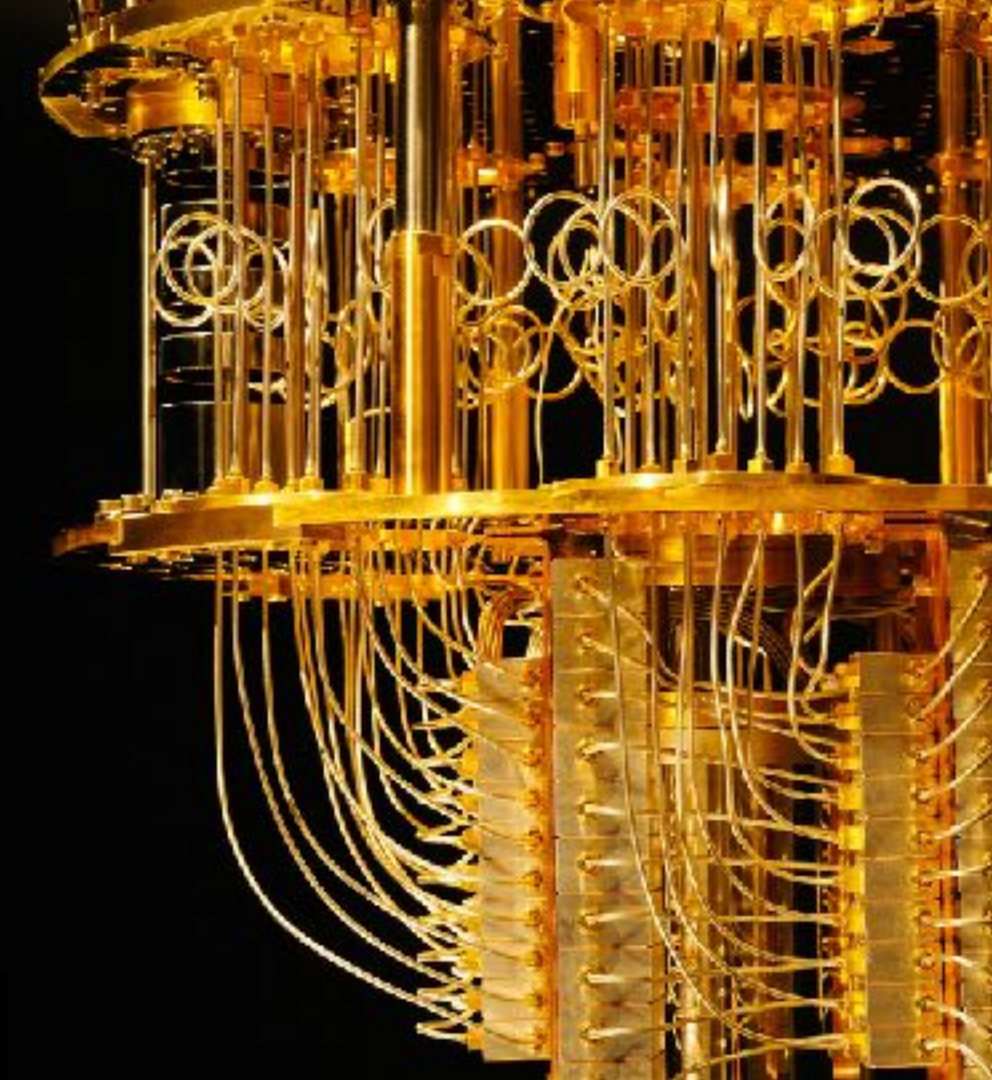
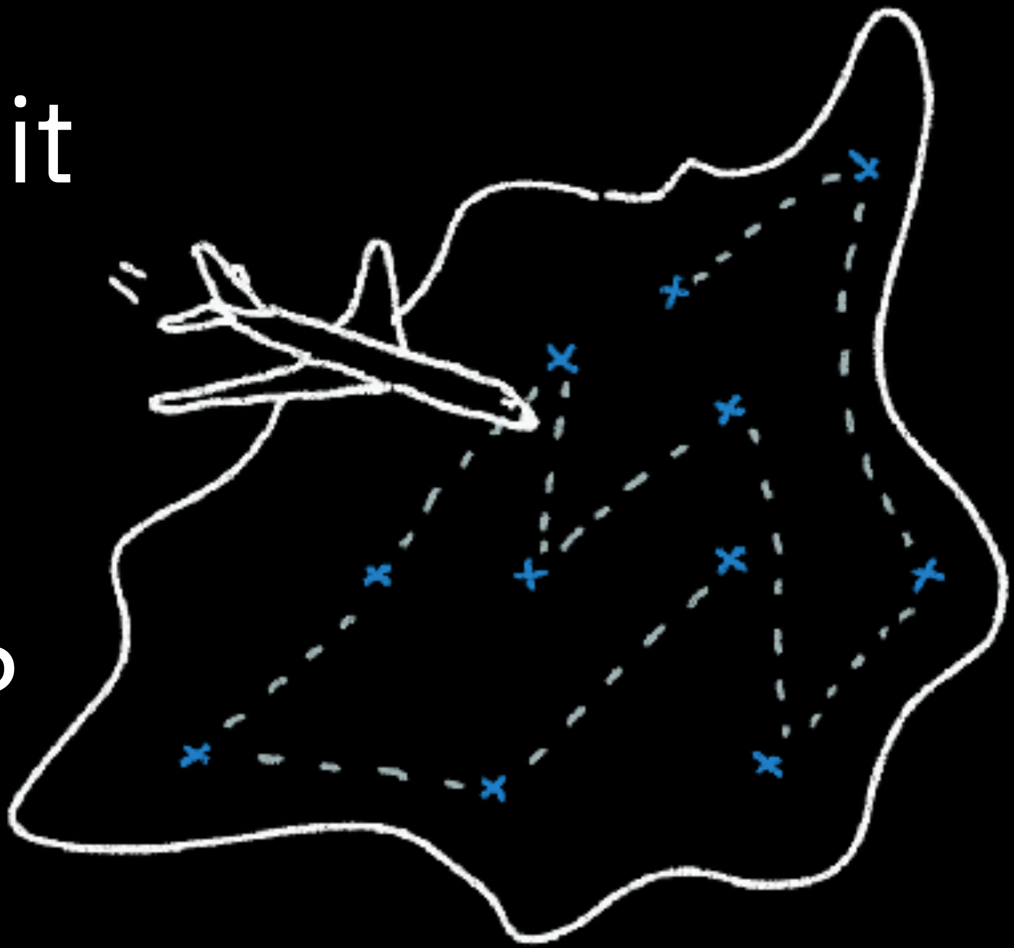
Cats, Qubits, and Clouds
The Quantum Future



