

# Hoe kun je rekenen met een quantumcomputer?

**Christian Schaffner**



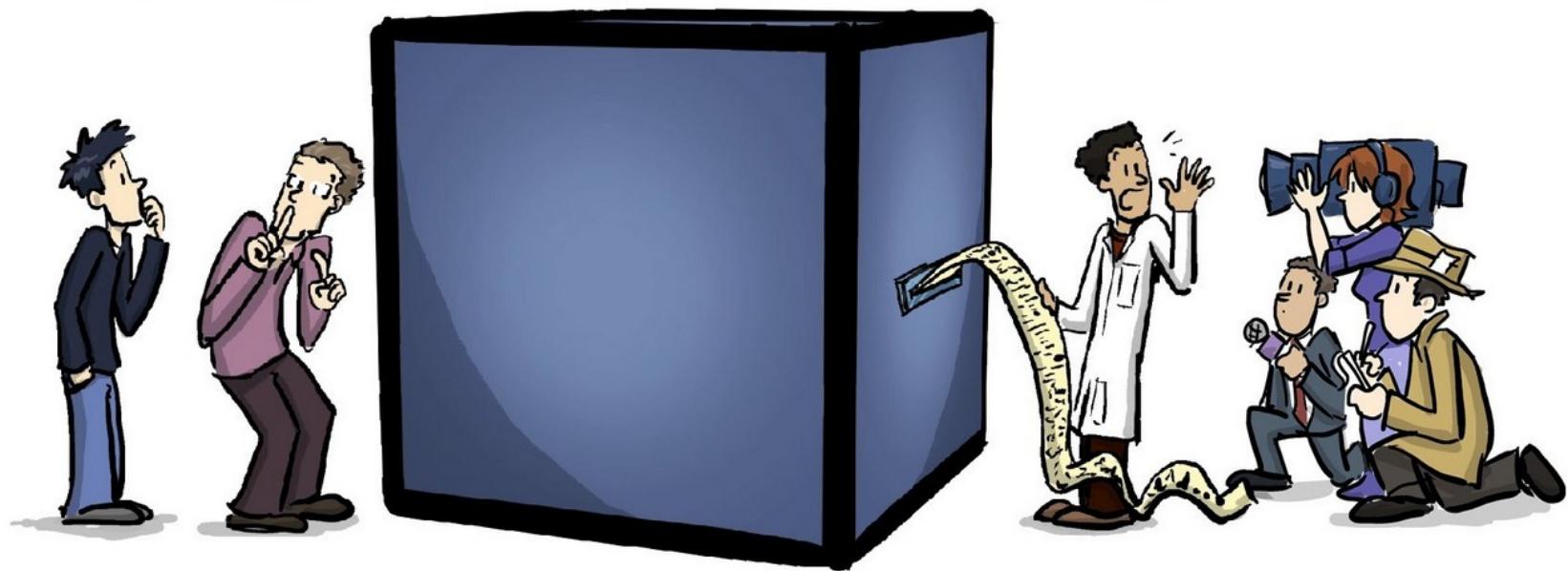
Institute for Logic, Language and Computation



Research Center for Quantum Software

*i&i conferentie 2019, donderdag 7 nov 2019  
(dank voor de slides aan Kareljan Schoutens!)*

# A Quantum COMPUTER



breaking news ...

TECH • QUANTUM COMPUTING

# Google Claims 'Quantum Supremacy,' Marking a Major Milestone in Computing

By [Robert Hackett](#) September 20, 2019

*Google Claims a Quantum Breakthrough That Could Change Computing*

GOOGLE \ SCIENCE \ TECH

## Google confirms 'quantum supremacy' breakthrough

*Its research paper is now available to read in its entirety*

By [Jon Porter](#) | [@JonPorty](#) | Oct 23, 2019, 6:31am EDT

# breaking news ...

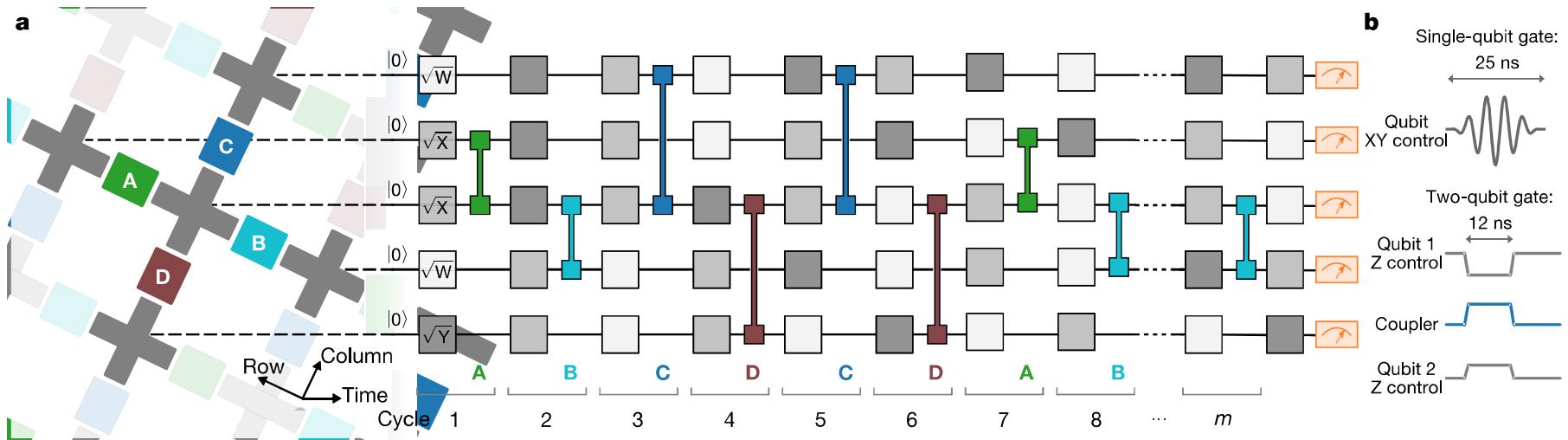
GOOGLE SCIENCE TECH

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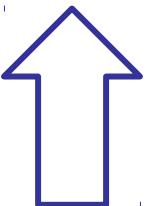
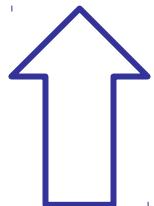
<https://www.nature.com/articles/s41586-019-1666-5>

