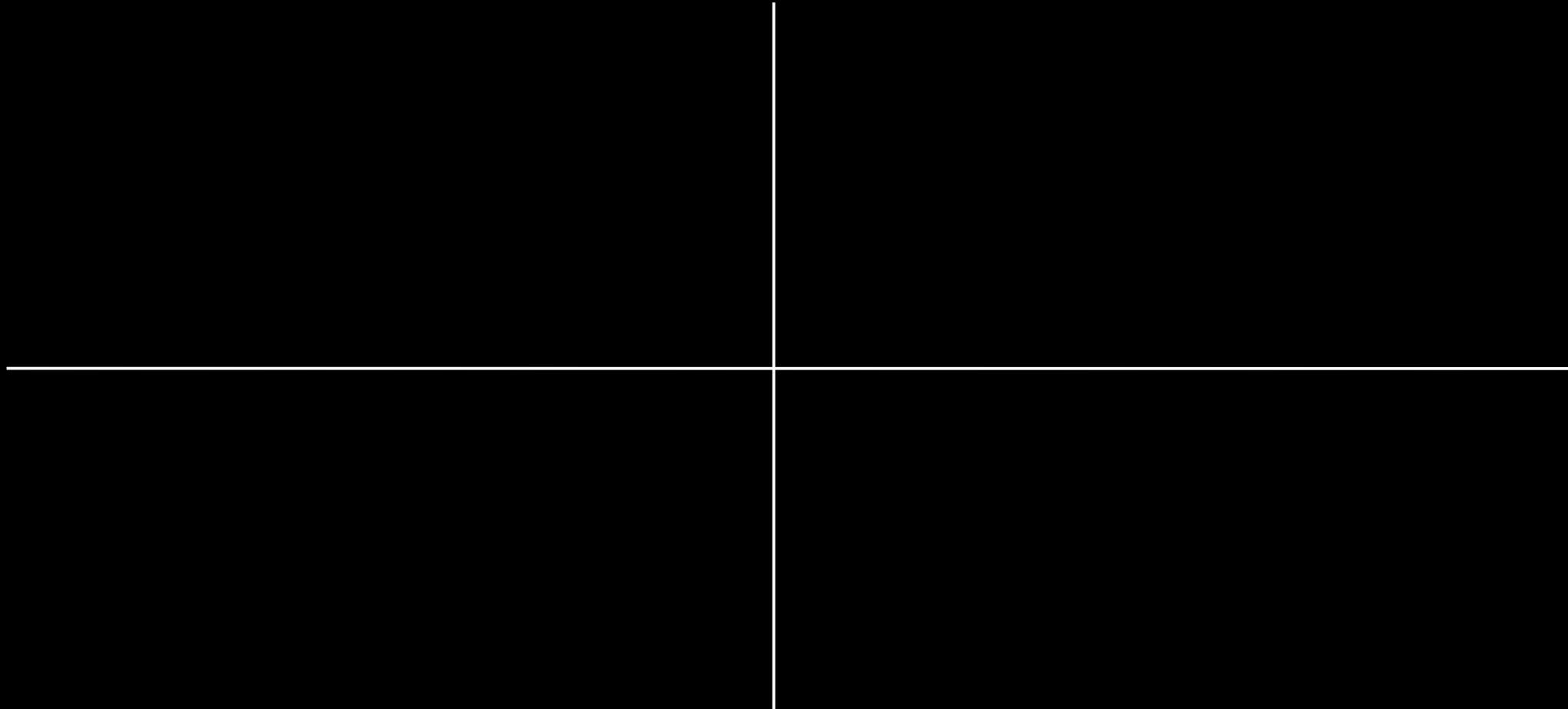
Q-Algorithms

Q-Bits

Q-Circuits

Hardware

Industry



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Algorithms

Q-Bits

Q-Circuits

Hardware

Industry

Superposition



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Algorithms

Q-Bits

Q-Circuits

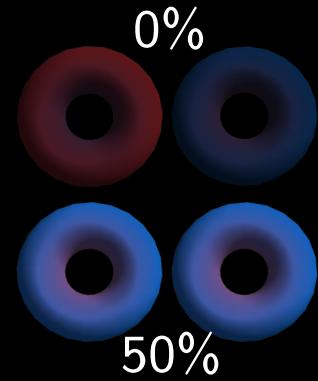
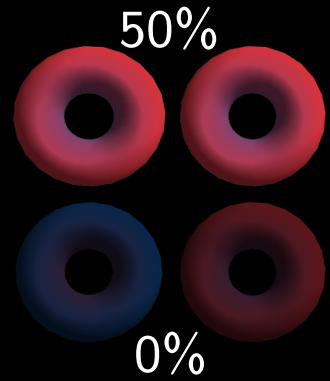
Hardware

Industry

Superposition



Entanglement



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Algorithms

Q-Bits

Q-Circuits

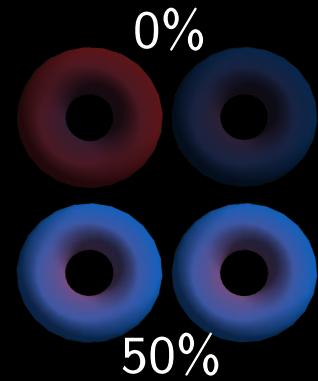
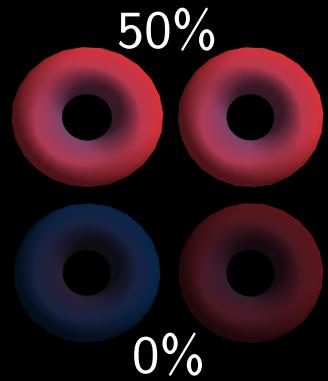
Hardware

Industry

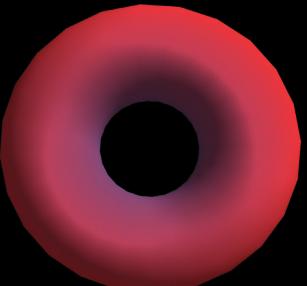
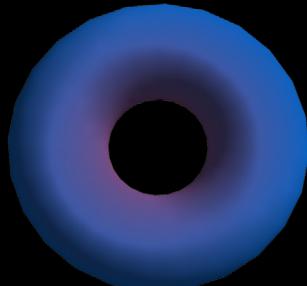
Superposition



Entanglement



Bit flip



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Algorithms

Q-Bits

Q-Circuits

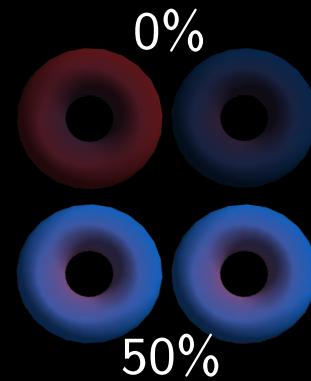
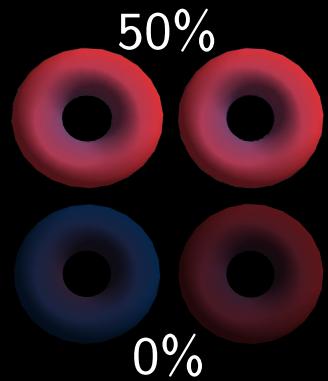
Hardware

Industry

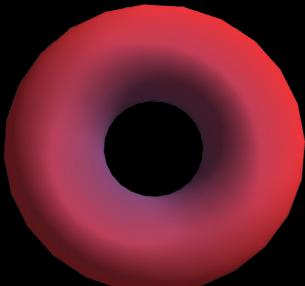
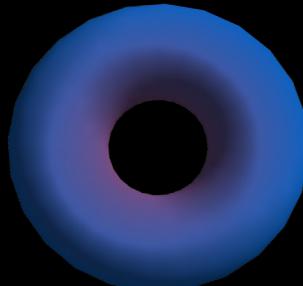
Superposition



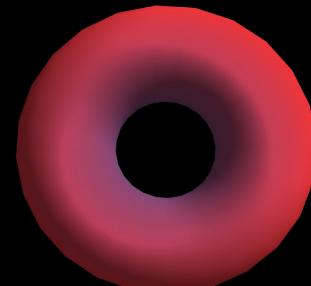
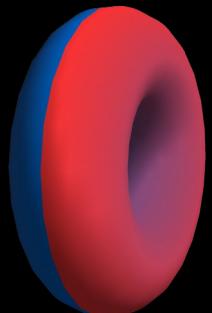
Entanglement



Bit flip



Measurement



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Algorithms

Q-Bits

Q-Circuits

Hardware

Industry

Hadamard H-gate:



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Algorithms

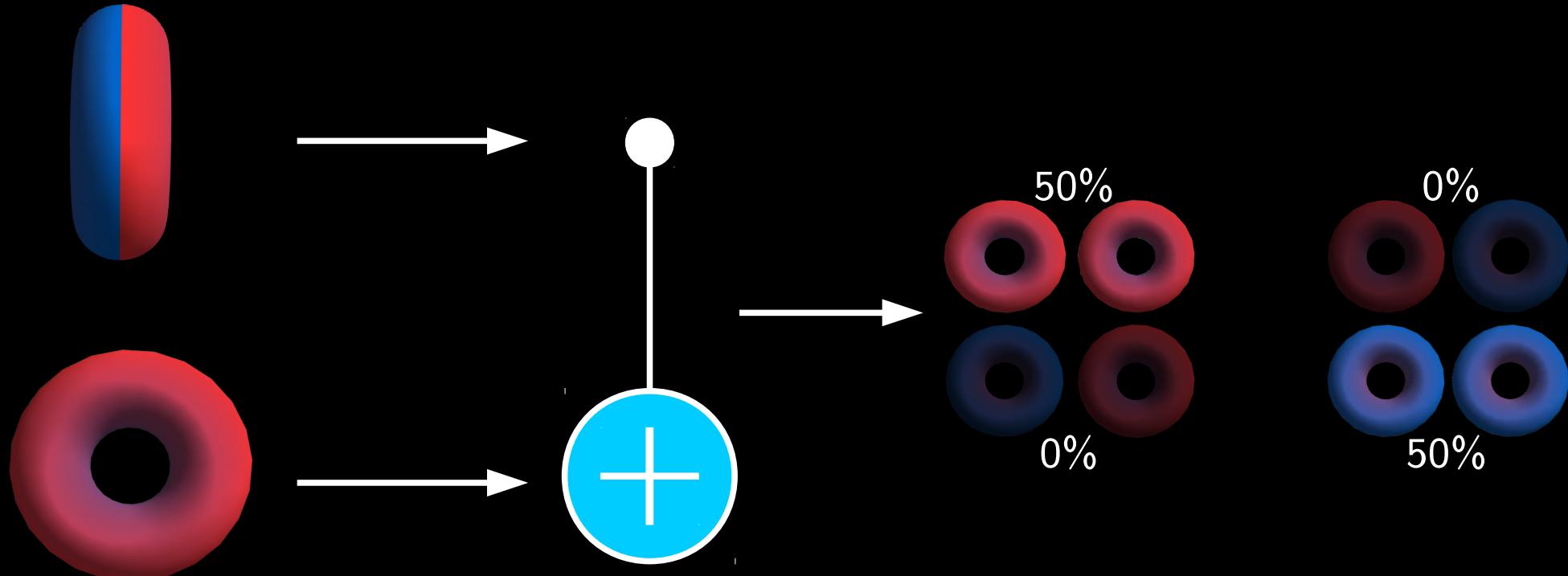
Q-Bits

Q-Circuits

Hardware

Industry

C-NOT gate:



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Algorithms

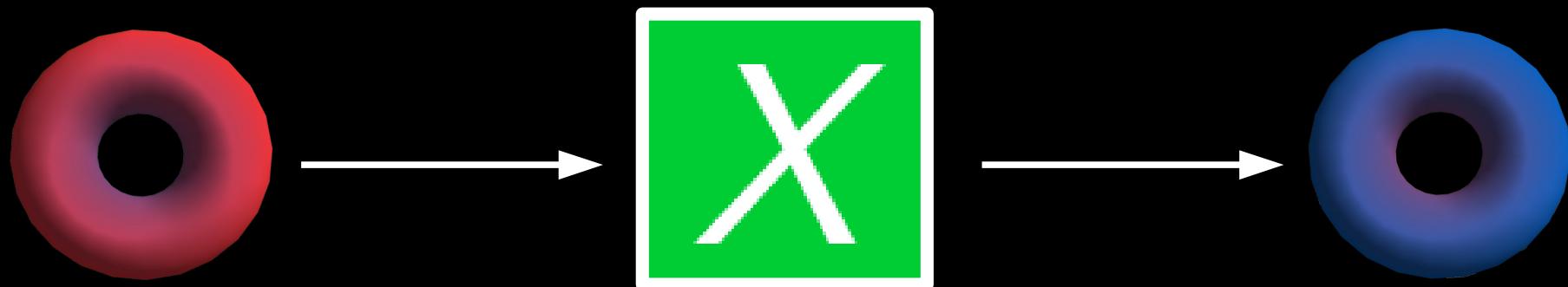
Q-Bits

Q-Circuits

Hardware

Industry

Bit flip X-gate:



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Algorithms

Q-Bits

Q-Circuits

Hardware

Industry

Measurement:



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Algorithms

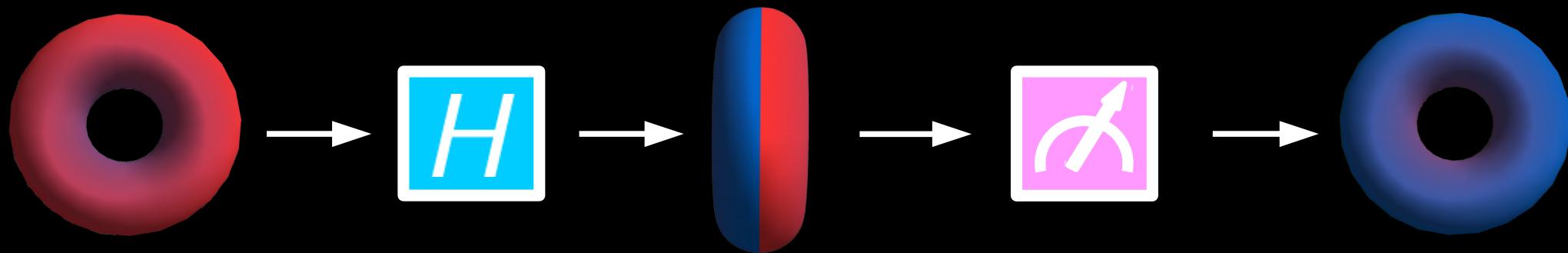
Q-Bits

Q-Circuits

Hardware

Industry

Quantum circuit:



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Algorithms

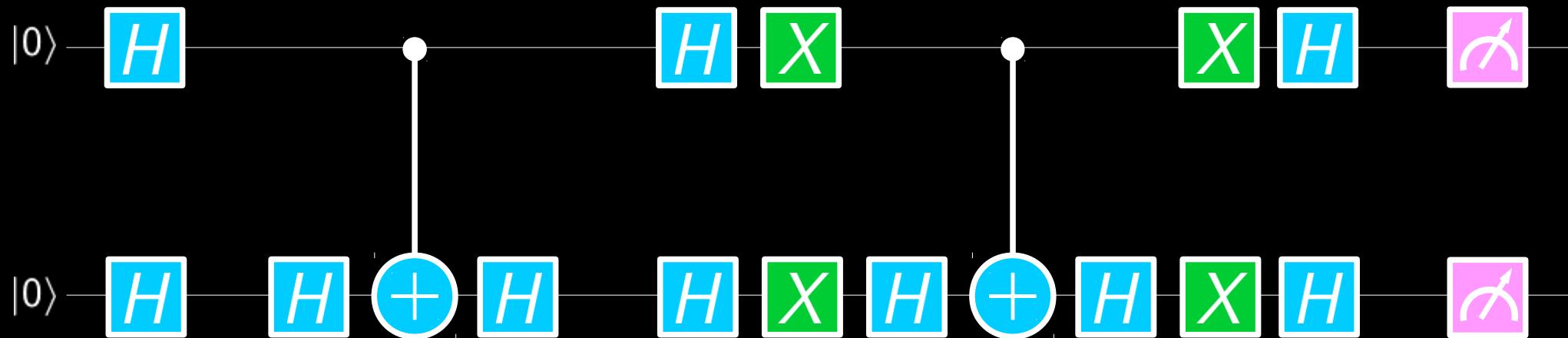
Q-Bits

Q-Circuits

Hardware

Industry

Grover's search:



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Algorithms

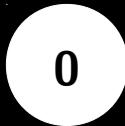
Q-Bits

Q-Circuits

Hardware

Industry

Grover's search:



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

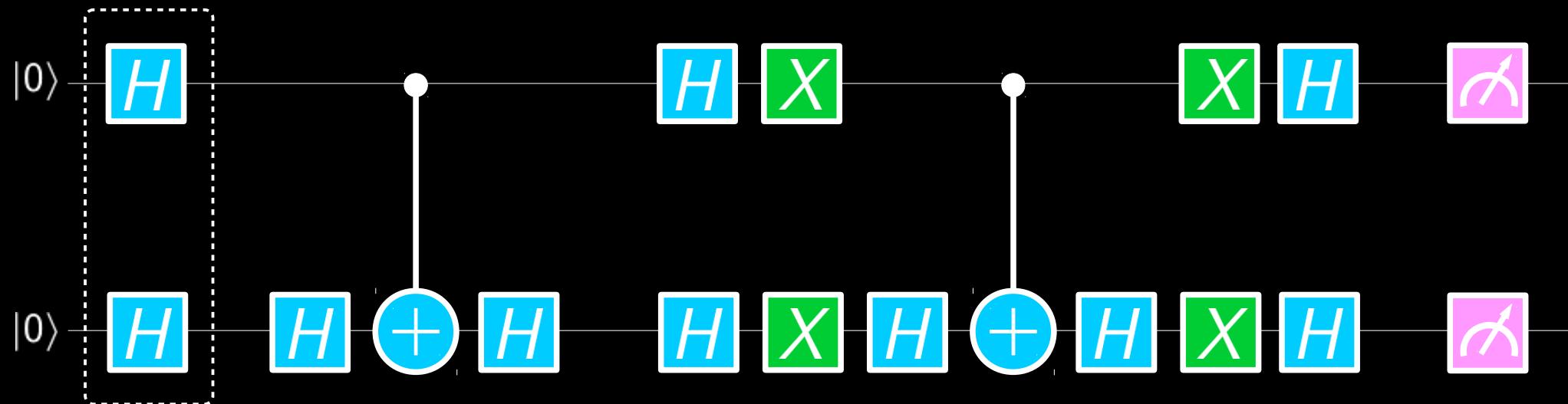
2

10

3

11

Grover's search: Step 1 – Superposition



Applications

Q-Algorithms

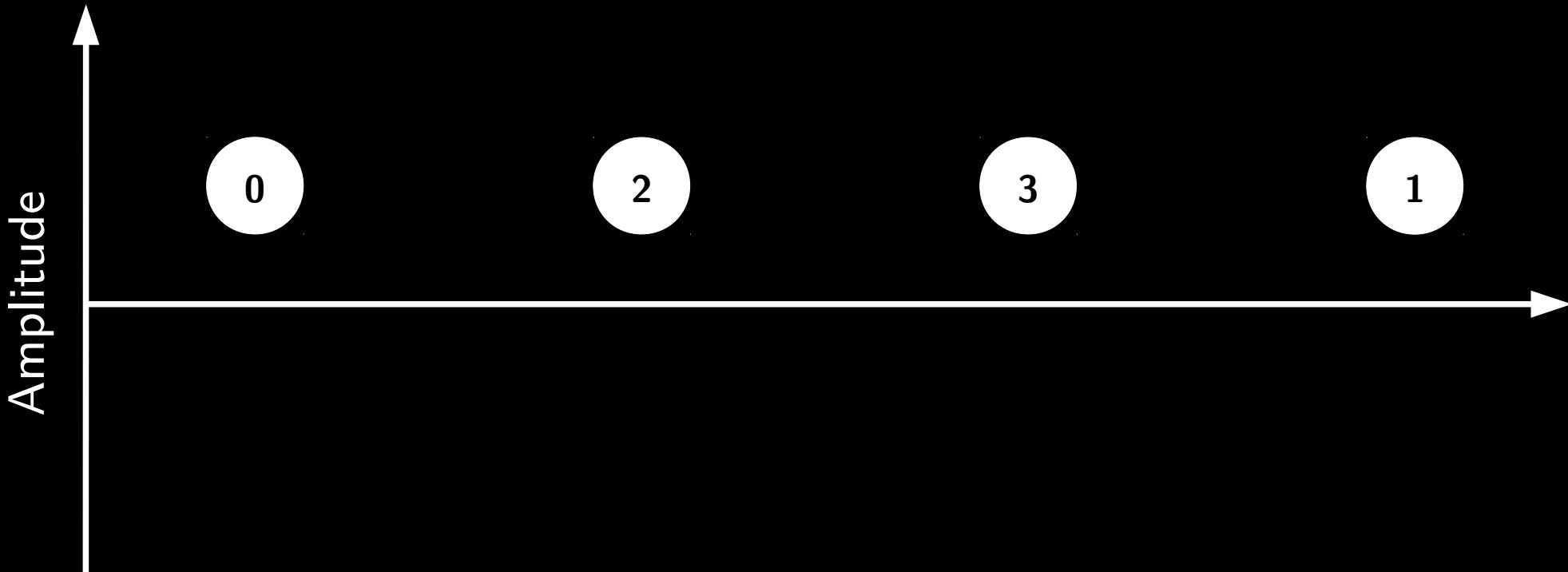
Q-Bits

Q-Circuits

Hardware

Industry

Grover's search: Step 1 – Superposition



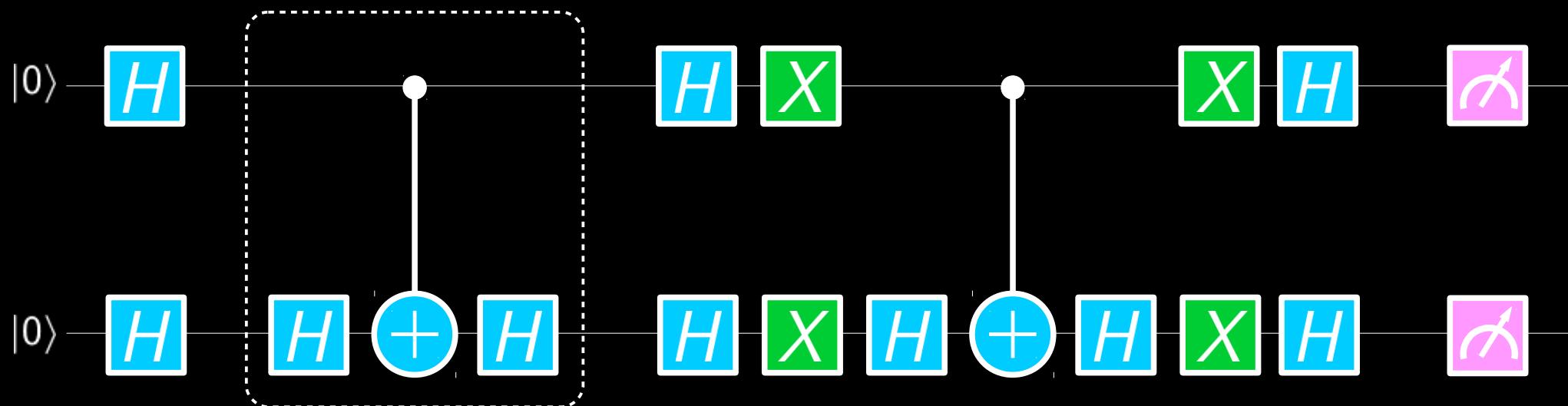
Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Grover's search: Step 2 – Oracle



Applications

Q-Algorithms

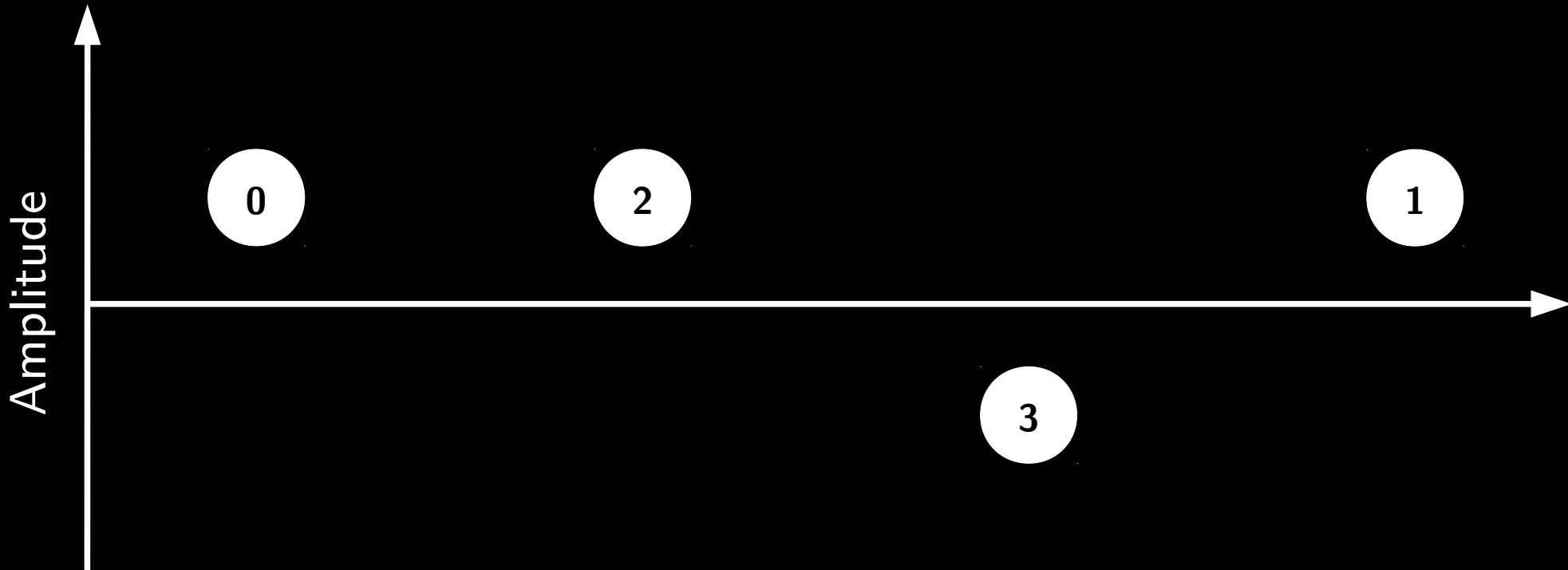
Q-Bits

Q-Circuits

Hardware

Industry

Grover's search: Step 2 – Oracle



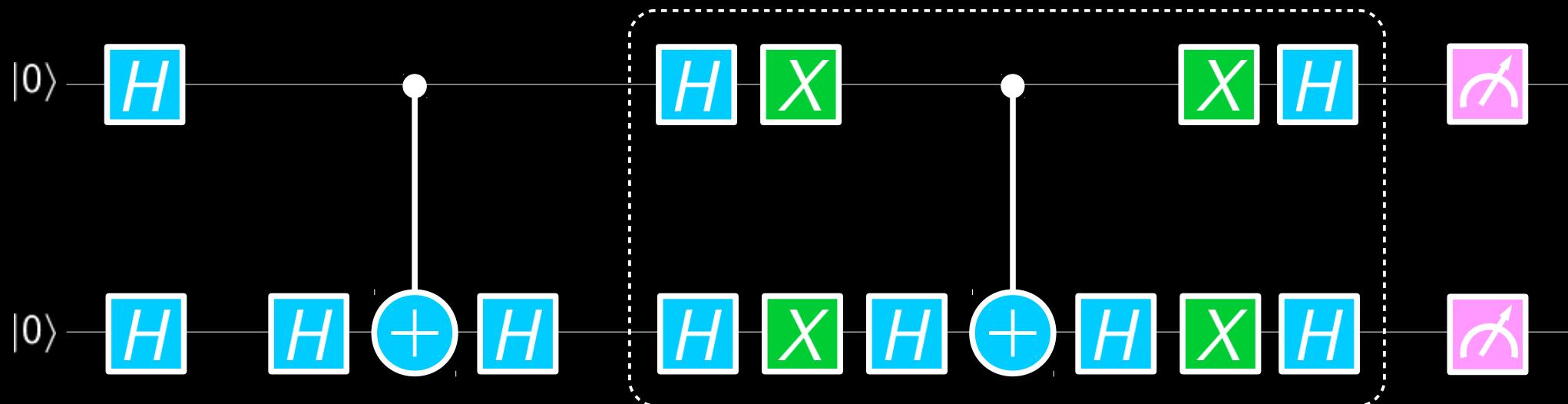
Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Grover's search: Step 3 – Reflection



