UNIVERSIDAD COMPLUTENSE MADRID

Ingeniería del Software para la Computación Cuántica: Retos y Oportunidades

Mario Piattini

Abril 2021

UCLM Universidad de Castilla-La Mancha
CAMPUS DE EXCELENCIA INTERNACIONAL

aQuantum

INDICE

aQuantum

- Experiencia en informática cuántica
- Conceptos básicos
- Ordenadores cuánticos
- Software cuántico
- Ingeniería del Software Cuántico
- Conclusiones

INDICE

- **Experiencia en informática cuántica**
- Conceptos básicos
- Ordenadores cuánticos
- Software cuántico
- Ingeniería del Software Cuántico
- Conclusiones


Software
Empirical
Engineering
techniques
methods
processes
tools
IS
QUALITY
(MAINTAINABILITY,
SUSTAINABILITY,
SECURITY …)

Alarcos Research Group

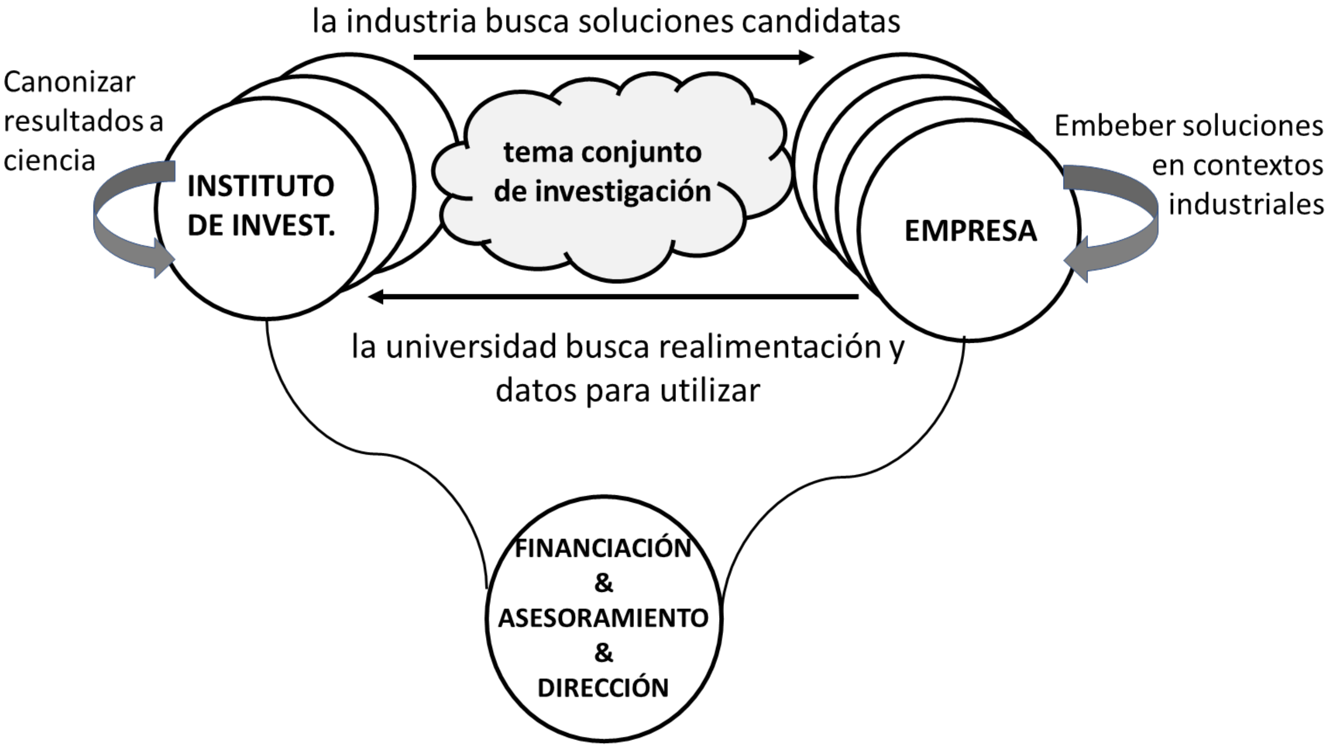
aQuantum

AQC LAB

dqTeam Business Data Quality

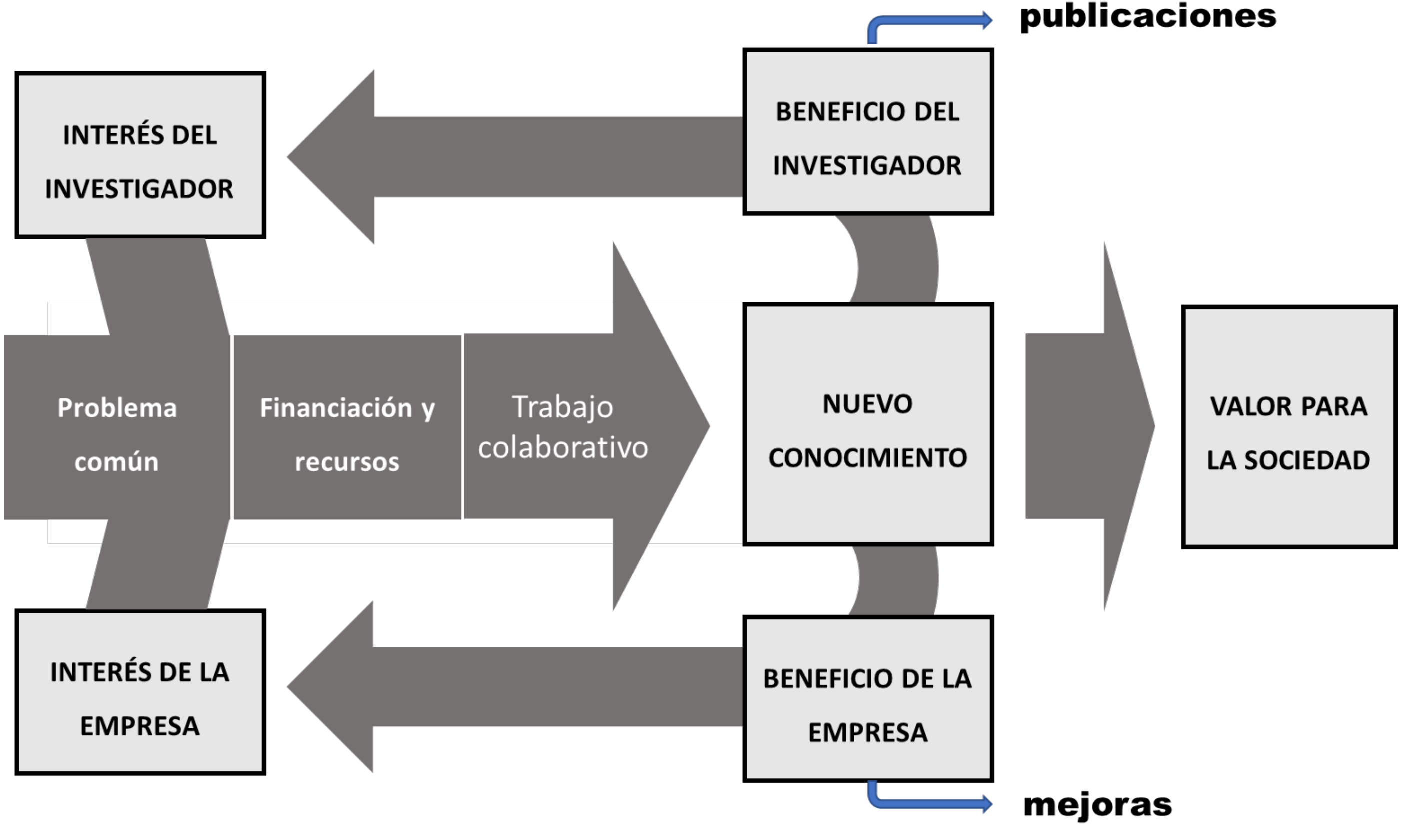
Transferencia tecnológica 2.0

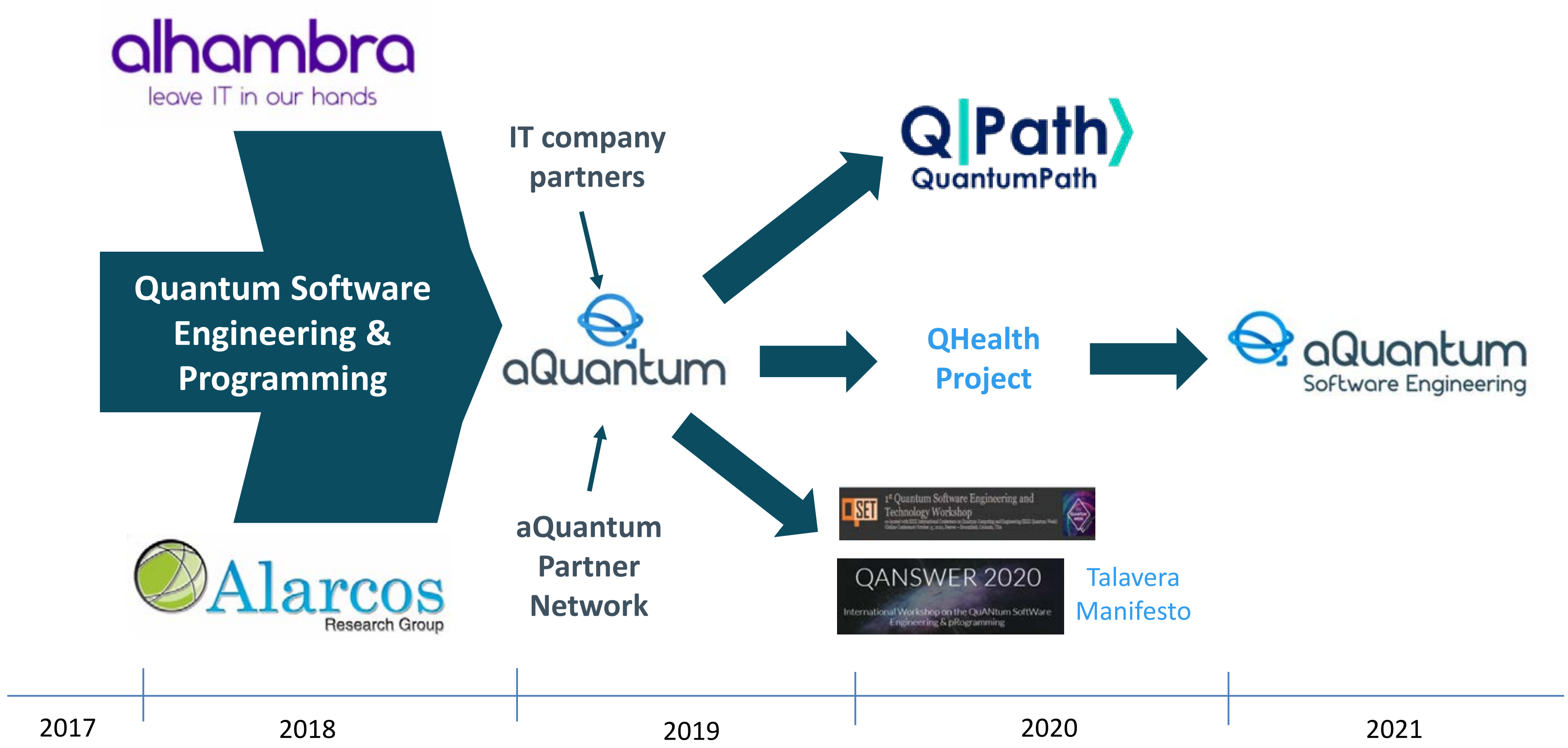
Mikkonen et al. (2018)



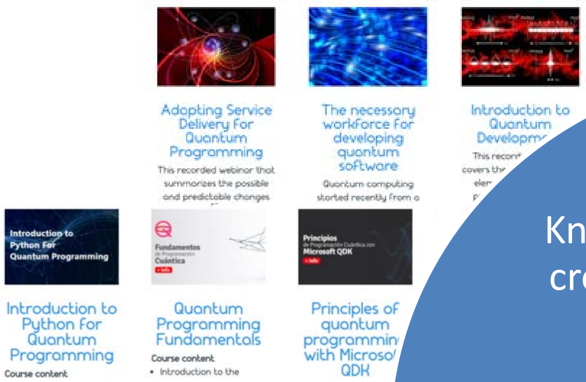
Modelo de coproducción

Sannö et al. (2019)



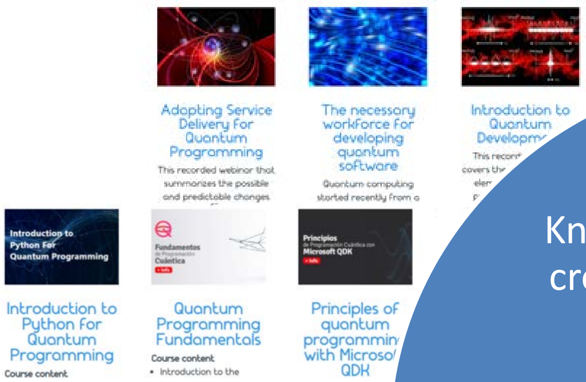

aQuantum
alhambra
leave IT in our hands
Quantum Software Engineering & Programming
Alarcos
Research Group
IT company partners
aQuantum
aQuantum Partner Network
Q|Path⟩
QuantumPath
QHealth Project
aQuantum
Software Engineering
QSET
1st Quantum Software Engineering and Technology Workshop
QANSWER 2020
International Workshop on the QuANtum SoftWare Engineering & pRogramming
Talavera Manifesto
2017
2018
2019
2020
2021

www.aquantum.es



www.aquantum.es

aQuantum



Knowledge creation & mgnt.

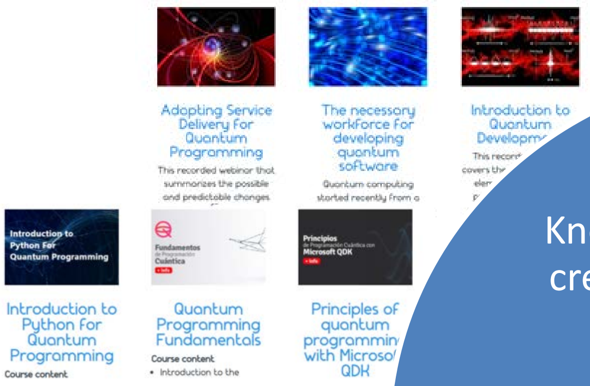
Events

Commercial systems & services

Research projects

www.aquantum.es

aQuantum



Knowledge creation & mgnt.

Events

Commercial systems & services

Research projects

aQuantum

1st Quantum Software Engineering and Technology Workshop
co-located with IEEE International Conference on Quantum Computing and Engineering (IEEE Quantum Week) (Online Conference) October 13, 2020, Denver – Broomfield, Colorado, USA

QUATIC 2020

QUATIC 2021

QANSWER 2020
International Workshop on the QuANtum SoftWare Engineering & pRogramming

QHealth
"Quantum pharmacogenomics applied to ageing"

www.aquantum.es

aQuantum

- Actividades aQuantum (www.aquantum.es)

QSalud: “Farmacogenómica cuántica aplicada al envejecimiento“

El objetivo general del proyecto QSalud es, ante todo, humano**: incrementar la longevidad y la calidad de vida de las personas mayores**, algo a lo que contribuirá gracias a la investigación que realiza de las relaciones entre los condicionantes genéticos y otras variables de la trayectoria de salud de las personas mayores a lo largo de su vida, incluyendo la **reacción que los medicamentos pueden desencadenar en las personas mayores**, de forma tal que se puedan predecir los posibles efectos adversos que un determinado medicamento pueda tener en la salud de una persona mayor en base a su historial de toma de medicamentos, los efectos de los mismos y sus condicionantes fisiológicas y genéticas.

aQuantum

gloin

MADRIJA

MINISTERIO DE CIENCIA E INNOVACIÓN

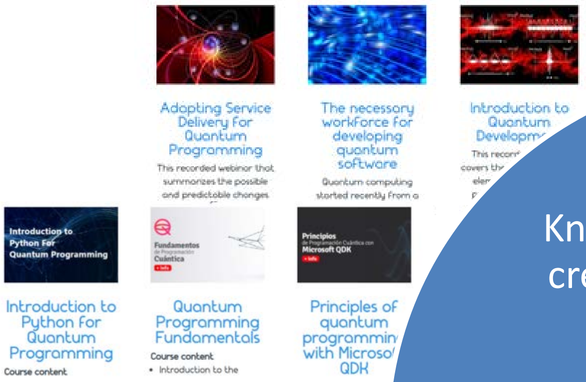
CDTI Centro para el Desarrollo Tecnológico Industrial

INUBE

UCLM

UEX

aQuantum



1st Quantum Software Engineering and Technology Workshop

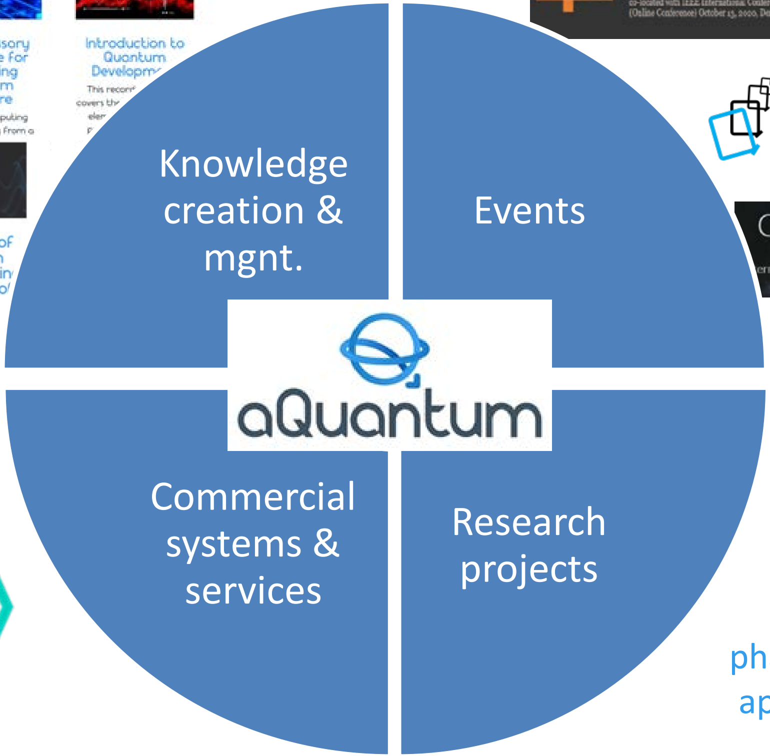
co-located with IEEE International Conference on Quantum Computing and Engineering (IEEE Quantum Week) (Online Conference) October 15, 2020, Denver – Broomfield, Colorado, USA

