INTRODUCTION TO QUANTUM COMPUTING AND QUANTUM SERVICE ORIENTED COMPUTING

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COMPUTAEX

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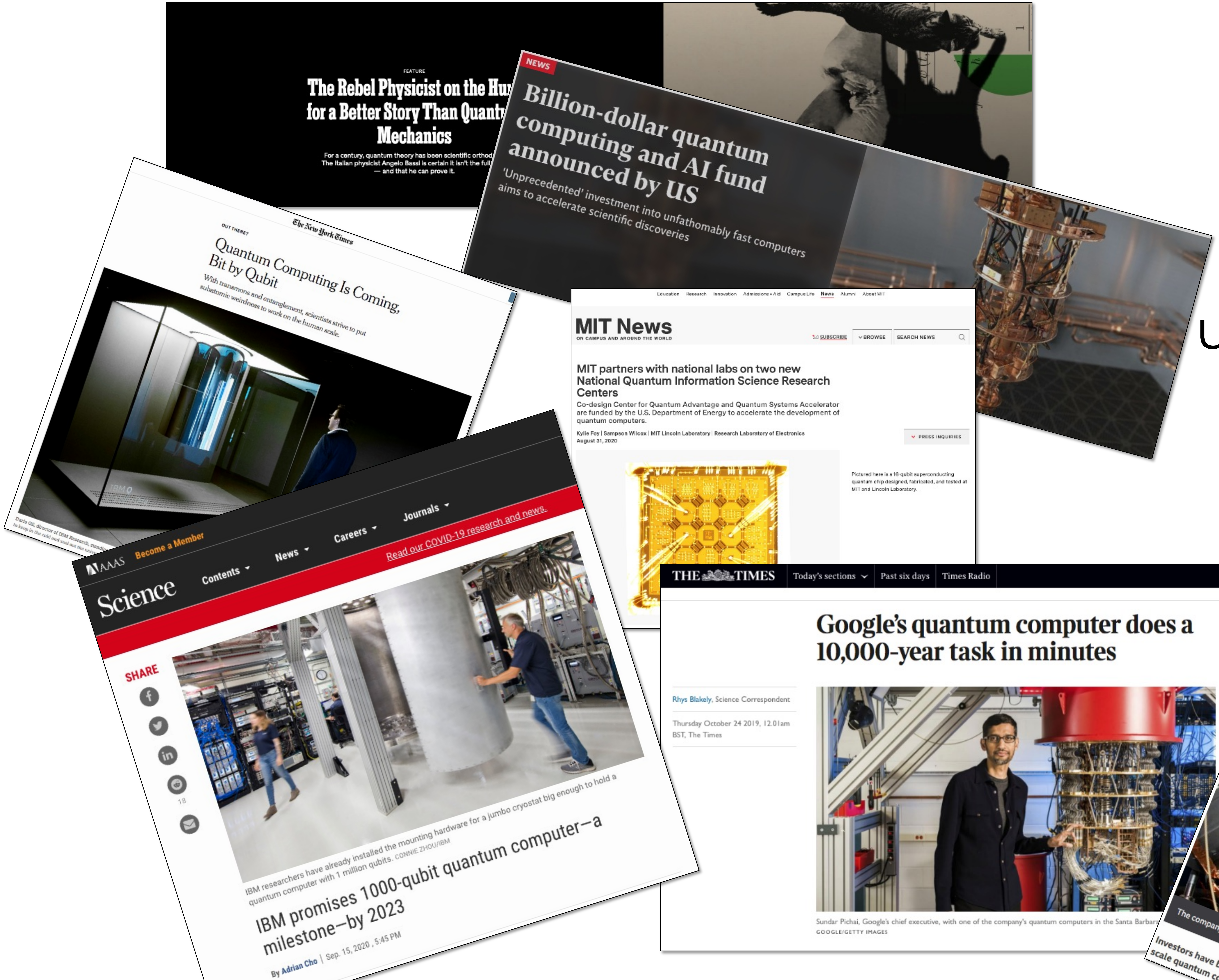
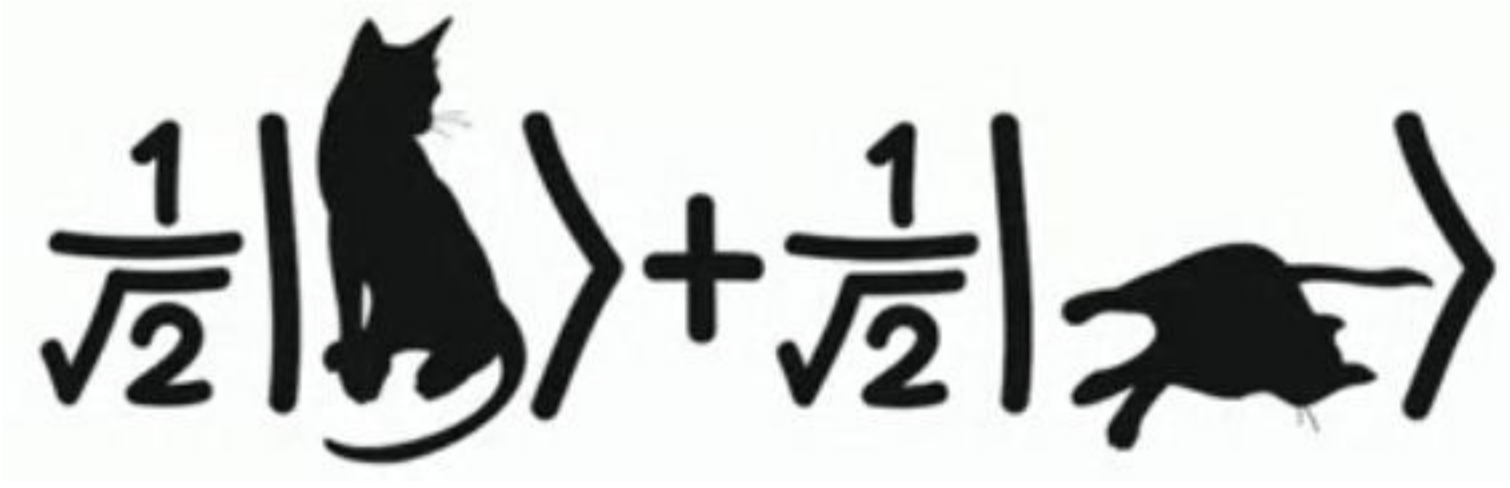
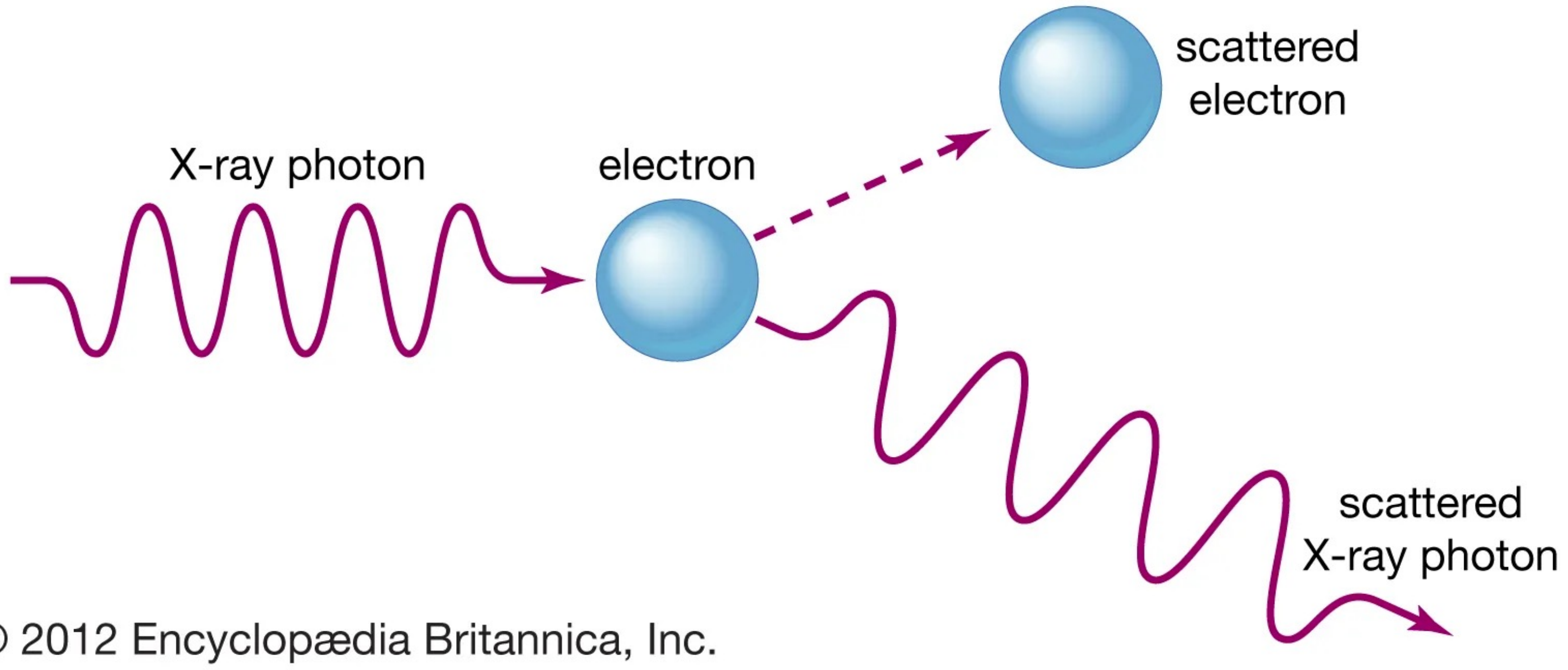
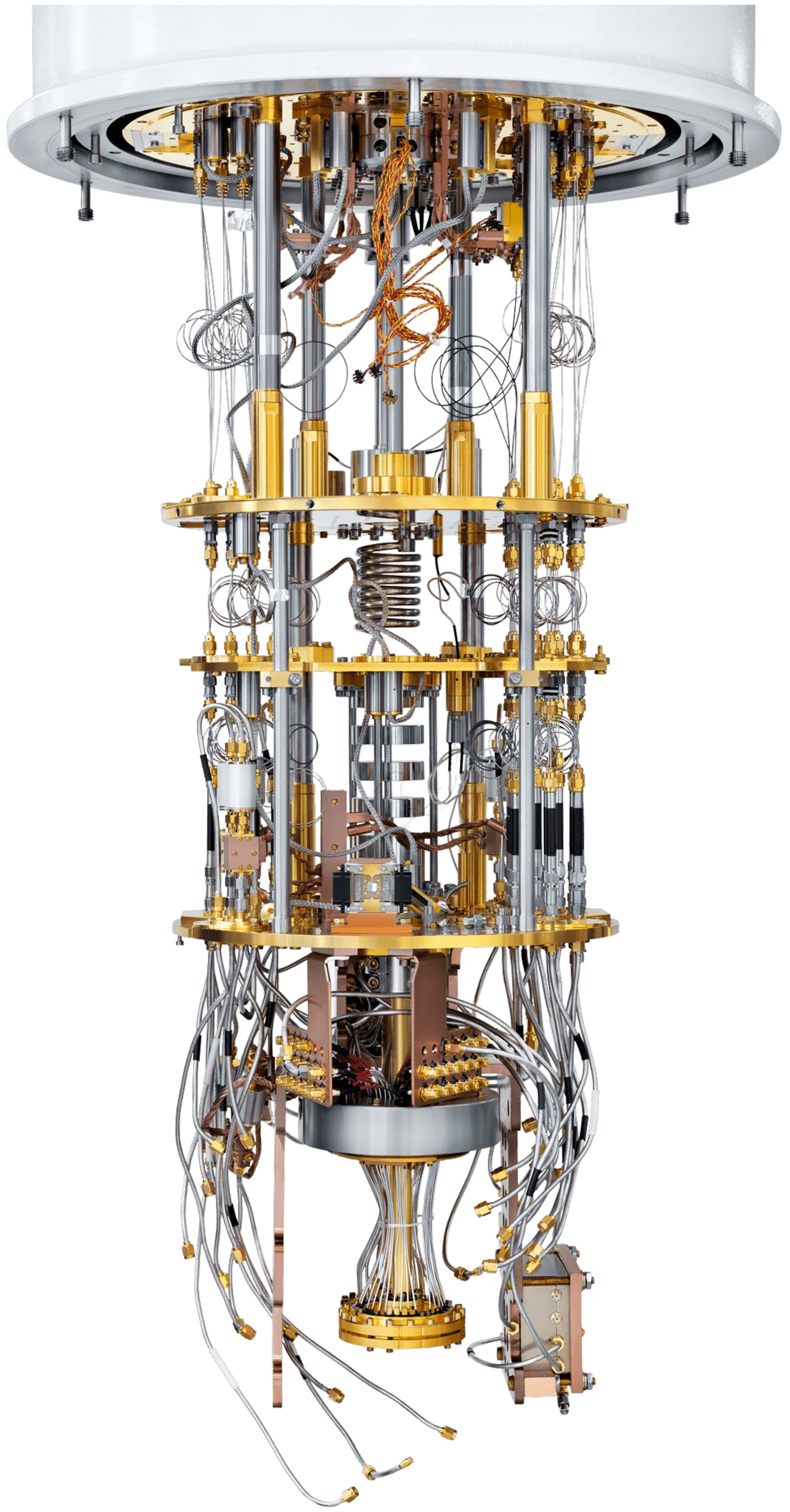
The arrival of Quantum Computing is already an unquestionable reality