# breaking news ...

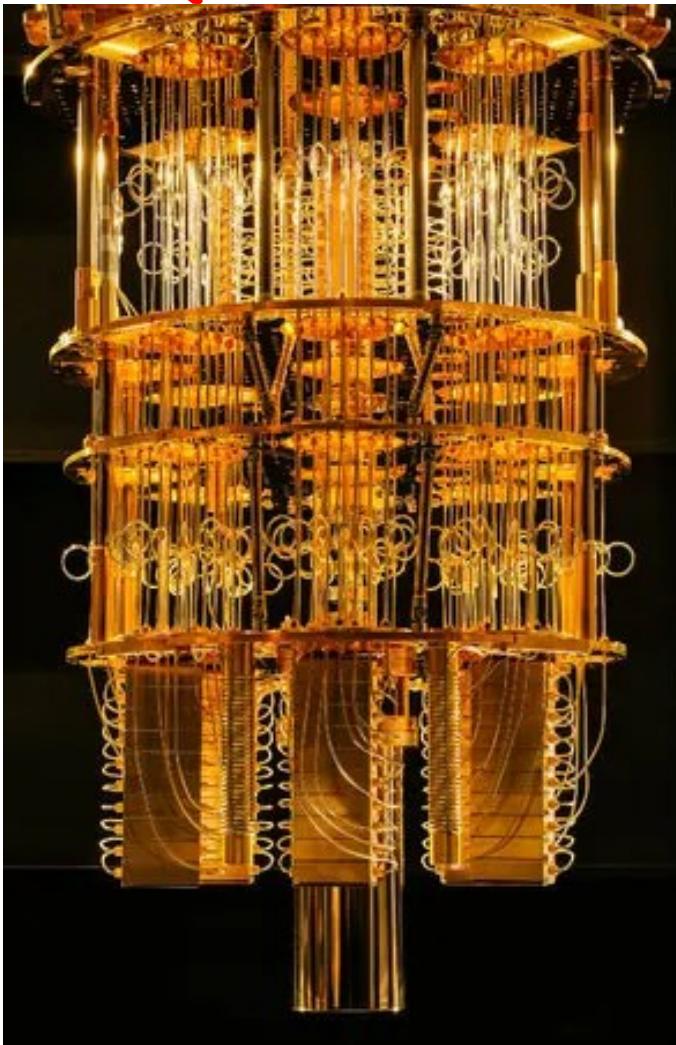
In what may be a huge milestone in computing, [Google](#) says it has achieved "[quantum supremacy](#)," an experimental demonstration of the superiority of a [quantum computer](#) over a traditional one.

The claim, made in a new scientific paper, is the most serious indication yet that the promise of quantum computers—an emerging but unproven type of machine—is becoming reality, including their potential to solve formerly ungraspable mathematical problems.

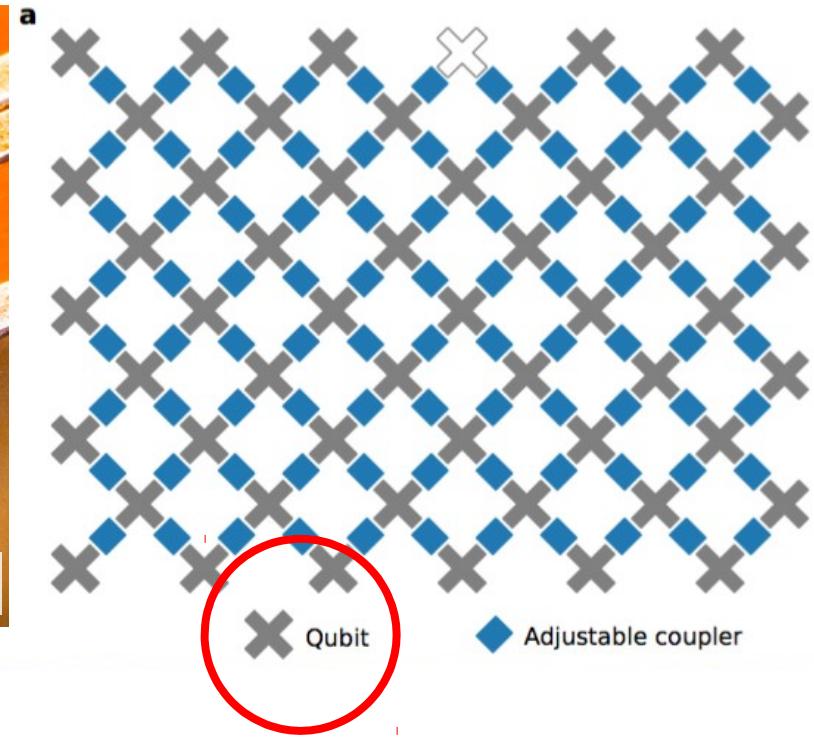
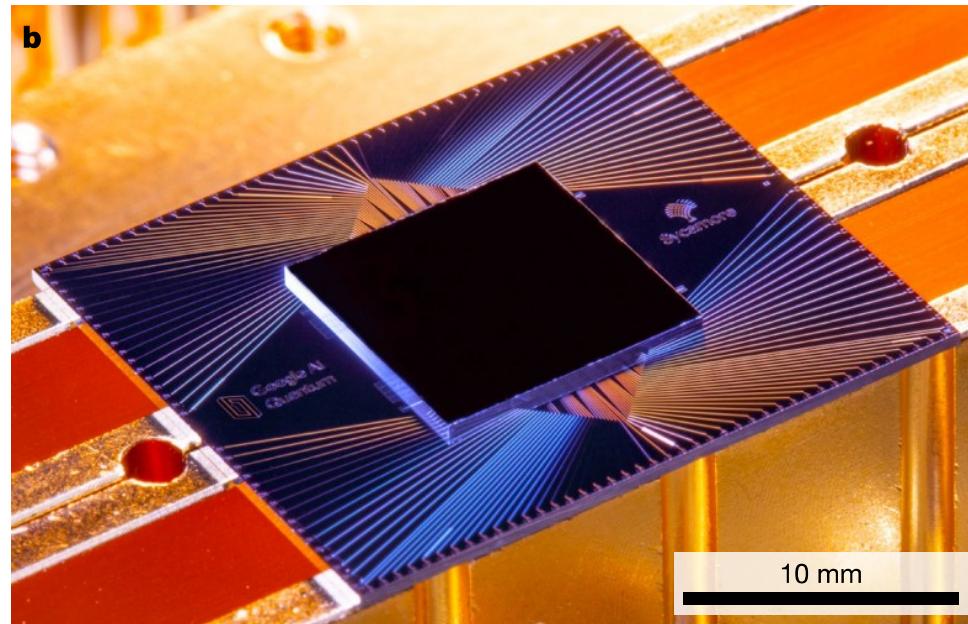
Essentially, Google purports to have pulled off a stunt on a quantum computer that no classical machine—not even the world's most powerful supercomputer—can replicate.



quantum computer



# Google's quantum computer



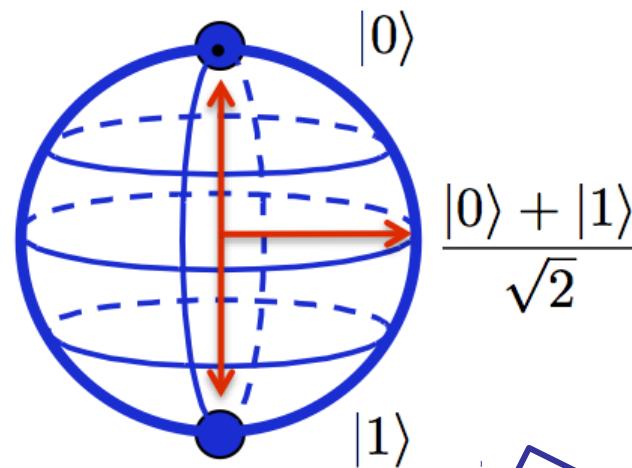
53 quantum bits (qubits)