QUATIC 2020

QUATIC 2021

QANSWER 2020

International Workshop on the QuANtum SoftWare Engineering & pRogramming

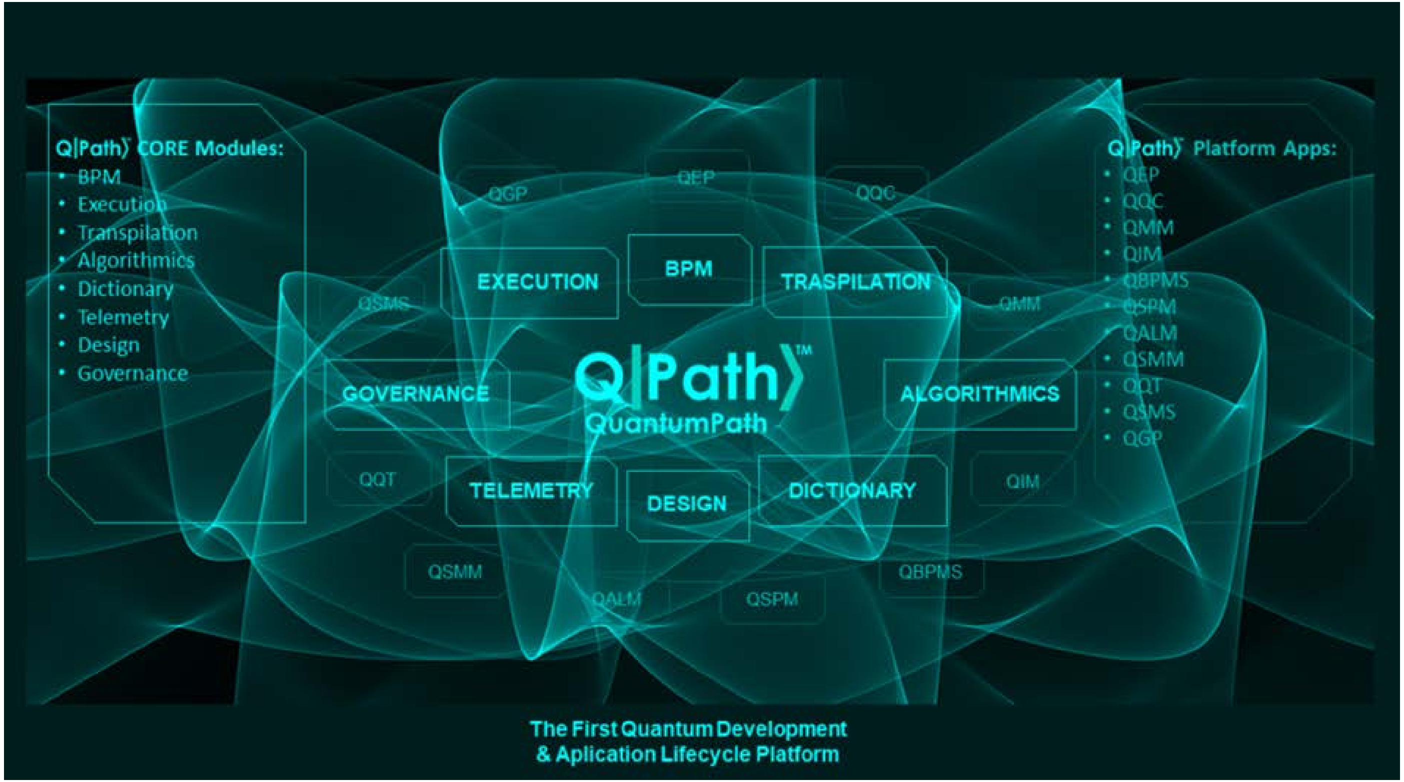


Q|Path⟩
QuantumPath

QHealth
“Quantum pharmacogenomics applied to ageing”

www.aquantum.es

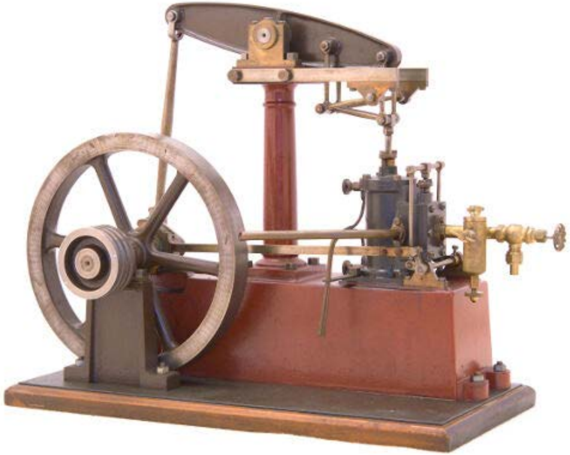
https://www.quantumpath.es/

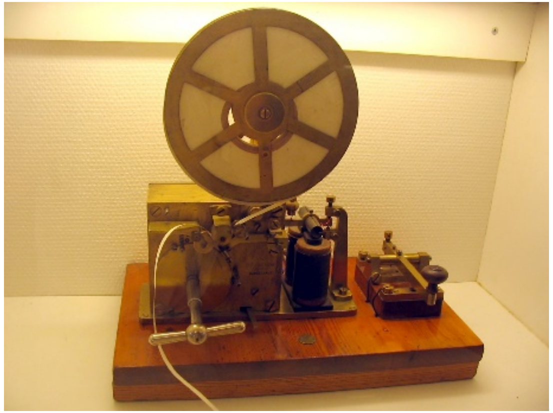


INDICE

- Experiencia en informática cuántica
- **Conceptos básicos**
- Ordenadores cuánticos
- Software cuántico
- Ingeniería del Software Cuántico
- Conclusiones

1R





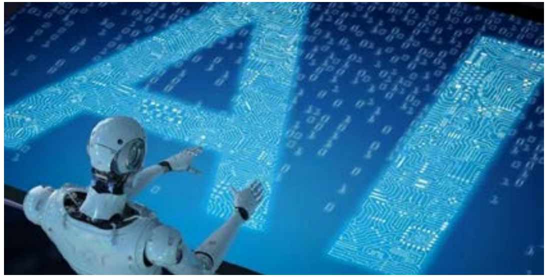
Revoluciones Industriales

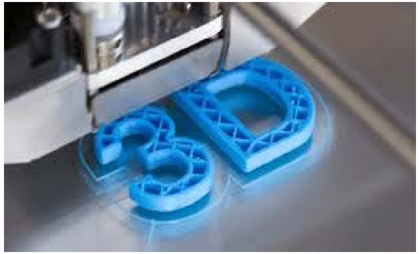
aQuantum

2R

Revoluciones Industriales

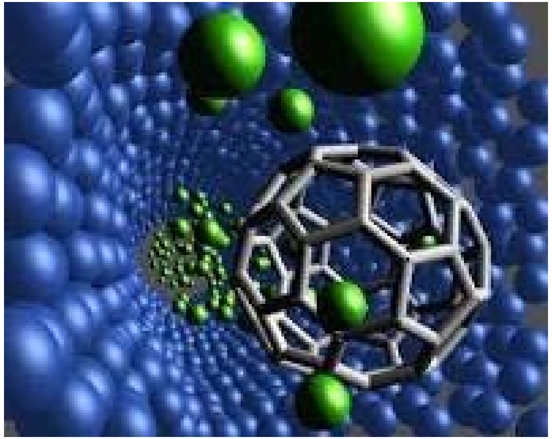
3R

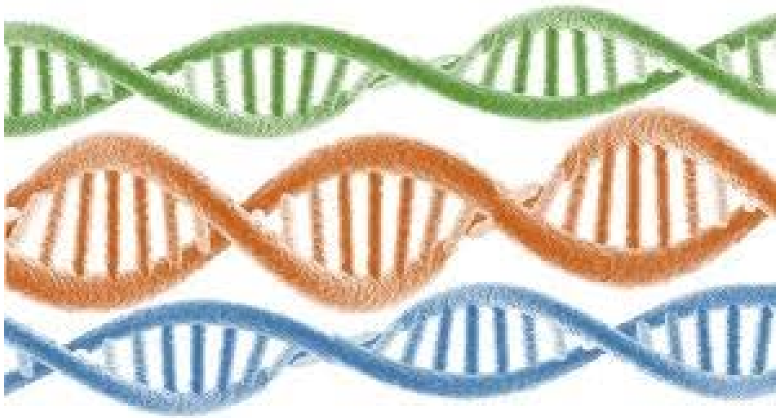


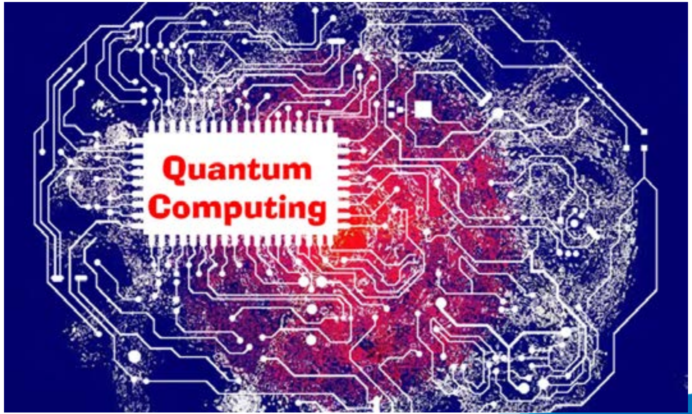


Revoluciones Industriales

4R





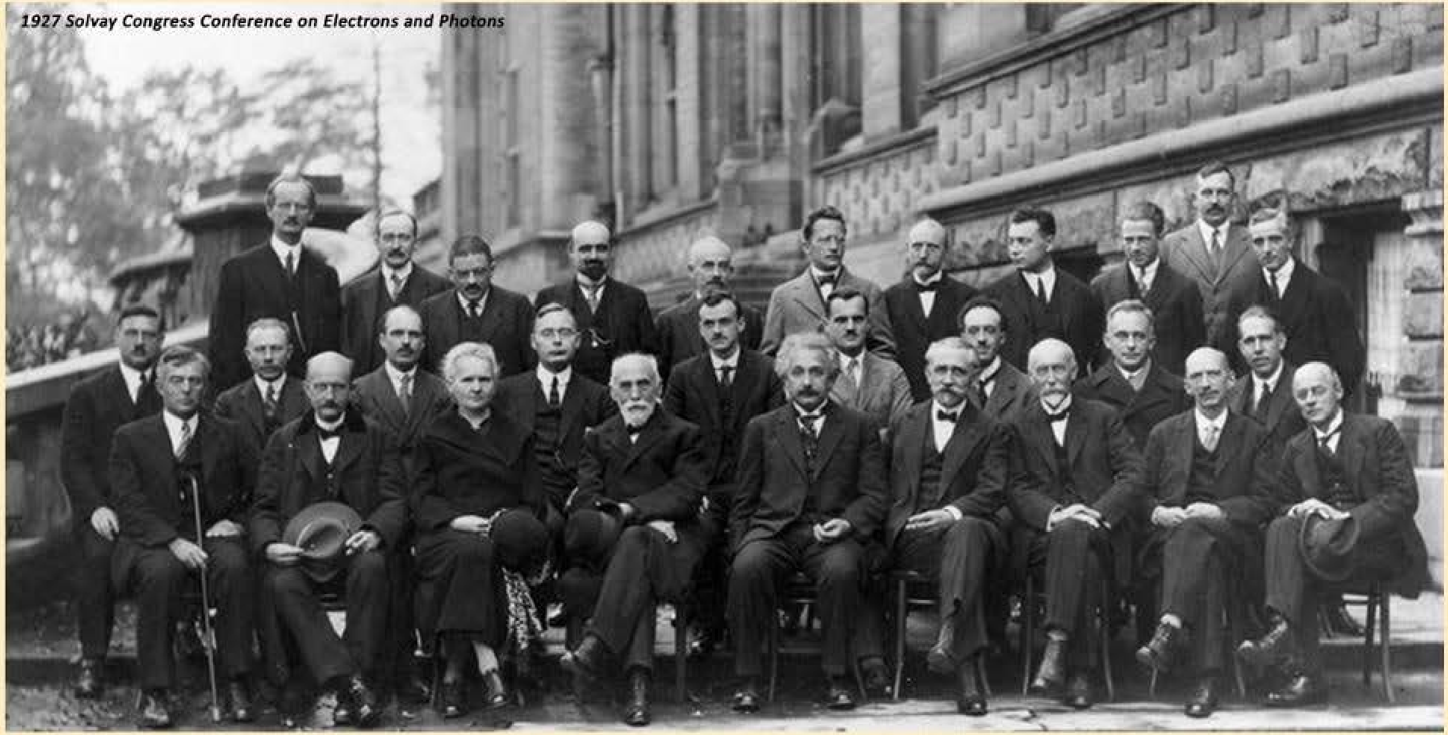


Computación Cuántica: Revoluciones

A. Piccard, E. Henriot, P. Ehrenfest, E. Herzen, Th. De Donder, E. Schrödinger, J.E. Verschaffelt, W. Pauli, W. Heisenberg, R.H. Fowler, L. Brillouin;
P. Debye, M. Knudsen, W.L. Bragg, H.A. Kramers, P.A.M. Dirac, A.H. Compton, L. de Broglie, M. Born, N. Bohr;
Langmuir, M. Planck, M. Curie, H.A. Lorentz, A. Einstein, P. Langevin, Ch. E. Guye, C.T.R. Wilson, O.W. Richardson

aQuantum

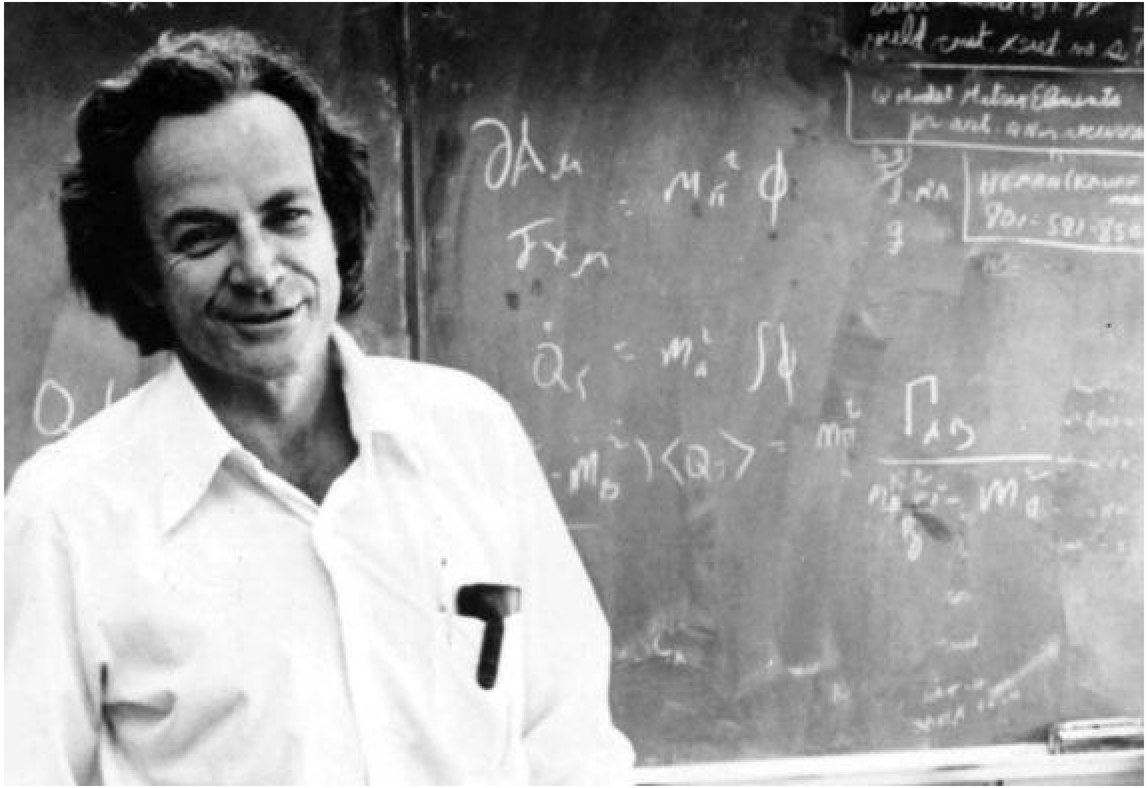
Computación Cuántica: Revoluciones



A. Piccard, E. Henriot, P. Ehrenfest, E. Herzen, Th. De Donder, E. Schrödinger, J.E. Verschaffelt, W. Pauli, W. Heisenberg, R.H. Fowler, L. Brillouin;
P. Debye, M. Knudsen, W.L. Bragg, H.A. Kramers, P.A.M. Dirac, A.H. Compton, L. de Broglie, M. Born, N. Bohr;
Langmuir, M. Planck, M. Curie, H.A. Lorentz, A. Einstein, P. Langevin, Ch. E. Guye, C.T.R. Wilson, O.W. Richardson

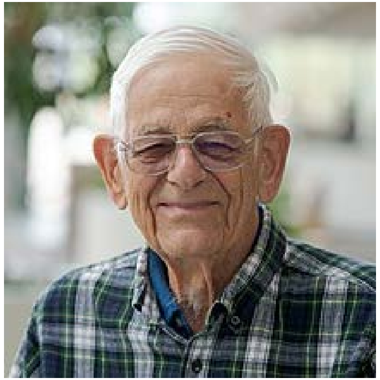
Computación Cuántica: Revoluciones

aQuantum



What kind of computer are we going to use to simulate physics? (Richard Feyman, 1982)

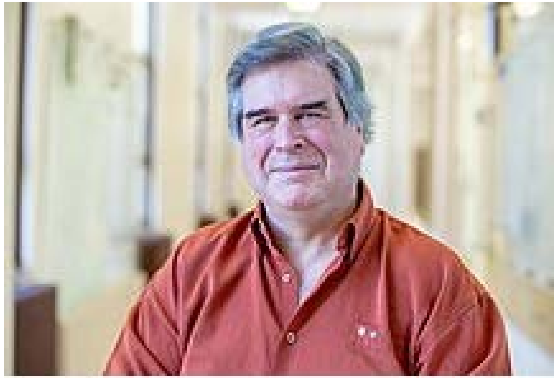
Computación Cuántica: Revoluciones



The Computer as a
Physical System
(Paul Benioff, 1980)

Computable and
Uncomputable
(Yuri Manin, 1980)

Universal Quantum
Computer
(David Deutsch, 1985)



Quantum cryptography: Public key distribution and coin tossing
(Charles Bennett y Gilles Brassard, 1984)

Computación Cuántica: Revoluciones

Deutsch y Jozsa (1992)

Shor (1994)

Grover (1996)

Computación Cuántica: Revoluciones

Juan Ignacio Cirac

VOLUME 74, NUMBER 20 PHYSICAL REVIEW LETTERS 15 MAY 1995

Quantum Computations with Cold Trapped Ions

J. I. Cirac and P. Zoller*
Institut für Theoretische Physik, Universiät Innsbruck, Technikerstrasse 25, A-6020 Innsbruck, Austria
(Received 30 November 1994)

A quantum computer can be implemented with cold ions confined in a linear trap and interacting with laser beams. Quantum gates involving any pair, triplet, or subset of ions can be realized by coupling the ions through the collective quantized motion. In this system decoherence is negligible, and the measurement (readout of the quantum register) can be carried out with a high efficiency.

VOLUME 75, NUMBER 25 PHYSICAL REVIEW LETTERS 18 DECEMBER 1995

Demonstration of a Fundamental Quantum Logic Gate

C. Monroe, D. M. Meekhof, B. E. King, W. M. Itano, and D. J. Wineland
National Institute of Standards and Technology, Boulder, Colorado 80303
(Received 14 July 1995)

We demonstrate the operation of a two-bit "controlled-NOT" quantum logic gate, which, in conjunction with simple single-bit operations, forms a universal quantum logic gate for quantum computation. The two quantum bits are stored in the internal and external degrees of freedom of a single trapped atom, which is first laser cooled to the zero-point energy. Decoherence effects are identified for the operation, and the possibility of extending the system to more qubits appears promising.

Computación Cuántica: Revoluciones

aQuantum

PHYSICAL REVIEW E

covering statistical, nonlinear, biological, and soft matter physics

Quantum annealing in the transverse Ising model

Tadashi Kadowaki and Hidetoshi Nishimori

Phys. Rev. E **58**, 5355 – Published 1 November 1998

ABSTRACT

We introduce quantum fluctuations into the simulated annealing process of optimization problems, aiming at faster convergence to the optimal state. Quantum fluctuations cause transitions between states and thus play the same role as thermal fluctuations in the conventional approach. The idea is tested by the transverse Ising model, in which the transverse field is a function of time similar to the temperature in the conventional method. The goal is to find the ground state of the diagonal part of the Hamiltonian with high accuracy as quickly as possible. We have solved the time-dependent Schrödinger equation numerically for small size systems with various exchange interactions. Comparison with the results of the corresponding classical (thermal) method reveals that the quantum annealing leads to the ground state with much larger probability in almost all cases if we use the same annealing schedule.