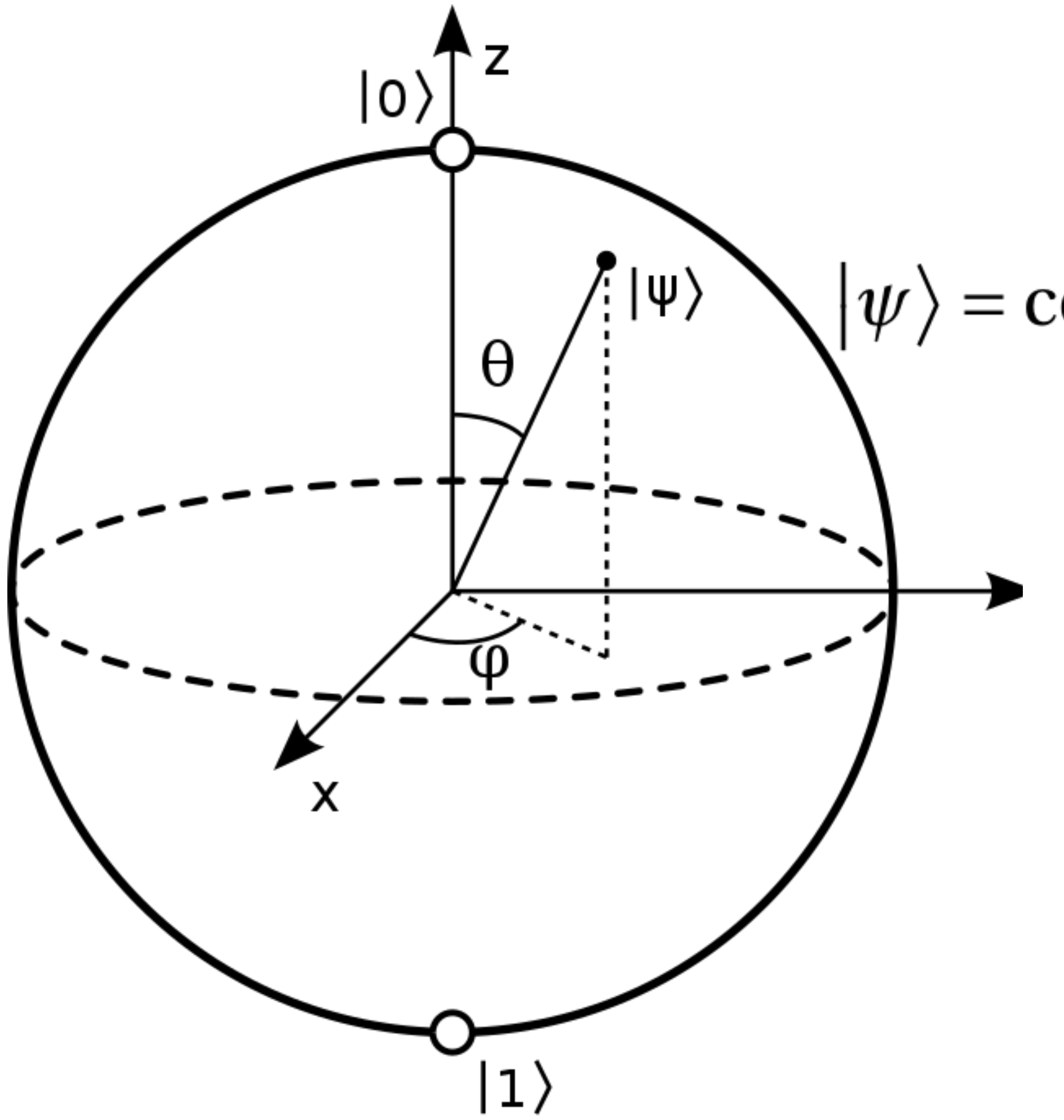




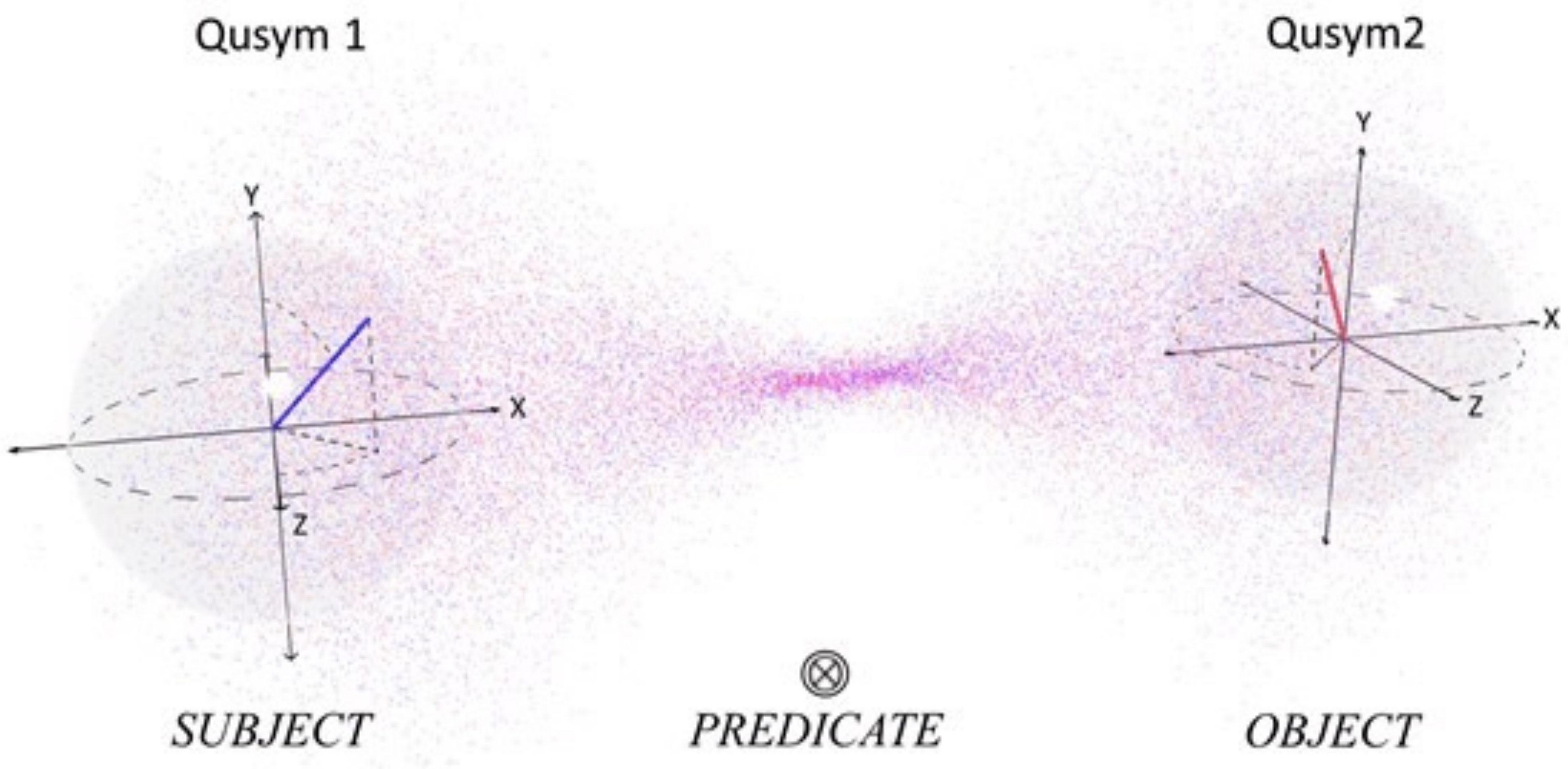


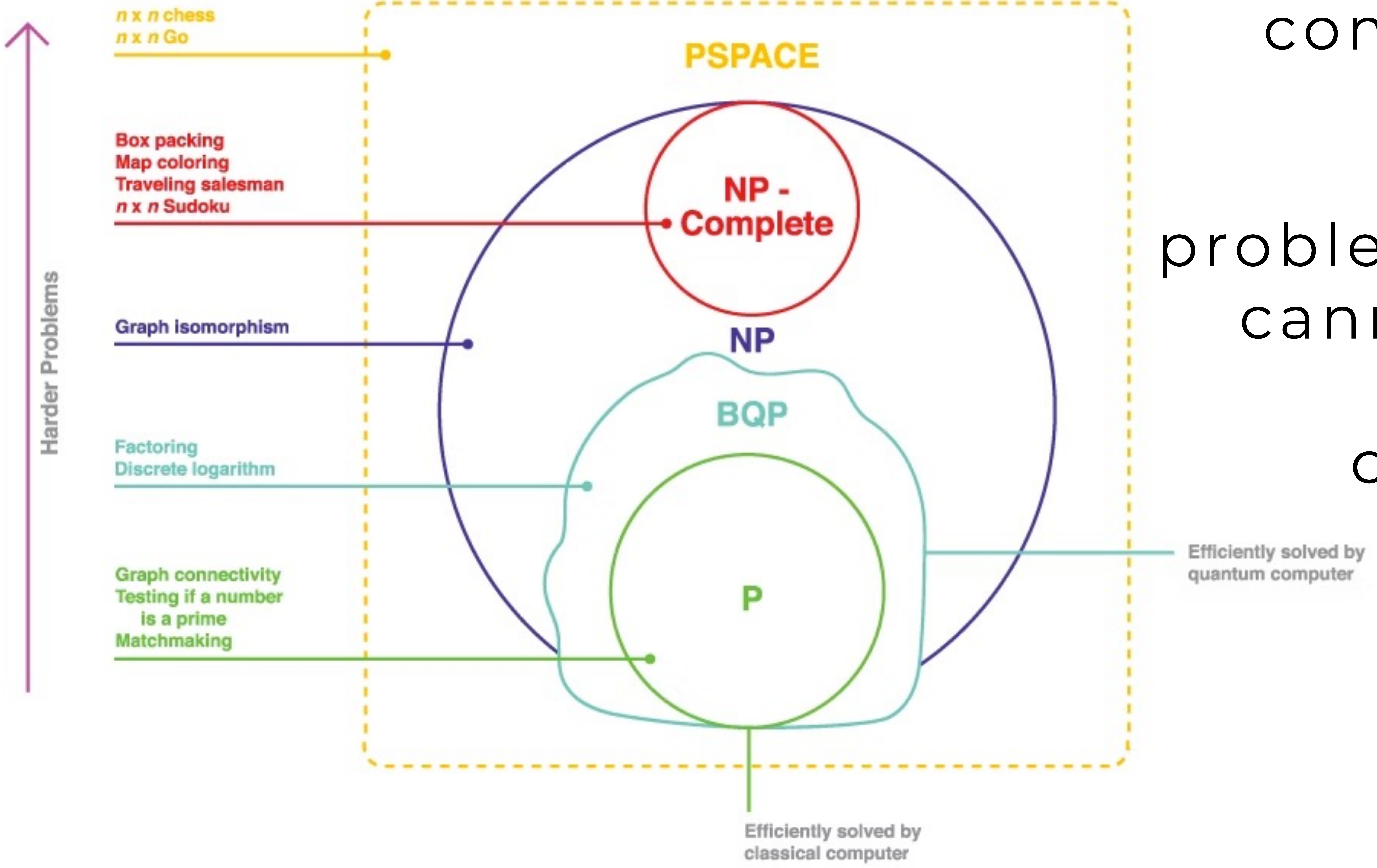
It introduces concepts and theories that are intellectually exciting





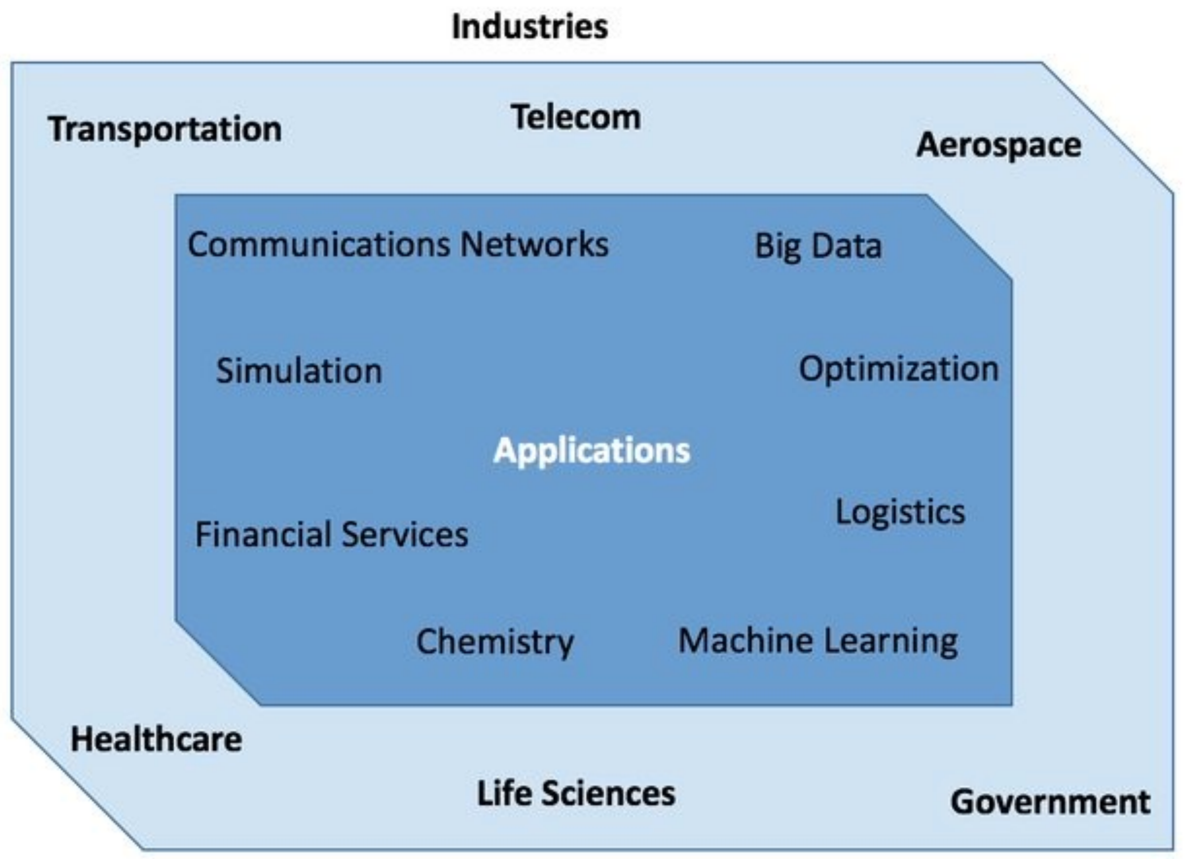
$$\left|\psi\right\rangle = \cos\frac{\theta}{2}\left|0\right\rangle + e^{i\phi}\sin\frac{\theta}{2}\left|1\right\rangle$$

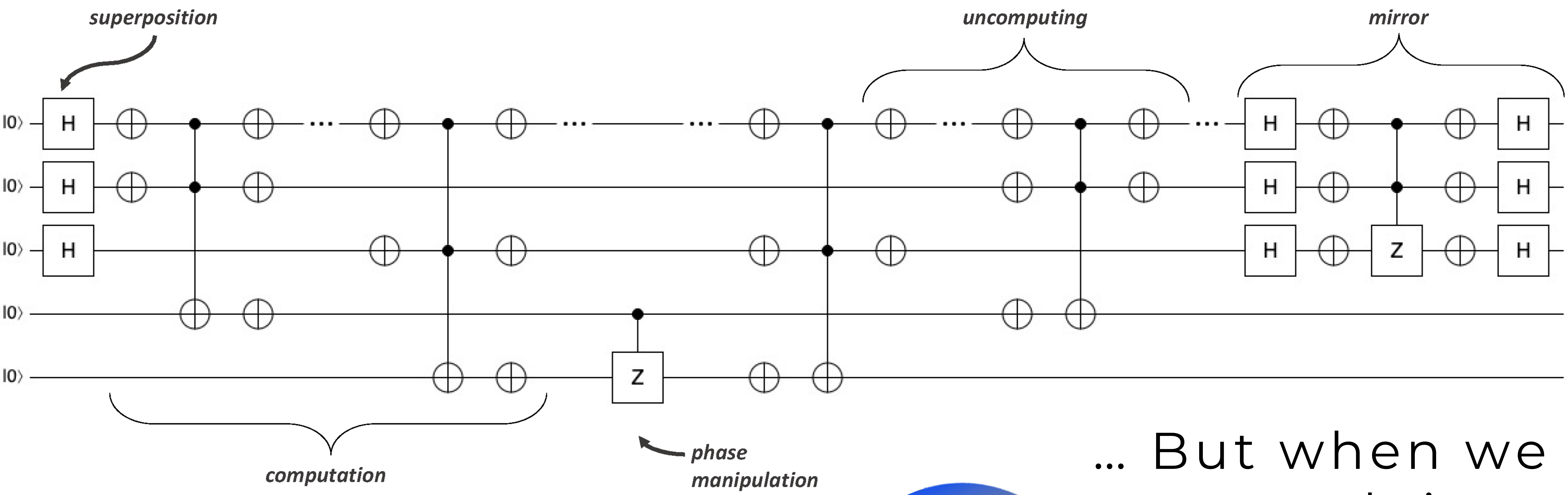




https://www.simonsfoundation.org/report2017/stories/scott-aaronson-quantum-and-classical-uncertainty/

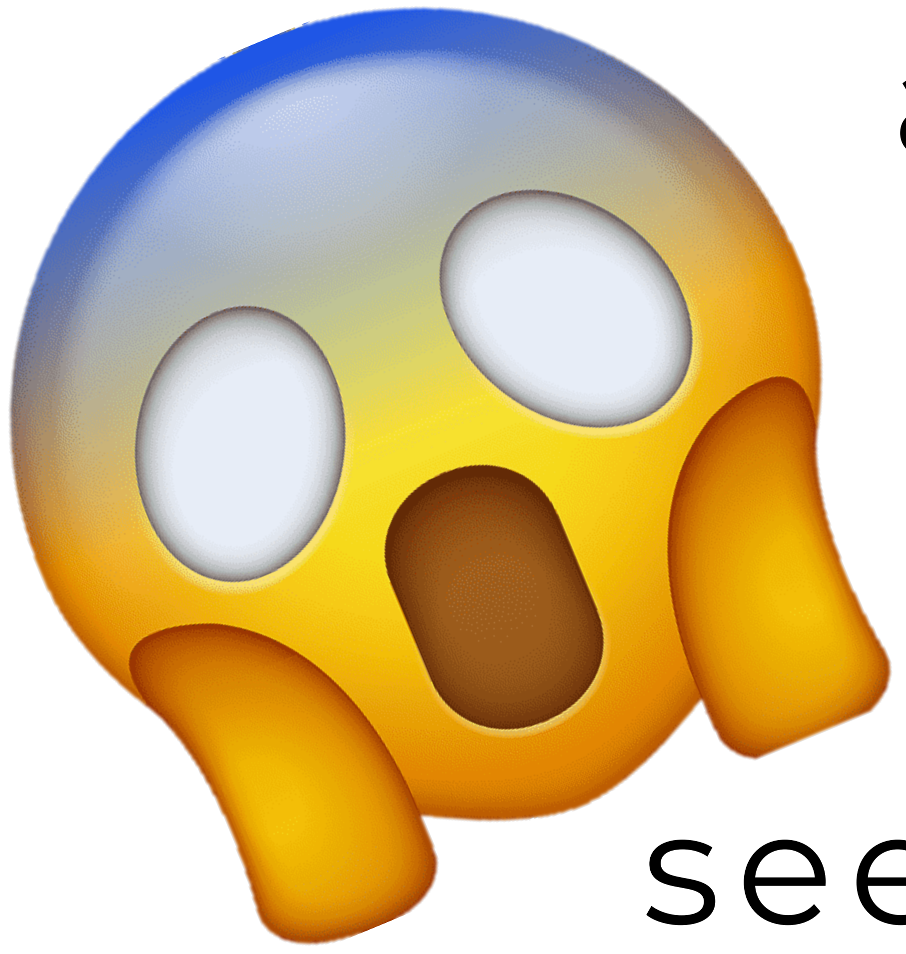
... It provides computational capacity to address problems that we cannot address in classical computing...





$$I \otimes H = \begin{pmatrix}1 & 0\\ 0 & 1\end{pmatrix} \otimes \begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}}\end{pmatrix} = \begin{pmatrix} 1\cdot\begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}}\end{pmatrix} & 0\cdot\begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}}\end{pmatrix}\\ 0\cdot\begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}}\end{pmatrix} & 1\cdot\begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}}\end{pmatrix}\end{pmatrix} =$$

$$\begin{pmatrix} 1\cdot\frac{1}{\sqrt{2}} & 1\cdot\frac{1}{\sqrt{2}} & 0\cdot\frac{1}{\sqrt{2}} & 0\cdot\frac{1}{\sqrt{2}}\\ 1\cdot\frac{1}{\sqrt{2}} & 1\cdot-\frac{1}{\sqrt{2}} & 0\cdot\frac{1}{\sqrt{2}} & 0\cdot-\frac{1}{\sqrt{2}}\\ 0\cdot\frac{1}{\sqrt{2}} & 0\cdot\frac{1}{\sqrt{2}} & 1\cdot\frac{1}{\sqrt{2}} & 1\cdot\frac{1}{\sqrt{2}}\\ 0\cdot\frac{1}{\sqrt{2}} & 0\cdot-\frac{1}{\sqrt{2}} & 1\cdot\frac{1}{\sqrt{2}} & 1\cdot-\frac{1}{\sqrt{2}}\end{pmatrix} = \begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 & 0\\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 & 0\\ 0 & 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ 0 & 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}}\end{pmatrix}$$



… But when we approach it as Computer Engineers, everything seems to be very far from us.