# quantum bits (qubits)

0

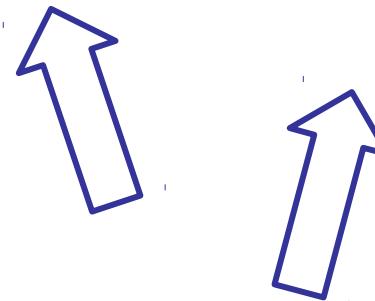
1

**Classical Bit**



**Qubit**

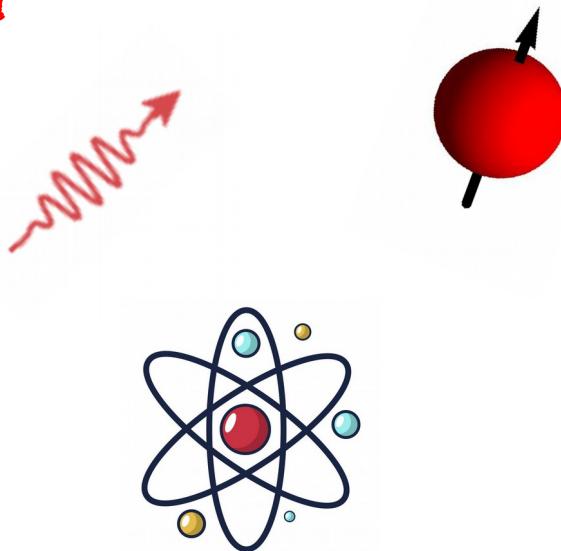
0



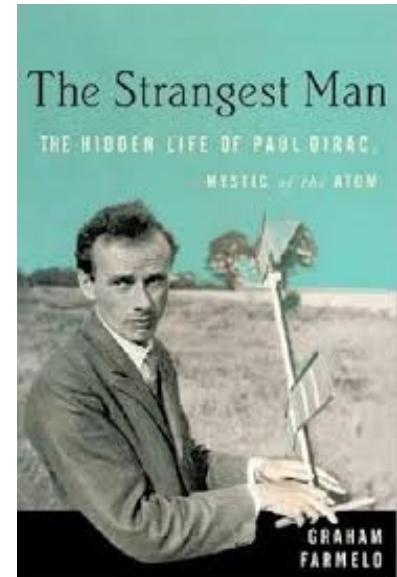
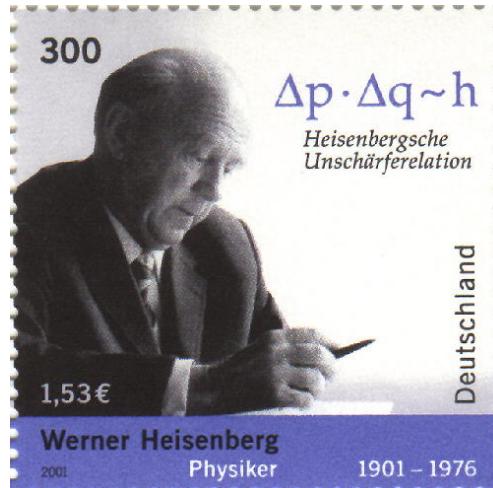
superpositie van  $|0\rangle$  en  $|1\rangle$

# Quantum informatica

$$\begin{aligned}
& \text{Left side: } \frac{\partial}{\partial t} \left( \frac{\psi(x,t)}{\psi_0(t)} \right) = \frac{\partial \psi}{\partial t} + \frac{\partial \psi_0}{\partial t} \frac{\psi}{\psi_0} = \frac{\partial \psi}{\partial t} + \frac{\partial \psi_0}{\partial t} \frac{\psi}{\psi_0} \\
& \text{Right side: } \frac{\hbar^2}{2m} \nabla^2 \left( \frac{\psi(x,t)}{\psi_0(t)} \right) = \frac{\hbar^2}{2m} \left( \frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi_0}{\partial t^2} \frac{\psi^2}{\psi_0^2} - \frac{2\psi_0 \partial \psi_0}{\psi_0^2} \frac{\psi}{\psi_0} \right) \\
& \text{Equating: } \frac{\partial \psi}{\partial t} + \frac{\partial \psi_0}{\partial t} \frac{\psi}{\psi_0} = \frac{\hbar^2}{2m} \left( \frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi_0}{\partial t^2} \frac{\psi^2}{\psi_0^2} - \frac{2\psi_0 \partial \psi_0}{\psi_0^2} \frac{\psi}{\psi_0} \right)
\end{aligned}$$



A graphic poster with a red background. At the top, the word "Warning" is written in large, white, sans-serif letters. Below it, the text reads: "Erwin Schrödinger will kill you like a cat in a box. Maybe." To the right of the text is a black and white caricature of the Austrian physicist Erwin Schrödinger. He is depicted with wild, curly hair, wearing round-rimmed glasses, and has a skeptical or weary expression.



# 3 quantum ingredienten



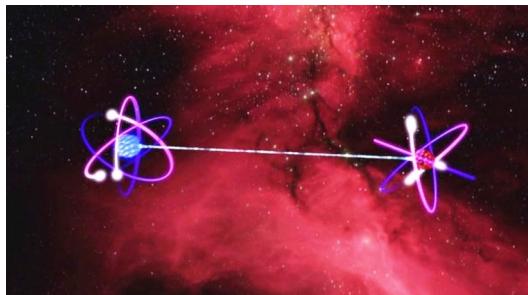
superpositie,

$$\text{bv } |0\rangle + |1\rangle$$



interferentie, bv

$$\begin{aligned} H(|0\rangle - |1\rangle) &= H|0\rangle - H|1\rangle \\ &= (|0\rangle + |1\rangle) - (|0\rangle - |1\rangle) = |1\rangle \end{aligned}$$