Received 30 April 1998

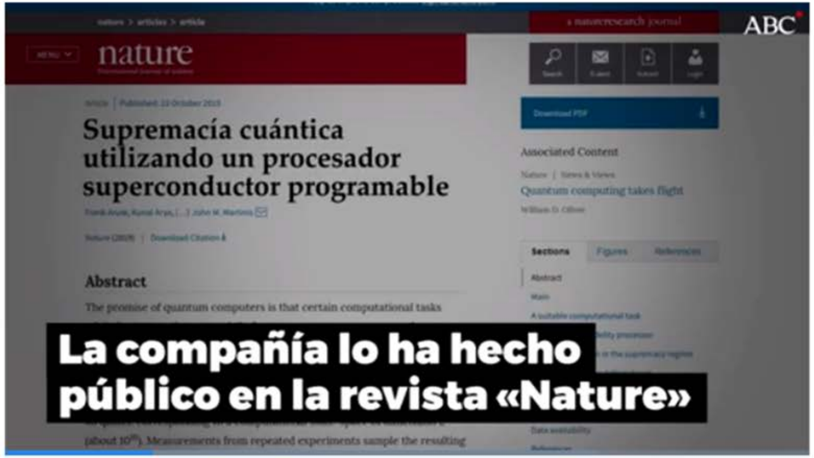
DOI: https://doi.org/10.1103/PhysRevE.58.5355

Computación Cuántica: Revoluciones

aQuantum

Google publica la demostración de la supremacía cuántica

- La compañía explica en «Nature» cómo su ordenador cuántico ha realizado un cálculo más allá del alcance del procesador clásico más avanzado del mundo
- Tardó 200 segundos en ejecutar una tarea que a la máquina más rápida le habría llevado 10.000 años
- IBM ya rechazó el lunes que el hito se haya conseguido



Sundar Pichai, presidente ejecutivo de Google, junto a un ordenador cuántico - Google

49

Judith de Jorge • SEGUIR

MADRID - Actualizado:25/10/2019 09:37h

GUARDAR

COMPUTACIÓN CUÁNTICA ›

El español que diseñó el mayor hito de la computación cuántica

El informático y filósofo Sergio Boixo ha sido una pieza central en el equipo de Google que ha reducido a minutos un cálculo que requiere siglos

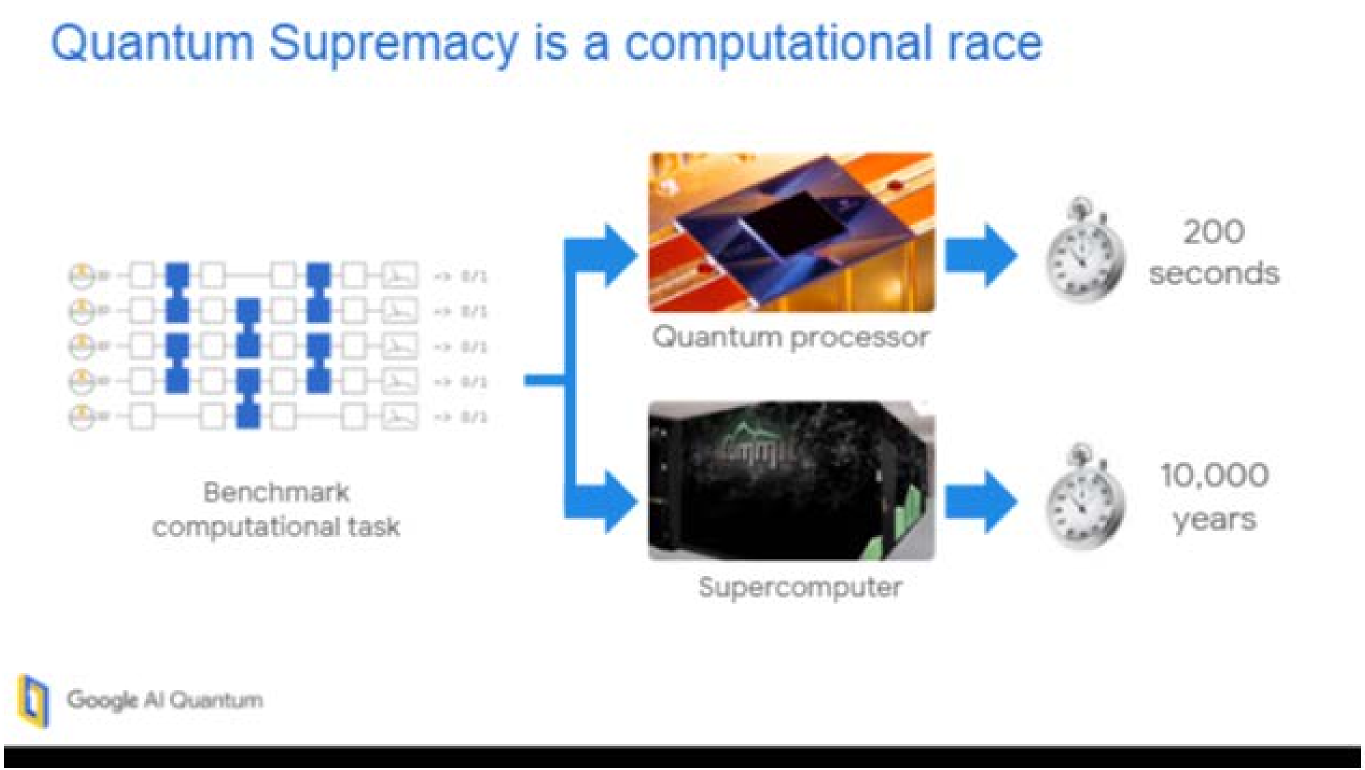
89

JORDI PÉREZ COLOMÉ

27 OCT 2019 - 16:32 CET

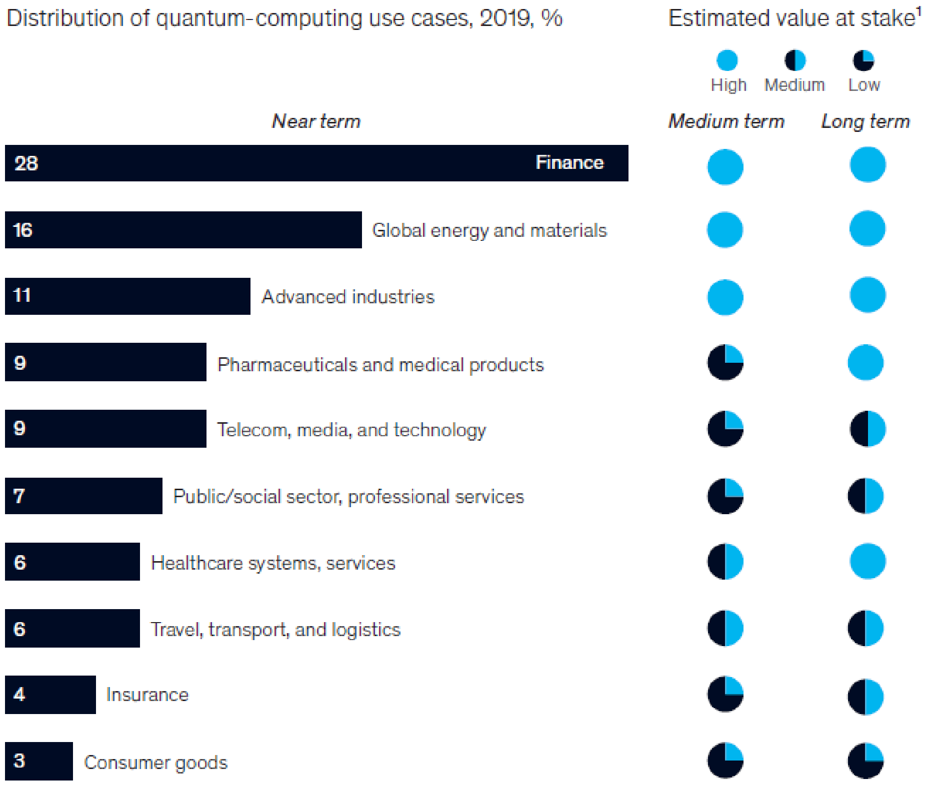
Sergio Boixo, jefe científico de teoría de la computación cuántica de Google, en la sede de la compañía

Computación Cuántica: Revoluciones



Aplicaciones

Aplicaciones



[1]Approximate timing for medium term is by the year 2025; for long term, by the year 2035. Experts consider these values at stake to be a snapshot in time. Fully developed quantum computing will lead to additional value within and shifts between industry verticals.

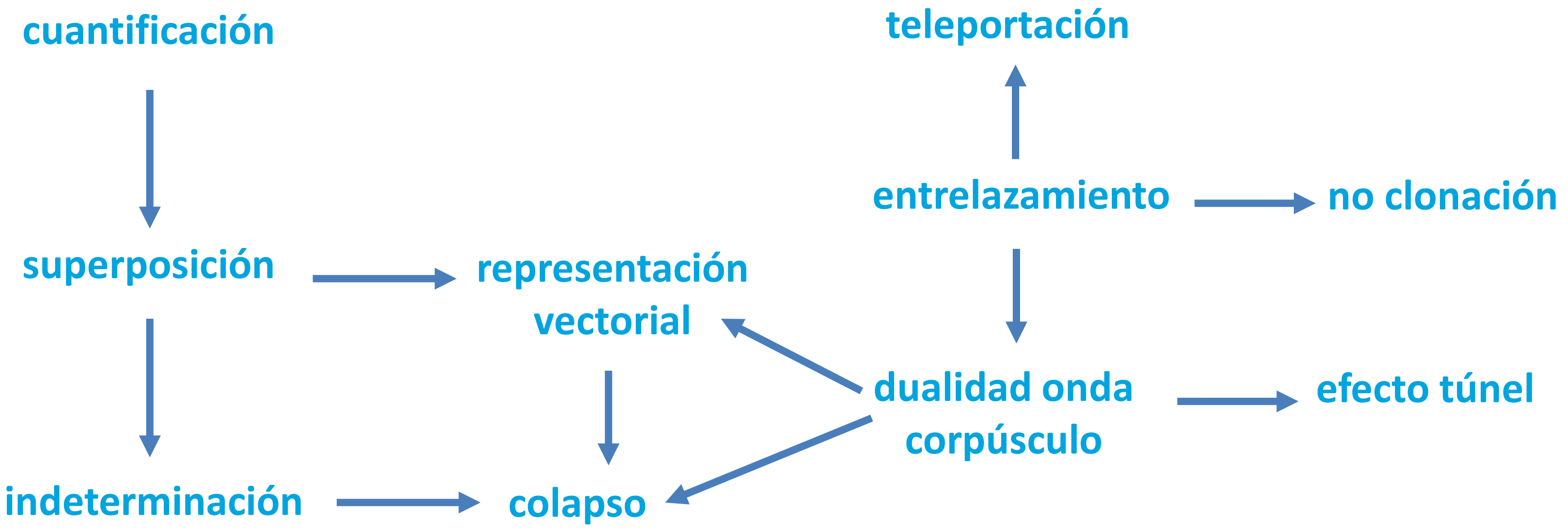
Source: Expert interviews; McKinsey analysis

McKinsey Quaterly
Febrero 2020

INDICE

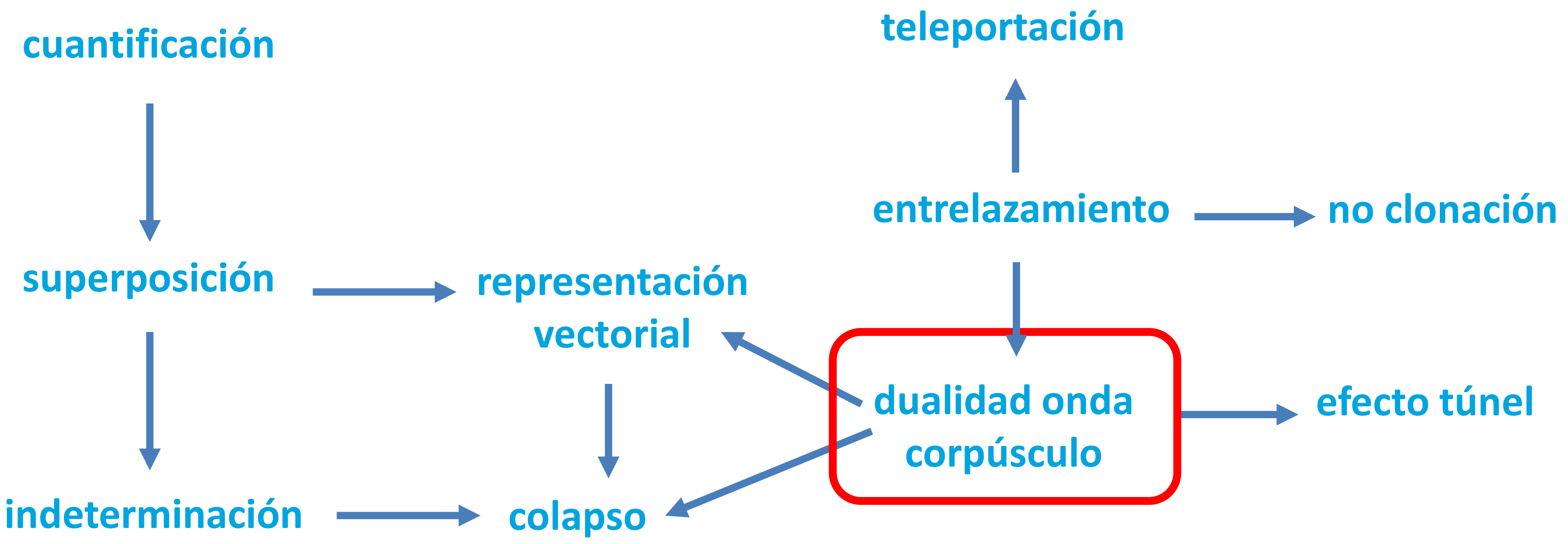
- Revoluciones industriales
- **Conceptos básicos**
- Ordenadores cuánticos
- Software cuántico
- Ingeniería del Software Cuántico
- Conclusiones

Conceptos básicos



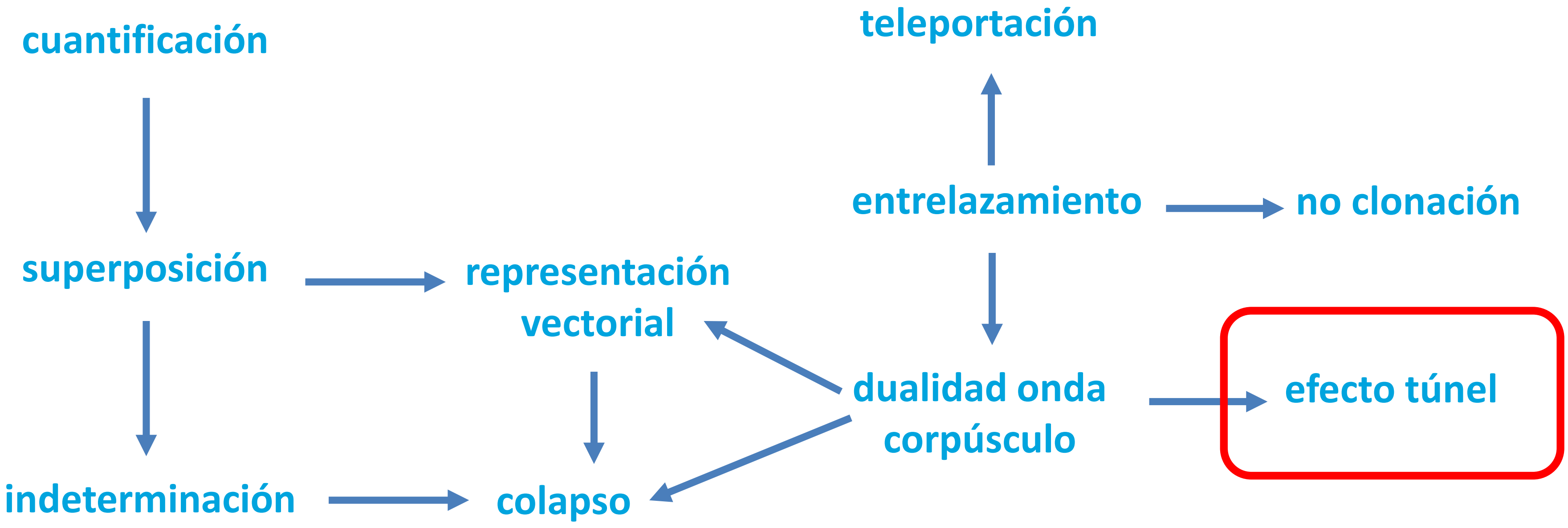
(Olivier Ezratty, 2019)

Conceptos básicos



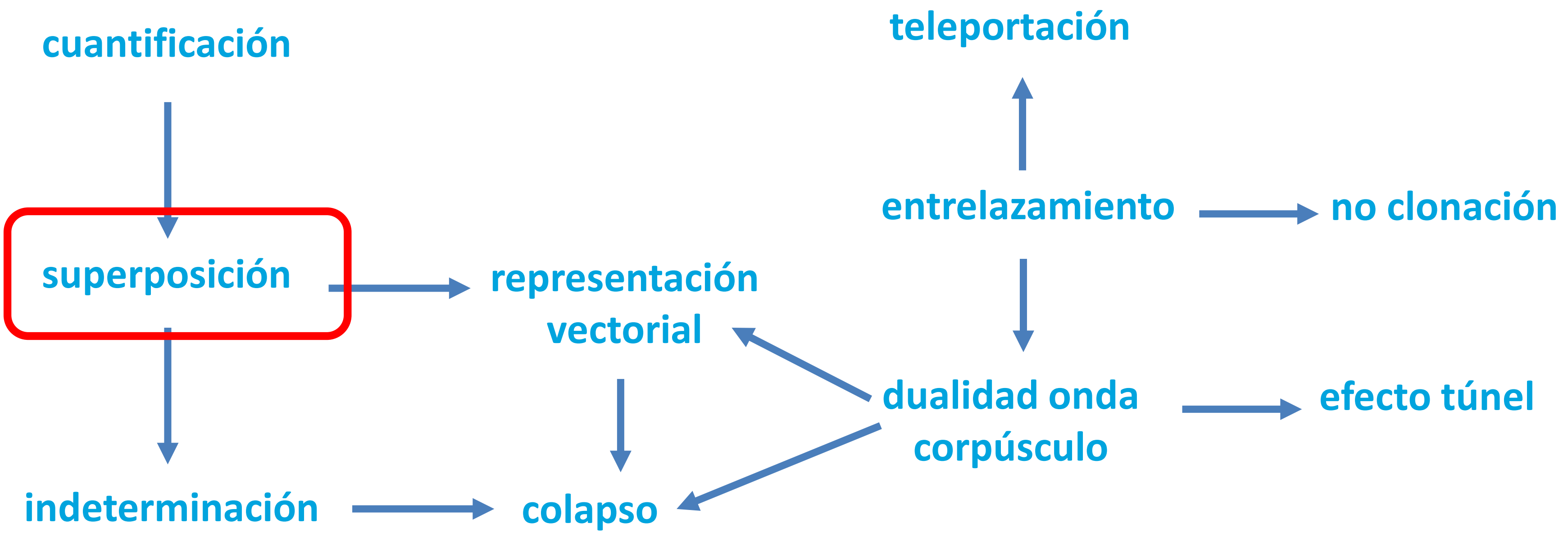
(Olivier Ezratty, 2019)

Conceptos básicos



(Olivier Ezratty, 2019)