Applications

Q-Algorithms

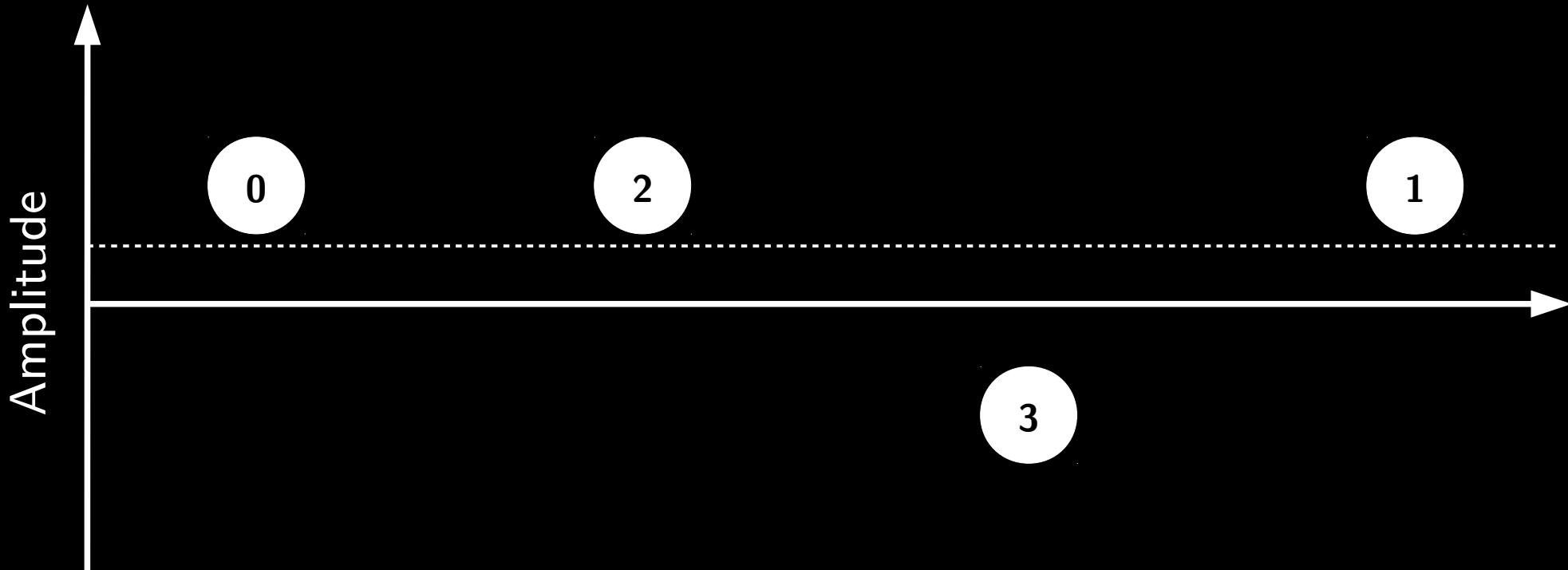
Q-Bits

Q-Circuits

Hardware

Industry

Grover's search: Step 3 – Reflection



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Q-Algorithms

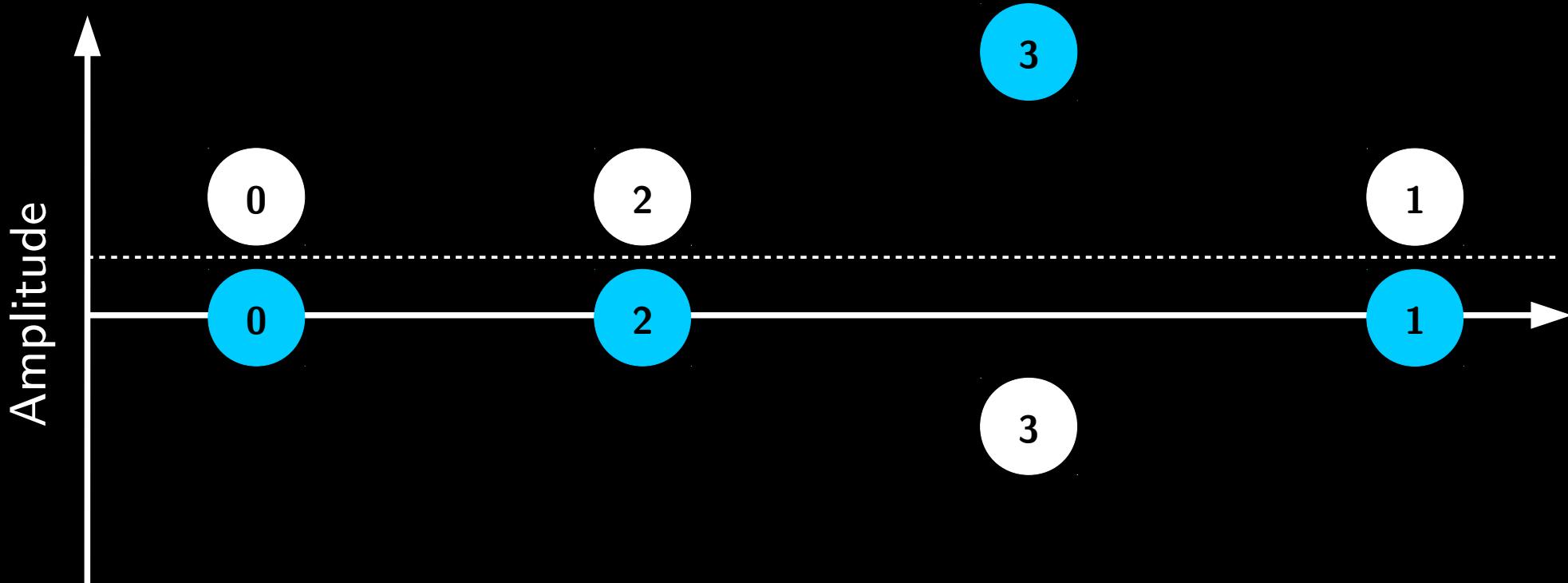
Q-Bits

Q-Circuits

Hardware

Industry

Grover's search: Step 3 – Reflection



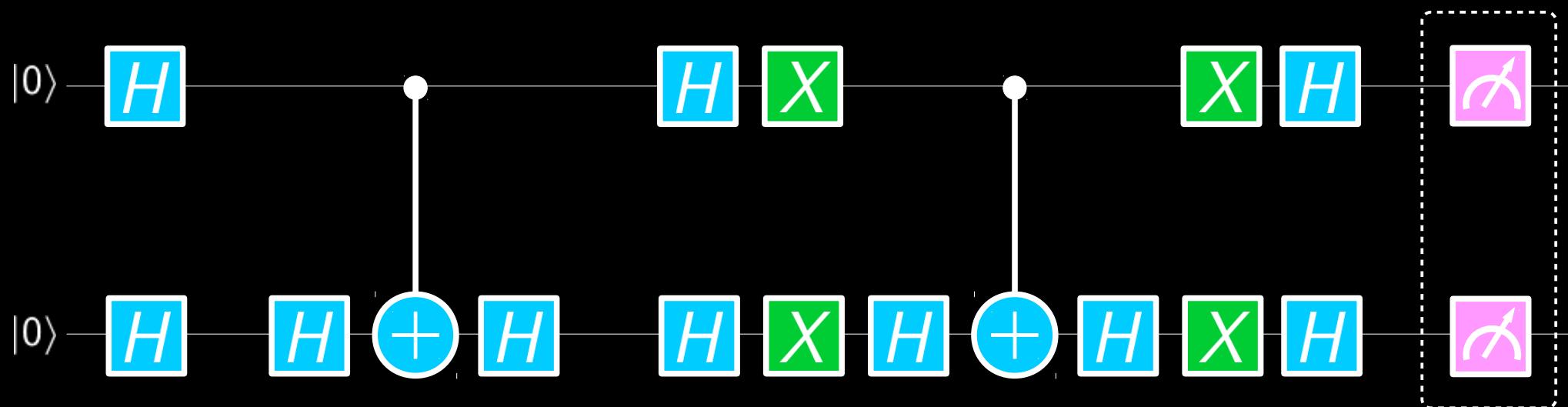
Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Grover's search: Step 4 – Measurement



Applications

Q-Algorithms

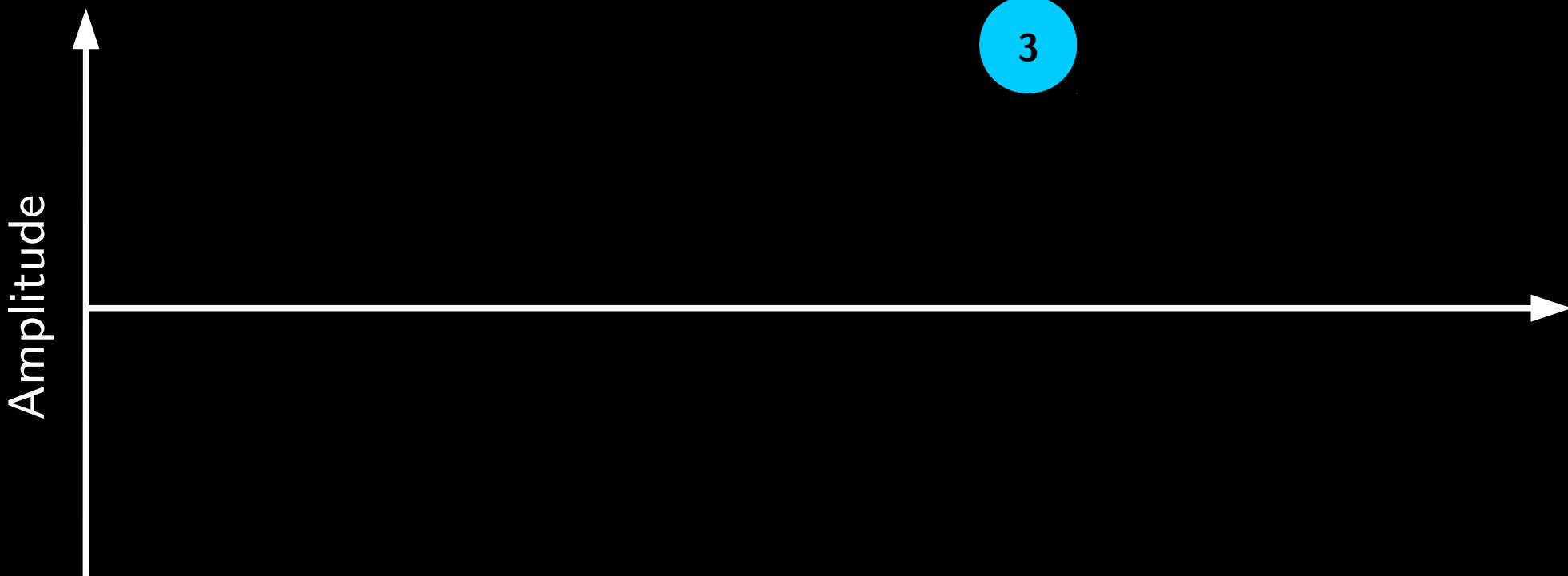
Q-Bits

Q-Circuits

Hardware

Industry

Grover's search: Step 4 – Measurement



Operations on Q-Bits

Q-Gates

Q-Circuit

Grover's search

Applications

Quantum Algorithms

Quantum Bits

Quantum Circuits

Hardware

Industry Landscape

Applications

Quantum Algorithms

Quantum Bits

Quantum Circuits

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.

Applications

Q-Algorithms

Q-Bits

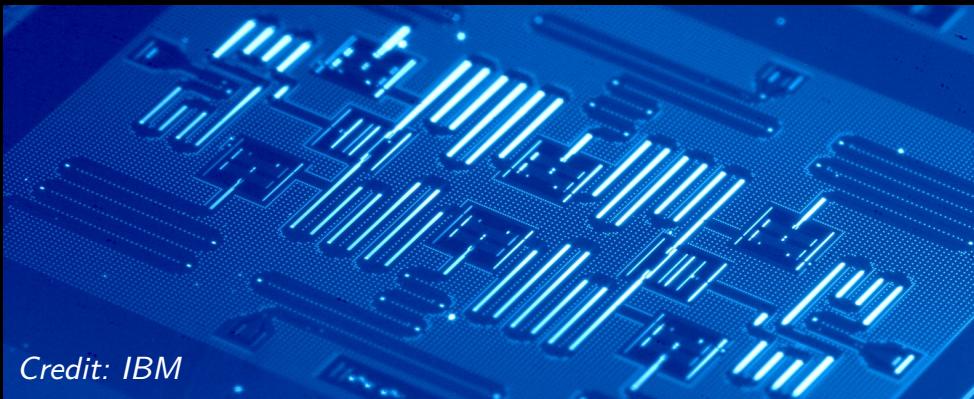
Q-Circuits

Hardware

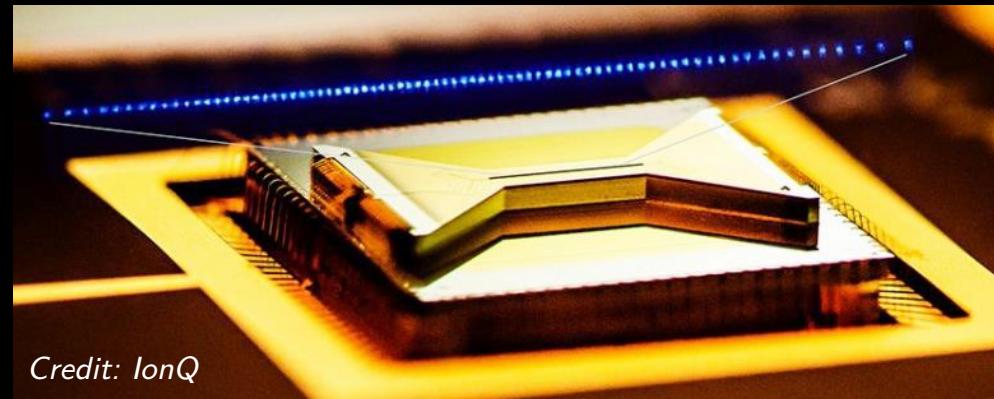
Industry

Superconducting circuits

Trapped ions



Credit: IBM



Credit: IonQ

Decoherence

Leading qubit platforms

Quantum supremacy

Other platforms

Error correction

NISQ era

Superconducting circuits

Trapped ions

Google, IBM, Rigetti, and others

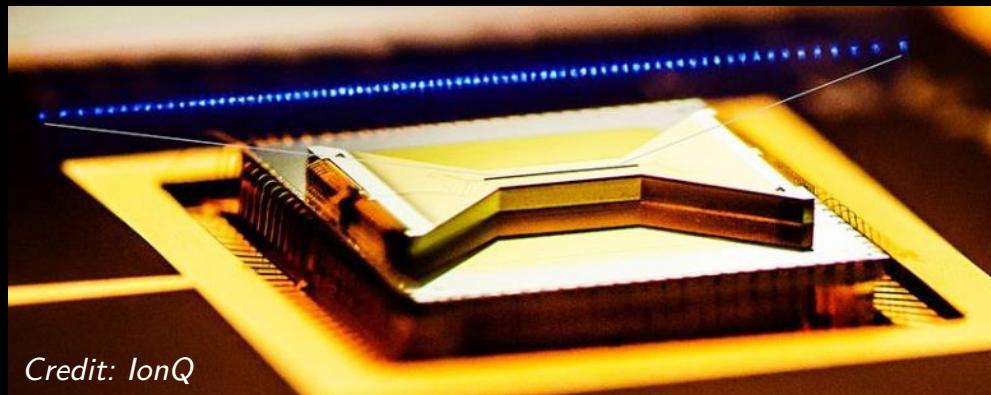
#Qubits: 72 (Google), 53 (IBM, Google)