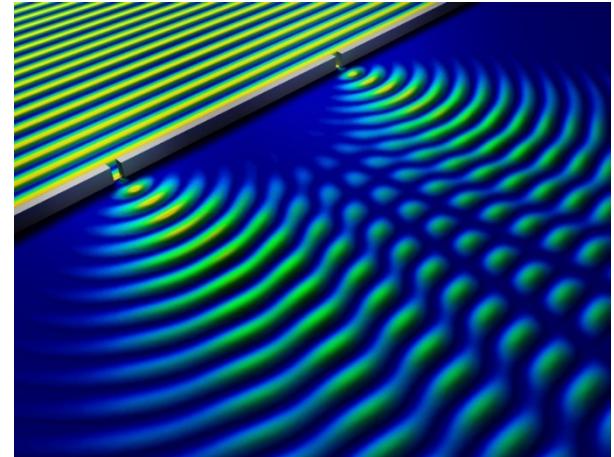
verstrekking,

$$\text{bv } |00\rangle + |11\rangle$$

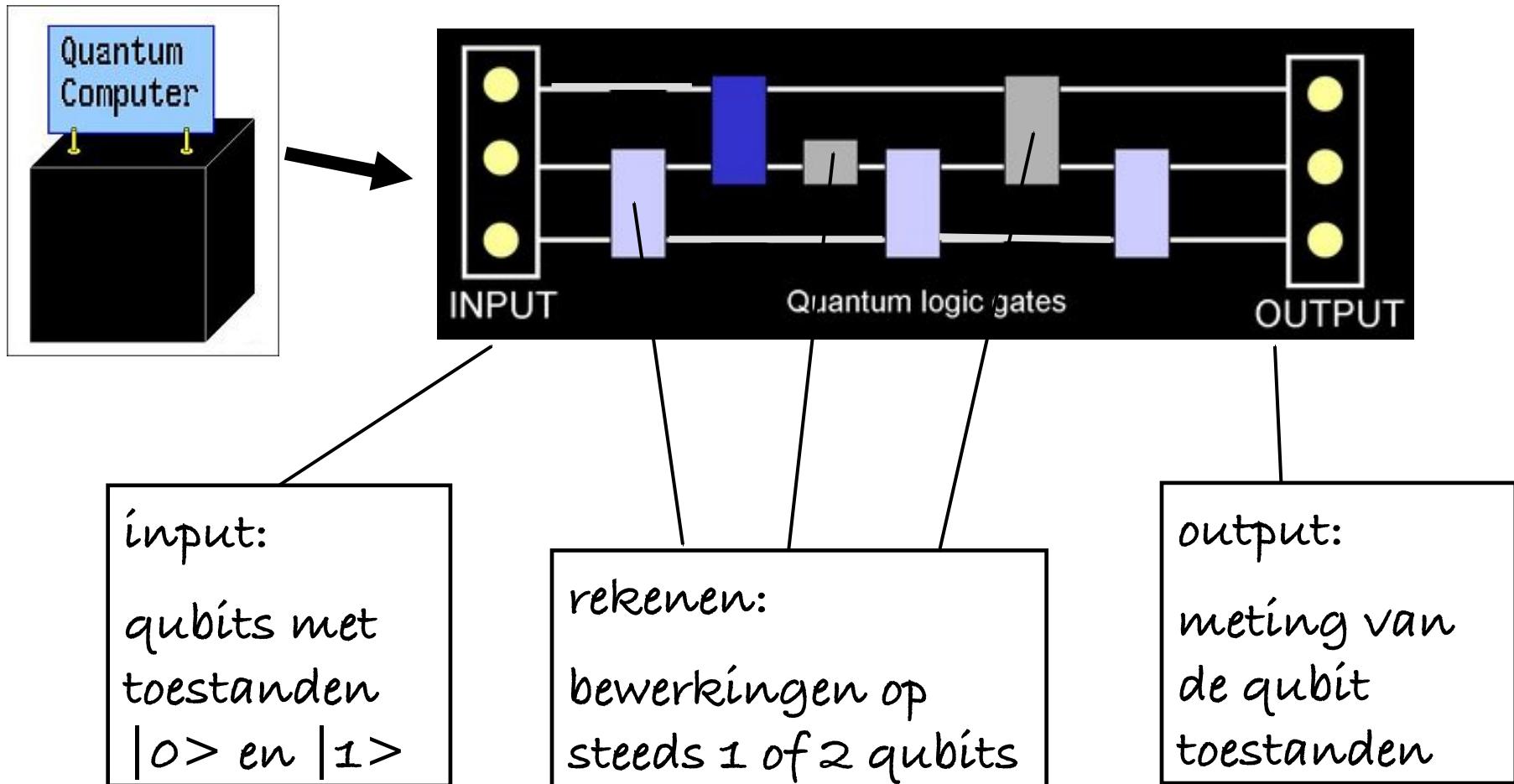
Quantum programmeren is net als  
mooie muziek maken

Geluidsgolven interfereren tot  
mooie muziek

Qubits in superpositie  
interfereren op een  
nuttige manier



# quantumcomputers



"quantum circuit"

# quantumberekening

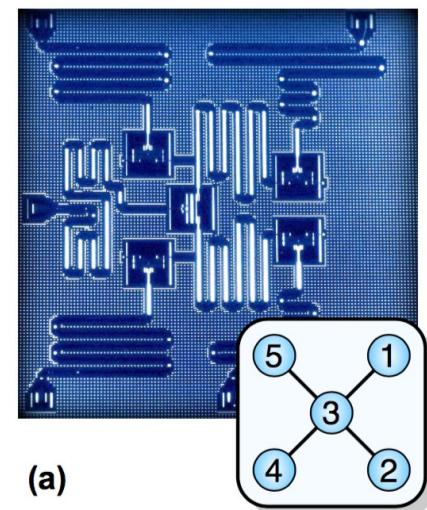
opdracht [1e jaars vak aan UvA, 2017]

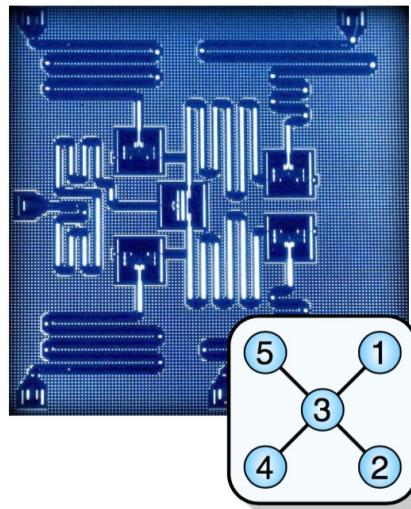
+ ontwerp quantumcircuit voor 5  
qubits met als output de GHZ toestand