Conceptos básicos

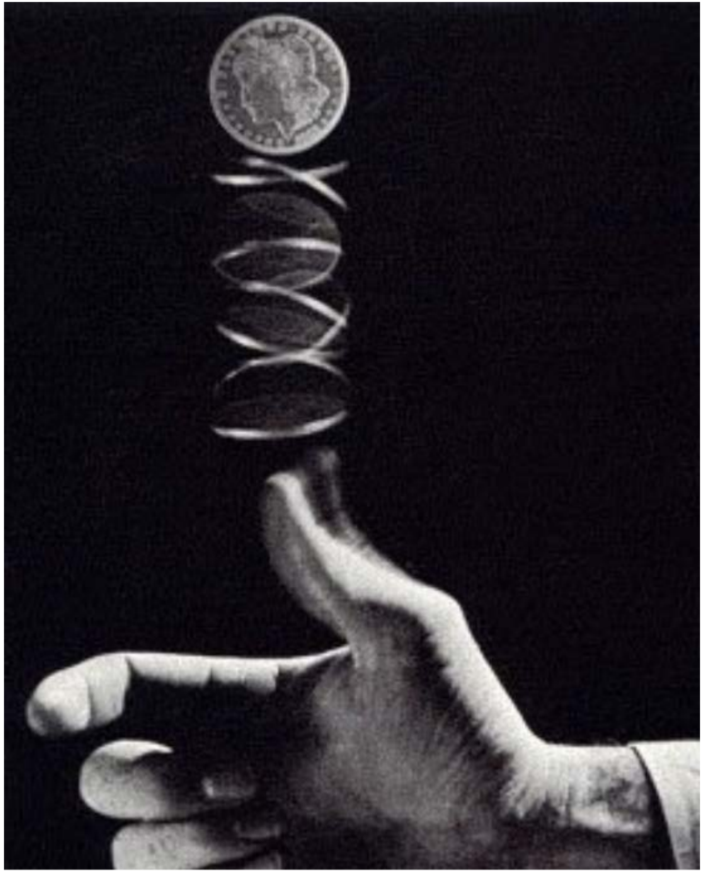


(Olivier Ezratty, 2019)

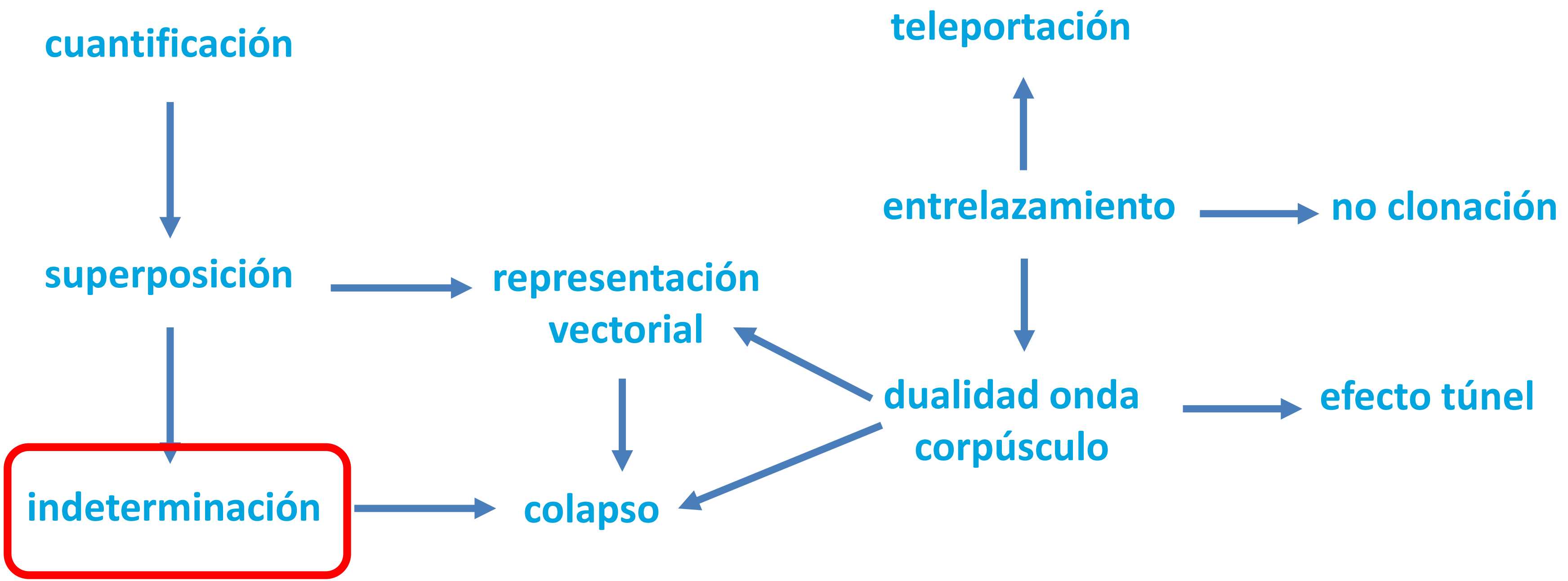

SCHRÖDINGER'S CAT IS

Conceptos básicos

Conceptos básicos



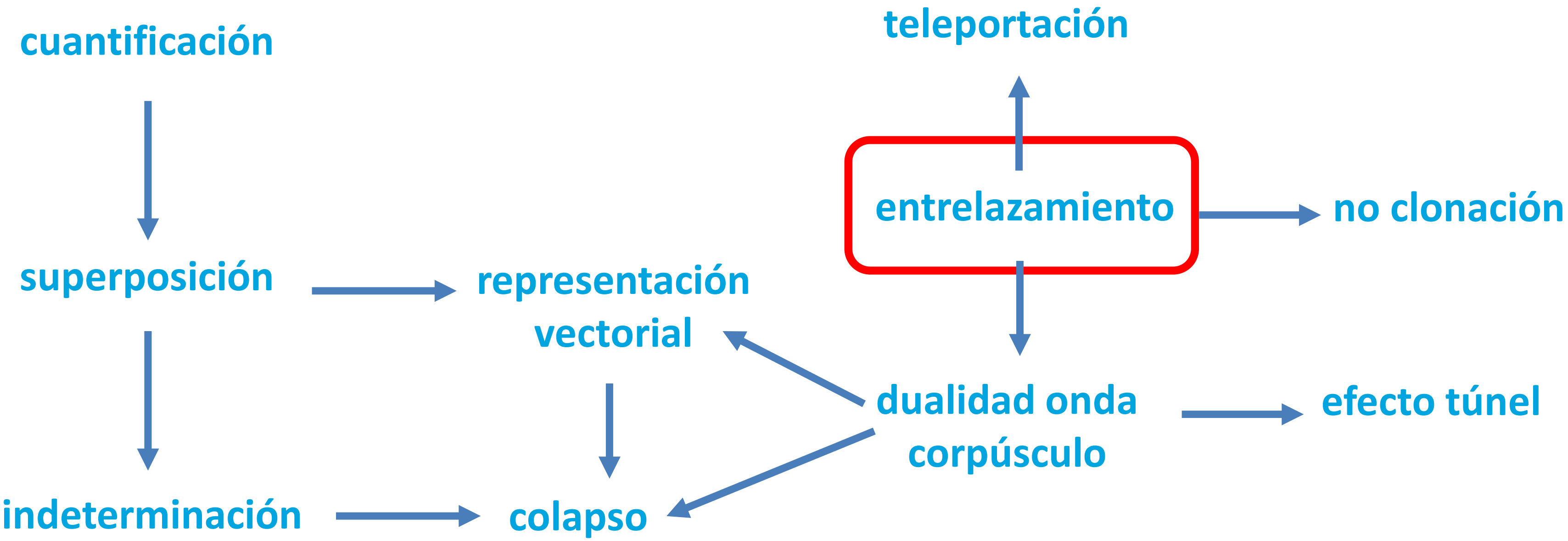
Conceptos básicos



(Olivier Ezratty, 2019)

Conceptos básicos

aQuantum



(Olivier Ezratty, 2019)

Conceptos básicos

The New York Times.

NEW YORK, SATURDAY, MAY 4, 1935. TWO CENTS

EINSTEIN ATTACKS QUANTUM THEORY

Scientist and Two Colleagues Find It Is Not 'Complete' Even Though 'Correct.'

Entanglement is a unique *quantum* resource:

"… fundamental resource of nature, of comparable importance to energy, information, entropy, or any other fundamental resource."

Nielsen & Chuang, Quantum Computation and Quantum Information

Conceptos básicos

aQuantum

Chinese Scientists Just Set the Record for the Farthest Quantum Teleportation

By Jesse Emspak July 15, 2017

(Image: © sakkmesterke/Shutterstock)

Chinese scientists have just shattered a record in teleportation. No, they haven't beamed anyone up to spaceship. Rather, they sent a packet of information from Tibet to a satellite in orbit, up to 870 miles (1,400 kilometers) above the Earth's surface.

BBC Sign in | News | Sport | Reel | Worklife | Travel | Future | Mo

NEWS

Home | Video | World | UK | Business | Tech | Science | Stories | Entertainment & Arts

Science & Environment

Teleportation: Photon particles today, humans tomorrow?

By Tom Spender
BBC News

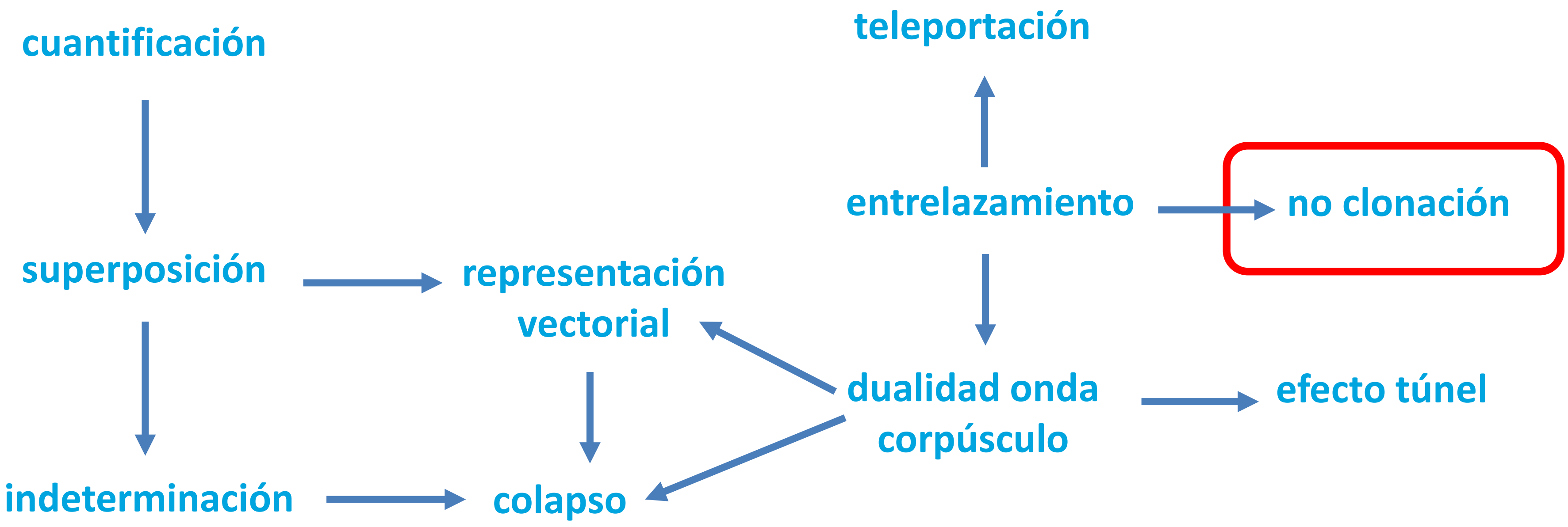
14 July 2017

Share

Are we about to boldly go where no-one has gone before?

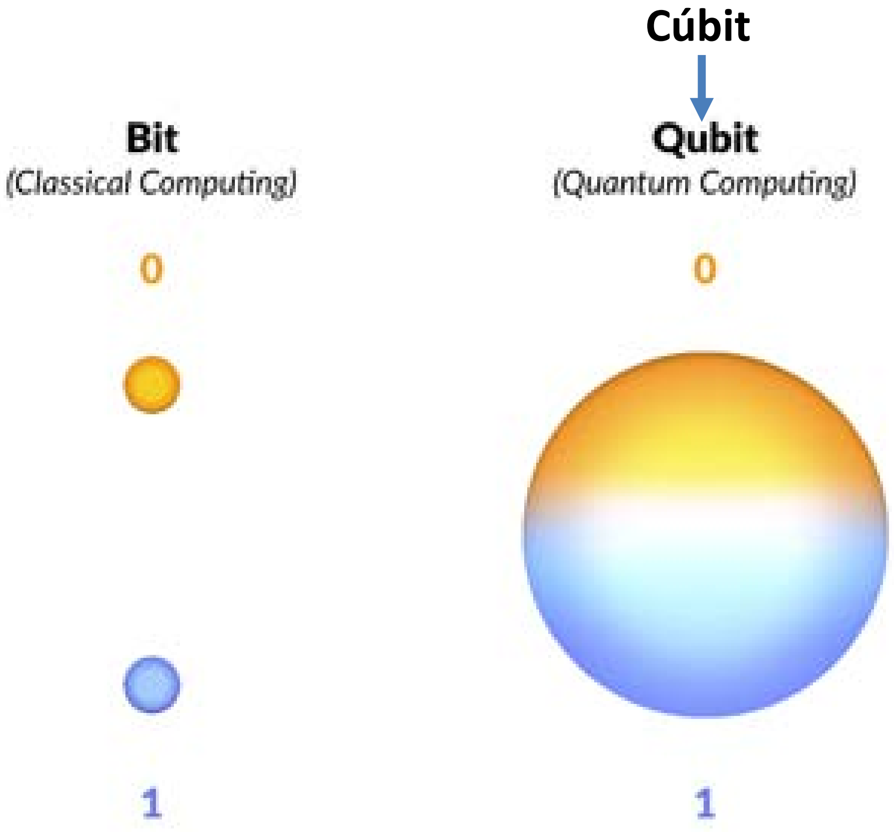
Chinese scientists say they have "teleported" a photon particle from the ground to a satellite orbiting 1,400km (870 miles) away.

Conceptos básicos

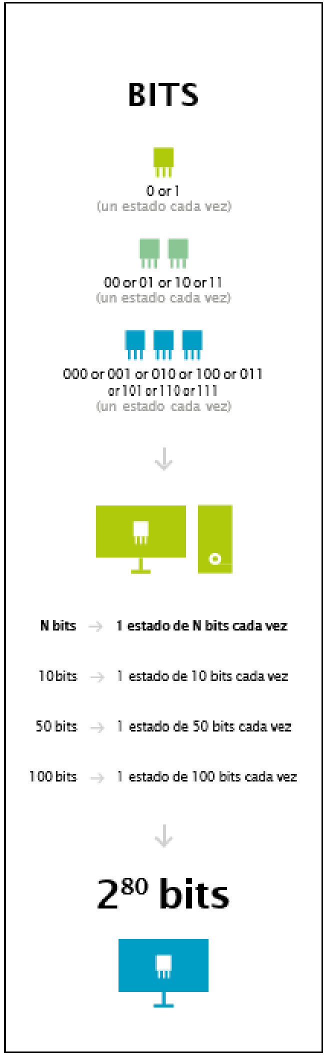


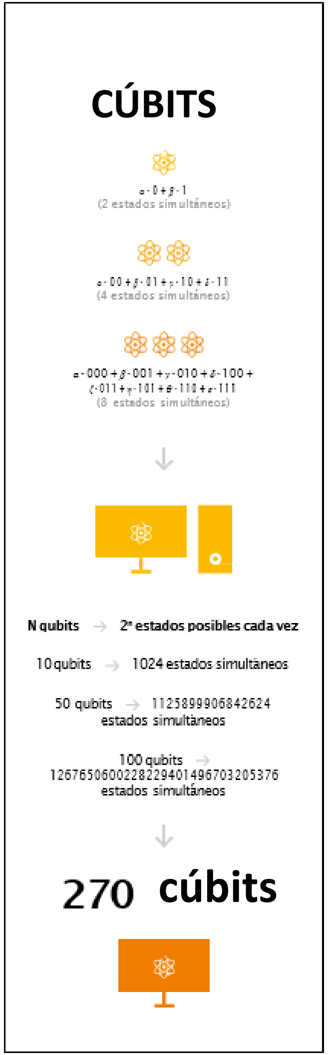
(Olivier Ezratty, 2019)

Conceptos básicos



Conceptos básicos

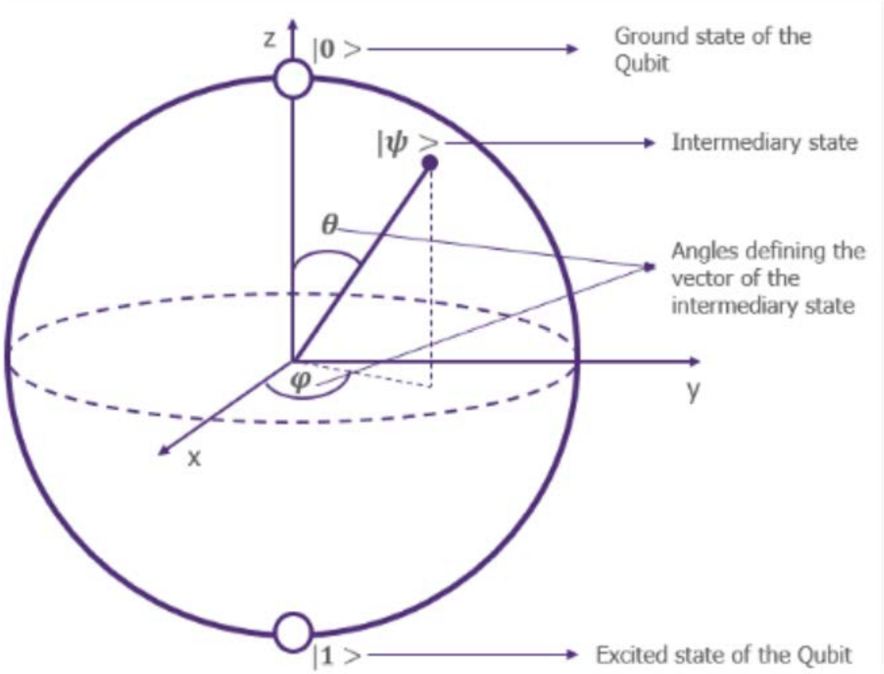




aQuantum

(Marcos Allende, 2019)