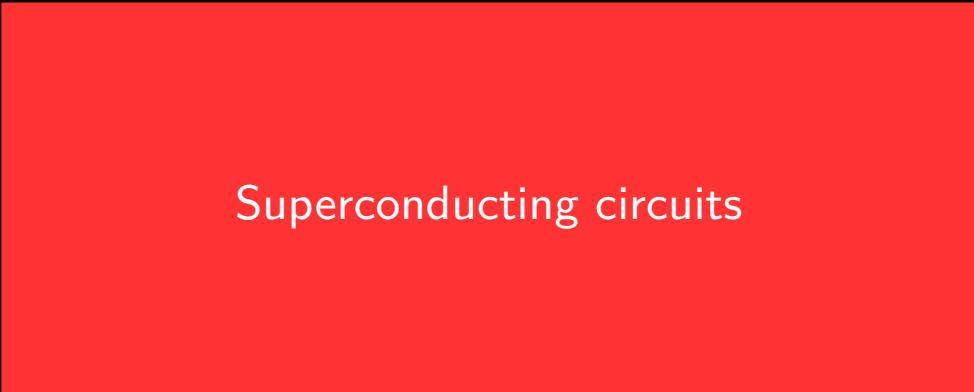
Controllability, Semiconductor industry



Coherence time, Gate fidelities, Near absolute zero, Nearest neighbours connectivity



Credit: IonQ



Superconducting circuits

Google, IBM, Rigetti, and others

#Qubits: 72 (Google), 53 (IBM, Google)



Controllability, Semiconductor industry



Coherence time, Gate fidelities, Near absolute zero, Nearest neighbours connectivity



Trapped ions

AQT, IonQ, and others

#Qubits: 79 (IonQ)



Coherence time, Gate fidelities, All-to-all connectivity



Controllability, Vacuum operation

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-Algorithms

Q-Bits

Q-Circuits

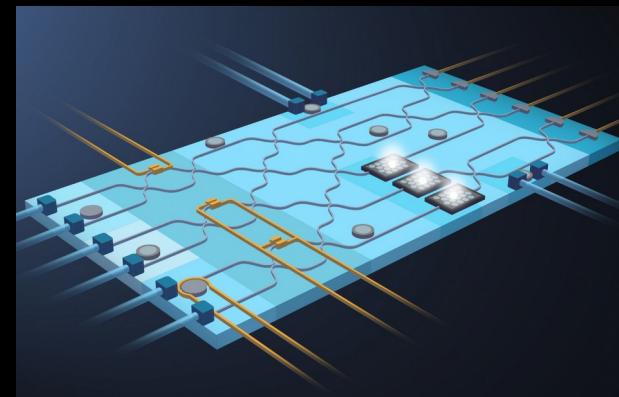
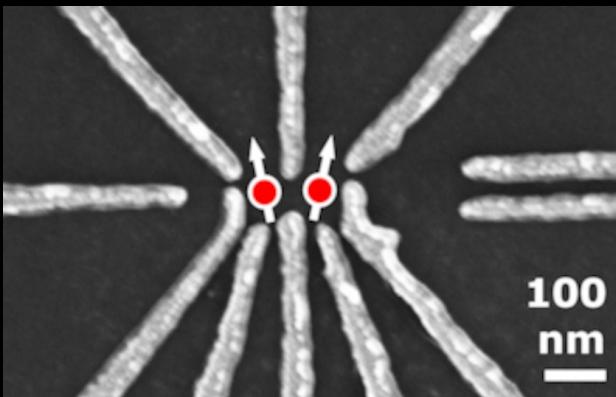
Hardware

Industry

Quantum dots

Photonic

Topological



Decoherence

Leading qubit platforms

Quantum supremacy

Other platforms

Error correction

NISQ era

Computation

Physics

Output

Measure
(fusion)

Compute
(apply gates)

Braid
anyons

Initialize

Create
anyons

Vacuum

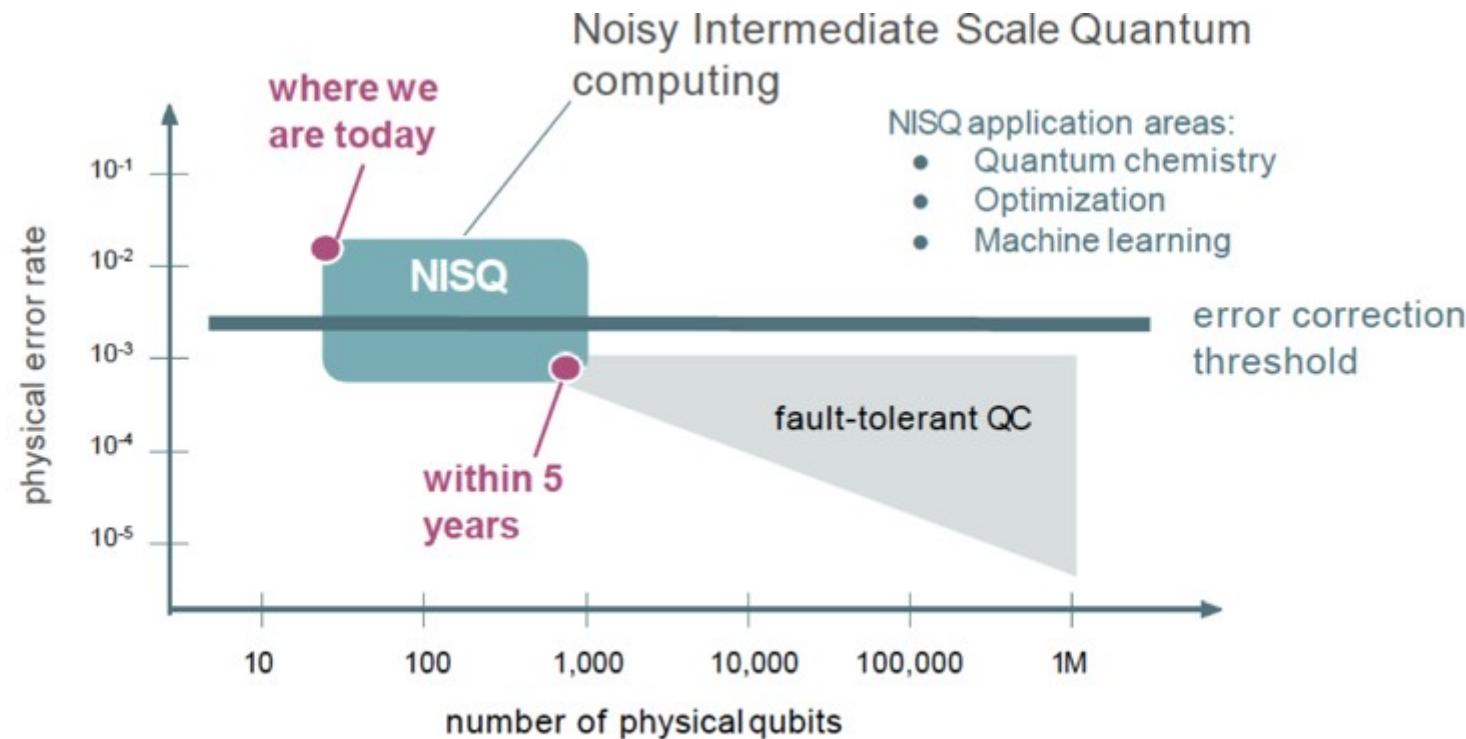
Quantum error correction

Long term goal → Fault-Tolerant QC

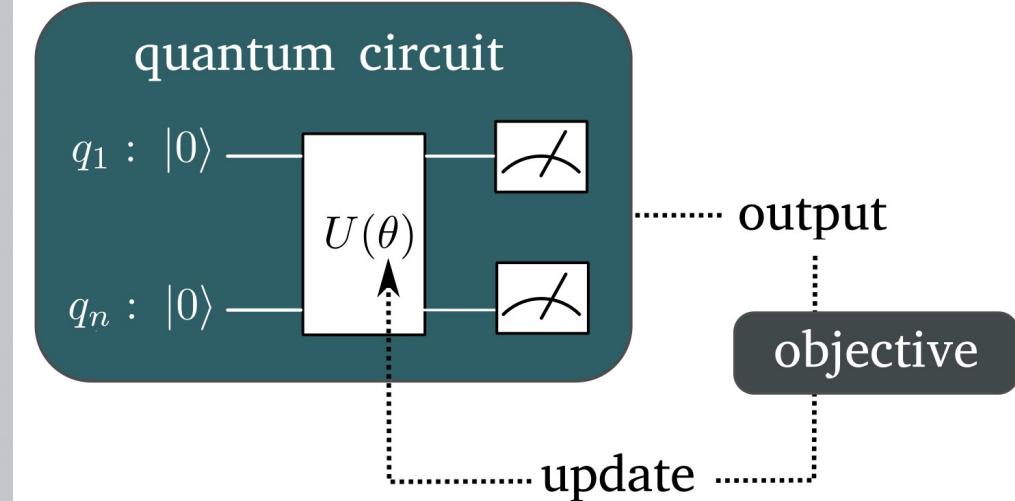
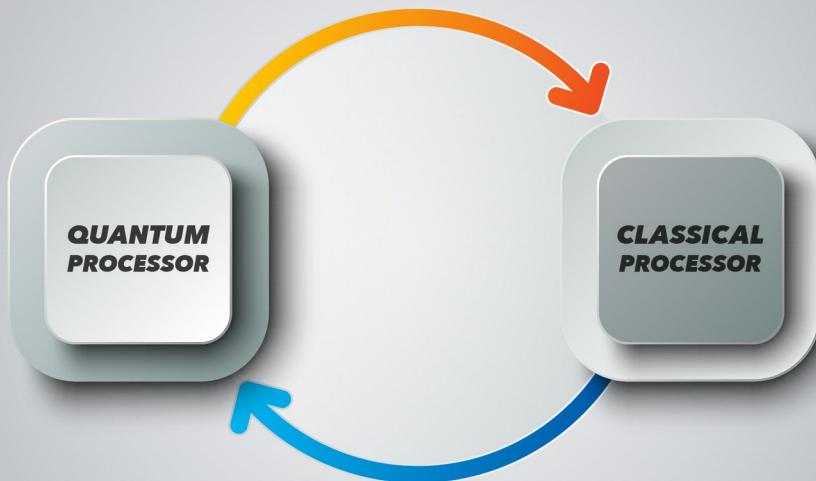
The protected “logical” quantum information is encoded in a highly entangled states of many physical qubits.