$$\frac{1}{\sqrt{2}}(|00000\rangle + |11111\rangle)$$

+ programmeer dit op een echte  
quantumcomputer

# IBM Q - 5 qubit quantumcomputer

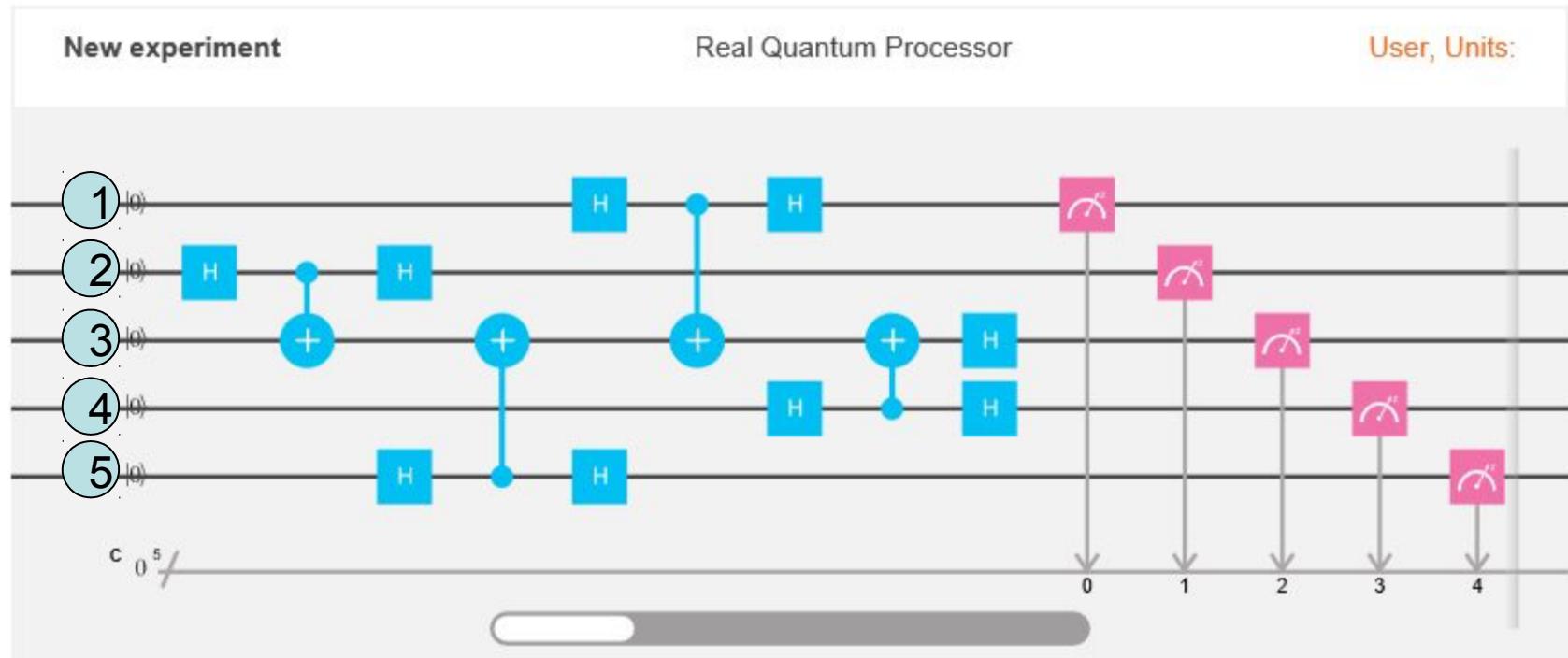




# IBM Q

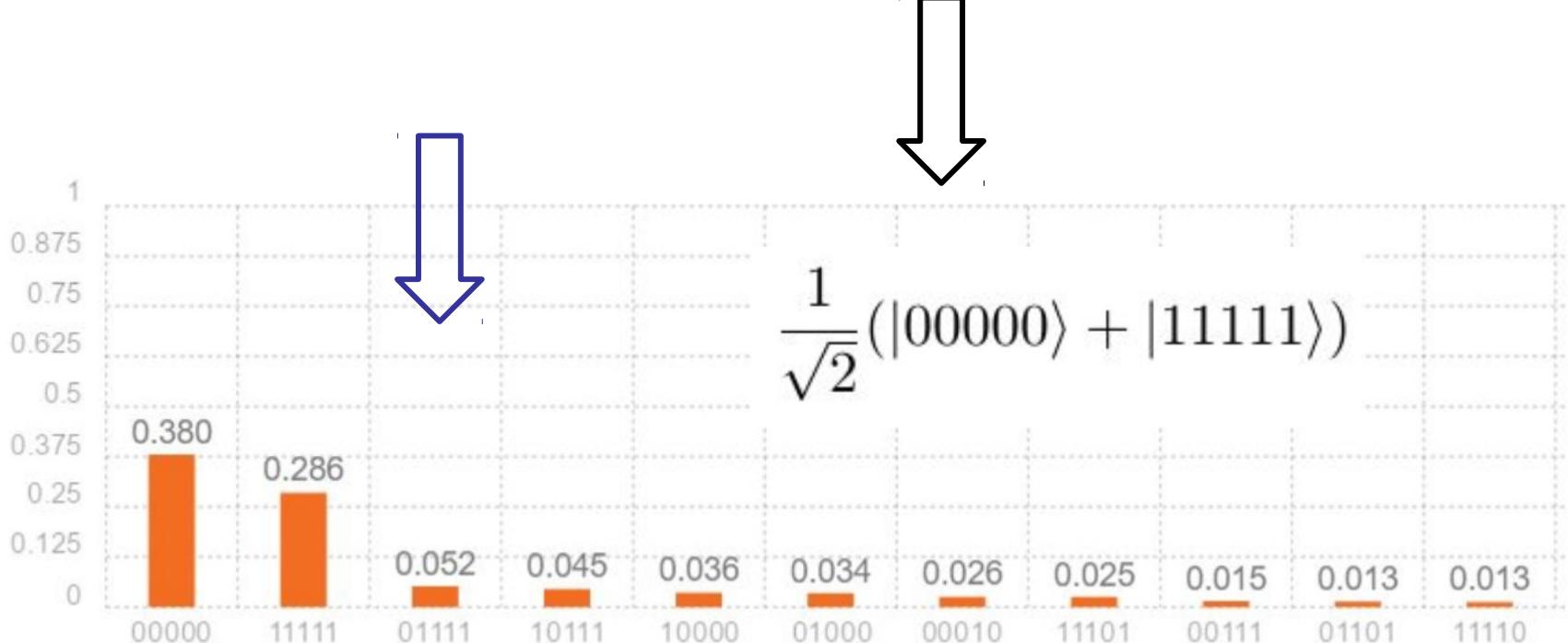
## quantumcircuit voor de toestand

$$\frac{1}{\sqrt{2}}(|00000\rangle + |11111\rangle)$$



quantum circuit voor  
de 5-qubit GHz toestand

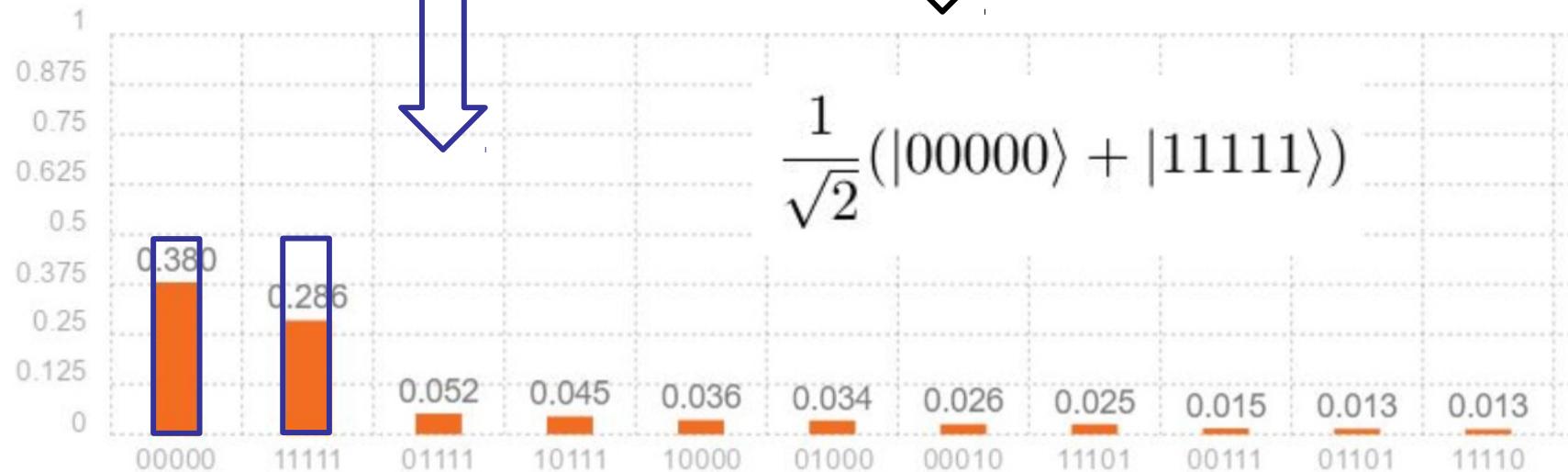
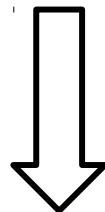
het werkt ...



quantum circuit voor  
de 5-qubit GHz toestand

het werkt ...

maar het is niet perfect!