Conceptos básicos

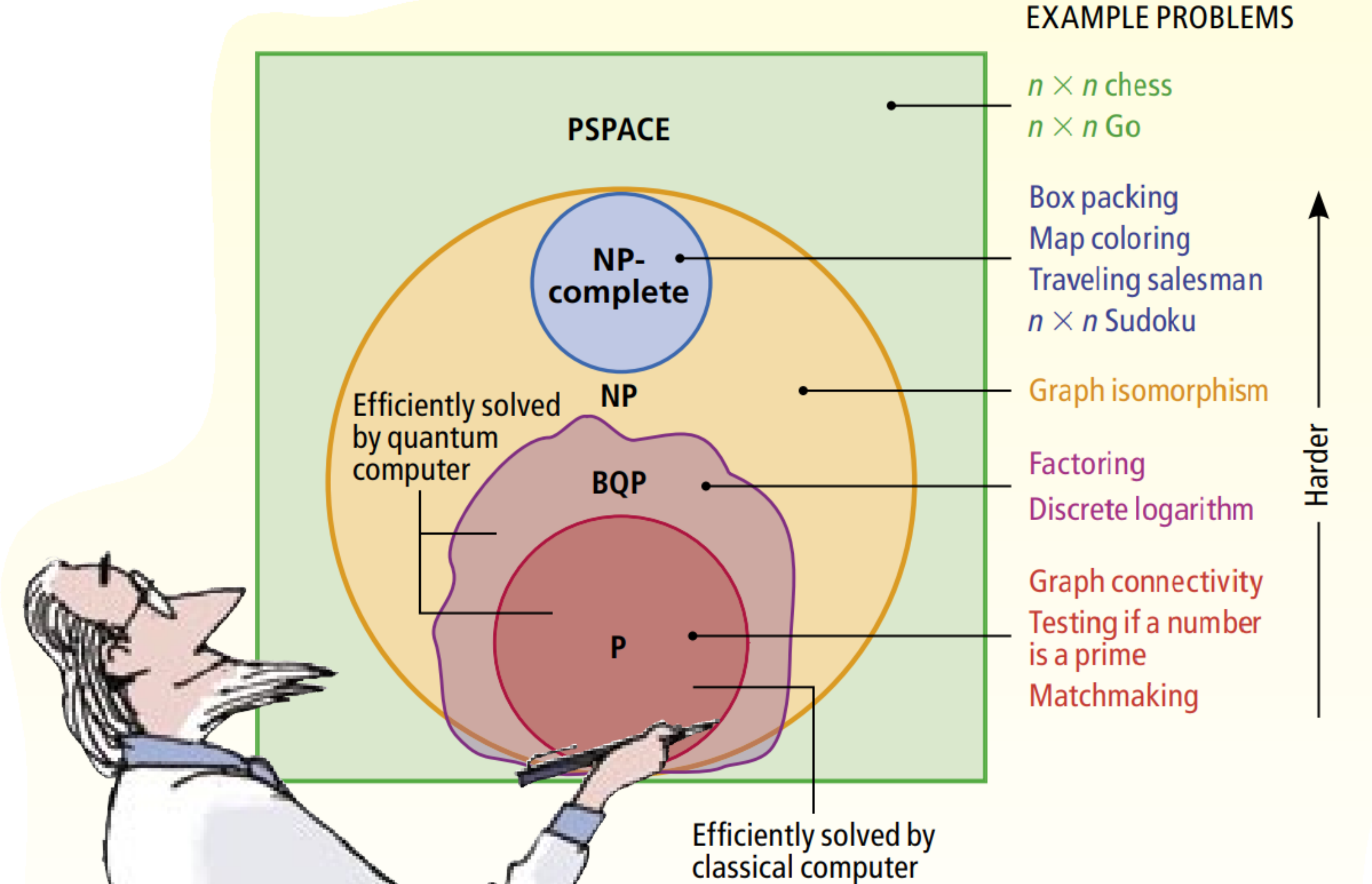


$$|\psi> = \alpha\,|0> + \beta\,|1>$$

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

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

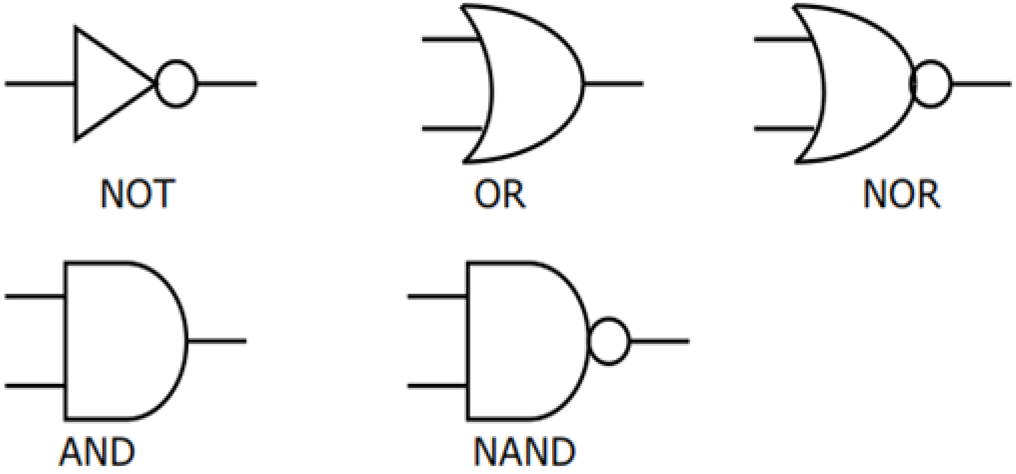
Conceptos básicos



Scott Aaronson (2018)

Conceptos básicos

Puertas clásicas



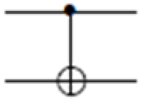
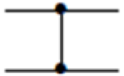
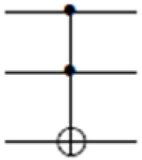
Conceptos básicos

Puertas cuánticas

Identity	I	$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$
Hadamard	H	$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$
Pauli-X	X	$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$
Pauli-Y	Y	$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$
Pauli-Z	Z	$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$
Rotation-X	$Rx(\theta$	$\begin{bmatrix} \cos\frac{\theta}{2} & -i\sin\frac{\theta}{2} \\ -i\sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{bmatrix}$
Rotation-Y	$Ry\theta$	$\begin{bmatrix} \cos\frac{\theta}{2} & \sin\frac{\theta}{2} \\ \sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{bmatrix}$
Rotation-Z	$Rz\theta$	$\begin{bmatrix} e^{-i\frac{\theta}{2}} & 0 \\ 0 & e^{i\frac{\theta}{2}} \end{bmatrix}$

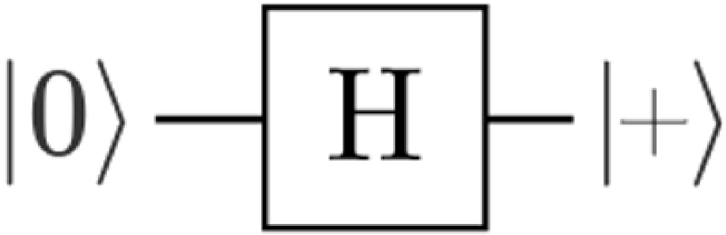
Conceptos básicos

aQuantum

T		$\begin{bmatrix} 1 & 0 \\ 0 & e^{i\frac{\pi}{4}} \end{bmatrix}$
Phase		$\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$
CNOT		$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$
CPhase		$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$
Toffoli		$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$

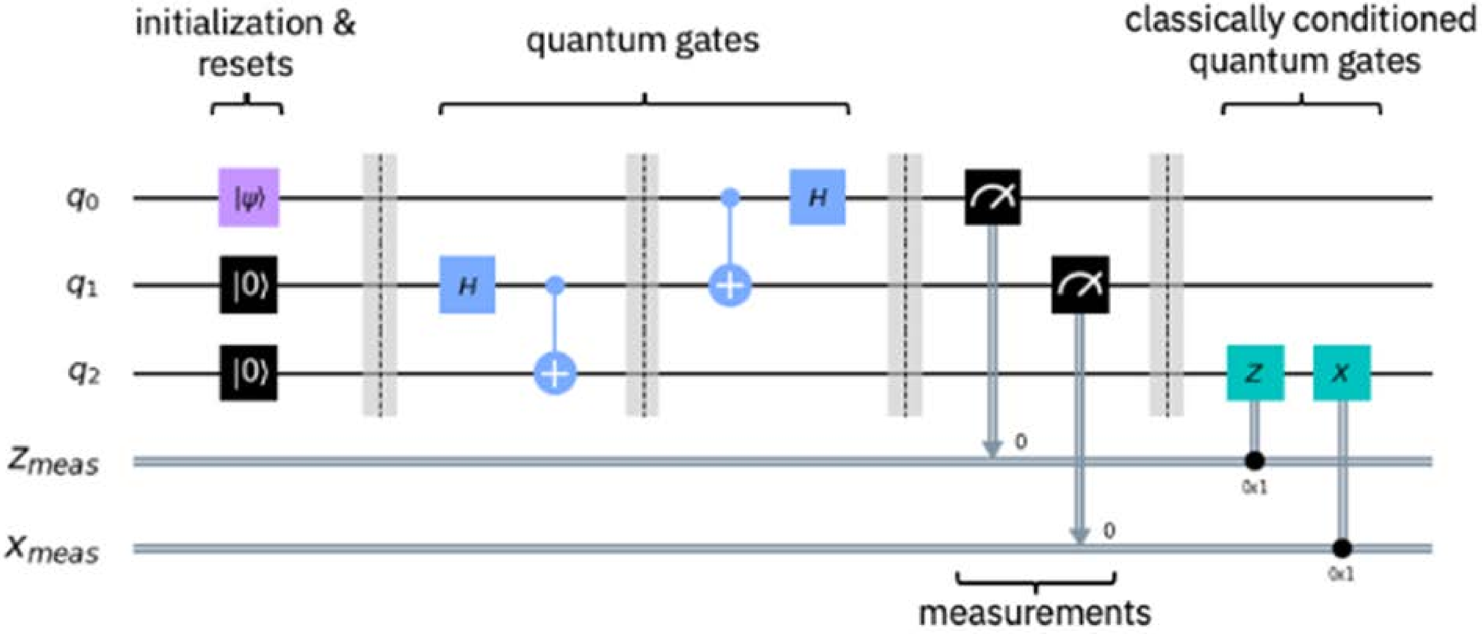
Conceptos básicos

Hadamard



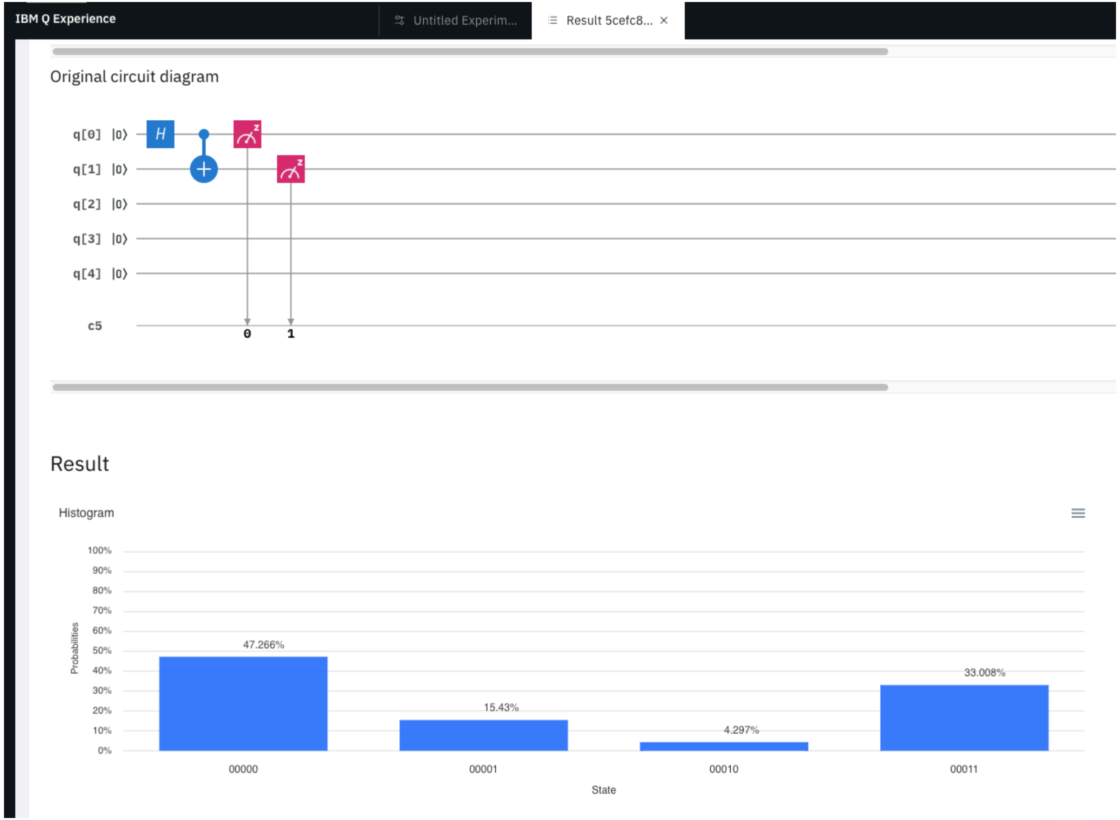
$$H = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

Quantum Circuit



Conceptos básicos

IBM Q Experience



INDICE

- Revoluciones industriales
- Conceptos básicos
- **Ordenadores cuánticos**
- Software cuántico
- Ingeniería del Software Cuántico
- Conclusiones

Ordenadores cuánticos

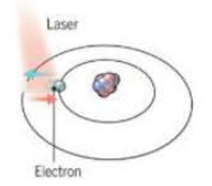
ORDENADOR CLÁSICO	ORDENADOR CUÁNTICO
Ord. (CPU) multipropósito integrado a gran escala	Ord. paralelo basado en mecánica cuántica
Almacenamiento de la información basado en bits	Almacenamiento de la información basado en cúbits
Se ejecuta sobre bits que pueden tener el valor 0 o 1	Los cúbits pueden estar en un estado indeterminado e influidos por otros cúbits
Número discreto de estados posibles: 0 o 1. Determinista	Infinito número de posibles estados (continuo). Probabilista
El procesamiento de la información se lleva a cabo mediante puertas lógicas de manera secuencial	El procesamiento de la información se lleva a cabo por puertas lógicas cuánticas de manera paralela
Sólo están disponibles los resultados definidos específicamente,	Las respuestas cuánticas son probabilistas, por lo que son posibles varias respuestas
El comportamiento del circuito se gobierna por la física clásica	El comportamiento del circuito se gobierna por la física cuántica
Las operaciones de definen por el álgebra de Boole	Las operaciones de definen por el álgebra lineal en un espacio de Hilbert
No existen restricciones para copiar o medir señales	Existen restricciones fuertes para copiar y medir señales
Los circuitos se implementan fácilmente en tecnologías macroscópicas, escalables y rápidas	Los circuitos deben usar técnicas microscópicas que son lentas, frágiles y todavía no escalables (NMR, etc.)

https://medium.com/@prasathbhuvana89/10-difference-between-classical-computing-and-quantum-computing-5e1777aa590d

átomos

electrones

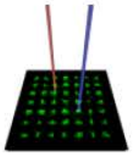
fotones



iones atrapados

IonQ Factory, IONQ, AQT, Honeywell, Sandia National Laboratories, NextGenQ

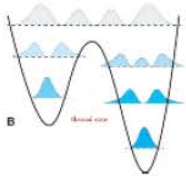
MIT, University of Maryland, IQST, JGU, IQOQI, KIT, universität innsbruck, Harvard University

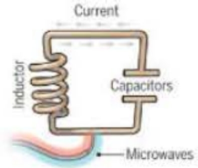


átomos neutrales

PASQAL, ATOM Computing, QuEra

cnrs, Harvard University, Jülich Forschungszentrum, EPFL, PennState, The Ohio State University





superconductores

D-Wave

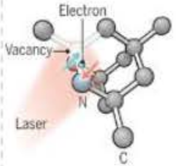
Google, intel, IBM, OQC, rigetti, Raytheon, bleximo, EeroQ, Oxford Quantum, MDR

cea, cnrs, qci, UCSB, ETH zürich, Universität des Saarlandes, QuTech

puntos cuánticos

intel, Quantum Motion, NTT, Silicon Quantum Computing, equal1.labs

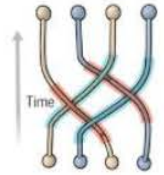
cea, cnrs, UNSW Australia, Yale University, University of Oxford, University of Bristol



centros NV (diamante)

QDTI, TURING

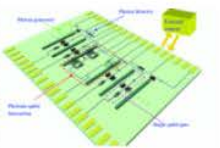
cnrs, cea, MIT, University of Maryland, TU Delft, Universität Stuttgart



cúbits topológicos

Microsoft, NOKIA

cnrs, cea, TU Delft, QuTech



fotones

XANADU, ORCA Computing, PSIQUANTUM, TUNDRA SYSTEMS GLOBAL LTD, LightOn, Quandela, QuiX

cnrs, University of Oxford, University of Bristol, universität wien, Università degli Studi di Milano, Sapienza Università di Roma

(Olivier Ezratty, 2019)

Ordenadores cuánticos

aQuantum

The Quantum Daily's Qubit Guide

THE QUANTUM DAILY
QUANTUM COMPUTING AND BEYOND

Classification	Description	Examples	Qubit lifetime (1)	Gate fidelity (2)	Gate operation time (3)	Connectivity	Scalability	Pros	Cons
Superconducting	Two level system of a superconducting circuit which forms a qubit (a transmon, first developed at Yale)	IBM, Google, Rigetti, Alibaba, Intel, Quantum Circuits	c.50-100μs	c.99.4%	c.10-50ns	Neighbours	Highly scalable (see OQC coaxmon tech)	- Fast gate times - Builds on existing semiconductor industry	- Typically low longevity - Must be kept very cold to work
Ion trap	Single charged ions trapped in magnetic fields. Energy level of its spin comprises the qubits	IonQ; Alpine Quantum Technologies; Honeywell	>1,000s	c.99.9%	c.3-50μs	All-to-all	TBC	- High gate fidelity - Very stable	- Slow operations
Photonics	Qubits made from single particles of light (photons) operating on silicon chips pathways	PsiQuantum, Xanadu	c. 150μs	c. 98.0%	c.1ns	Unknown	Highly scalable (see Psi Quantum)	- Highly scalable - Utilises existing SC industry infrastructure - No temperature requirements	- Nascent technology - Connectivity to be demonstrated
Neutral atoms	Qubits made from individual atoms (rather than ions which have a charge)	Atom Computing, PASQAL, QuEra	Similar to ion trap	c.95%	TBC	TBC	TBC	- Long qubit coherence times	- Must be kept cold - Nascent
Silicon	Artificial atoms made by adding an electron to a small piece of pure silicon and microwaves control the electrons state	Intel, Silicon Quantum Computing	c. 1-10s	c. 99%	c.1-10ns	Neighbours	Expect high scalability	- Stable - Utilises existing semiconductor industry infrastructure	- Must be kept cold - Nascent
Topological qubits	Qubits made from non-Abelian forms of matter	Microsoft (WIP)	Very high	Very high	Unknown	Unknown	Unknown	- Estimated long lifetime and high fidelities	- Existence to be confirmed

Notes: (1) *Record coherence time for a single qubit position state;* (2) *Highest reported fidelity for two qubit gate operations;* (3) *Speed of gate operations*
Sources: Literature review, TQD expert interviews. Special reference to BCG reports, Science Mag and NAE report on quantum computing.
s = seconds
μs = microsecond (10^ -6 seconds)
ns = nanosecond (10^ -9 seconds)

www.thequantumdaily.com

Criterios de DiVicenzo (2000)

1) Sistema físico escalable con cúbits bien caracterizados
2) Capacidad de inicializar el estado de los cúbits a un simple estado de referencia
3) Tiempos de coherencia relevantemente largos
4) Conjunto “universal” de puertas cuánticas
5) Capacidad de medición específica de cúbits

Comunicación cuántica:

1) Capacidad de convertir cúbits estáticos en cúbits que se desplazan
2) Capacidad de transmitir fielmente cúbits entre ubicaciones

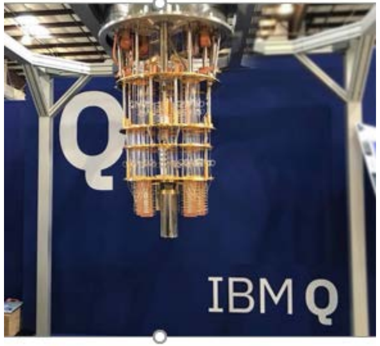
https://en.wikipedia.org/wiki/DiVincenzo%27s_criteria

Ordenadores cuánticos

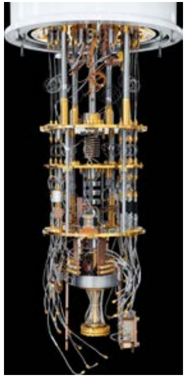
Ordenadores cuánticos

aQuantum

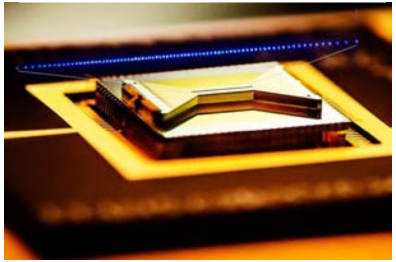
Google



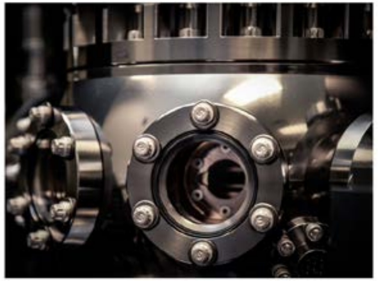
rigetti

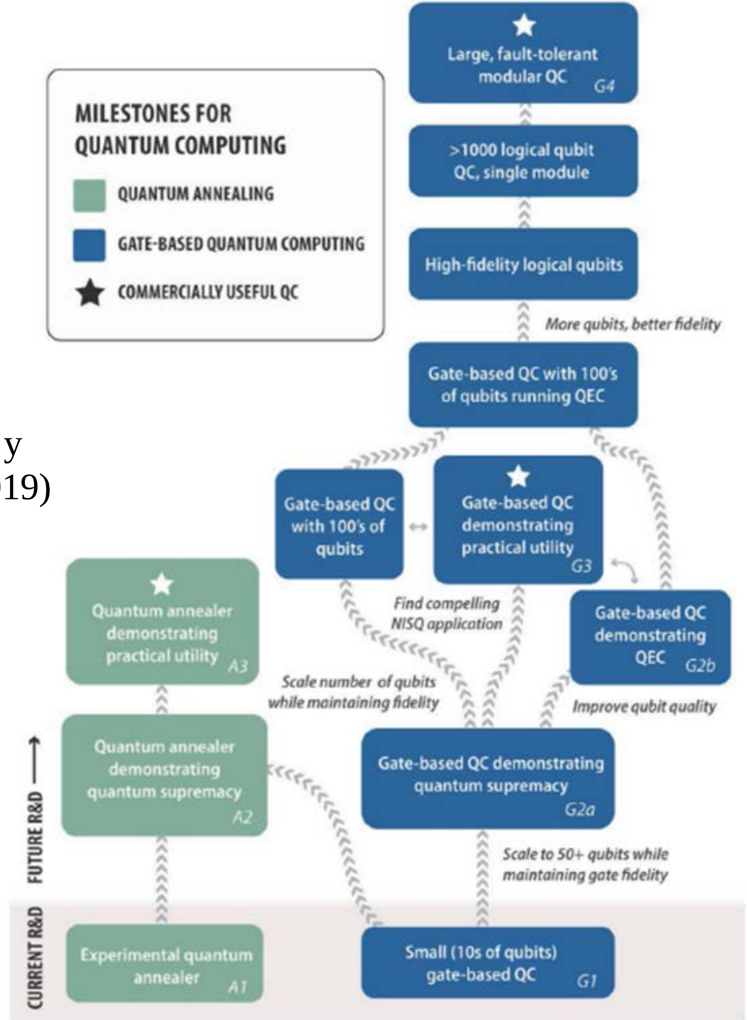


IONQ



Honeywell





Grumbling y Horowitz (2019)

NISQ
(Noisy Intermediate-Scale Quantum)

QEC
(Quantum Error Correction)

D-Wave announces availability of first Quantum Computer built for Business

September 29, 2020 / wp_swiss

D-Wave Systems announced the general availability of its next-generation quantum computing platform, incorporating new hardware, software, and tools to enable and accelerate the delivery of in-production quantum computing applications.