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)



Hybrid quantum/classical approach in the NISQ era



Applications

Quantum Algorithms

Quantum Bits

Quantum Circuits

Hardware

Industry Landscape

Applications

Quantum Algorithms

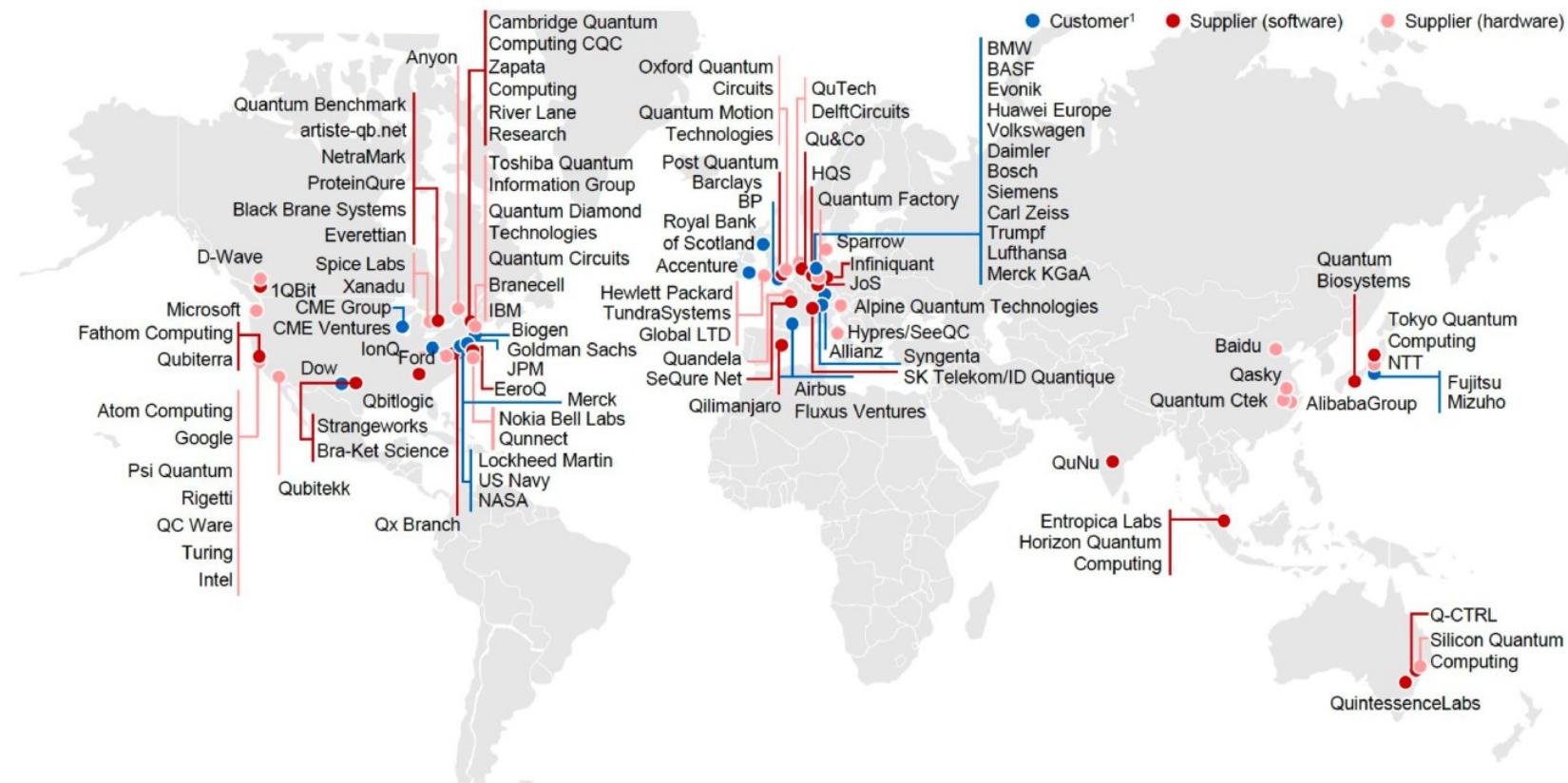
Quantum Bits

Quantum Circuits

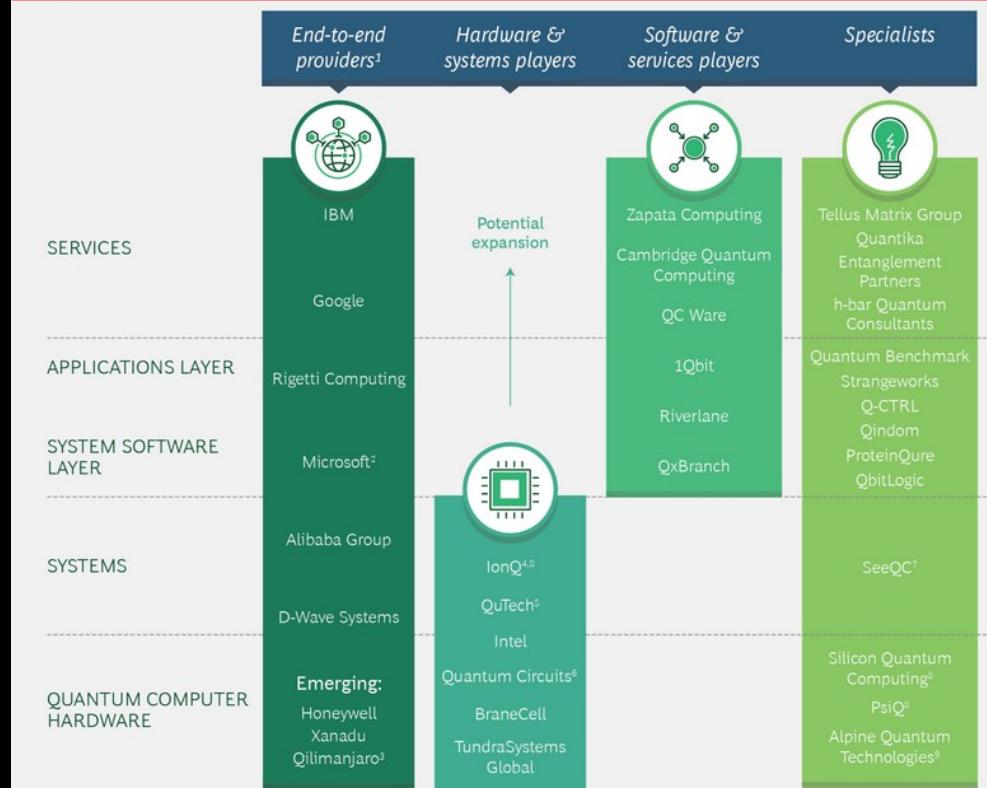
Hardware

Industry Landscape

Non-exhaustive overview of quantum computing players (2019)



BCG report on Quantum Computing (2019)



Azure Quantum

The full-stack, cloud ecosystem to enable quantum impact *today*.

Application Areas



Optimization



Machine Learning



Quantum Simulation

Software Tools & Services



Development Tools



Quantum Solutions



Simulators



Resource Estimators

Classical Hardware



Be future
ready

Build on
your terms

Operate hybrid
seamlessly

Trust
your cloud

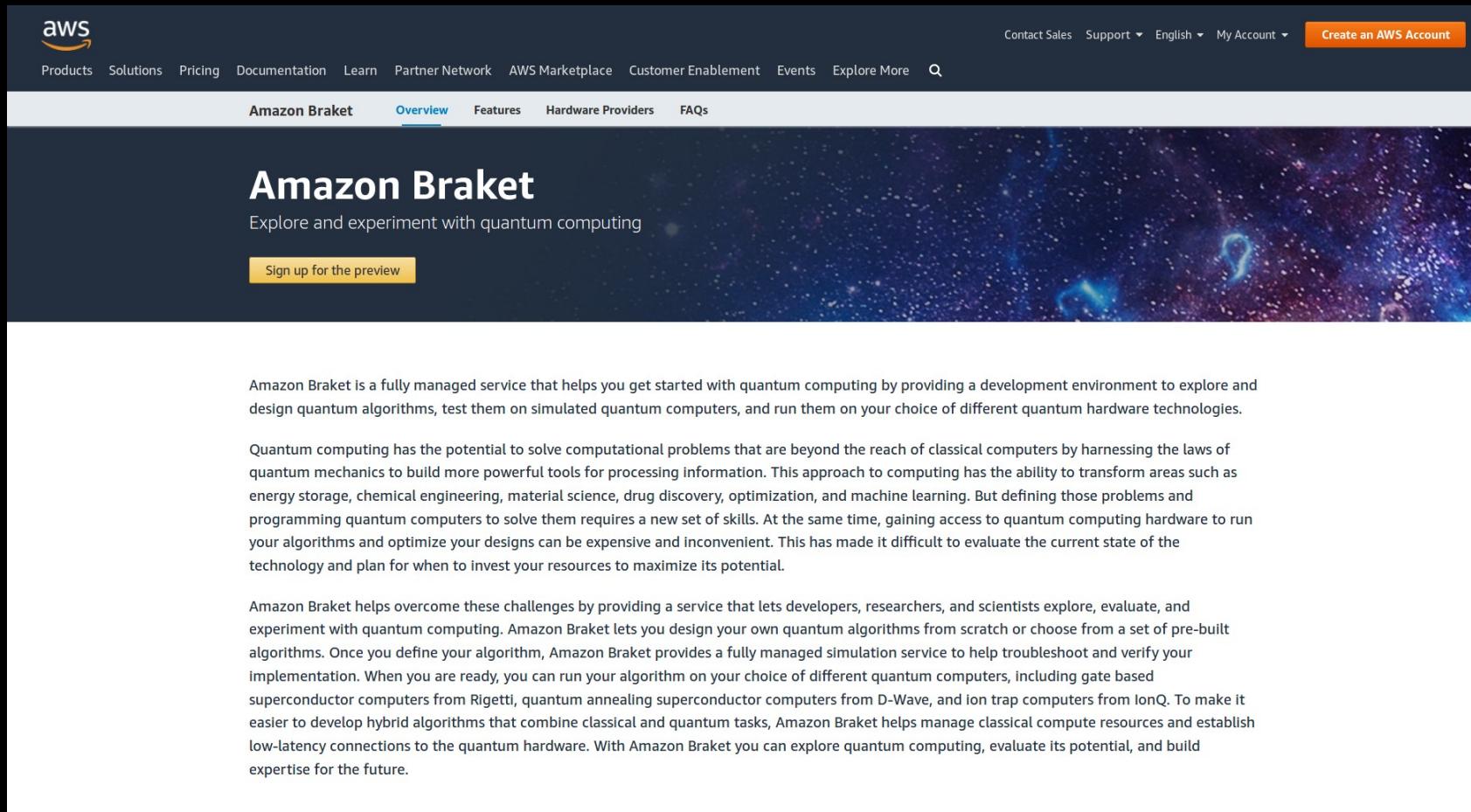
Quantum Hardware



Topological (Future)