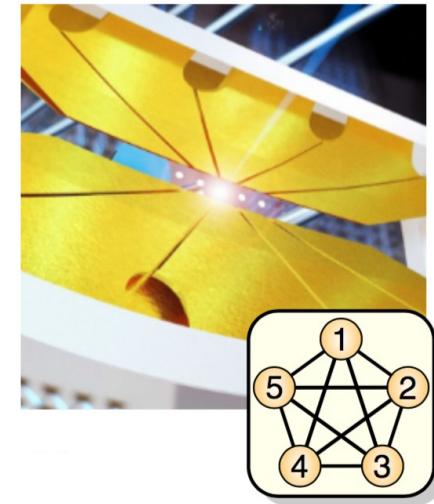
ref: Thomas Goldman, Jair Lenssen en Roy van der Linden,  
eindproject, honours extensie af1, 2017

**IonQ – quantumrekenen met ionen**

**Atoms make better  
quantum computers.**



COLLEGE PARK, MD — DECEMBER 11, 2018



**IonQ harnesses single-atom  
qubits to build the world's most  
powerful quantum computer.**

# Quantum zoekalgoritme



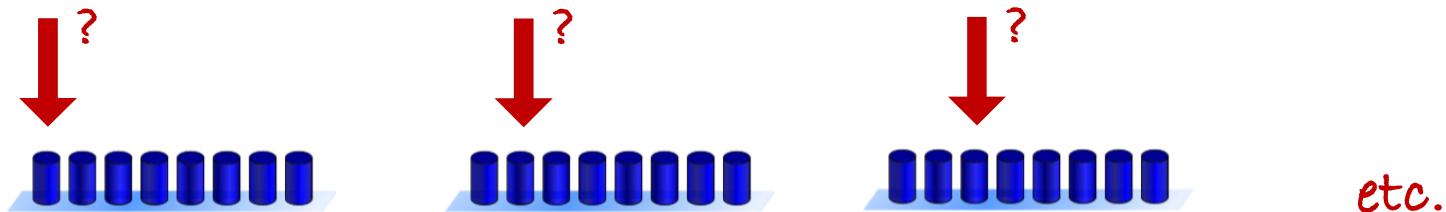
Probleem: gegeven een data-bestand met  $N$  elementen (telefoonboek), vindt één speciaal element (persoon met bepaald nummer) waarbij je het boek zo weinig mogelijk wilt raadplegen

# Quantum zoekalgoritme

Probleem: zoek speciaal element in data-bestand  
(telefoonboek)

beste strategie met gewone computer

brute force search

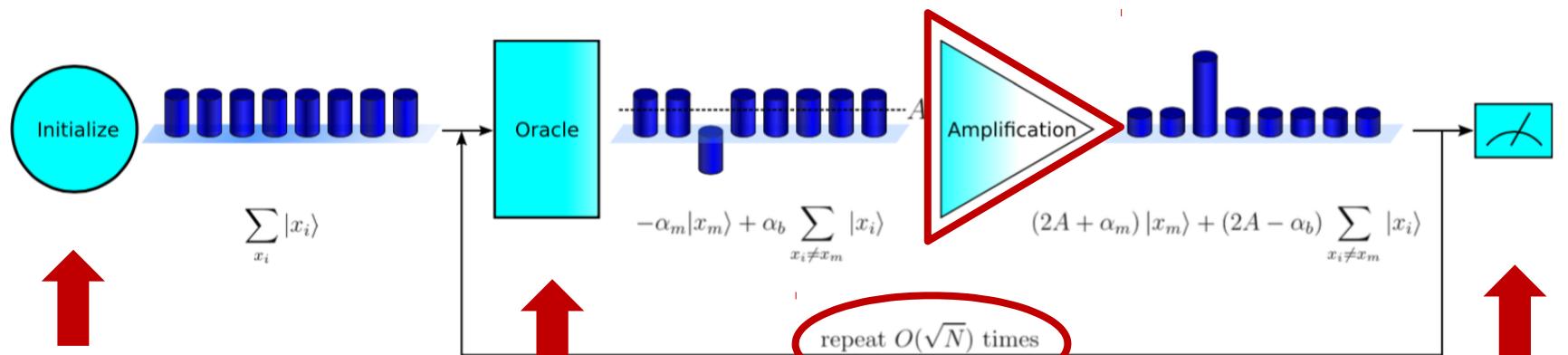


nodig: gemiddeld  $N/2$  maal het boek raadplegen

# Quantum zoekgoritme

Probleem: zoek speciaal element in data-bestand  
(telefoonboek)

strategie op quantum computer



quantum toestand met  
all amplitudes gelijk

het 'boek'  
raadplegen

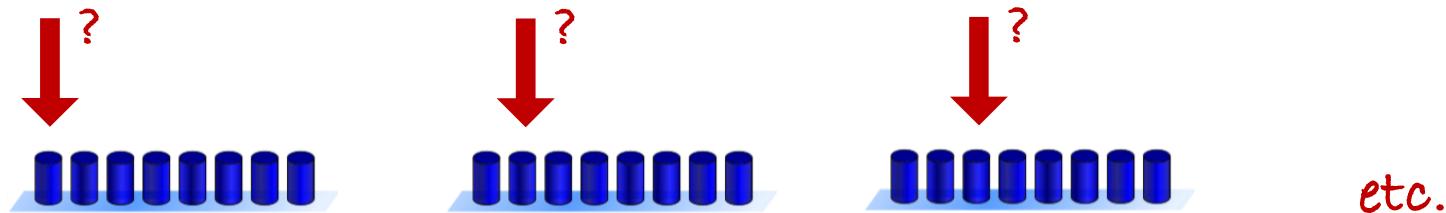
meting van de  
quantum toestand

# Quantum zoekalgoritme

Probleem: zoek speciaal element in data-bestand  
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beste strategie met gewone computer

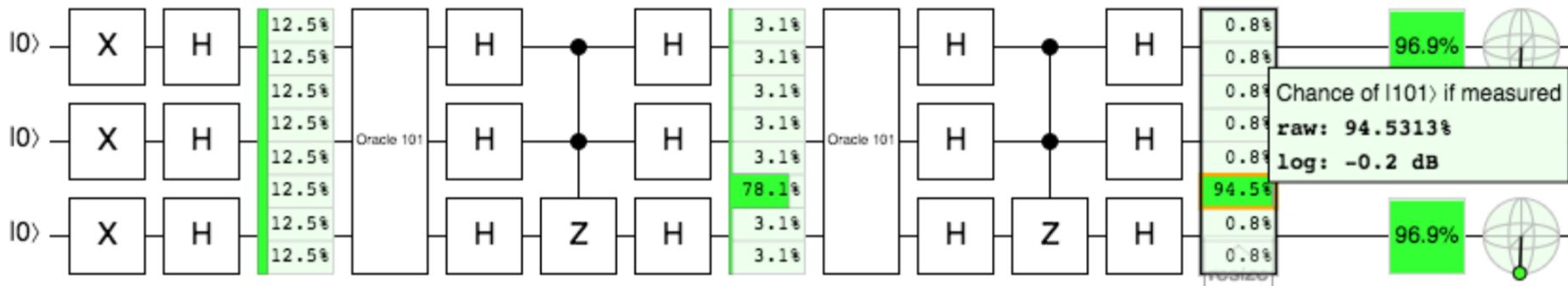
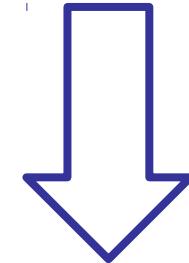
brute force search