Available today in the Leap™ quantum cloud service, the platform includes the Advantage™ quantum system, with more than 5000 qubits and 15-way qubit connectivity, in addition to an expanded hybrid solver service that can run problems with up to one million variables. The combination of the computing power of Advantage and the scale to address real-world problems with the hybrid solver service in Leap enables businesses to run performant, real-time,

50+ User-developed early quantum applications on D-Wave systems, including airline scheduling, election modeling, quantum chemistry simulation, automotive design, preventative healthcare, logistics, and much more.

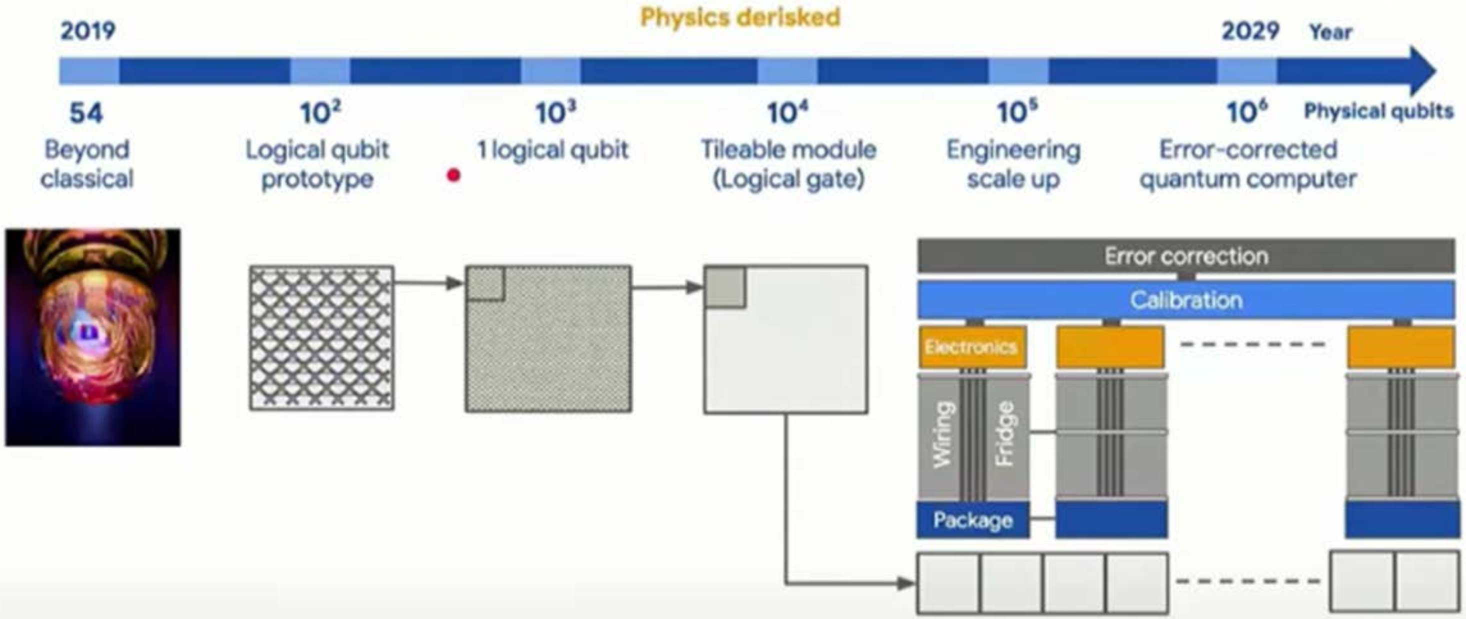
Optimization | Machine Learning | Materials Science

IBM publishes its quantum roadmap, says it will have a 1,000-qubit machine in 2023

Frederic Lardinois

@fredericl / 3:00 am PDT • September 15, 2020

Google AI Quantum hardware roadmap



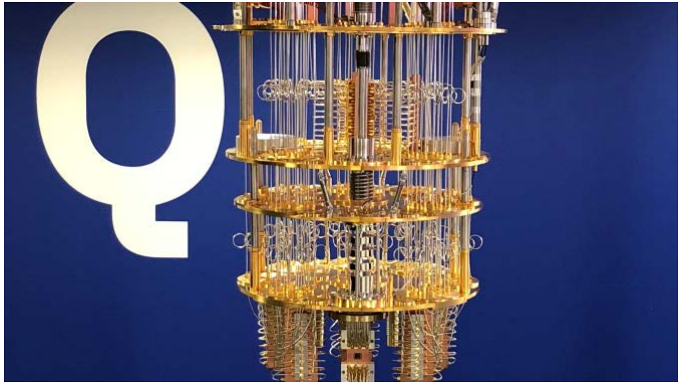
Ordenadores cuánticos

aQuantum

SW
&
datos

ORDENADOR

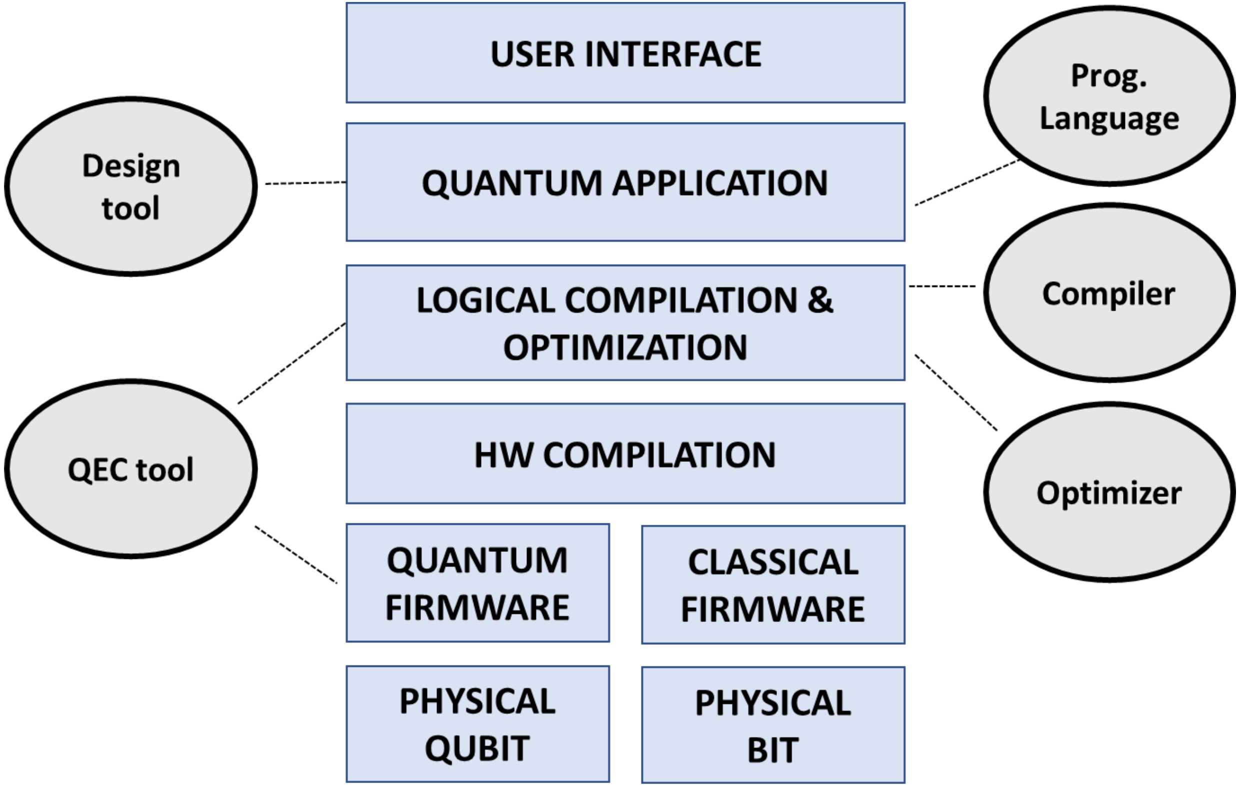
CLÁSICO



INDICE

- Revoluciones industriales
- Conceptos básicos
- Ordenadores cuánticos
- **Software cuántico**
- Ingeniería del Software Cuántico
- Conclusiones

Ordenadores cuánticos



LENGUAJES DE PROGRAMACIÓN

- Imperativos: QASM, QCL, QGCL, Q, LanQ, Scaffold, Silq, QUA, ...
- Funcionales: QML, QFC, Quipper, QuaFL, …
- Otros: FJQuantum, QuECT, …
- Multiparadigma: Q#, Strawberry Fields, …

Software cuántico

aQuantum

```
# File:   test2.qasm
# Date:   29-Mar-04
# Author: I. Chuang
#
# Sample qasm input file - simple teleportation circuit
#
        qubit   q0
        qubit   q1
        qubit   q2

        h       q1      # create EPR pair
        cnot    q1,q2
        cnot    q0,q1   # Bell basis measurement
        h       q0
        nop     q1
        measure q0
        measure q1
        c-x     q1,q2   # correction step
        c-z     q0,q2
```

https://www.media.mit.edu/quanta/qasm2circ/

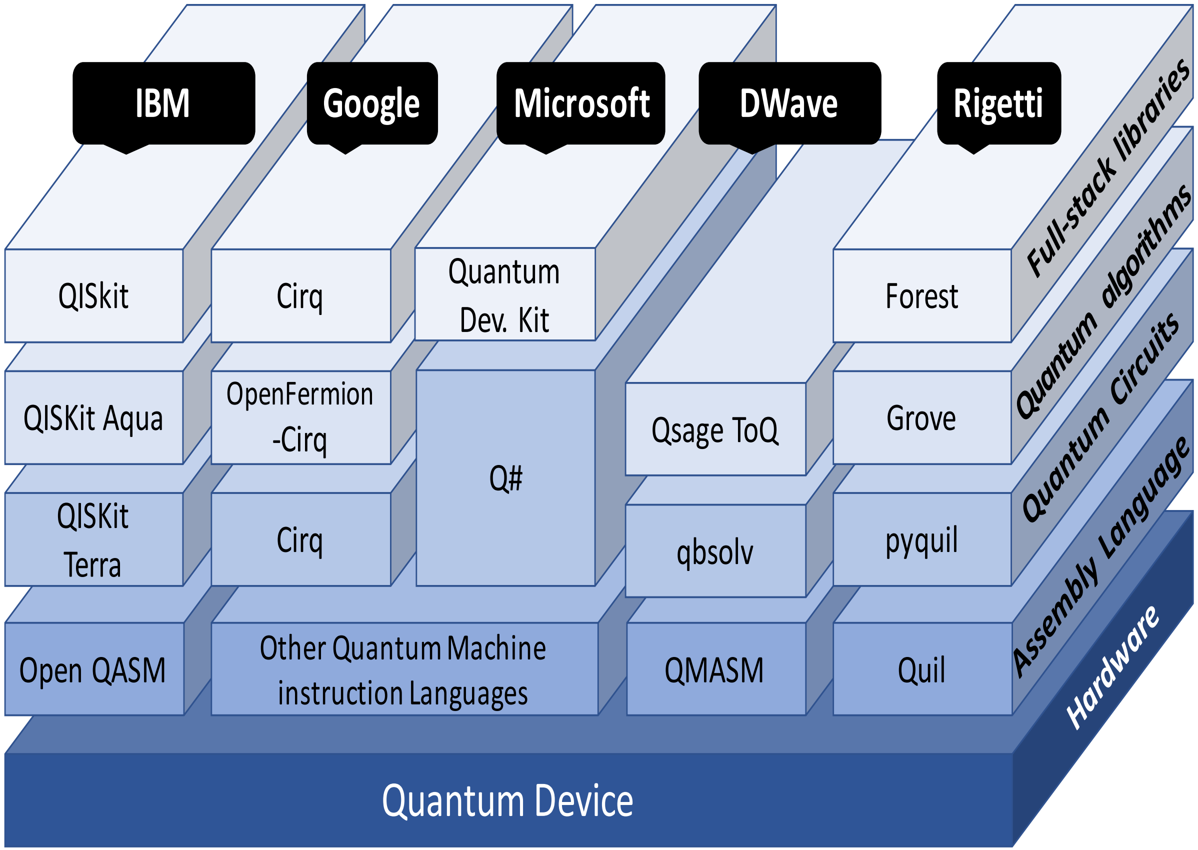
Software cuántico

aQuantum

```
def solve[n:!ℕ](bits:!𝔹^n){
  // prepare superposition between 0 and 1
  x:=H(0:𝔹);
  // prepare superposition between bits and 0
  qs := if x then bits else (0:int[n]) as 𝔹^n;
  // uncompute x
  forget(x=qs[0]); // valid because `bits[0]==1`
  return qs;
}

// EXAMPLE CALL

def main(){
  // example usage for bits=1, n=2
  x := 1:!int[2];
  y := x as !𝔹^2;
  return solve(y);
}
```

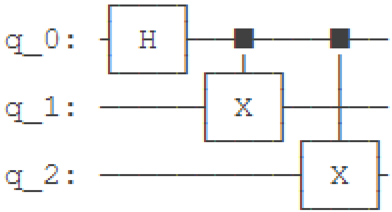
https://silq.ethz.ch/examples

Software cuántico



Software cuántico

```python
from qiskit import QuantumCircuit
# Create a circuit with a register of three qubits
circ = QuantumCircuit(3)
# H gate on qubit 0, putting this qubit in a superposition of |0> + |1>.
circ.h(0)
# A CX (CNOT) gate on control qubit 0 and target qubit 1 generating a Bell state.
circ.cx(0, 1)
# CX (CNOT) gate on control qubit 0 and target qubit 2 resulting in a GHZ state.
circ.cx(0, 2)
# Draw the circuit
circ.draw()
```



https://qiskit.org/documentation/apidoc/circuit.html

Software cuántico

aQuantum

Q# Copiar

```
operation TestBellState(count : Int, initial : Result) : (Int, Int, Int) {
    mutable numOnes = 0;
    mutable agree = 0;
    using ((q0, q1) = (Qubit(), Qubit())) {
        for (test in 1..count) {
            Set(initial, q0);
            Set(Zero, q1);

            H(q0);
            CNOT(q0, q1);
            let res = M(q0);

            if (M(q1) == res) {
                set agree += 1;
            }

            // Count the number of ones we saw:
            if (res == One) {
                set numOnes += 1;
            }
        }

        Set(Zero, q0);
        Set(Zero, q1);
    }

    // Return number of times we saw a |0> and number of times we saw a |1>
    return (count-numOnes, numOnes, agree);
}
```