OUTLINE

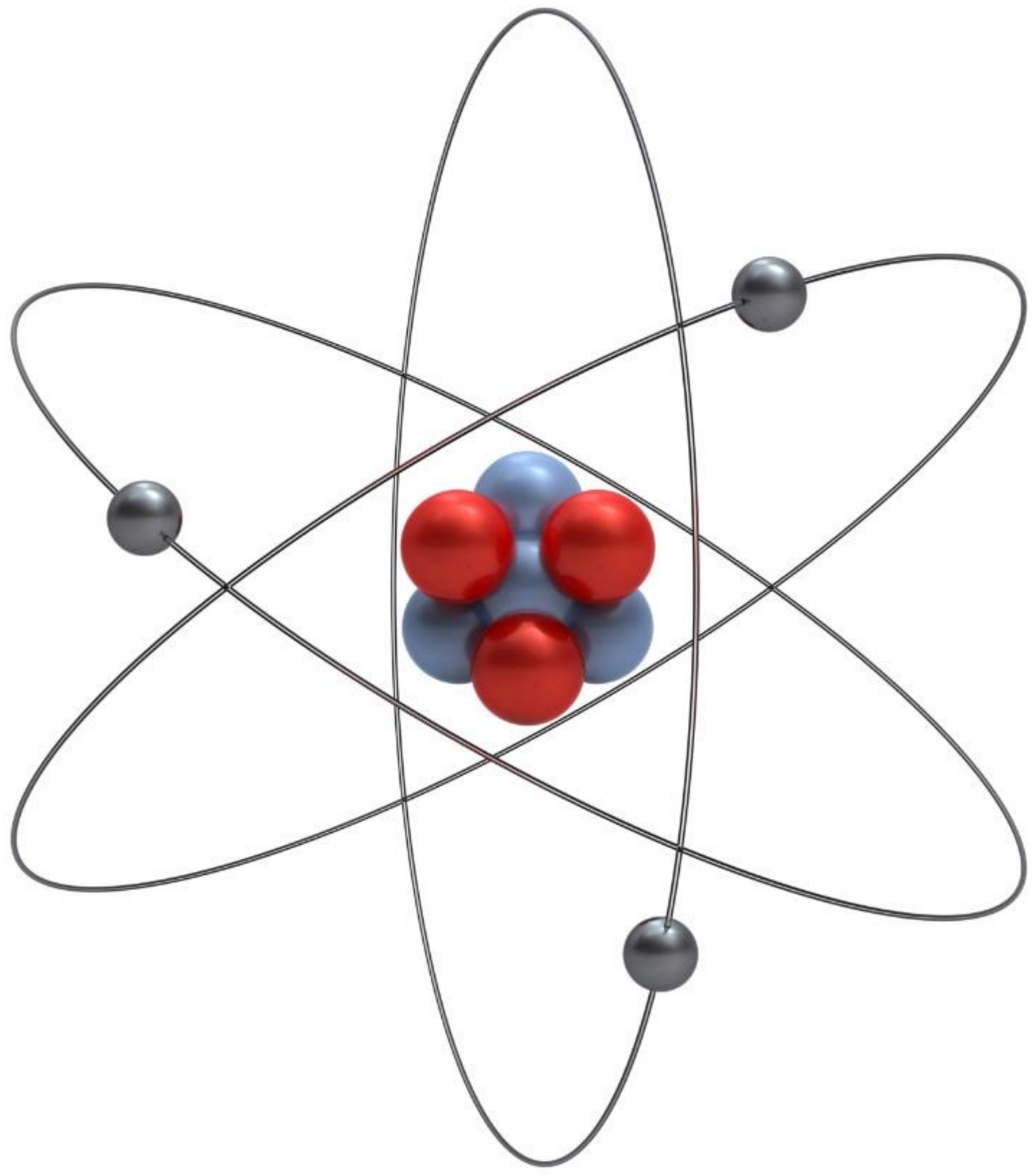
1. Introduction to Quantum Computing
2. Quantum Programming
3. Quantum SOC

QUANTUM COMPUTING

WHAT

Introduction to Quantum Computing. WHAT

Taking advantage of quantum mechanics in computing…physical properties of nature at the scale of atoms and subatomic particles

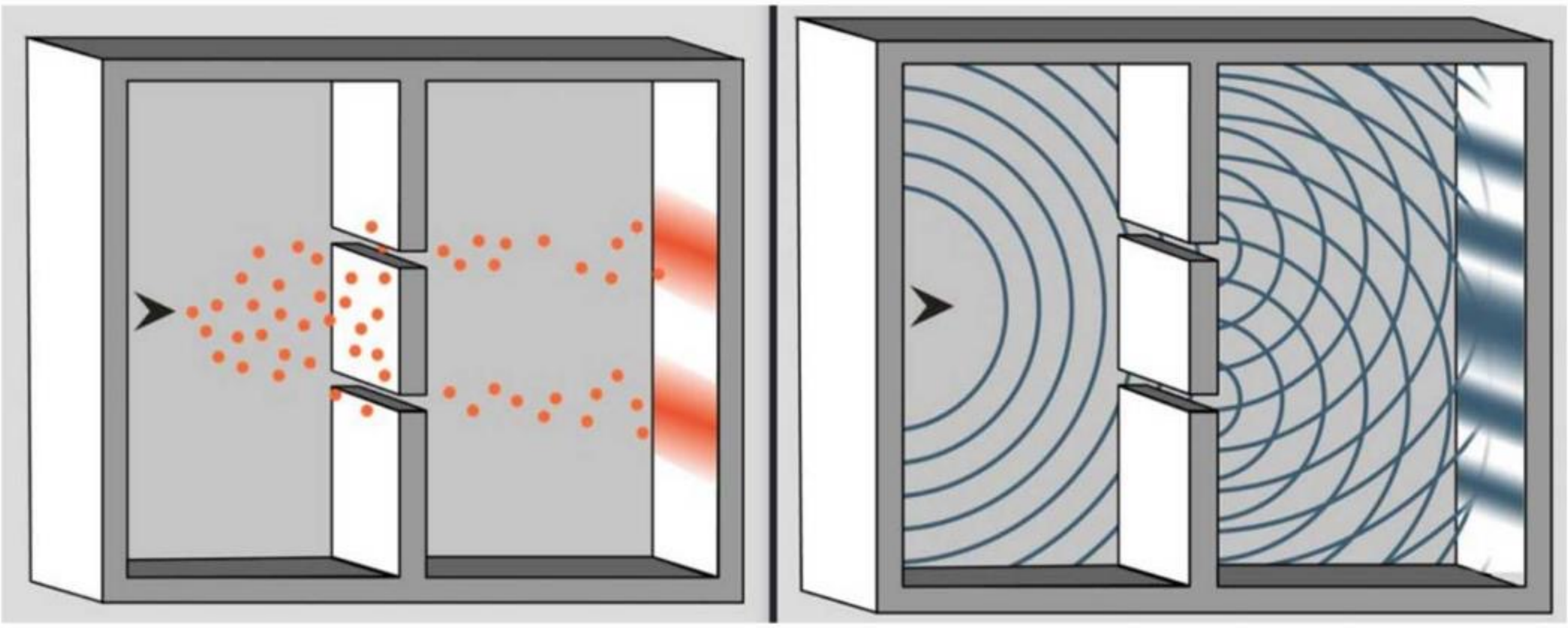


Introduction to Quantum Computing. WHAT

Quantum Computers use **the properties of Quantum Mechanics**

- Wave–particle duality

  -by Thomas Young



Source: Y las ondas se convirtieron en partículas

Introduction to Quantum Computing. WHAT

The properties of Quantum Mechanics used by Quamtum Computig:

- Superposition.
- Collapse
- Entaglement

A quantum computer is a machine that performs calculations based on the laws of quantum mechanics. A theoretical model is the Quantum Turing machine

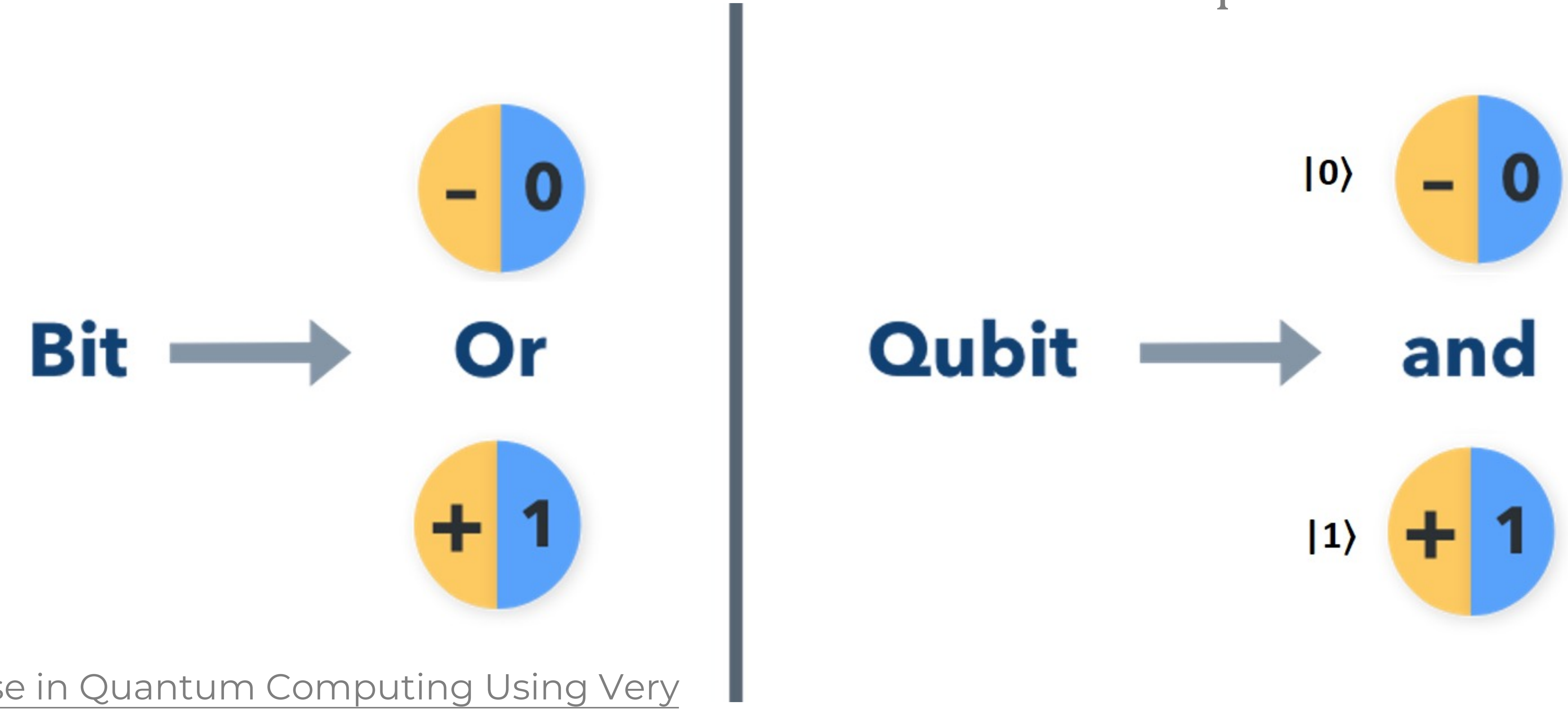
HOW

Introduction to Quantum Computing. HOW

Using quantum information theory:

Using **Qubit** instead of bit.

Escriba aquí la ecuación.

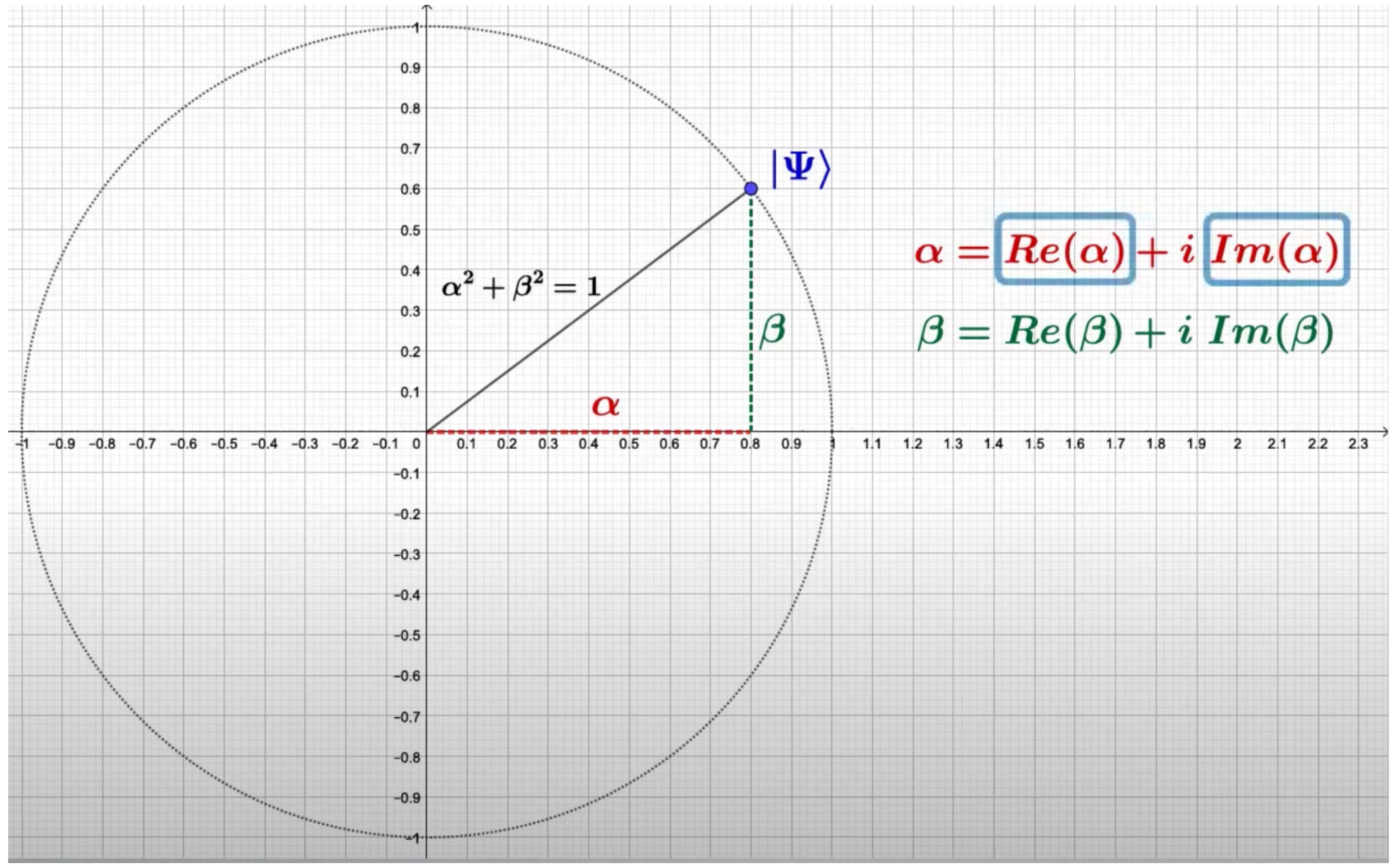


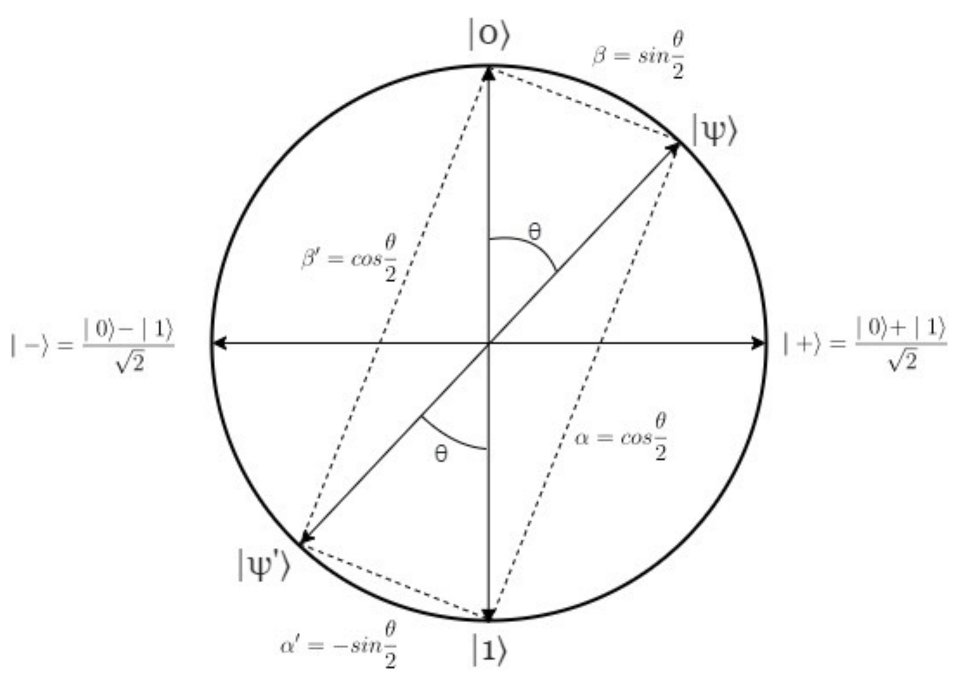
$$\alpha \mid 0\rangle + \beta \mid 1\rangle$$