Superconducting

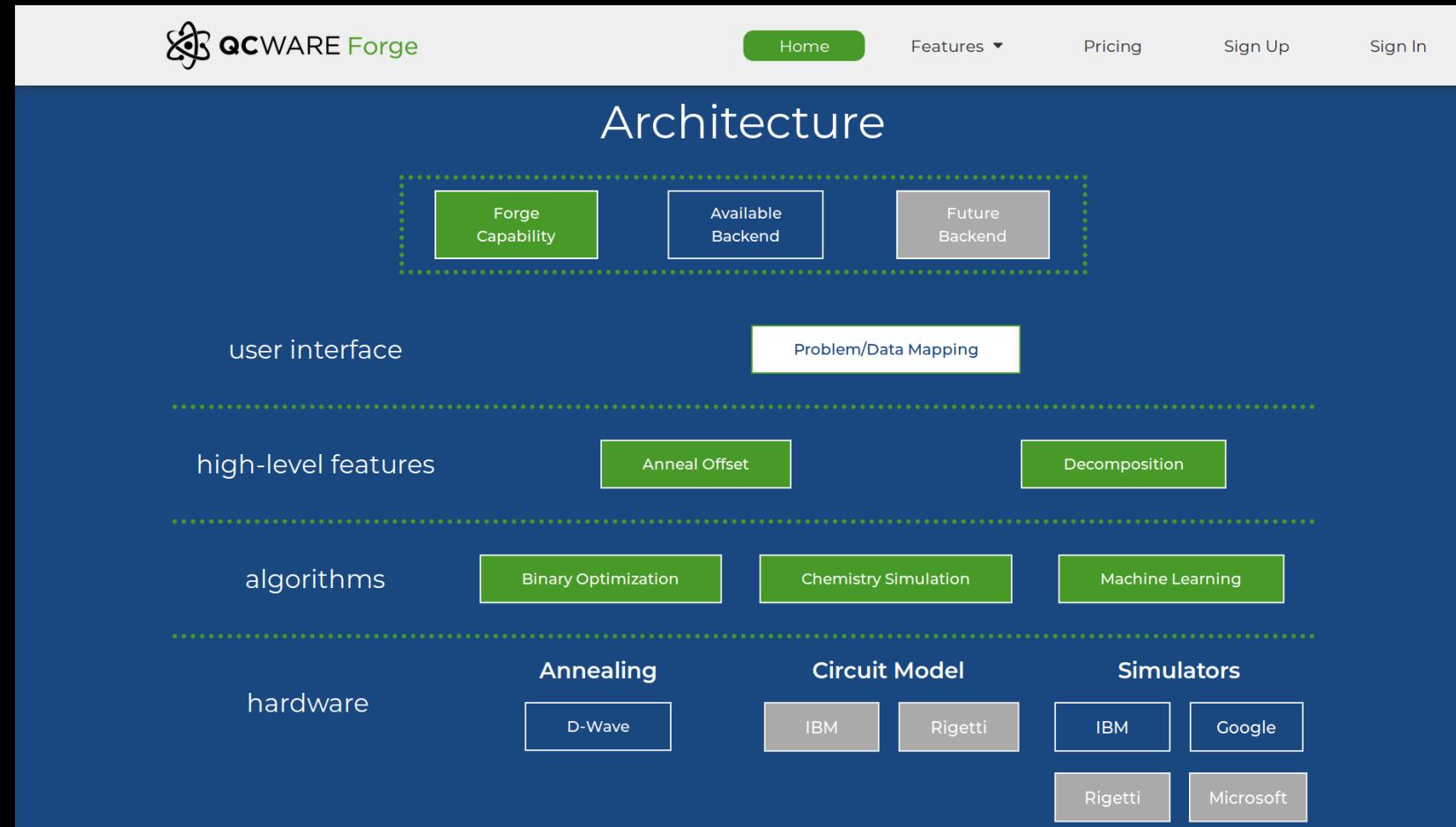


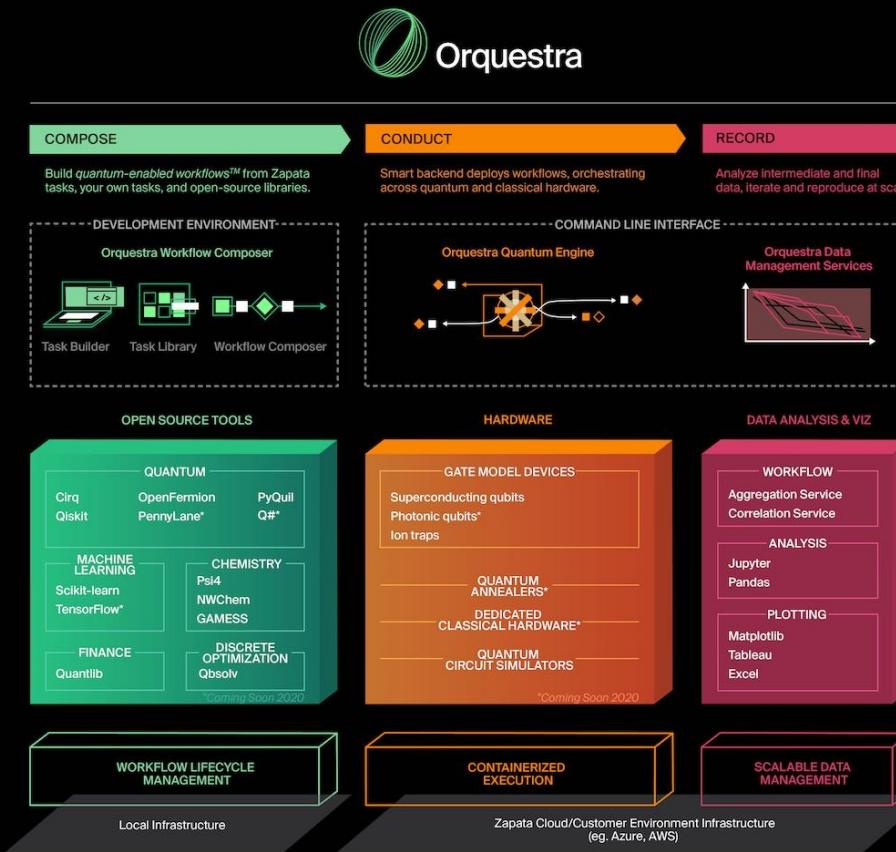
The screenshot shows the AWS Amazon Braket service landing page. At the top, there's a navigation bar with links for Products, Solutions, Pricing, Documentation, Learn, Partner Network, AWS Marketplace, Customer Enablement, Events, Explore More, and a search icon. On the far right of the top bar are buttons for Contact Sales, Support, English, My Account, and a prominent orange "Create an AWS Account" button. Below the top bar, the page title "Amazon Braket" is displayed, followed by a sub-header "Explore and experiment with quantum computing". A yellow "Sign up for the preview" button is visible. The main content area features a dark background with a starry, nebula-like pattern. It contains three paragraphs of text explaining what Amazon Braket is, its potential, and how it helps overcome challenges in quantum computing. The text is presented in white and light blue font.

Amazon Braket is a fully managed service that helps you get started with quantum computing by providing a development environment to explore and design quantum algorithms, test them on simulated quantum computers, and run them on your choice of different quantum hardware technologies.

Quantum computing has the potential to solve computational problems that are beyond the reach of classical computers by harnessing the laws of quantum mechanics to build more powerful tools for processing information. This approach to computing has the ability to transform areas such as energy storage, chemical engineering, material science, drug discovery, optimization, and machine learning. But defining those problems and programming quantum computers to solve them requires a new set of skills. At the same time, gaining access to quantum computing hardware to run your algorithms and optimize your designs can be expensive and inconvenient. This has made it difficult to evaluate the current state of the technology and plan for when to invest your resources to maximize its potential.

Amazon Braket helps overcome these challenges by providing a service that lets developers, researchers, and scientists explore, evaluate, and experiment with quantum computing. Amazon Braket lets you design your own quantum algorithms from scratch or choose from a set of pre-built algorithms. Once you define your algorithm, Amazon Braket provides a fully managed simulation service to help troubleshoot and verify your implementation. When you are ready, you can run your algorithm on your choice of different quantum computers, including gate based superconductor computers from Rigetti, quantum annealing superconductor computers from D-Wave, and ion trap computers from IonQ. To make it easier to develop hybrid algorithms that combine classical and quantum tasks, Amazon Braket helps manage classical compute resources and establish low-latency connections to the quantum hardware. With Amazon Braket you can explore quantum computing, evaluate its potential, and build expertise for the future.





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Canada

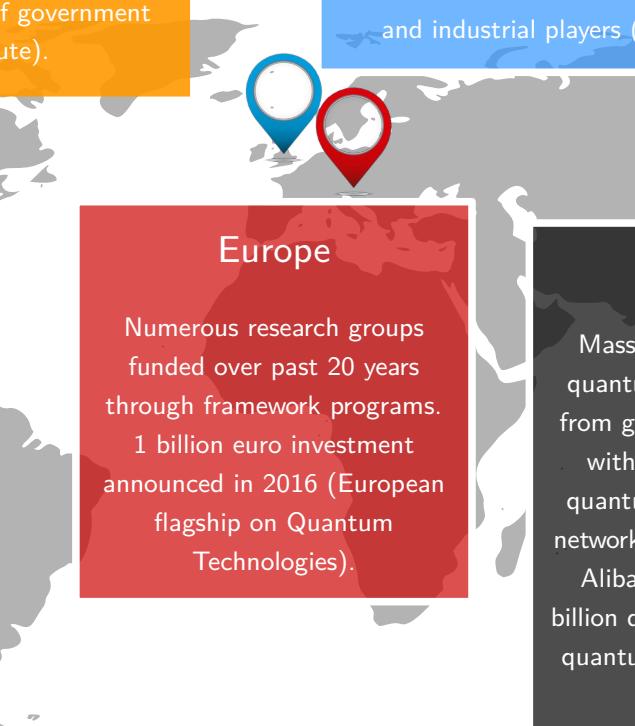
D-Wave, 1Qbit notable private investment. Creative Destruction Lab in Toronto accelerates market launch of deep tech startups in quantum technologies. Hundreds of millions of government funding invested (IQC, Perimeter Institute).