nodig: gemiddeld  $N/2$  maal het boek raadplegen

# Quantum zoekalgoritme

Grover's quantum zoek-algoritme:  
implementatie op 3 qubits

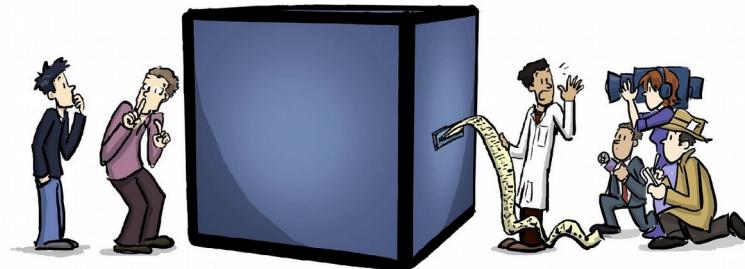


vindt het speciale getal  $5 = 101$  binnen een dataset met 8 mogelijke getallen  $0, 1, 2, \dots, 7$

# Wat kan een quantumcomputer?

- + Snelle quantumalgoritmes voor zoeken door grote databestanden
- + rekenen aan chemie en materialen
- + optimalisatie problemen
- + Codes kraken

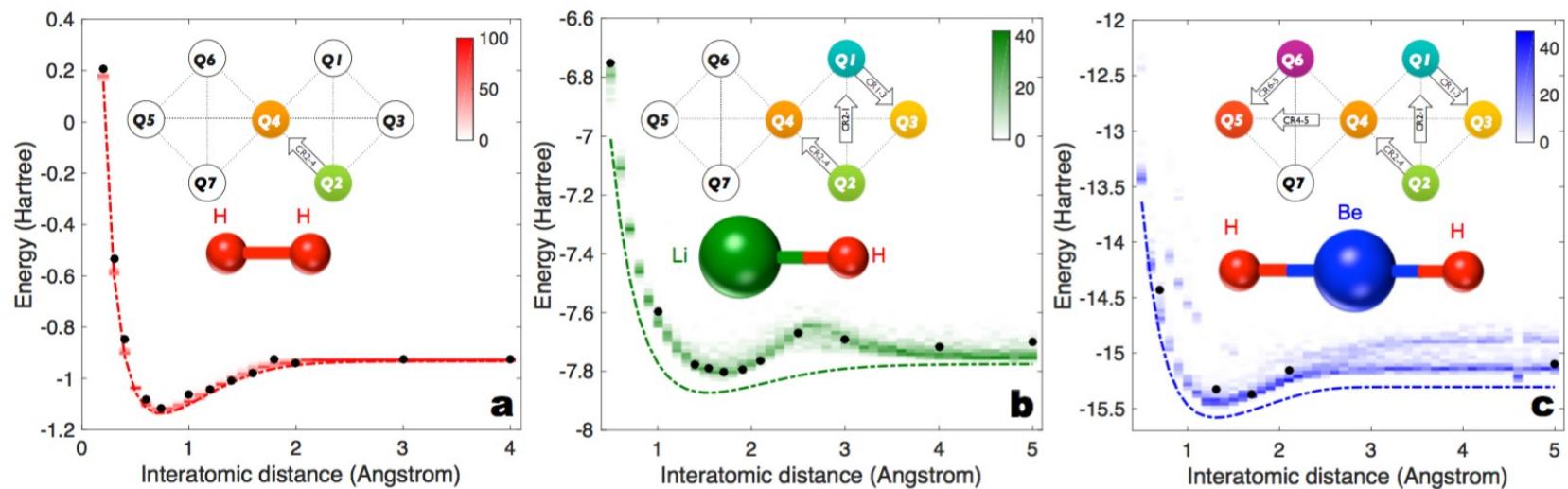
A Quantum  
COMPUTER



# chemie met een quantumcomputer

berekeningen aan de structuur van (kleine) moleculen op een quantum computer

(<https://arxiv.org/abs/1704.05018>)



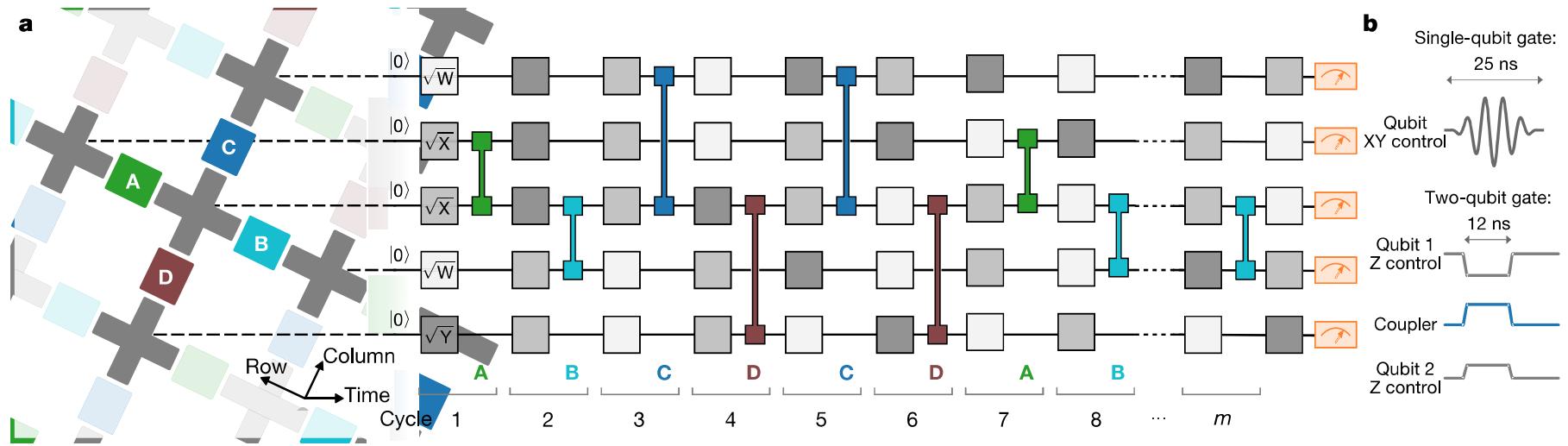
# Codes kraken met een quantumcomputer

Alle huidige public-key cryptografie (RSA, elliptic curves) kan gebroken worden door een (grootschalige) quantum computer.

- Hoe kunnen we de huidige cryptografie vervangen door systemen die veilig zijn tegen quantum aanvallers?
- Hoe kunnen we wel veilig communiceren met de hulp van quantum communicatie?

Luister naar [Cryptocast #87](#) over de impact op cryptocurrencies

# breaking news ...



Probleem : 'random circuit sampling'  
Circuit: 53 qubits,  
1113 1-qubit gates,  
430 2-qubit gates

# breaking news ...

Dario Gil, head of IBM Research, advises against using quantum supremacy as a metric with which to measure progress in the field. "The experiment and the 'supremacy' term will be misunderstood by nearly all," he told *Fortune*.