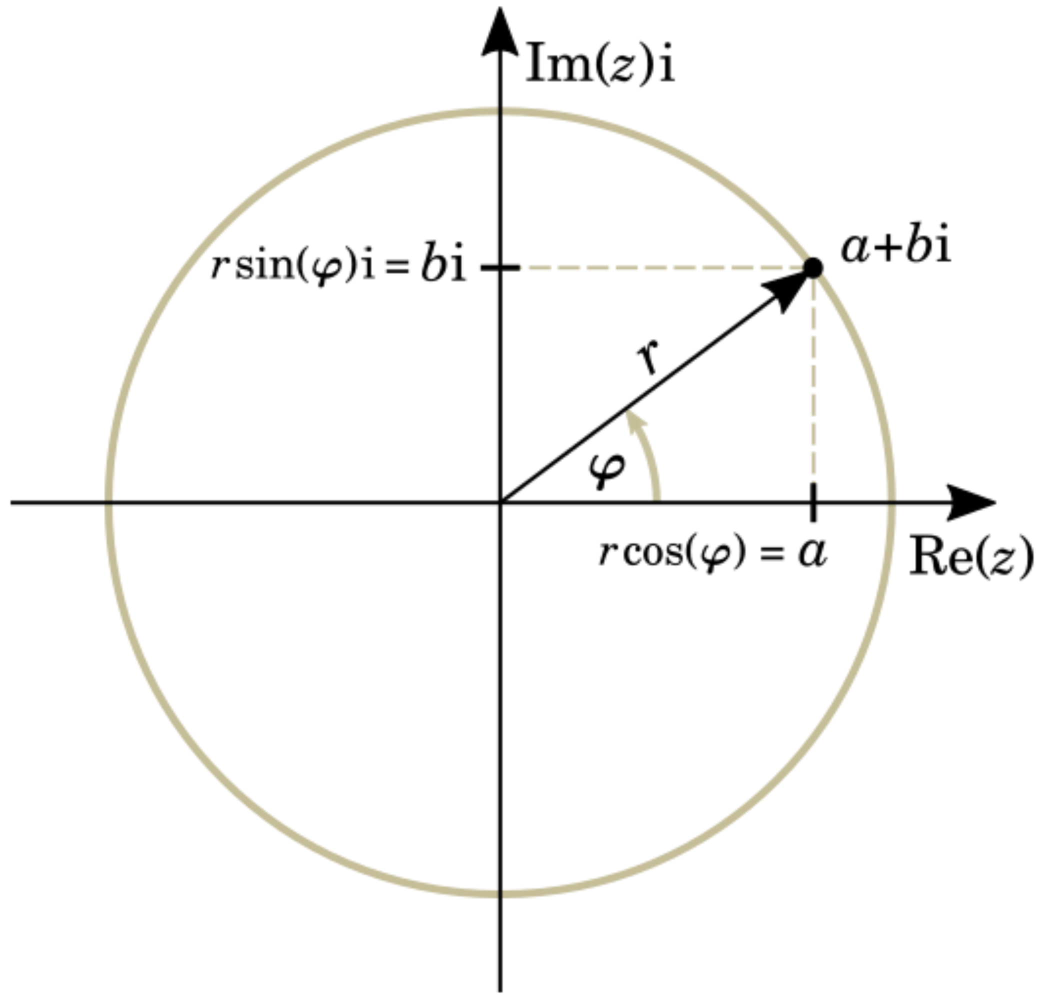
$\boldsymbol{\alpha}$ y $\boldsymbol{\beta}$ represent the amplitudes of probability of the qbit

Source: Crash Course in Quantum Computing Using Very Colorful Diagrams

Introduction to Quantum Computing. HOW







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

$$|\alpha|^2 + |\beta|^2 = 1$$

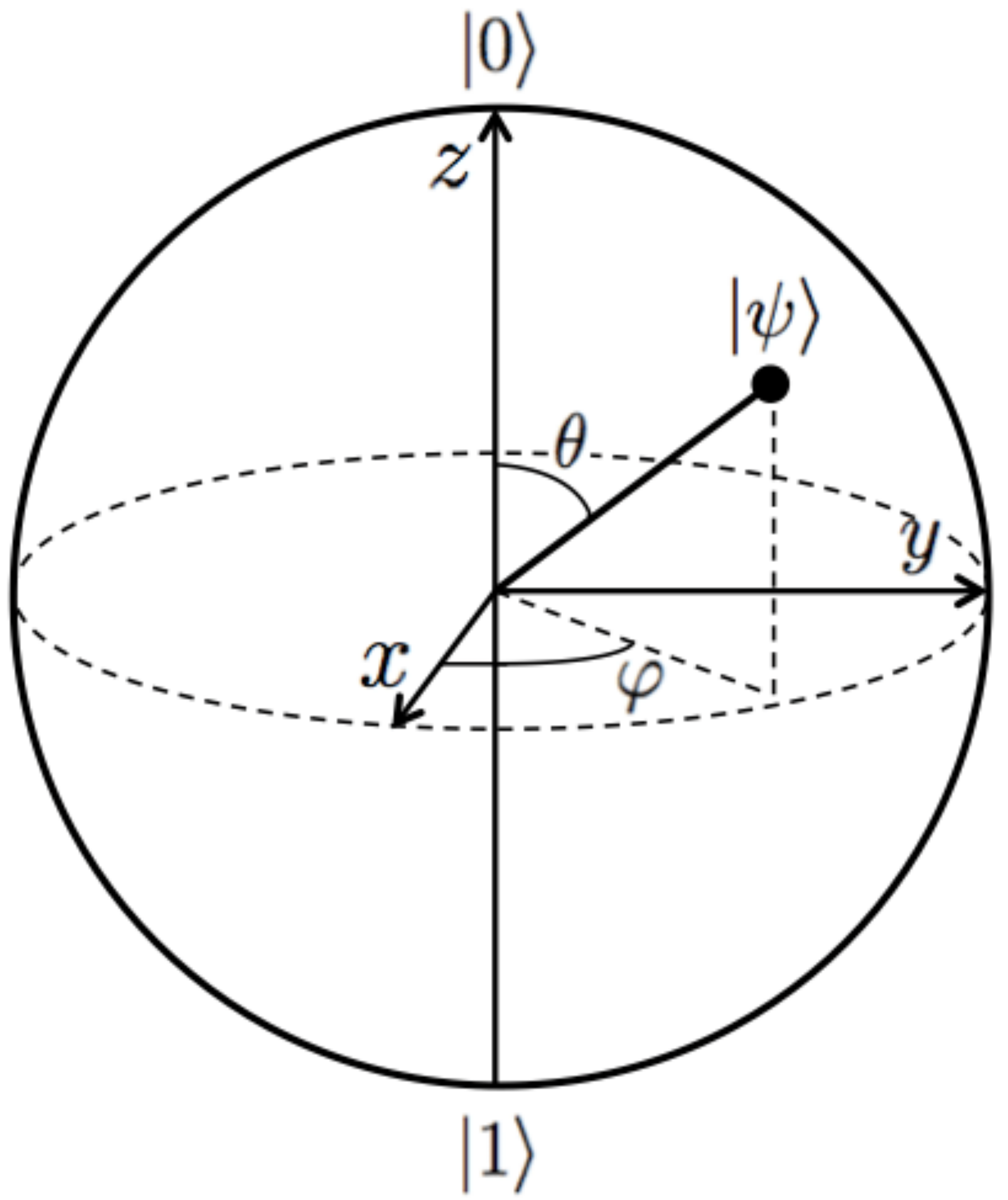
$$|\psi\rangle = (a_\alpha + b_\alpha i)|0\rangle + (a_\beta + b_\beta i)|1\rangle$$

$$|\psi\rangle = r_\alpha e^{i\varphi_\alpha}|0\rangle + r_\beta e^{i\varphi_\beta}|1\rangle$$

$$|r_\alpha|^2 + \left|r_\beta\right|^2 = 1$$

$$|\psi\rangle = e^{i\varphi_\alpha}\left(r_\alpha|0\rangle + r_\beta e^{i(\varphi_\alpha - \varphi_\beta)}|1\rangle\right)$$

Introduction to Quantum Computing. HOW

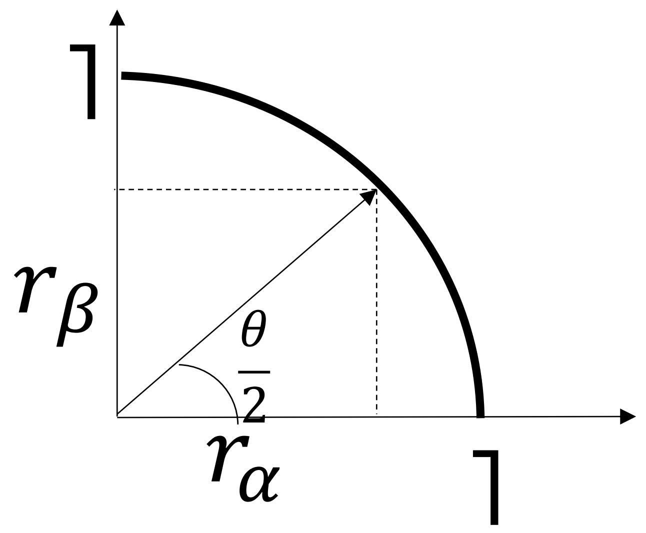


This sphere is often called the **Bloch sphere**, and it provides a useful means to visualize the state of a single qubit

Source: Visualizing Single Qubit Quantum Logic Gates

$$|\psi\rangle = e^{\overbrace{\boxed{i\varphi_\alpha}}^{\text{Irrelevant factor}}}\left(r_\alpha|0\rangle + r_\beta e^{i\left(\underbrace{\boxed{\varphi_\alpha-\varphi_\beta}}_{\phi}\right)}|1\rangle\right)$$

$$|r_\alpha|^2 + \left|r_\beta\right|^2 = 1$$

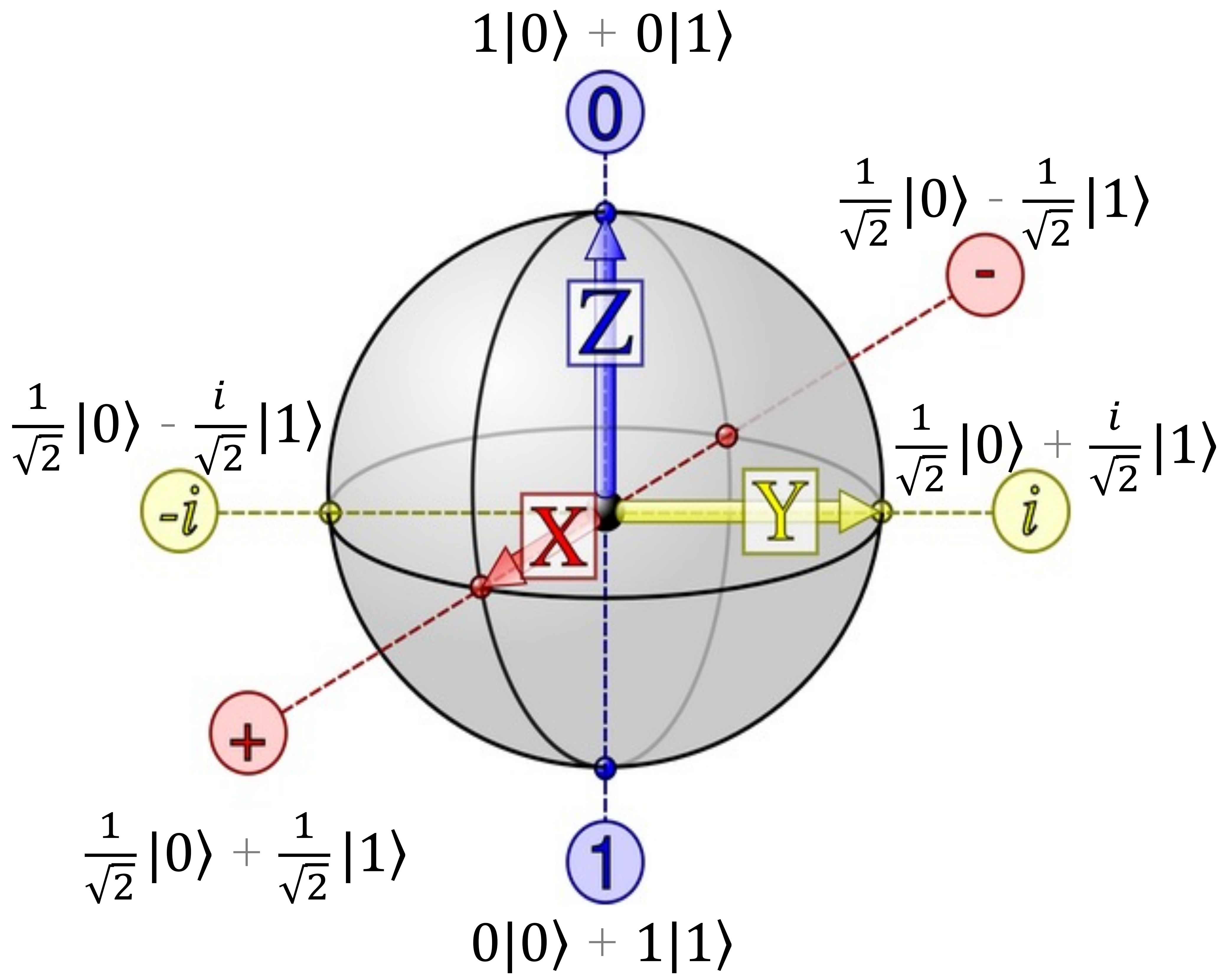


$$r_\alpha = \cos\frac{\theta}{2} \qquad r_\beta = \sin\frac{\theta}{2} \qquad 0 \le \theta \le \pi$$

$$0 \le \varphi \le 2\pi$$

$$|\psi\rangle = \cos\frac{\theta}{2}|0\rangle + e^{i(\phi)}\sin\frac{\theta}{2}|1\rangle$$

Introduction to Quantum Computing. HOW



Irrelevant factor

$$|\psi\rangle = e^{\boxed{i\varphi_\alpha}}\left(r_\alpha|0\rangle + r_\beta e^{i(\boxed{\varphi_\alpha - \varphi_\beta})}|1\rangle\right)$$

$$|r_\alpha|^2 + |r_\beta|^2 = 1 \qquad \phi$$

$$r_\alpha = \cos\frac{\theta}{2} \qquad r_\beta = \sin\frac{\theta}{2}$$

$$|\psi\rangle = \cos\frac{\theta}{2}|0\rangle + e^{i(\phi)}\sin\frac{\theta}{2}|1\rangle$$