**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).

**U.K.**

U.K. National Quantum Technologies programme launched in 2013 with 270M pounds invested. Additional investment plan of 350M pounds from both government agencies (150M) and industrial players (200M) announced in 2019 with a focus on quantum computing.

Japan

Japan has set aside more than 270M dollars in a 10-year research plan. Major Japanese tech players are following suit.

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

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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

Applications

Q-Algorithms

Q-Bits

Q-Circuits

Hardware

Industry



QC players

Funding – National initiatives

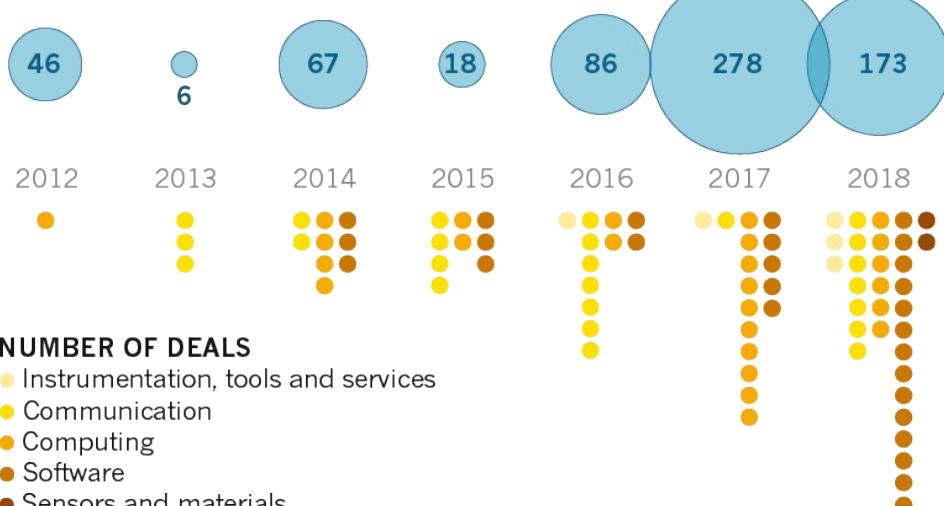
Funding – VC funds

Short-term plan

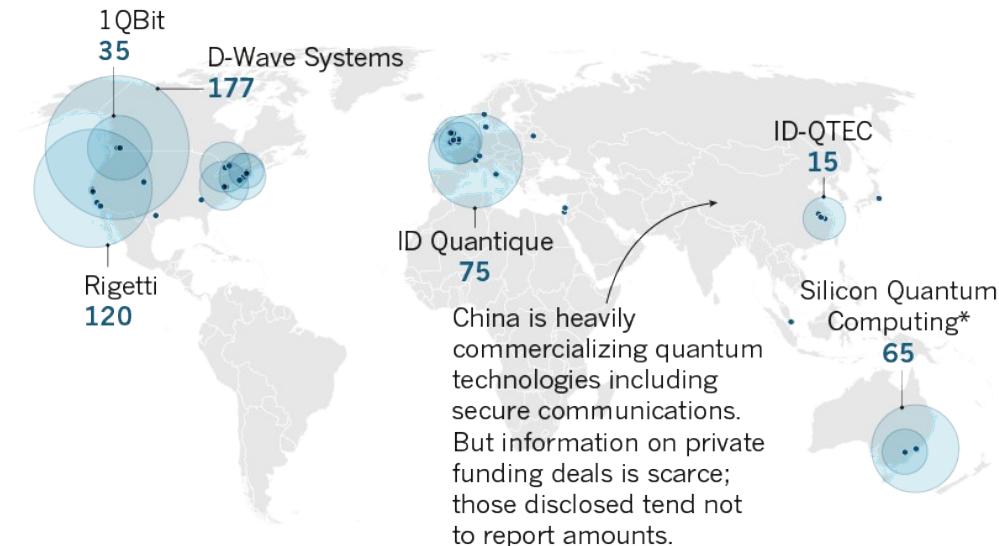
Long-term plan

Private investments (VC funds) - Nature's report on Quantum Technologies (2019)

TOTAL VALUE OF DEALS
(US\$, millions)



LOCATION OF INVESTMENTS 2012–18
(US\$, millions)

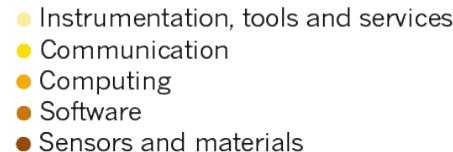


Private investments (VC funds) - Nature's report on Quantum Technologies (2019)

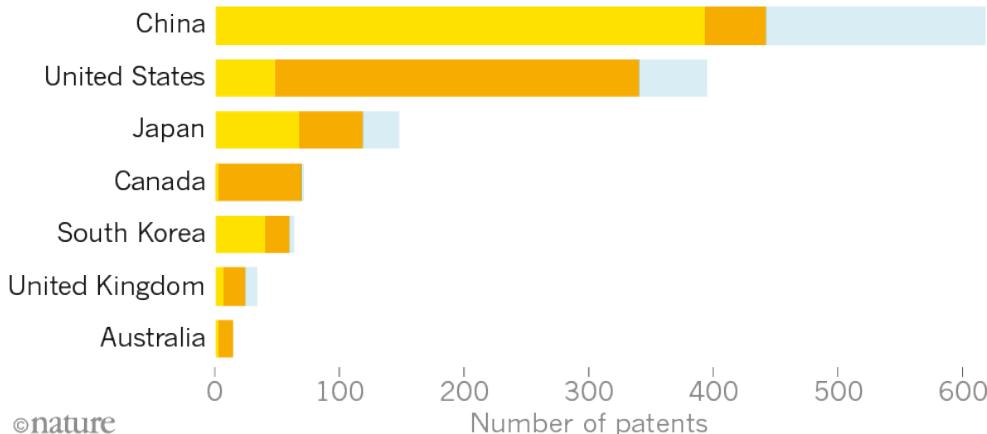
TOTAL VALUE OF DEALS (US\$, millions)



NUMBER OF DEALS



- Quantum key distribution (quantum communication)
- Quantum computing (including software)
- Other quantum technology



©nature

"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.

Entrepreneur



Alice&Bob raises \$3.3 million to create the first fault-tolerant quantum computer



CHRIS O'BRIEN @OBRIEN MAY 25, 2020 11:00 PM

Alice & Bob

WE BUILD
UNIVERSAL, FAULT-TOLERANT
QUANTUM COMPUTERS

Alice&Bob has raised \$3.3 million to join the quantum computing arms race by accelerating research that promises to make this type of next-generation computing more stable.

Elaia Partners and Breega led the round for the Paris-based startup, which has developed its first prototype. The company is using research that has been developed across an unusual consortium of French universities and research institutes.

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pasqal @pasqalio Suivre

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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BPIFRANCE PRESENTS THE FIRST EDITION OF THE QUANTUM COMPUTING BUSINESS CONFERENCE, IN PARIS ON JUNE 20, 2019

Meet all the Quantum Computing ecosystem for a single day of conference in Paris.

Philippe NIEUWBOURG
April 26th 2019 | 492 readers



Photo bpifrance

Engage with QC (customer side): Short-term plan

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3. Test initial use cases.
4. Create a timeline for how these use cases will scale with quantum computing advancements.

Applications

Q-Algorithms

Q-Bits

Q-Circuits

Hardware

Industry

Engage with QC (customer side): Long-term plan

QC players

Funding – National initiatives

Funding – VC funds

Short-term plan

Long-term plan

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1. - 2. - 3. 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.

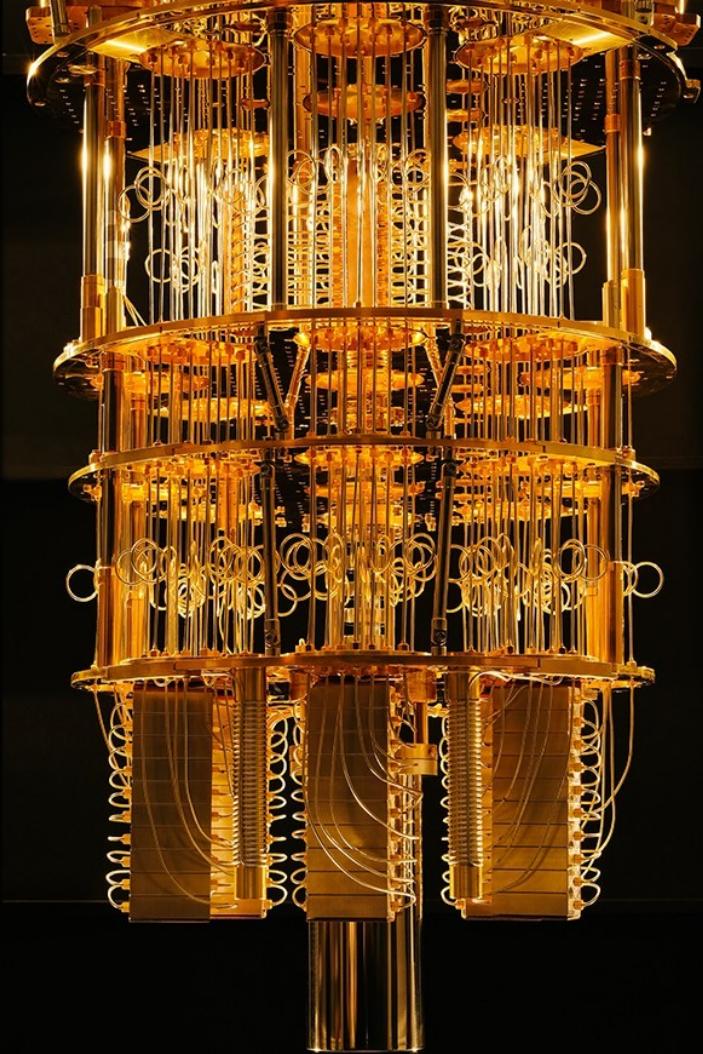
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This is not the conclusion, it's just the beginning !



Thank you for
your attention !

Let's keep in touch !

[LinkedIn](#) → Bruno Fedrici, PhD

[E-mail](mailto:bruno.fedrici@gmail.com) → bruno.fedrici@gmail.com

[Mobile](tel:+33(0)622068719) → +33 (0)6 22 06 87 19