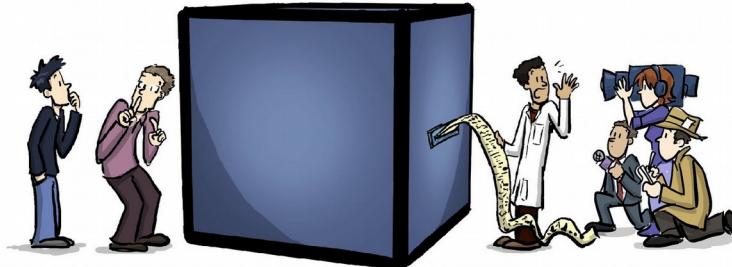
Gil described the experiment as a highly special case "laboratory experiment" that has "no practical applications." He added, "Quantum computers will never reign 'supreme' over classical computers, but will rather work in concert with them, since each have their unique strengths."

# breaking news ...

Jim Clarke, Intel Labs' director of quantum hardware, called Google's update "a notable mile marker." He said that "a commercially viable quantum computer will require" many R&D advancements before becoming a reality.

"While development is still at mile one of this marathon, we strongly believe in the potential of this technology," Clarke added.

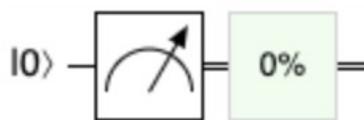
## A Quantum COMPUTER



vragen?

# Opdracht 1

- <https://www.quantum-quest.nl/>
- Download & browse lecture notes  
“The Quantum Quest”
- Section 1.3: Get started with  
<https://www.quantum-quest.nl/quirky/>
- Measure a qubit:

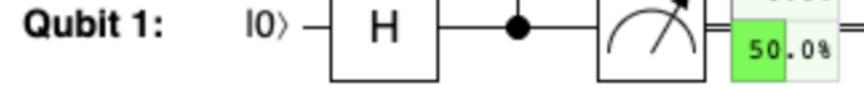
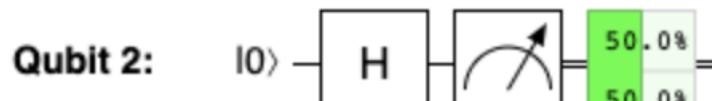
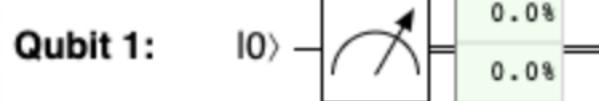
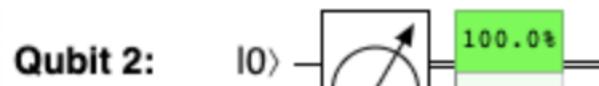


## Opdracht 2

- Create a Superposition:



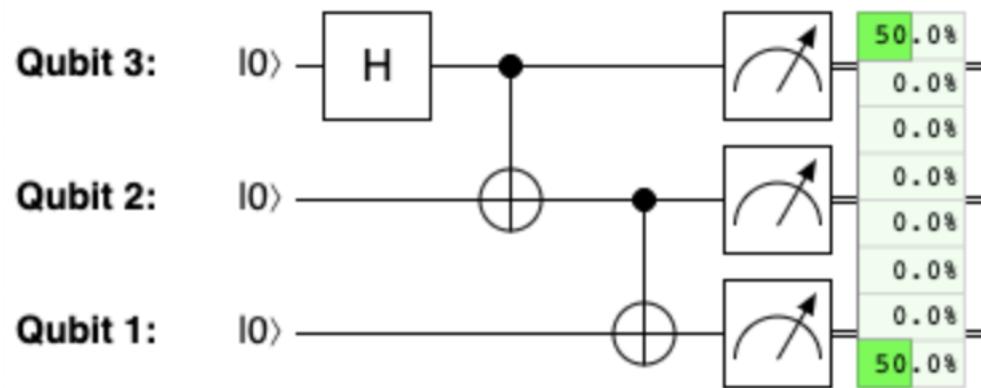
- Play with two qubits: (Quirky Quest 2)



verstrekking!

## Opdracht 3

- Create a GHZ state: (Quirky Quest 3)



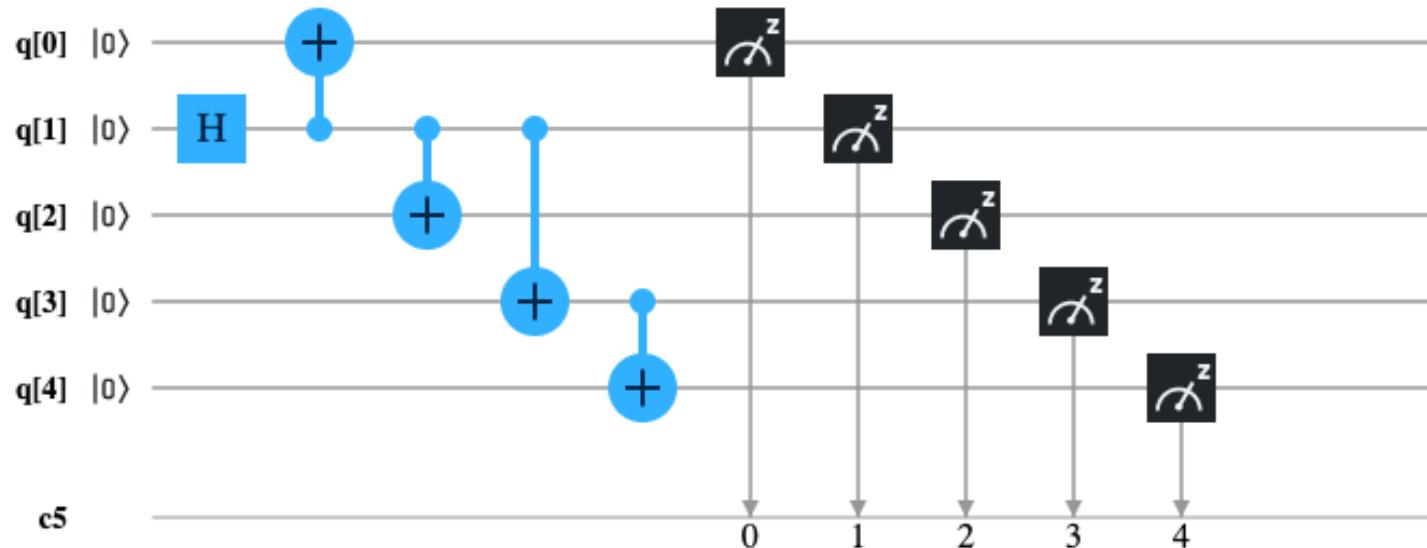
$$\frac{|0000\rangle + |1111\rangle}{\sqrt{2}}$$

- Can you make a 4-qubit GHZ state?

$$\frac{|0000\rangle + |1111\rangle}{\sqrt{2}}$$

## Opdracht 4

- Get access to the IBM Q experience:  
<https://quantum-computing.ibm.com/login>



- Program this circuit and run it on a real quantum computer
- What does it do? How well does it work?