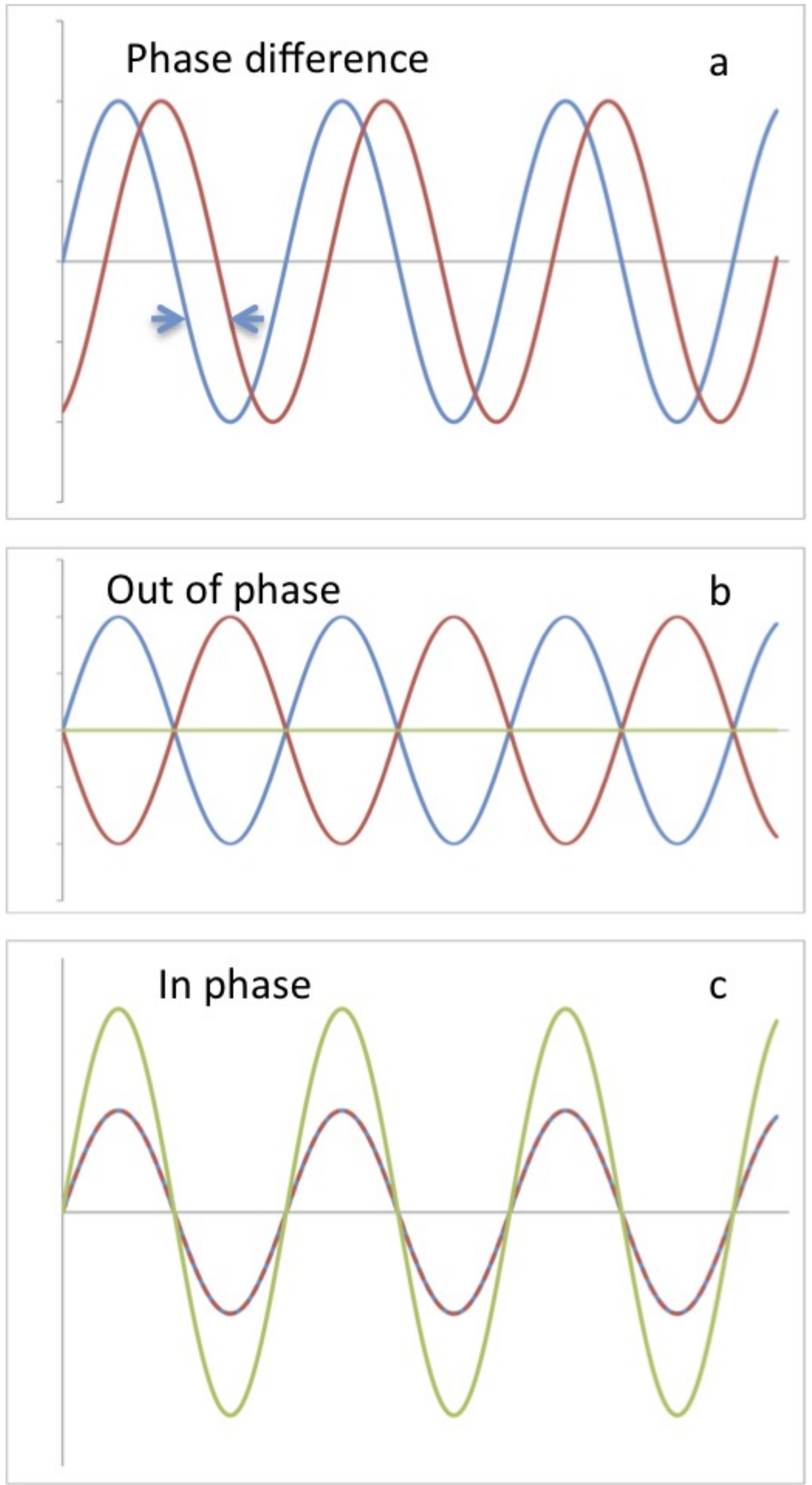
Source; La ciencia de la mula Francis https://francis.naukas.com/2014/07/31/medida-de-la-trayectoria-en-la-esfera-de-bloch-de-un-cubit-superconductor/dibujo20140731-bloch-sphere-qubit-nature-com/

Introduction to Quantum Computing. HOW

Having the Concept of Qbit and its mathematical definition we still need:

- Phisical Qbit implementatio: Electrons, Photons, Spins….
- A way to initialize the Qbit to a given state
- Operations to manipulate de amplitudes and phase (positioning que qbuit at any point of the Bloch Sphere): Quantum gates
- A way to measure (collapese) the system.

Introduction to Quantum Computing. HOW



Irrelevant factor

$$|\psi\rangle = e^{\boxed{i\varphi_\alpha}}\left(r_\alpha|0\rangle + r_\beta e^{i\left(\boxed{\varphi_\alpha - \varphi_\beta}\right)}|1\rangle\right)$$

$$\phi$$

$$|r_\alpha|^2 + |r_\beta|^2 = 1$$

$$r_\alpha = \cos\frac{\theta}{2} \qquad r_\beta = \sin\frac{\theta}{2}$$

$$|\psi\rangle = \cos\frac{\theta}{2}|0\rangle + e^{i(\phi)}\sin\frac{\theta}{2}|1\rangle$$

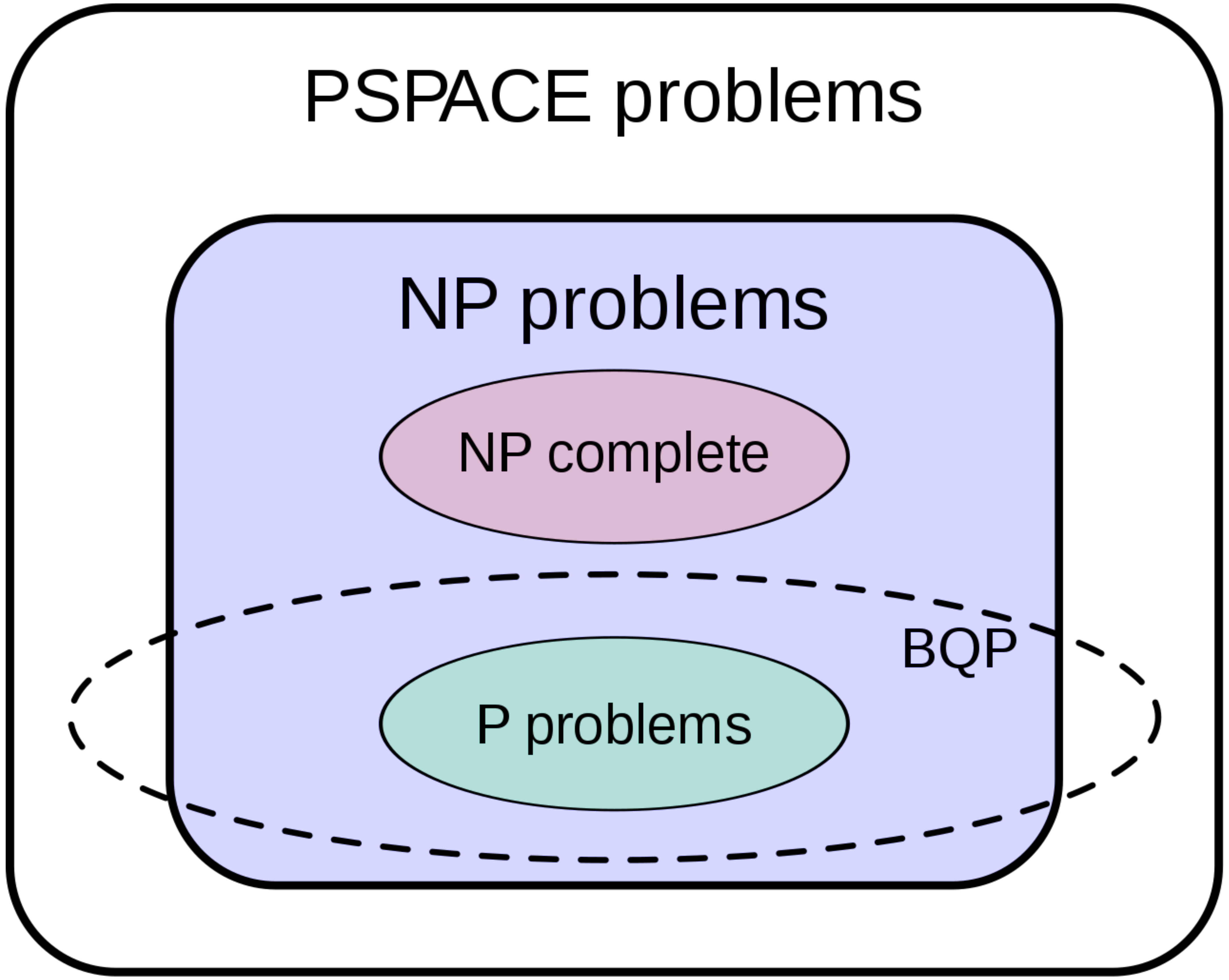
LIMITATIONS: QUANTUM DECOHERENCE

Lost of the phase relation between the states of a quantum computer due to external factors. It introduces errors in the results

WHY

Introduction to Quantum Computing. WHY

Bounded-error Quantum Polynomial time (BQP) is the class of decision problems solvable by a quantum computer in polynomial time, with an error probability of at most 1/3 for all instances



Source: Bounded-error Quantum Polynomial time

Introduction to Quantum Computing. WHY

Difficult Problems Quantum Computing can solve easily:

Problems	Explication	Quantum Complexity	Classical Complexity
Factorization	Decomposition of a number into a product of smaller integers	O(logN)	$\Theta\left(\exp\left(\left(\frac{32}{9}n\right)^{\frac{1}{3}}(\log n)^{\frac{2}{3}}\right)\right)$
Search	Search in an unordered sequence of data	O(√n)	O(n)

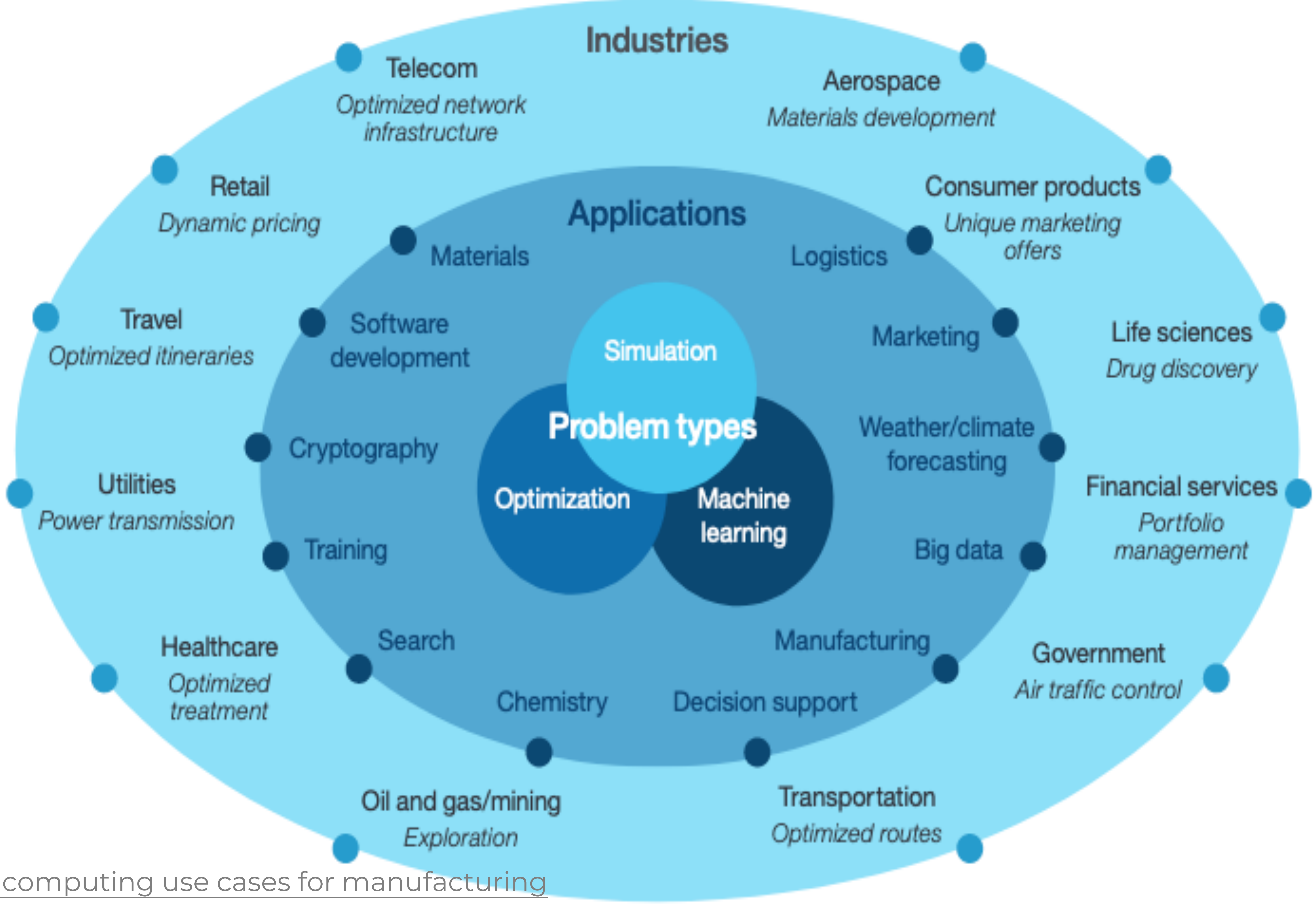
Introduction to Quantum Computing. WHY

The power comes not from the fact that they compute faster but from the fact that they compute differently.

While classical computers with registers of size n (bits) can manage only one state of size n at a time, a quantum computer with registers of n (qbits) manages 2^n states of size n simultaneously (in superposition)

Quantum computing is much more powerful than parallel computing because the superposition states are manipulated as a single one....this "magic" happens when the properties of quantum mechanics are applied to the superposition states.