Python Copiar

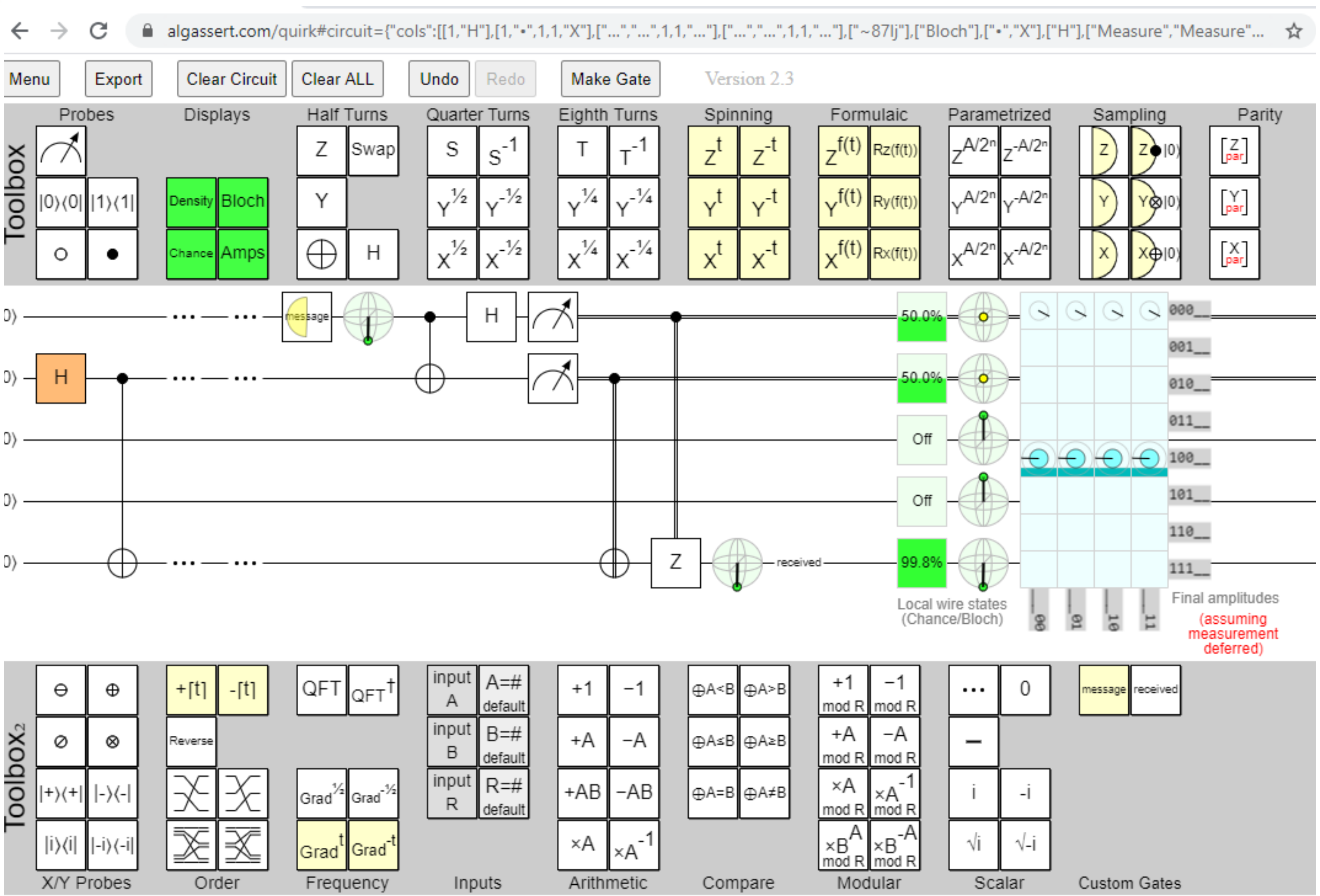
```
import qsharp

from qsharp import Result
from Quantum.Bell import TestBellState

initials = {Result.Zero, Result.One}

for i in initials:
    res = TestBellState.simulate(count=1000, initial=i)
    (num_zeros, num_ones, agree) = res
    print(f'Init:{i: <4} 0s={num_zeros: <4} 1s={num_ones: <4} agree={agree: <4}')
```

https://docs.microsoft.com/es-es/quantum/tutorials/explore-entanglement?tabs=tabid-python

aQuantum

OTRAS HERRAMIENTAS

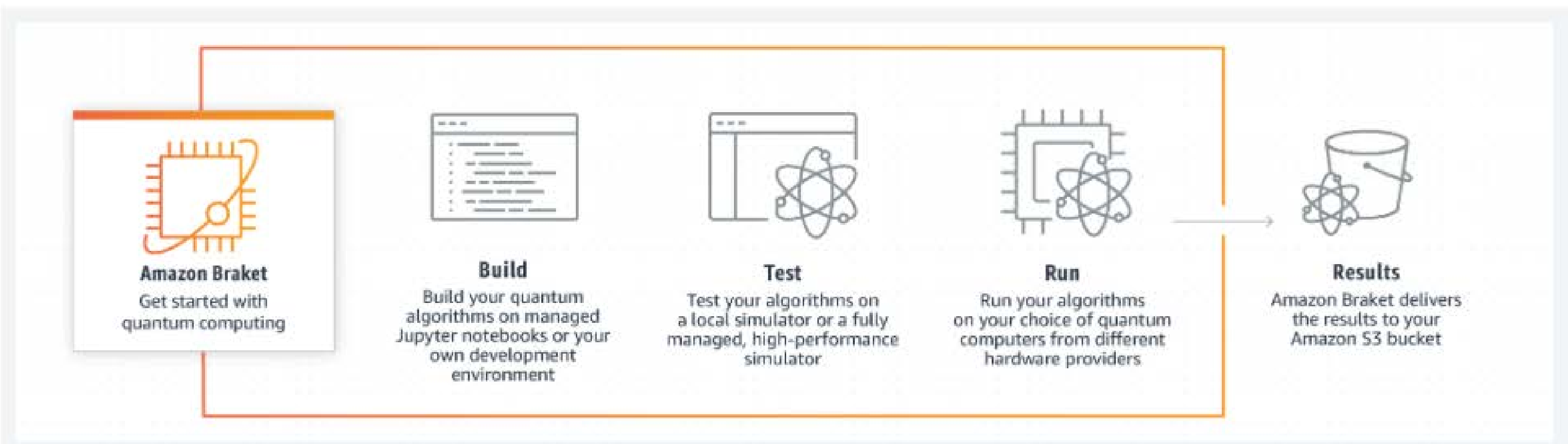
- Simuladores: Intel-QS, QX, QuIDDPro, ProjectQ, Atos QLM, …
- Optimizadores: Feynman, Topt, RevKit, …
- Herramientas de corrección de errores: Devkit, Black Opal, Boulder Opal, …
- Diseñadores de circuitos: Quirk, Atom QASM Quantum Circuit Previewer, ...
- Entornos de desarrollo: Orquestra, 1QCloud, Strangeworks Quantum Computing Platform, AliroQuantum, t|ket⟩, Amazon's bracket , ...



aQuantum

https://algassert.com/quirk


Amazon Braket
Información general
Características
Precios
Preguntas frecuentes
Introducción
Proveedores de hardware
Clientes
Amazon Braket
Realice investigaciones y experimentos con la informática cuántica
Introducción a Amazon Braket


Amazon Braket
Get started with quantum computing
Build
Build your quantum algorithms on managed Jupyter notebooks or your own development environment
Test
Test your algorithms on a local simulator or a fully managed, high-performance simulator
Run
Run your algorithms on your choice of quantum computers from different hardware providers
Results
Amazon Braket delivers the results to your Amazon S3 bucket

INDICE

aQuantum

Historia de la Informática “clásica”

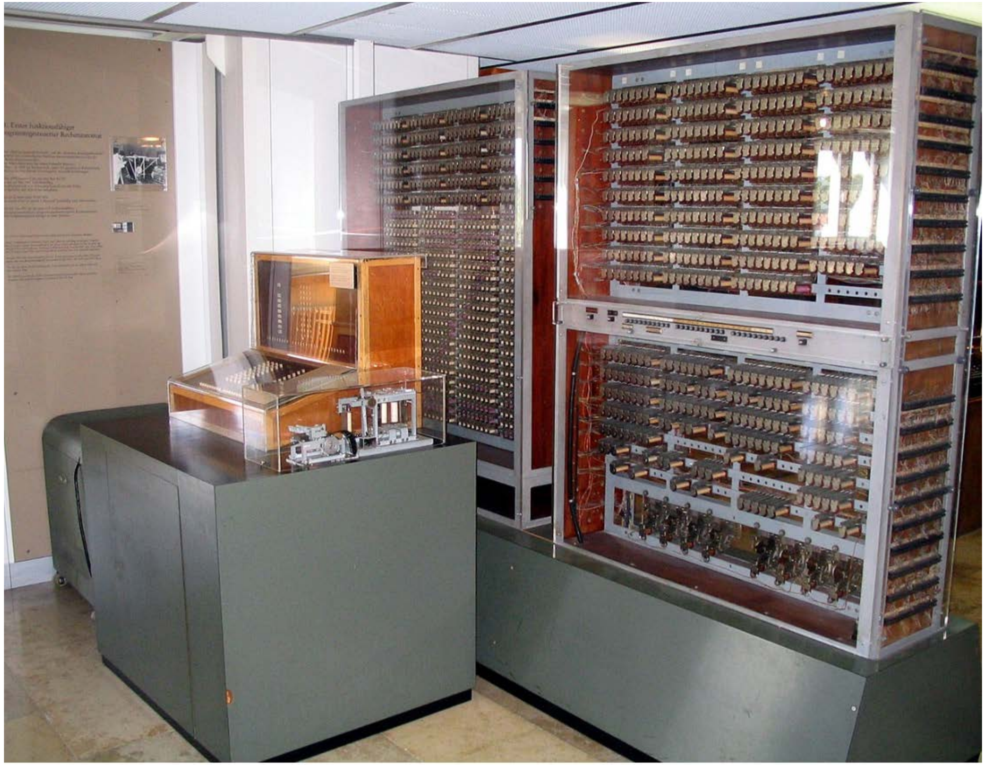
aQuantum

Kurt Gödel

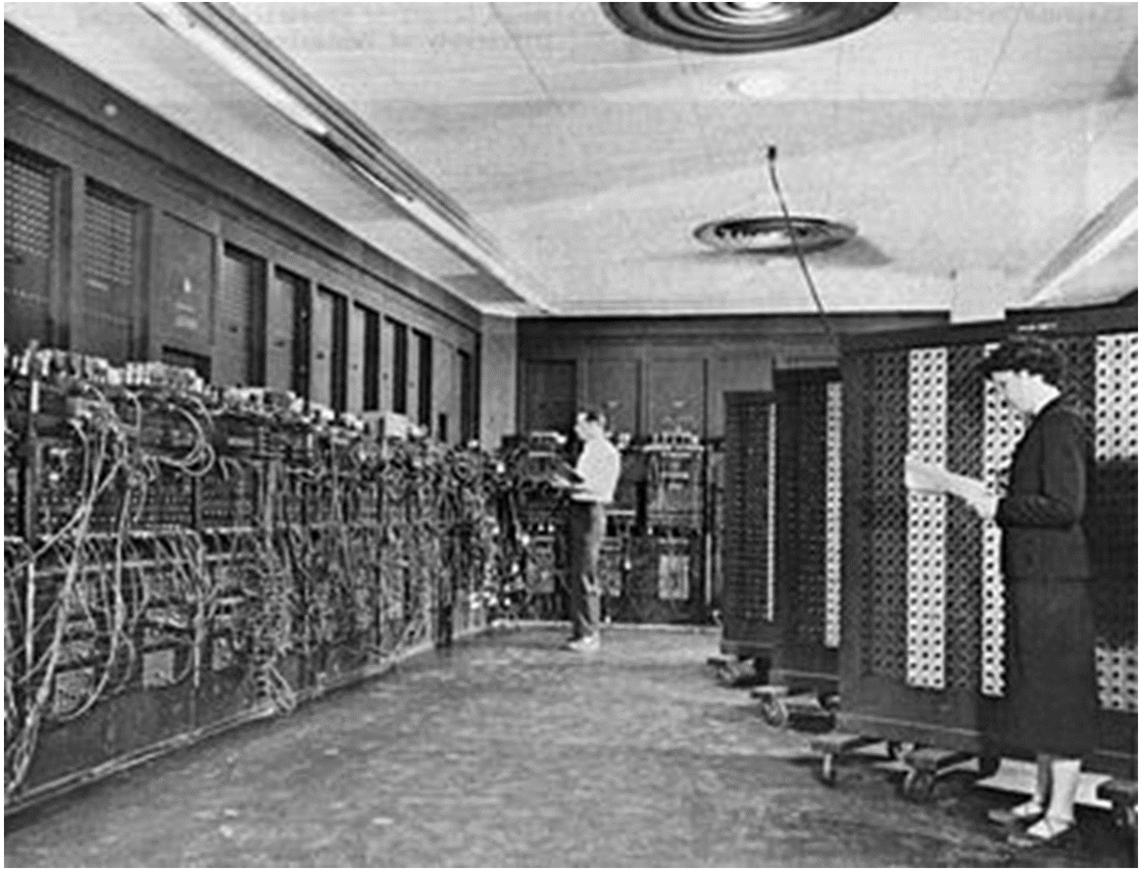
Alan Turing

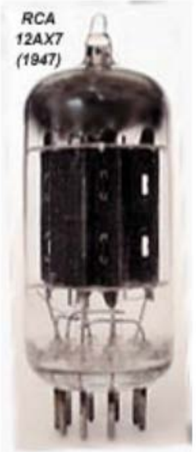
Alonzo Church

Historia de la Informática “clásica”

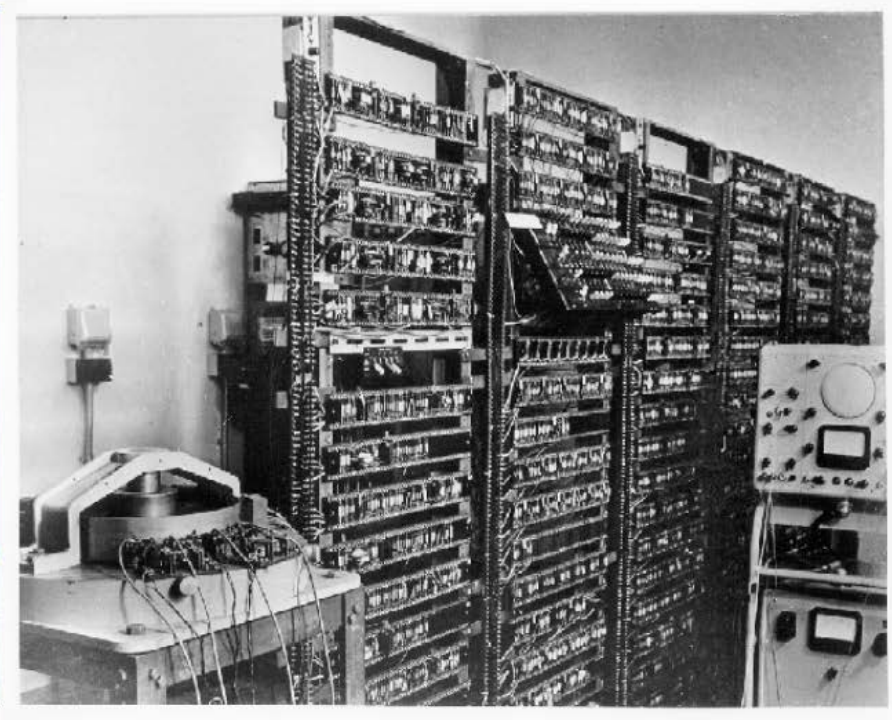


Historia de la Informática "clásica"

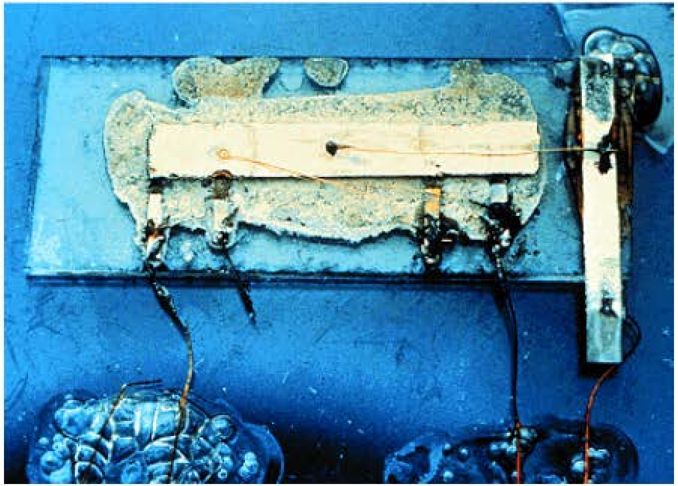


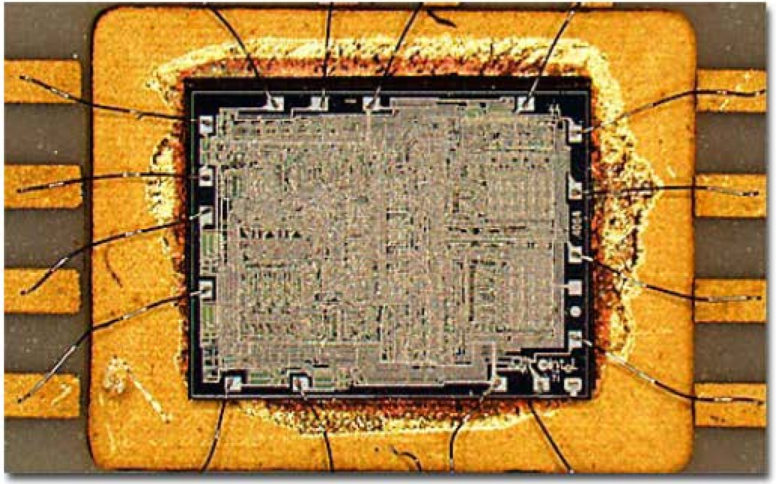


Historia de la Informática “clásica”



Historia de la Informática "clásica"





Intel 4004 uP, 2,300 transistors

Historia de la Informática “clásica”

"Eras" del desarrollo de software

aQuantum

1ª

FORTRAN, COBOL, Pascal, etc

Diseño (Warnier, Jackson, Yourdon, Constantine, etc.) y Análisis Estructurado (Gane, Sarson, DeMarco, Weinberg, etc.).

Metodologías: Merise, SSADM, Information Engineering, Métrica V2.

2ª

C++, Objective-C, Eiffel, Java, …

Diseño y Análisis Orientado a Objetos (UML, Unified Process, RUP, etc)

Metodologías ágiles (XP, Scrum, etc.)

3ª

DevOps (IaC, CI/CD, Contenedores, Orquestación, etc.)

Ingeniería del software continua

Conclusiones

aQuantum

ACM SIGSOFT Software Engineering Newsletter Page 12 July 2020 Voume 45 Number 3

Quantum Computing: A New Software Engineering Golden Age

Mario Piattini
aQuantum by Alarcos Research Group
Pº de la Universidad 4, 13071 Ciudad Real, Spain
mario.piattini@uclm.es

Guido Peterssen
aQuantum by Alhambra
Calle Albasanz 16, 28037 Madrid, Spain
guido.peterssen@a-e.es

Ricardo Pérez-Castillo
aQuantum by Alarcos Research Group
Pº de la Universidad 4, 13071 Ciudad Real, Spain
ricardo.pdelcastillo@uclm.es

DOI: 10.1145/3402127.3402131
https://doi.acm.org/10.1145/3402127.3402131

ABSTRACT

Quantum computing, and to an even greater extent quantum technology, is changing the world. Quantum computing is not an evolution of classical computer science; it is actually a revolution that completely changes the computing paradigm. Quantum computers are based on the principles of quantum mechanics, such as superposition and entanglement, and they seek to boost computational power exponentially. Many problems that have until now been impossible to solve, in practical terms, might very well be able to be addressed by means of quantum

science did not lag behind, and it started to take advantage of quantum mechanics in the eighties, when Richard Feynman (Nobel laureate) claimed to be able to simulate physics with computers [1]. This was the seed for the concept of quantum computers, and the second quantum revolution began.

Quantum computers, in their effort to provide faster computing speed, attempt to use various "counterintuitive" principles, such as superposition (objects can be in different states at the same time) and entanglement (objects can be deeply connected without any direct physical interaction). Quantum computational power lies in the concept

The Talavera Manifesto for Quantum Soft. Eng. and Programming

aQuantum

El Manifesto es resultado de la discusión y los diferentes puntos de vista de académicos y profesionales de la industria que se unieron al primer Taller Internacional sobre Ingeniería del Software y Programación Cuántica (QANSWER) promovido por la UCLM y aQuantum celebrado en Febrero 2020 en Talavera de la Reina.