Introduction to Quantum Computing. WHY

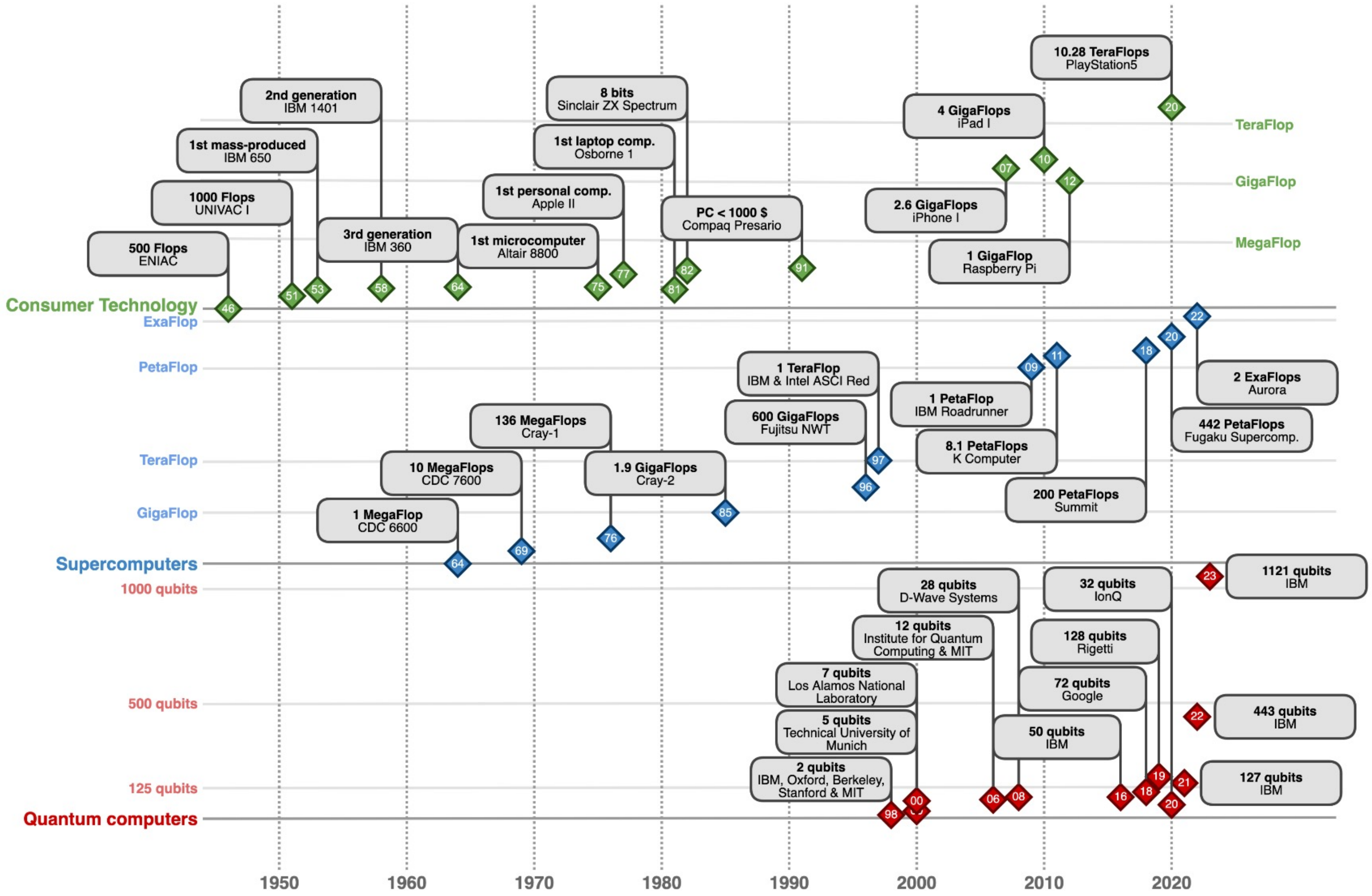


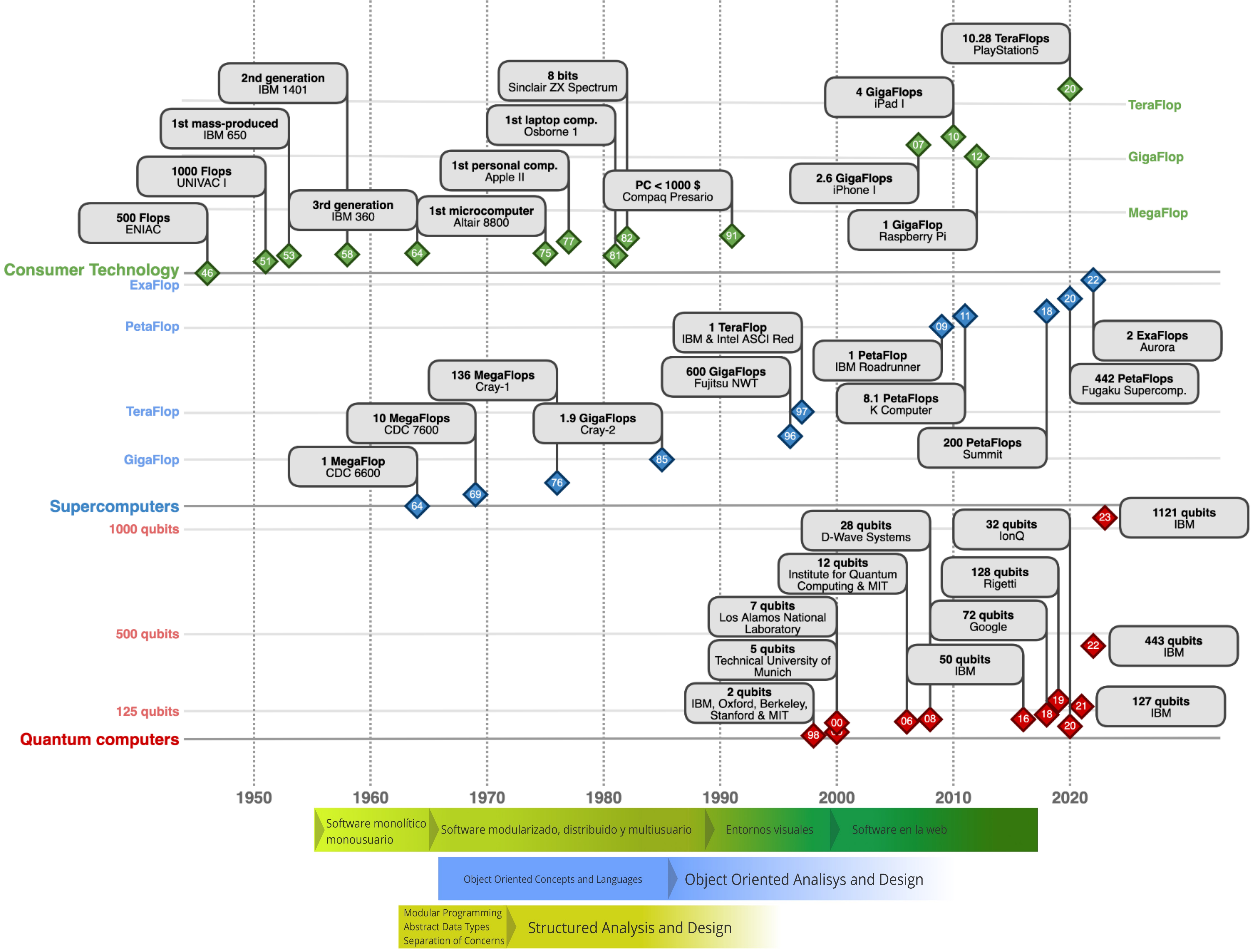
Source: Exploring quantum computing use cases for manufacturing

WHEN

Introduction to Quantum Computing. WHEN

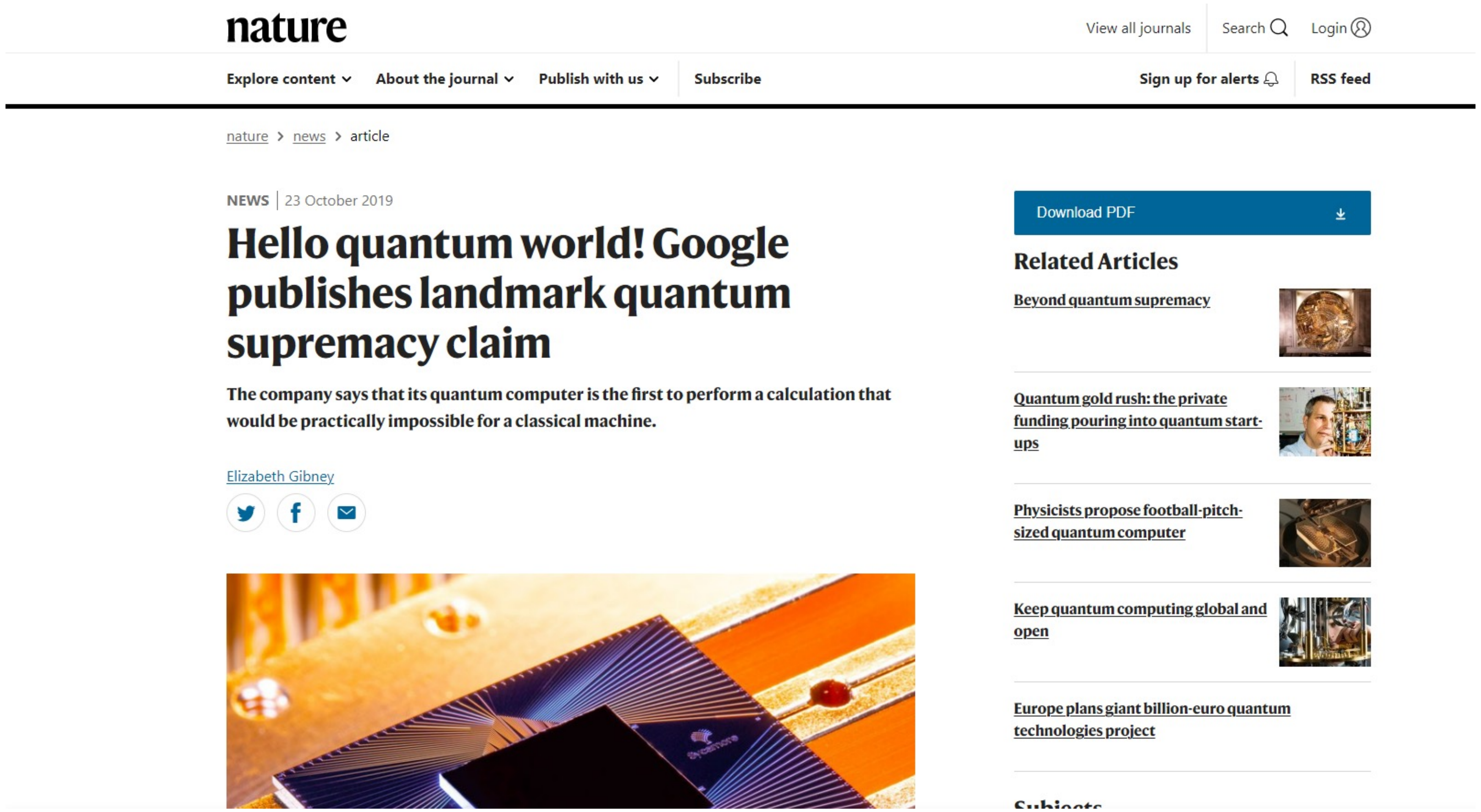
Introduction to Quantum Computing. WHEN




Consumer Technology
500 Flops ENIAC
1000 Flops UNIVAC I
1st mass-produced IBM 650
2nd generation IBM 1401
3rd generation IBM 360
1st microcomputer Altair 8800
1st personal comp. Apple II
1st laptop comp. Osborne 1
8 bits Sinclair ZX Spectrum
PC < 1000 $ Compaq Presario
2.6 GigaFlops iPhone I
1 GigaFlop Raspberry Pi
4 GigaFlops iPad I
10.28 TeraFlops PlayStation5
TeraFlop
GigaFlop
MegaFlop
Supercomputers
ExaFlop
PetaFlop
TeraFlop
GigaFlop
1 MegaFlop CDC 6600
10 MegaFlops CDC 7600
136 MegaFlops Cray-1
1.9 GigaFlops Cray-2
600 GigaFlops Fujitsu NWT
1 TeraFlop IBM & Intel ASCI Red
1 PetaFlop IBM Roadrunner
8.1 PetaFlops K Computer
200 PetaFlops Summit
442 PetaFlops Fugaku Supercomp.
2 ExaFlops Aurora
Quantum computers
1000 qubits
500 qubits
125 qubits
2 qubits IBM, Oxford, Berkeley, Stanford & MIT
5 qubits Technical University of Munich
7 qubits Los Alamos National Laboratory
12 qubits Institute for Quantum Computing & MIT
28 qubits D-Wave Systems
50 qubits IBM
72 qubits Google
128 qubits Rigetti
32 qubits IonQ
127 qubits IBM
443 qubits IBM
1121 qubits IBM
1950
1960
1970
1980
1990
2000
2010
2020
Software monolítico monousuario
Software modularizado, distribuido y multiusuario
Entornos visuales
Software en la web
Object Oriented Concepts and Languages
Object Oriented Analisys and Design
Modular Programming
Abstract Data Types
Separation of Concerns
Structured Analysis and Design

Introduction to Quantum Computing. WHEN

Quantum supremacy refers to quantum computers being able to solve a problem that all classical computers together cannot



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Elizabeth Gibney

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By Matthew Sparkes

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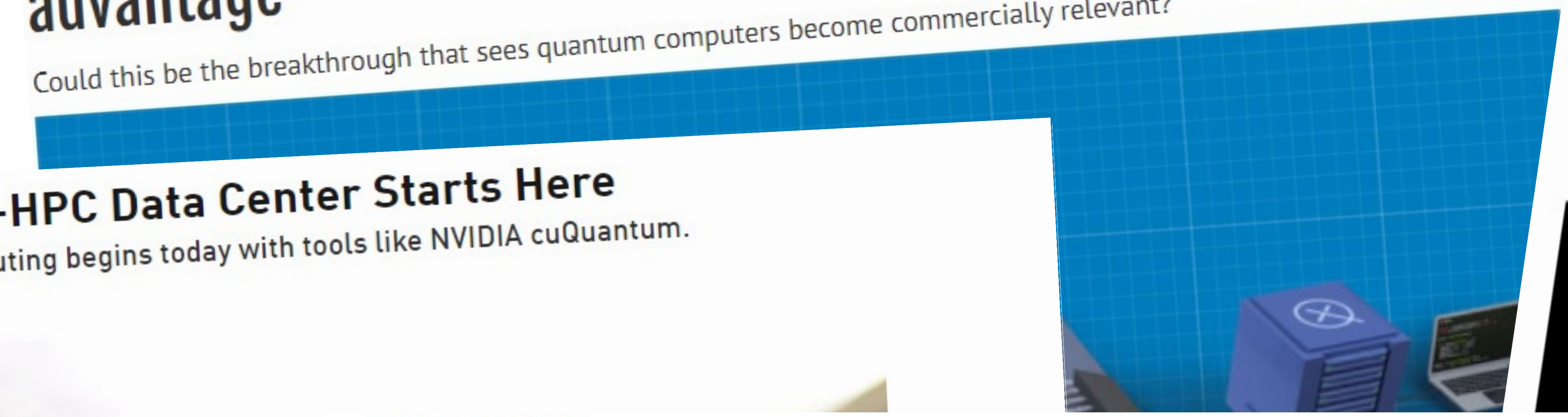
Introduction to Quantum Computing. WHEN

Present Status

A novel quantum computer Borealis achieves computational advantage

Could this be the breakthrough that sees quantum computers become commercially relevant?



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By Joel Khalili published December 21, 2021

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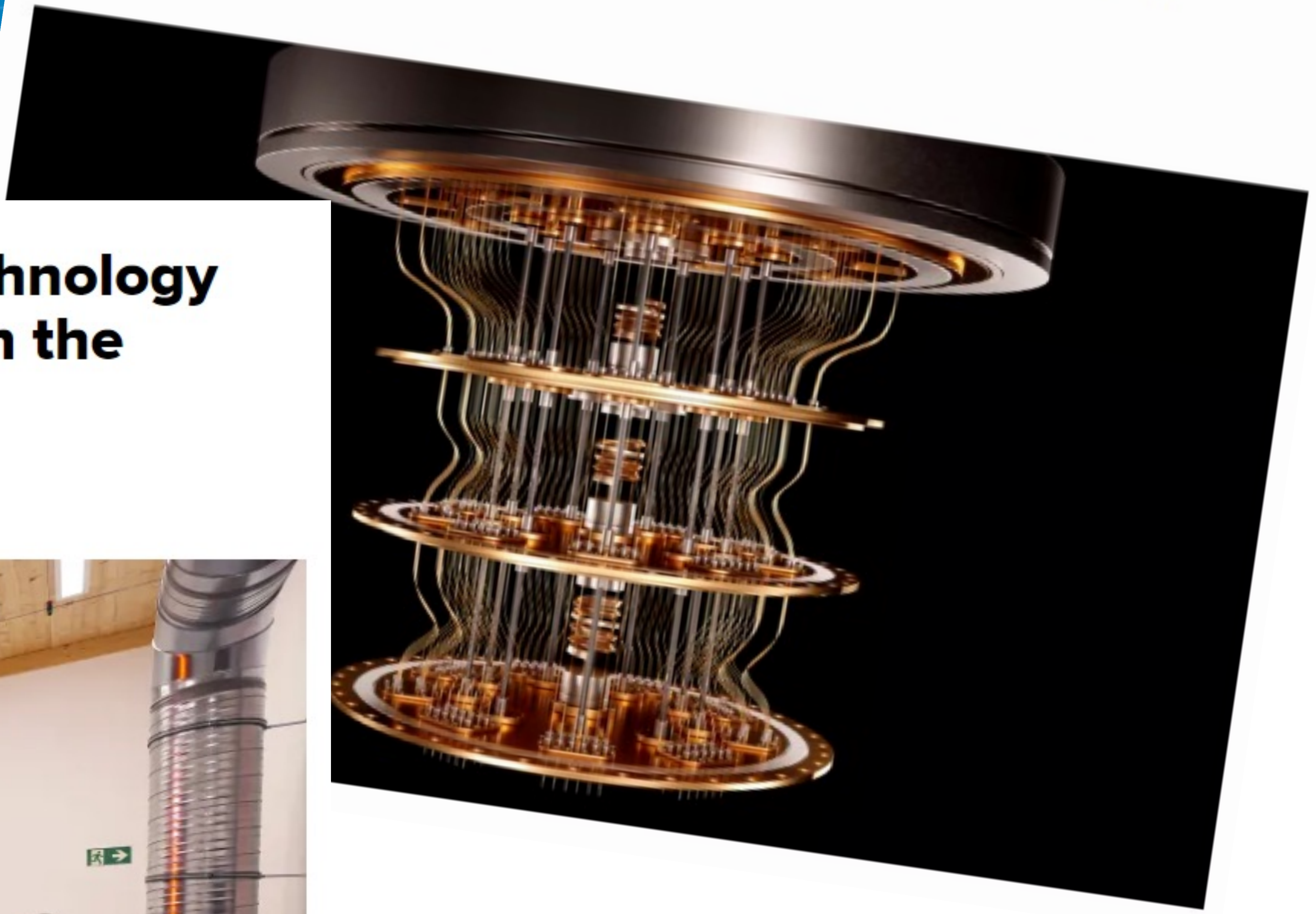

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Introduction to Quantum Computing. WHEN

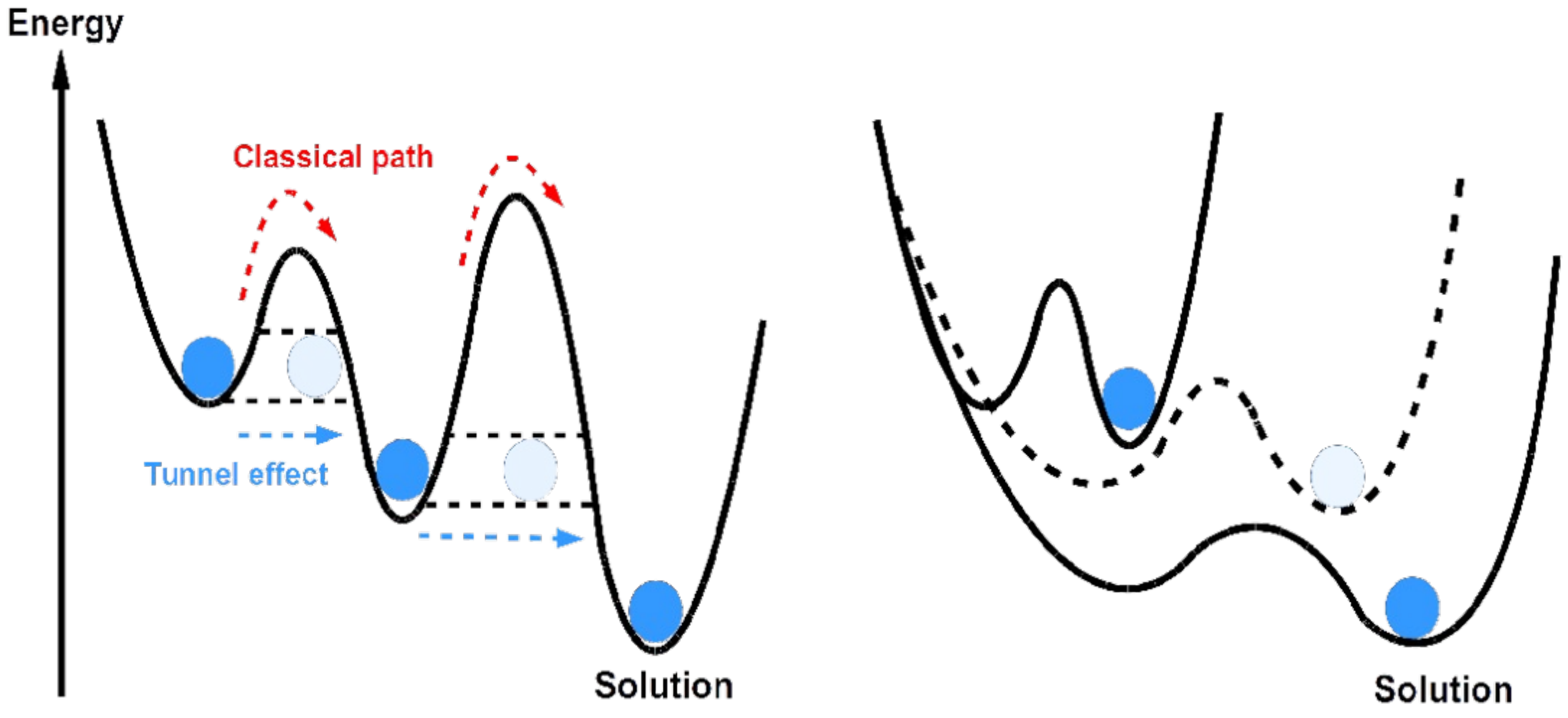
Future Research

QUANTUM PROGRAMMING

Quantum Programming

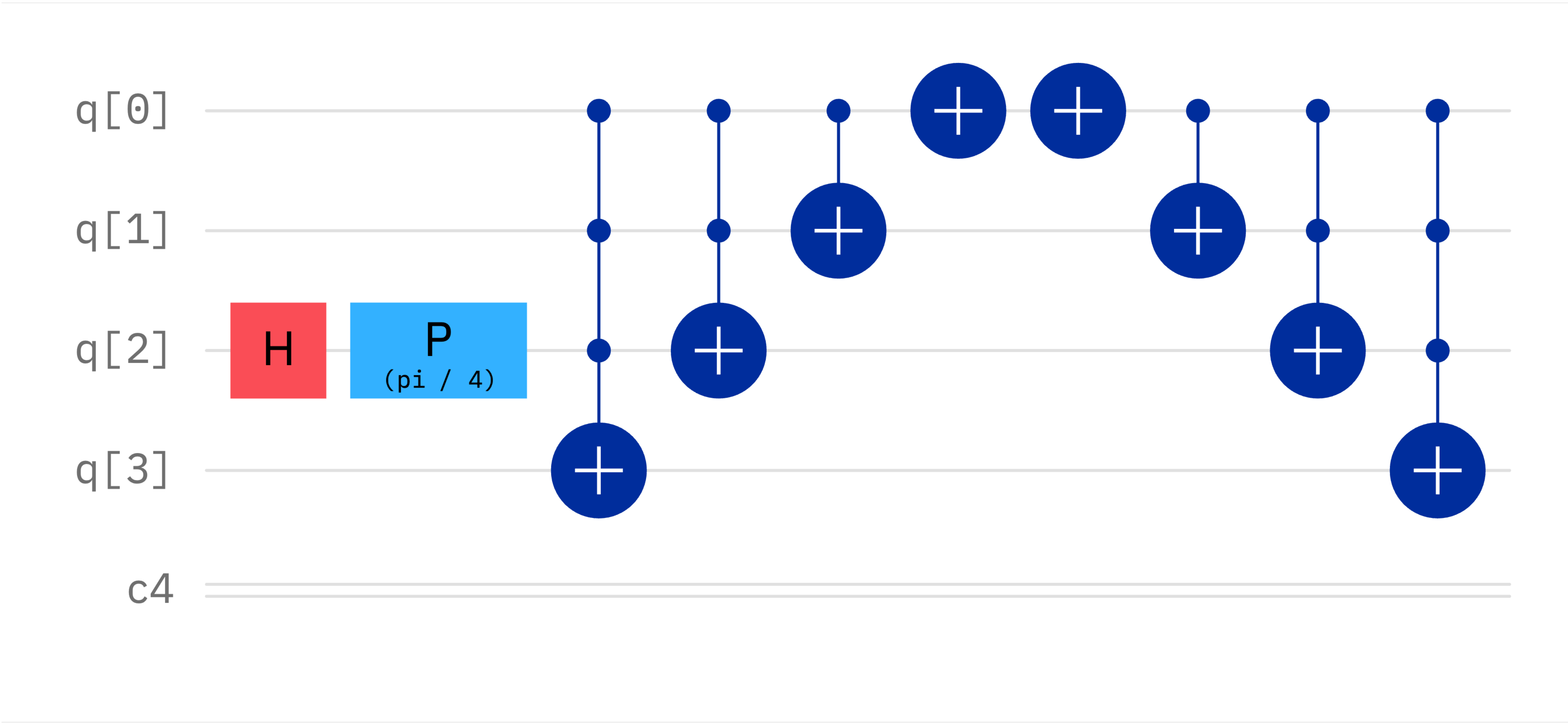
Quantum annealing (which also includes adiabatic quantum computation) is a quantum computing method used to find the optimal solution of problems involving many solutions

Universal quantum gate model is based on creating quantum structures using stable qubits and solving today's problems with **quantum circuits.** These circuits are based on the Turing machine model



Quantum Tunnelling

Adiabatic evolution



Quantum Programming

Principal Gates

	Name	Gate in IBM Composer (Qiskit)	Equivalent in AWS Braket
Single Qubit	Pauli-X	x	x
	Hadamard	h	h
	Phase	p	Phaseshift
	Controlled-X	cx	cnot
Multiple Qubits	Toffoli	ccx	ccnot
	CPhase	cu1	cphaseshift
	Swap	swap	swap
	Measure	measure	-
	Barrier	barrier	

Quantum Programming

Name	Gate in IBM Composer (Qiskit)	Equivalent in AWS Braket
Pauli-X	x	x

Composer Reference

Matrix

$$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

Reverse

$$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

itself

$$A|0\rangle + B|1\rangle \; - \boxed{X} - \; B|0\rangle + A|1\rangle$$

Quantum Programming

Name	Gate in IBM Composer (Qiskit)	Equivalent in AWS Braket
Hadamard	h	h

Composer Reference

Matrix

$$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

$$|0\rangle \; - \boxed{H} - \; \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

$$|1\rangle \; - \boxed{H} - \; \frac{1}{\sqrt{2}}|0\rangle - \frac{1}{\sqrt{2}}|1\rangle$$

Reverse

$$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

itself

Quantum Programming

Name	Gate in IBM Composer (Qiskit)	Equivalent in AWS Braket
Phase	p	phaseshift

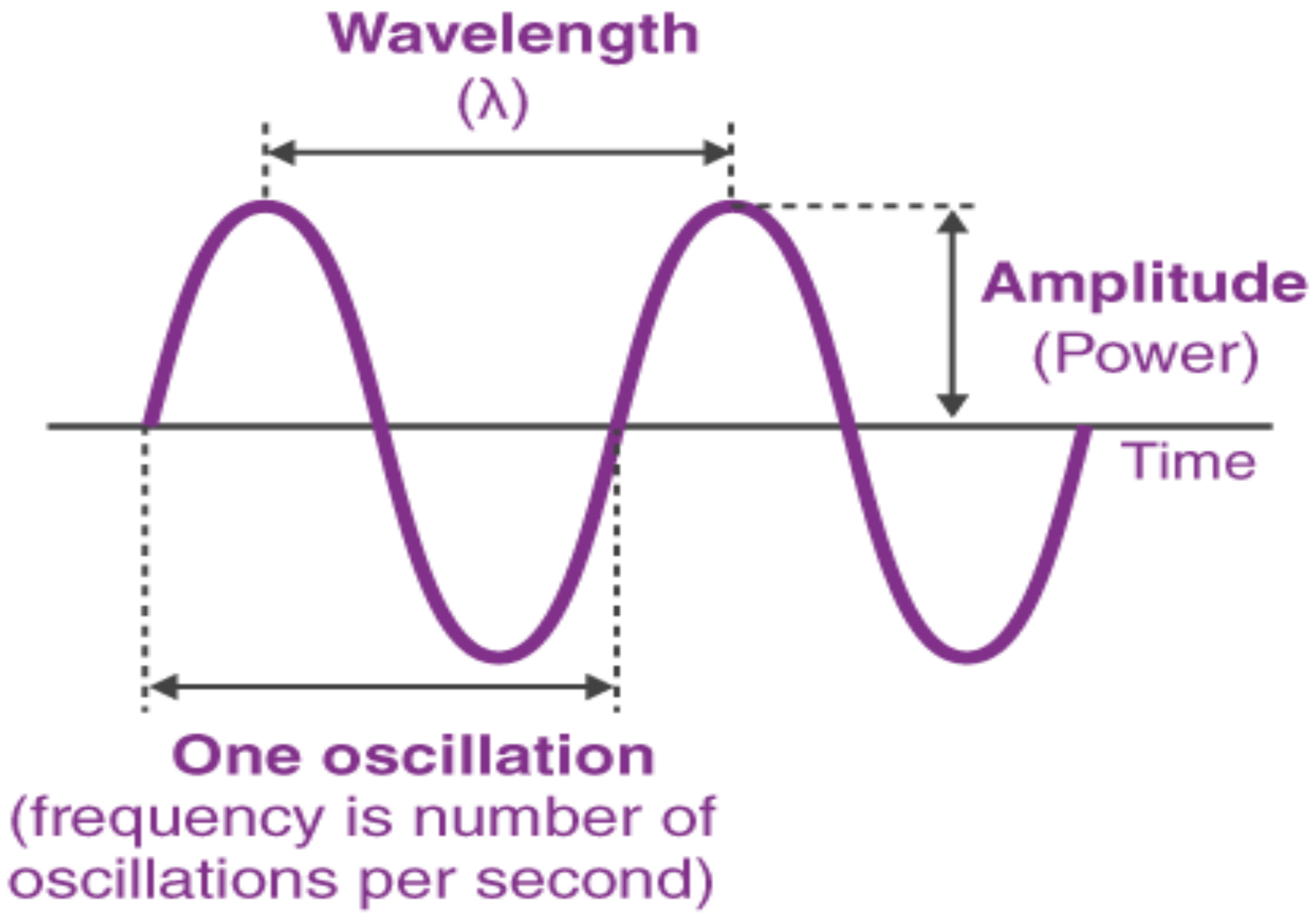
Composer Reference

Matrix

$$P(\varphi) = \begin{bmatrix} 1 & 0 \\ 0 & e^{i\varphi} \end{bmatrix}$$

Reverse

$$P(-\varphi) = \begin{bmatrix} 1 & 0 \\ 0 & e^{-i\varphi} \end{bmatrix}$$



Quantum Programming

Name	Gate in IBM Composer (Qiskit)	Equivalent in AWS Braket
Controlled-X	cx	cnot

Composer Reference

Matrix

$$\mathrm{CNOT} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

Reverse

$$\mathrm{CNOT} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Quantum Programming

Name	Gate in IBM Composer (Qiskit)	Equivalent in AWS Braket
Toffoli	ccx	ccnot

Composer Reference

Matrix

$$\mathrm{CCNOT} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{pmatrix}$$

Reverse

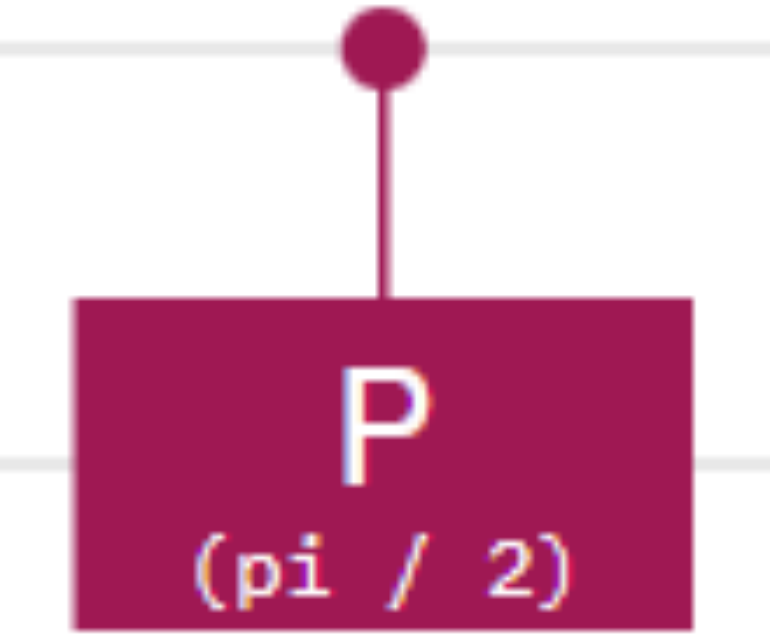
$$\mathrm{CCNOT} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{pmatrix}$$

itself

Quantum Programming

Name	Gate in IBM Composer (Qiskit)	Equivalent in AWS Braket
CPhase	cu1	cphaseshift

Composer Reference

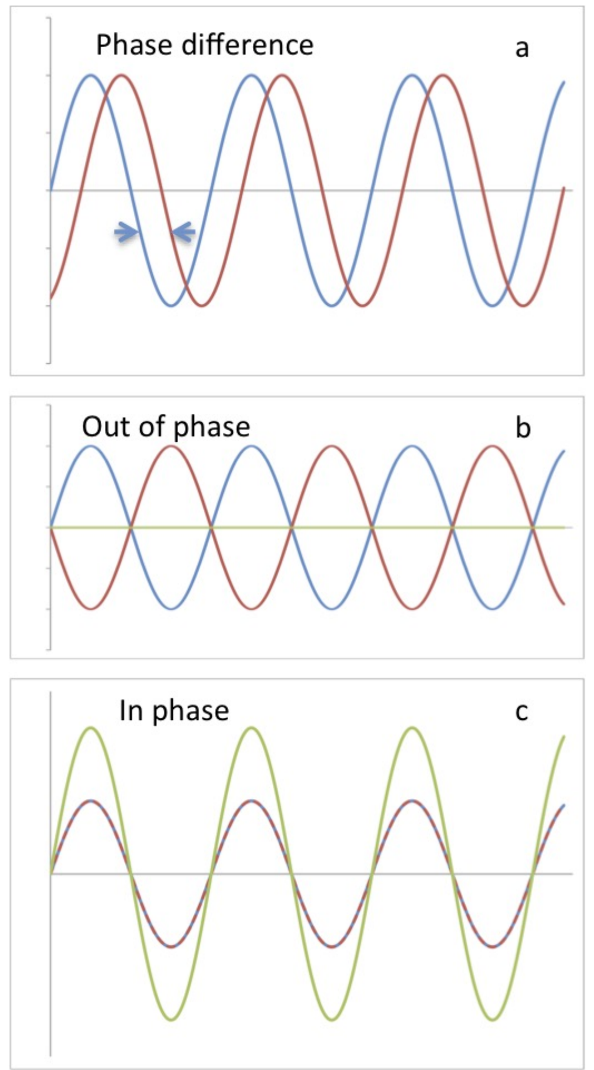


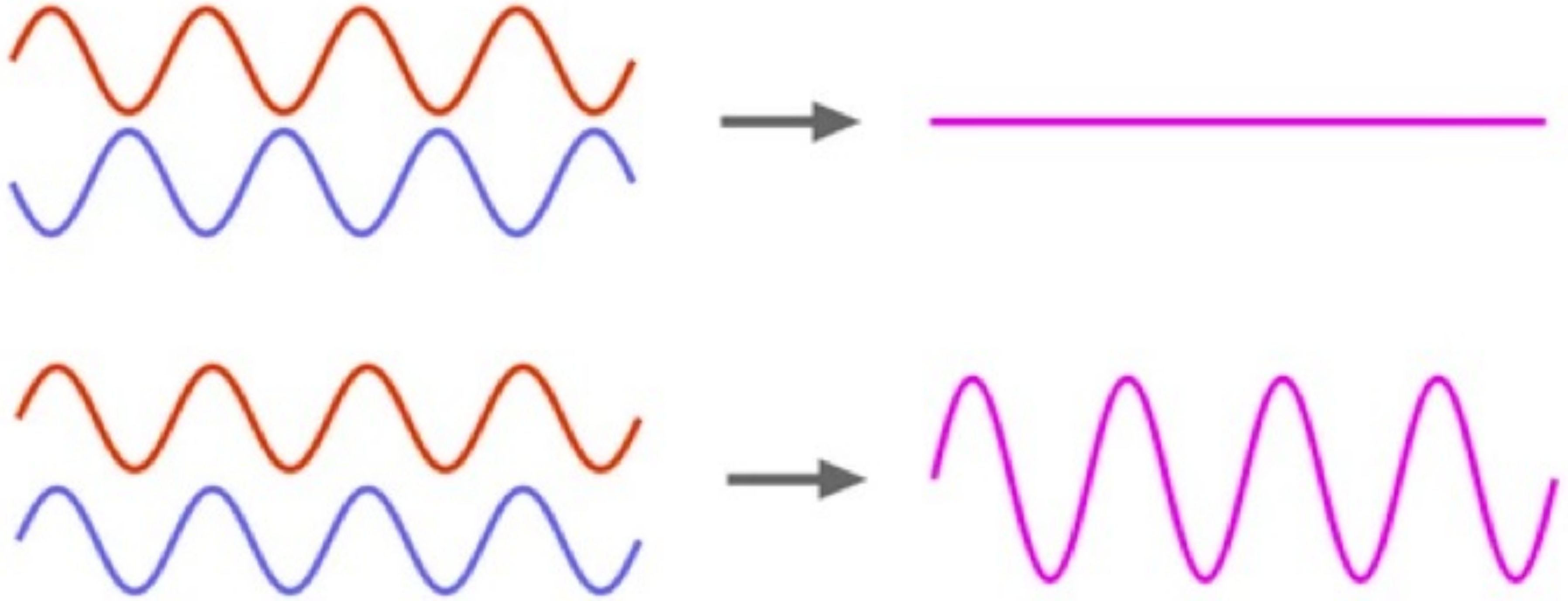
Matrix

$$\mathrm{CPHASE}(\varphi) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & e^{i\varphi} \end{bmatrix}$$