Disponible en: https://www.aquantum.es/manifesto

PRINCIPLES

- QSE is **agnostic** regarding quantum prog. languages and technologies

PRINCIPLES

- QSE is **agnostic** regarding quantum prog. languages and technologies
- QSE embraces the **coexistence** of classical and quantum computing

PRINCIPLES

- QSE is **agnostic** regarding quantum prog. languages and technologies
- QSE embraces the **coexistence** of classical and quantum computing
- QSE allows the management of quantum software development **projects**

aQuantum

PRINCIPLES

- QSE is **agnostic** regarding quantum prog. languages and technologies
- QSE embraces the **coexistence** of classical and quantum computing
- QSE allows the management of quantum software development **projects**
- QSE deals with the **evolution** of quantum software

PRINCIPLES

- QSE is **agnostic** regarding quantum prog. languages and technologies
- QSE embraces the **coexistence** of classical and quantum computing
- QSE allows the management of quantum software development **projects**
- QSE deals with the **evolution** of quantum software
- QSE attempts to deliver quantum programs with desirable **zero defects**

PRINCIPLES

- QSE is **agnostic** regarding quantum prog. languages and technologies
- QSE embraces the **coexistence** of classical and quantum computing
- QSE allows the management of quantum software development **projects**
- QSE deals with the **evolution** of quantum software
- QSE attempts to deliver quantum programs with desirable **zero defects**
- QSE is concerned about the **quality** of quantum software

aQuantum

PRINCIPLES

- QSE is **agnostic** regarding quantum prog. languages and technologies
- QSE embraces the **coexistence** of classical and quantum computing
- QSE allows the management of quantum software development **projects**
- QSE deals with the **evolution** of quantum software
- QSE attempts to deliver quantum programs with desirable **zero defects**
- QSE is concerned about the **quality** of quantum software
- QSE is in favour of quantum software **reuse**

PRINCIPLES

- QSE is **agnostic** regarding quantum prog. languages and technologies
- QSE embraces the **coexistence** of classical and quantum computing
- QSE allows the management of quantum software development **projects**
- QSE deals with the **evolution** of quantum software
- QSE attempts to deliver quantum programs with desirable **zero defects**
- QSE is concerned about the **quality** of quantum software
- QSE is in favour of quantum software **reuse**
- QSE is aware of the need for security and **privacy by design**

The Talavera Manifesto for Quantum Soft. Eng. and Programming

aQuantum

PRINCIPLES

- QSE is **agnostic** regarding quantum prog. languages and technologies
- QSE embraces the **coexistence** of classical and quantum computing
- QSE allows the management of quantum software development **projects**
- QSE deals with the **evolution** of quantum software
- QSE attempts to deliver quantum programs with desirable **zero defects**
- QSE is concerned about the **quality** of quantum software
- QSE is in favour of quantum software **reuse**
- QSE is aware of the need for security and **privacy by design**
- QSE covers the **governance and management** of software

CALL TO ACTION

- Software practitioners
- Educators
- Technology vendors
- Customers
- Researchers
- Government and funding bodies
- Professional associations
- Users

CALL TO ACTION

- Software practitioners
- **Educators**
- Technology vendors
- Customers
- Researchers
- Government and funding bodies
- Professional associations
- Users

- **Software Engineering** Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering
- **MSIS** Global Competency Model for Graduate Degree Programs in Information Systems
- **Information Technology** Curricula
- **Computer Engineering** Curricula: “4.2 Strategies for Emerging Technologies”
- **Computer Science** Curricula: “Information Assurance and Security KA”
- **Cybersecurity** Curricula: “Data Security - Cryptography”

- **UDEMY**: "QC151 Quantum Physics for Quantum Computing", "QC051: Math Prerequisites for Quantum Computing", y "C101 Quantum Computing & Quantum Physics for Beginners", "Master Quantum Computing, Quantum Cryptography, and Quantum Physics with Microsoft Q# (Q Sharp) & IBM Quantum Experience".
- **edX**; cursos de la Delft University of Technology, y "Professional Certificate in Quantum 101: Quantum Computing & Quantum Internet. Tambíén: "Quantum Machine Learning" de la University of Toronto; y cursos del MIT
- **Coursera**: "The Introduction to Quantum Computing" de la Saint Petersburg State University.
- **Brilliant** (con Microsoft y Alphabet X): Information, Circuits, Foundational Algorithms, Near-Term Algorithms, Advanced Algorithms, Physical Qubits, etc.

CC: Computación Cuántica

PC: Programación Cuántica

DSC: Desarrollo de Sistemas Cuánticos

IAC: Soporte Cuántico a la Inteligencia Artificial

SC: Seguridad cuántica

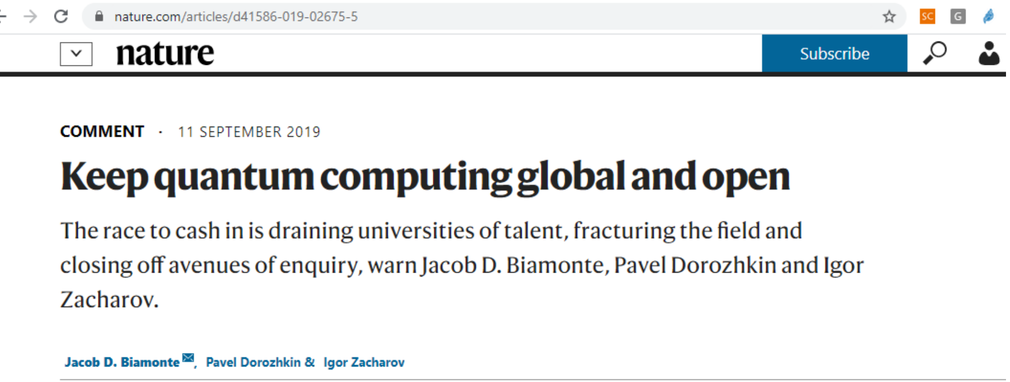
SIC: Sistemas de Información Cuánticos

The Talavera Manifesto for Quantum Soft. Eng. and Programming

Grado / Especialización	Asignaturas					
	CC	PC	DSC	IAC	SC	SIC
Ciencias de la Computación	◆	◆		◆		
Tecnologías de la Información		◆	◆			◆
Tecnología de Ordenadores	◆	◆				
Ingeniería del Software		◆	◆			◆
Sistemas de Información			◆		◆	◆
Ciencia (e Ingeniería) de Datos	◆	◆		◆		
(Ingeniería de la) Ciberseguridad	◆				◆	◆

Conclusiones

aQuantum


nature.com/articles/d41586-019-02675-5

nature

Subscribe

COMMENT · 11 SEPTEMBER 2019

Keep quantum computing global and open

The race to cash in is draining universities of talent, fracturing the field and closing off avenues of enquiry, warn Jacob D. Biamonte, Pavel Dorozhkin and Igor Zacharov.

Jacob D. Biamonte, Pavel Dorozhkin & Igor Zacharov


1888 views | Jun 19, 2019, 08:45am EDT

Building The Quantum Workforce Of The Future

Jeremy Hilton Forbes Councils Member
Forbes Technology Council COUNCIL POST | Paid Program
Innovation

POST WRITTEN BY
Jeremy Hilton

Jeremy Hilton is D-Wave's Senior Vice President of Systems, responsible for overseeing the development of quantum systems.

Guido Peterssen

"Impact of quantum technology: the workforce necessary for the development of quantum software

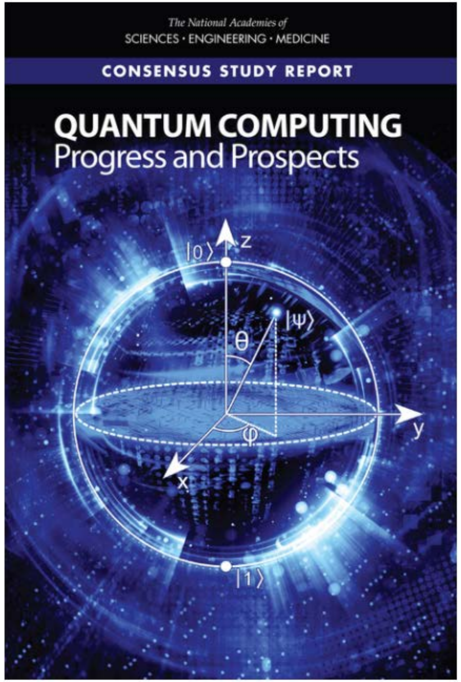
"The rupture between the offer and demand of quantum workforce, that currently is disproportionate and chronic…In this state of the quantum workforce, there is fierce competition due to the great lack of quantum workforce with skills, both at national level as international level"

CALL TO ACTION

- Software practitioners
- Educators
- Technology vendors
- Customers
- Researchers
- **Government and funding bodies**
- Professional associations
- Users

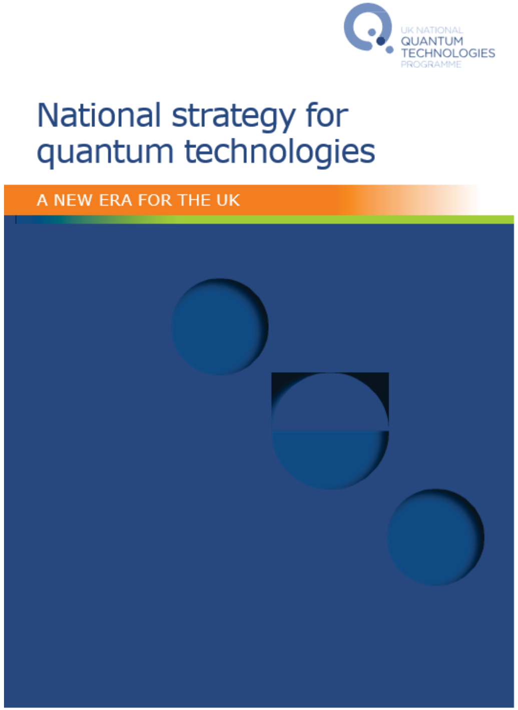
aQuantum

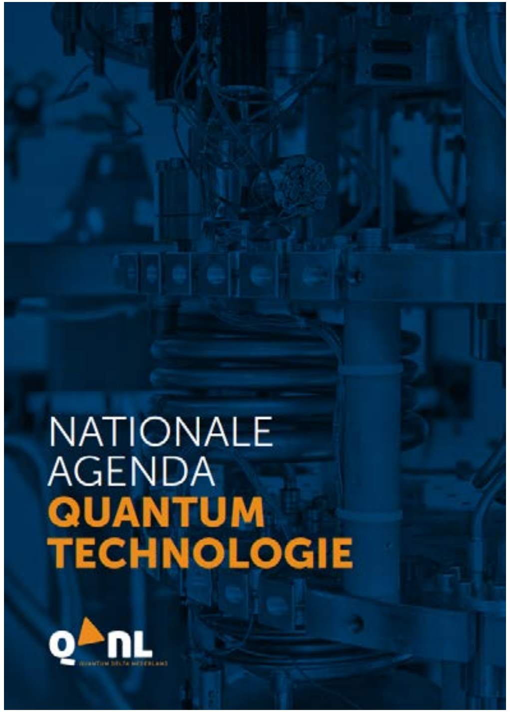

CONGRESS.GOV
Advanced Searches
Browse
Legislation
Co
Legislation
Examples: hr5, sres9, "health care"
MORE OPTIONS
Home > Legislation > 115th Congress > H.R.6227
H.R.6227 - National Quantum Initiative Act
115th Congress (2017-2018)
LAW
Hide Overview
Sponsor: Rep. Smith, Lamar [R-TX-21] (Introduced 06/26/2018)
Committees: House - Science, Space, and Technology | Senate - Commerce, Science, and Transportation
Committee Meetings: 06/27/18 10:00AM
Committee Reports: H. Rept. 115-950
Latest Action: 12/21/2018 Became Public Law No: 115-368. (TXT | PDF) (All Actions)
Roll Call Votes: There has been 1 roll call vote
Tracker:
Introduced
Passed House
Passed Senate
Resolving Differences
To President
Became Law


The National Academies of
SCIENCES · ENGINEERING · MEDICINE
CONSENSUS STUDY REPORT
QUANTUM COMPUTING
Progress and Prospects

aQuantum


Strategic
Research
Agenda
QUANTUM
FLAGSHIP


UK NATIONAL
QUANTUM
TECHNOLOGIES
PROGRAMME
National strategy for
quantum technologies
A NEW ERA FOR THE UK


NATIONALE
AGENDA
QUANTUM
TECHNOLOGIE

CALL TO ACTION

- Software practitioners
- Educators
- Technology vendors
- Customers
- **Researchers**
- Government and funding bodies
- Professional associations
- Users

INVESTIGACION EN INFORMÁTICA CUÁNTICA

- Modernización de software cuántico
- Pruebas de software cuántico
- Calidad de software cuántico
- Gobierno y gestión de software cuántico

FEATURE ARTICLE: QUANTUM SOFTWARE

Toward a Quantum Software Engineering

Mario Piattini, *University of Castilla—La Mancha*
Manuel Serrano, *University of Castilla—La Mancha*
Ricardo Perez-Castillo, *University of Castilla—La Mancha*
Guido Petersen, *aQuantum*
Jose Luis Hevia, *aQuantum*

Nowadays, we are at the dawn of a new age, the quantum era. Quantum computing is no longer a dream; it is a reality that needs to be adopted. But this new technology is taking its first steps, so we still do not have models, standards, or methods to help us in the creation of new systems and the migration of current ones. Given the current state of quantum computing, we need to go back to the path software engineering took in the last century to achieve the new golden age for quantum software engineering.

If the 19th century was the machine era and 20th century was the information era, several experts agree that 21st century will be the quantum era. In fact, "The thing driving the hype is the realization that quantum computing is actually real. It is no longer a physicist's dream—it is an engineer's nightmare."[1]

Over the past three decades, our understanding of "quantum computers" has expanded drastically,[2] as the efforts to realize such an exotic computer have made steady, yet remarkable progress.[3] Using various "counterintuitive" principles of quantum mechanics, such as superposition and entanglement, quantum computers will provide faster computing speed,[4] providing high value for specific tasks in various important applications. For example, applications include, but are not limited to, the following:

- privacy and cryptography: certification of randomness and authentication;[5]
- supply chain and logistics: optimization problems in procurement, production and distribution, vehicle routing optimization, etc.;
- chemistry: simulations of complex molecules, discovery of new materials, advanced molecular design, etc.;
- economics and financial services: portfolio risk optimization and fraud detection, actual randomness for financial models, simulations and scenario analysis, etc.;
- energy and agriculture: production of ammonia, better distribution of resources, asset degradation modeling, etc.;
- medicine and health: protein folding and drug discovery, disease detection, noninvasive and high-precision surgeries, targeted drugs design, tailored medicine, improvement of the quality of life, prediction of therapeutic prescriptions, etc.;
- defense and national security programs.

In these areas, the quantum software engineer will implement "killer" software applications, in which the speed afforded by quantum computers will have real-world impact.[4]

As Humble and DeBenedictis[6] highlight, the prospects of quantum computing are exciting, and extraordinary expectations are now fueling a global effort to perfect quantum computing. Many countries (China, U.S., Japan, Russia, U.K., etc.) are investing huge quantities in quantum technology. Also, the most important companies (Google, IBM, Microsoft, Intel, Atos, Alibaba, etc.) are investigating how to take the most of this new technology for their businesses.

Stepney *et al.* from the University of York proposed a "Grand Challenge for Computing Research"[7] about Quantum Software Engineering—which covers the development of a full discipline of Quantum Software Engineering, ready to exploit the full potential of commercial quantum computer hardware, once it arrives. This challenge is to build the corresponding languages, tools and techniques for quantum software engineering." They emphasize the need to raise the level of thinking about quantum programs. Also, Van den Brink

1520-9202 © 2021 IEEE
Digital Object Identifier 10.1109/MITP.2020.3019522
Date of current version 29 January 2021.

Conclusiones

INVESTIGACION EN INFORMÁTICA CUÁNTICA

- Verificación formal

Verification of quantum computation: An overview of existing approaches. https://arxiv.org/abs/1709.06984

A Deductive Verification Framework for Circuit-building Quantum Programs https://arxiv.org/pdf/2003.05841.pdf

FORMALLY VERIFIED QUANTUM PROGRAMMING

Robert Rand

A DISSERTATION

in

Computer and Information Science

Presented to the Faculties of the University of Pennsylvania
in
Partial Fulfillment of the Requirements for the
Degree of Doctor of Philosophy

2018

Supervisor of Dissertation

Steve Zdancewic
Professor of Computer and Information Science

Graduate Group Chairperson

Rajeev Alur
Professor of Computer and Information Science

Dissertation Committee
Stephanie Weirich, Professor of Computer and Information Science, Chair
Val Tannen, Professor of Computer and Information Science
Benjamin Pierce, Professor of Computer and Information Science
Prakash Panangaden, Professor of Computer Science, McGill University

- Lenguajes/Modelado

Towards a Quantum Software Modeling Language
https://arxiv.org/abs/2006.16690

INVESTIGACION EN INFORMÁTICA CUÁNTICA

- Seguridad: cuántica y criptografía postcuántica

  https://cacm.acm.org/magazines/2020/7/245691-the-quantum-threat/fulltext

  https://csrc.nist.gov/projects/post-quantum-cryptography

- Algoritmos cuánticos e híbridos: finanzas, tráfico, logística, etc.

  https://quantumalgorithmzoo.org/

  https://qiskit.org/textbook/ch-algorithms/

INVESTIGACION EN INFORMÁTICA CUÁNTICA

- QEC

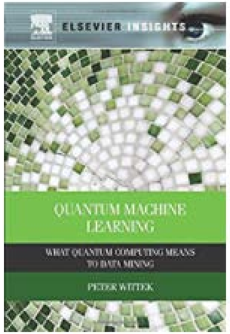
  Quantum Error Correction: An Introductory Guide
  https://arxiv.org/abs/1907.11157

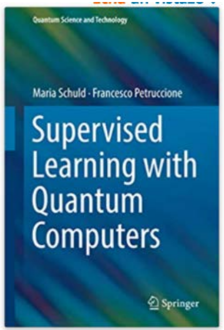
  Software tools for quantum control: Improving quantum computer performance through noise and error suppression
  https://arxiv.org/abs/2001.04060

- QAI/QML/QDL

  Recent advances in quantum machine learning
  https://onlinelibrary.wiley.com/doi/abs/10.1002/que2.34

  Advances in Quantum Deep Learning: An Overview
  https://arxiv.org/abs/2005.04316





INDICE

- Revoluciones industriales
- Conceptos básicos
- Ordenadores cuánticos
- Software cuántico
- Ingeniería del Software Cuántico
- **Conclusiones**

Conclusiones

Conclusiones

Computer hoy.com

Samsung convierte el Galaxy A71 5G en un móvil con tecnología cuántica

Marta Sanz Romero hace 1 día

© Redacción Samsung Galaxy A Quantum

Samsung convierte el Galaxy A71 5G en un móvil con tecnología cuánticaMarta Sanz Romero 14 de mayo de 2020 - 12:05h

Conclusiones

“Quantum information is a radical departure in information technology, more fundamentally different from current technology than the digital computer is from the abacus”

(William Daniel Phillips, 1997)

aQuantum

“No obstante, en realidad ha sido hace pocos años que **se ha encontrado una explicación única y maravillosamente simple a estos hechos inexplicables y a otros no menos inexplicables y de la más variada naturaleza y, por último, a casi todos los fenómenos conocidos por los físicos** y que hasta ahora carecían de explicación suficiente: la que ofrecen los principios de **la mecánica cuántica. Esta extraordinaria teoría tiene una base tan sólida en la experiencia como quizás no la tuvo ninguna otra en el pasado**.”

El valor de las leyes estadísticas en la Física y en las Ciencias Sociales
(Ettore Majorana, 1942)

Conclusiones

aQuantum

“**Los acontecimientos cotidianos, además, son tremendamente complejos cuando los expresamos en términos de la física fundamental**. Si llenamos una tetera con agua y encendemos el gas, ni todos los superordenadores de la Tierra trabajando durante un tiempo equivalente a la edad actual del universo podrían resolver las ecuaciones necesarias para predecir cómo van a comportarse todas esas moléculas de agua”.

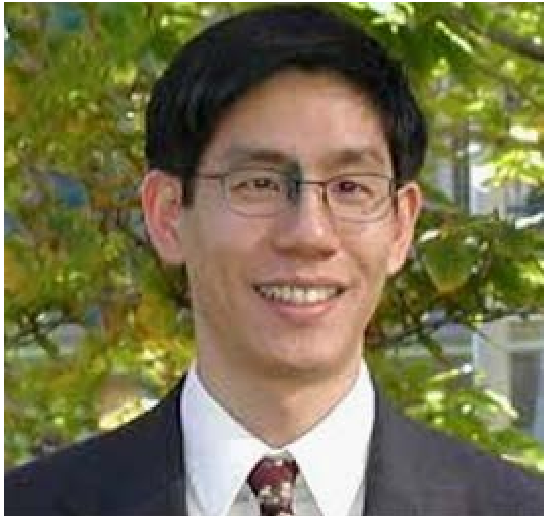
“**La teoría cuántica es la explicación más profunda conocida por la ciencia**. Viola muchos de los supuestos del sentido común y de toda la ciencia anterior ... Y sin embargo, este territorio aparentemente extraño es la realidad de la que nosotros y todo lo que experimentamos formamos parte. No hay otra.”

El comienzo del infinito (David Deutsch, 2011)

aQuantum

"The history of the universe is, in effect, a huge and ongoing quantum computation. The universe is a quantum computer."

(Seth Lloyd, 2006)



“The thing driving the hype is the realization that quantum computing is actually real. It is no longer a physicist’s dream — it is an engineer’s nightmare”

(Isaac Chuang, 2018)

Conclusiones

aQuantum

Quantum Software Engineering

Quantum Programming

Quantum Computer Science: Algorithms

Quantum Computers: Technology

Quantum Mechanics: Physics

Ingeniería del Software para la Computación Cuántica: Retos y Oportunidades

Mario Piattini

Marzo 2021