Reverse

$$CPHASE(-\varphi) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & e^{-i\varphi} \end{bmatrix}$$





Quantum Programming

Name	Gate in IBM Composer (Qiskit)	Equivalent in AWS Braket
Swap	swap	swap

Composer Reference

Matrix

$$\mathrm{SWAP} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Reverse

$$\mathrm{SWAP} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

itself

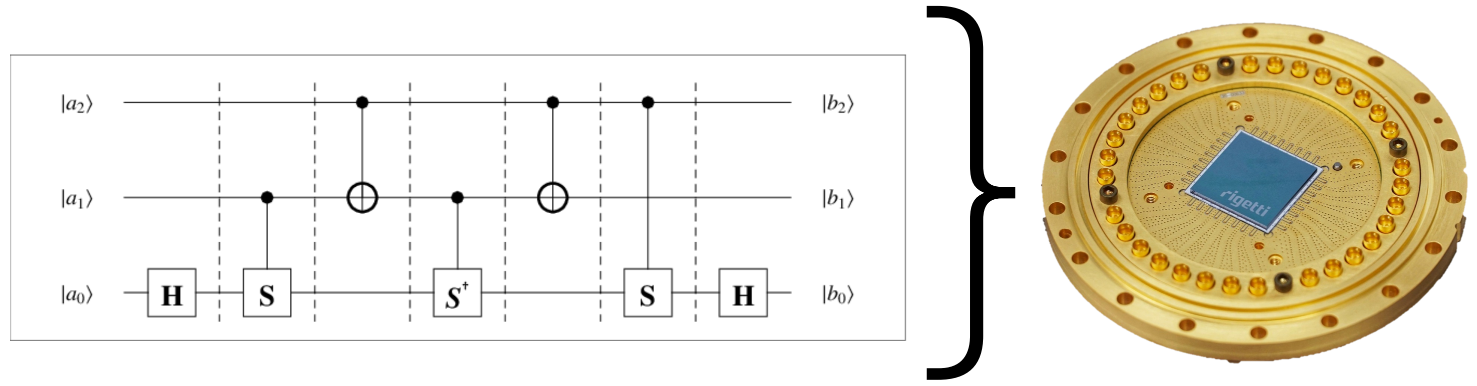
QUANTUM SERVICE ORIENTED COMPUTING

TODAY's SOFTWARE SYSTEMS…

Connected
Software
Pieces

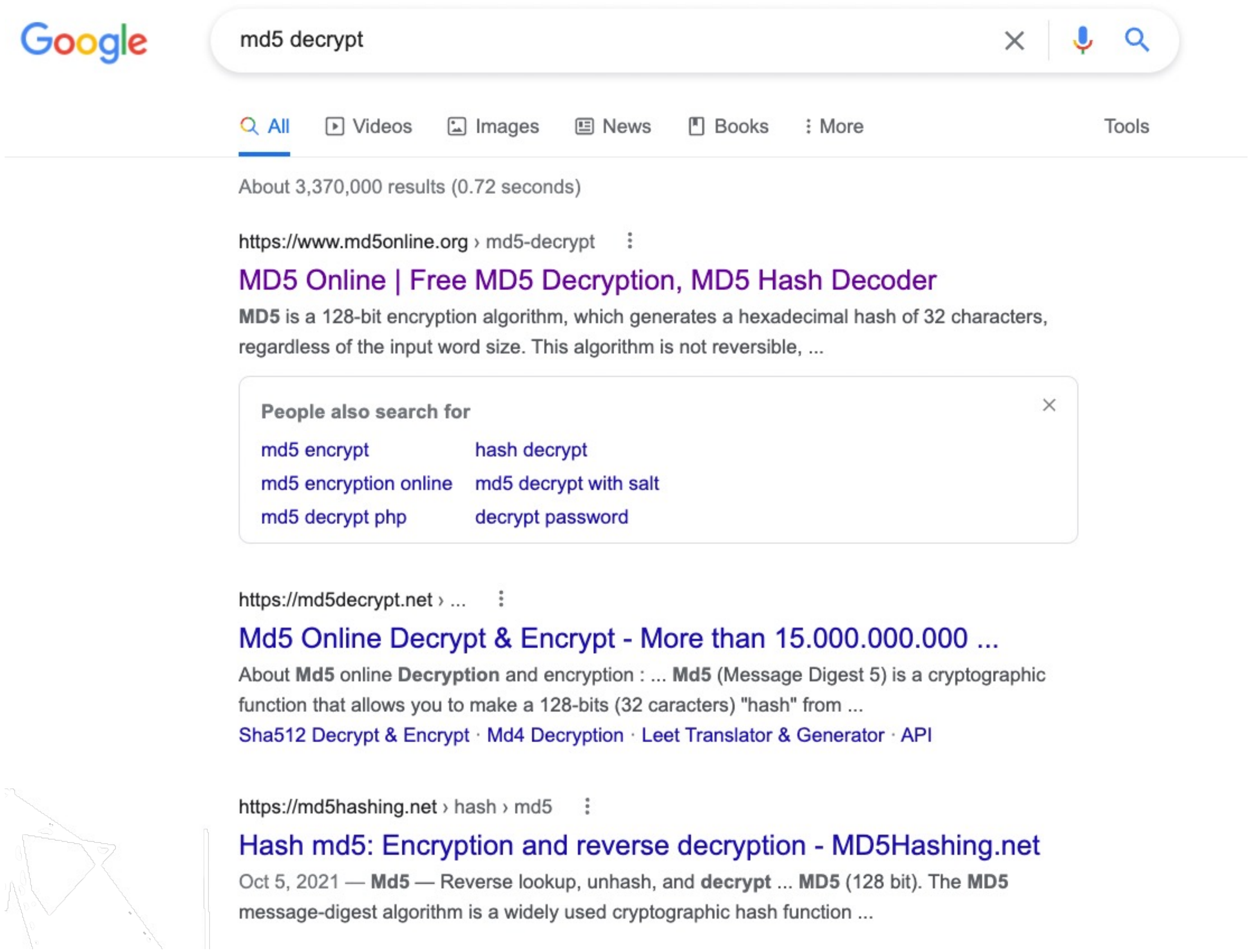
Supported by…
Service Oriented
Mobile
Cloud
Fog

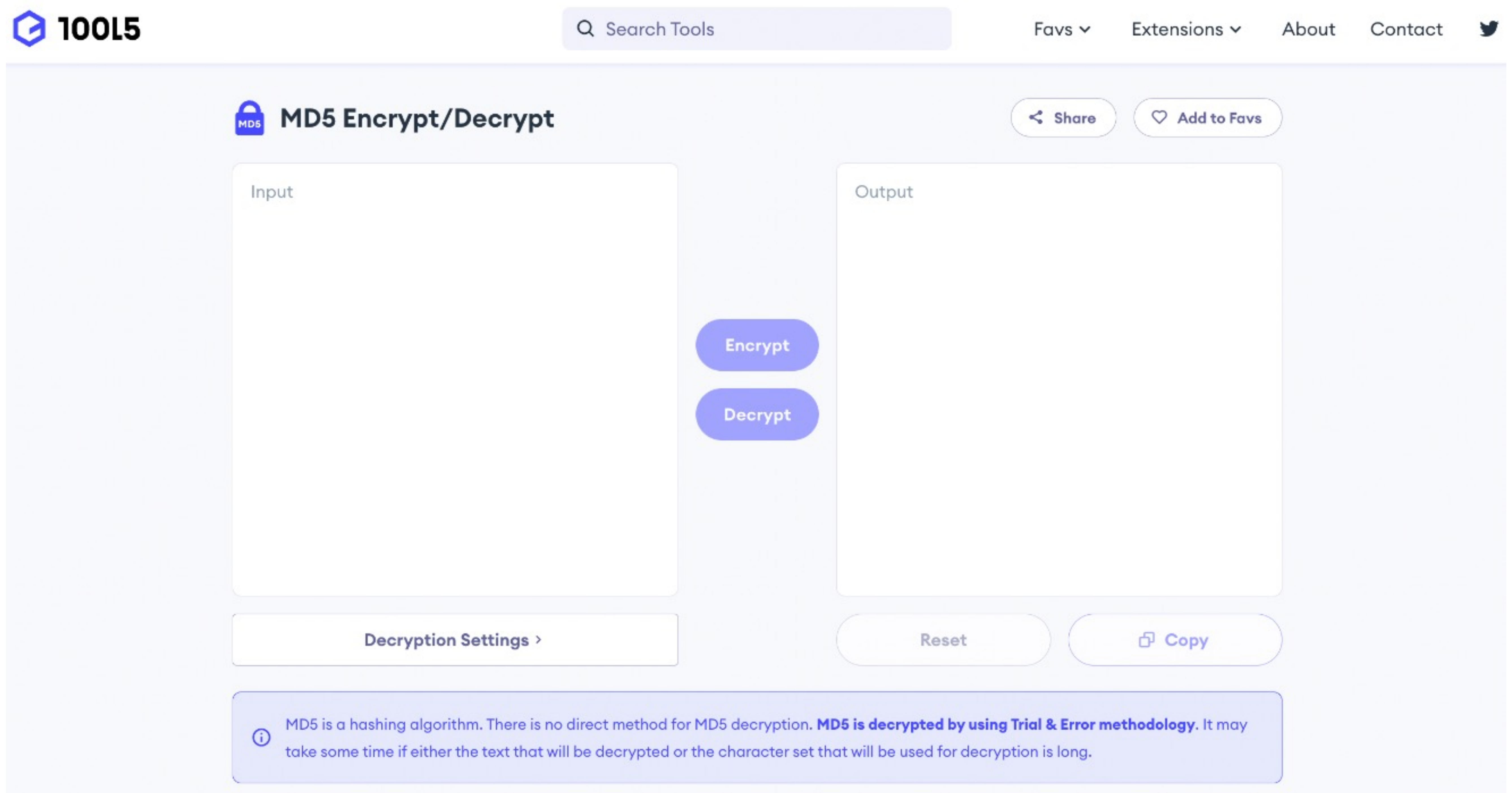
Many advantages
- Pay per Use
- Platform independent
- Location independent
- Decoupled
- Flexible
- Reusable
- Maintainable
- Reliable
- Scalable



Globaly
Distributed

THE CASE OF STEFAN THOMAS





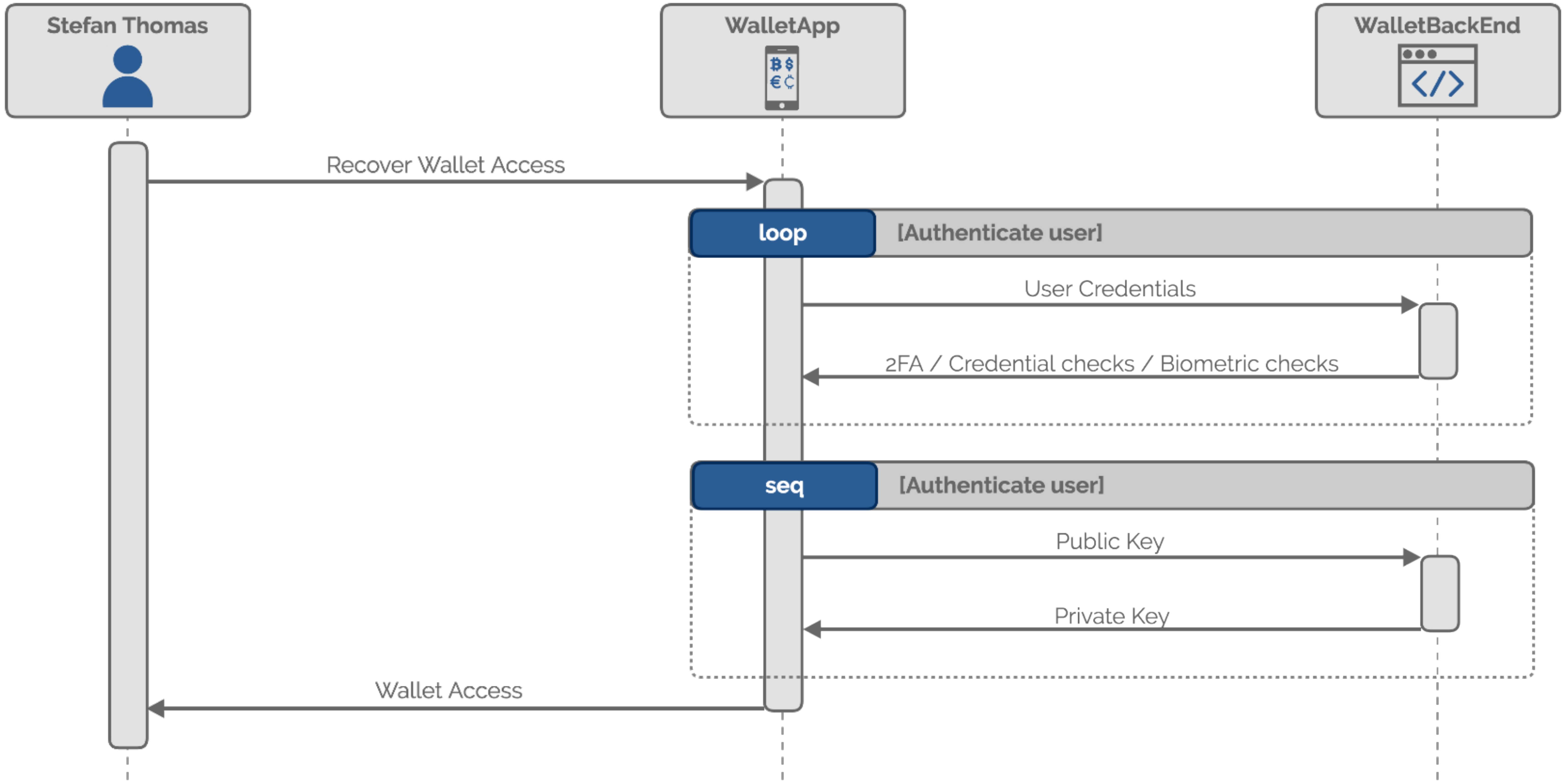
THE CASE OF STEFAN THOMAS


The New York Times

Lost Passwords Lock Millionaires Out of Their Bitcoin Fortunes

Bitcoin owners are getting rich because the cryptocurrency has soared. But what happens when you can't tap that wealth because you forgot the password to your digital wallet?

Stefan Thomas, a programmer in San Francisco, owns 7,002 Bitcoin that he cannot retrieve because he lost the password to his digital wallet. Nicholas Albrecht for The New York Times



A GOOD CLASSIC SERVICE IMPLEMENTATION

QUANTUM SERVICE IMPLEMENTATION

THANK YOU VERY MUCH FOR YOUR ATTENTION

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