Dr. Holly Cummins
IBM **Cloud** Garage
World Wide Garage Development Lead
IBM Q Ambassador
@holly_cummins

How can we visit multiple destinations with the least amount of fuel?



We don’t know.

We have the formula, but calculating the answer takes too **long**.

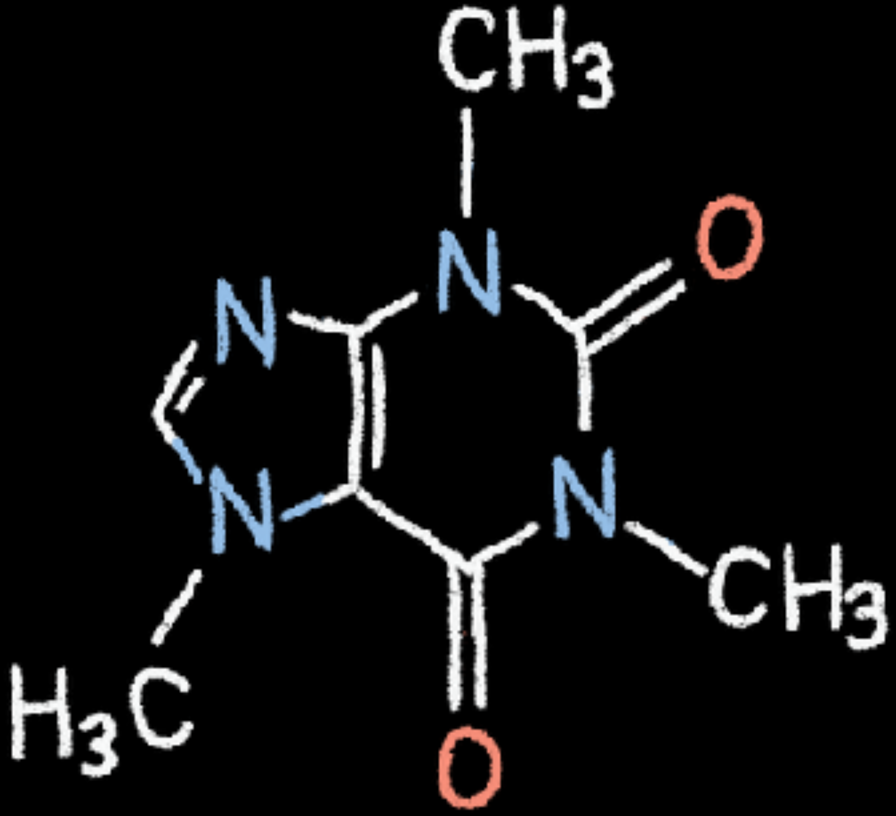
10 cities:
answer in
25 minutes

10 cities:
answer in
25 minutes

16 cities:
answer in
27 years


THINK

Caffeine



Everything interacts with **everything** else.

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For a simple molecule,
the equation doesn't look
like this …

$$\begin{bmatrix} a \\ b \end{bmatrix}\begin{bmatrix} c \\ d \end{bmatrix}$$

Everything interacts with **everything** else.

For a simple molecule, the equation doesn't look like this …

$$\begin{bmatrix} a \\ b \end{bmatrix} \begin{bmatrix} c \\ d \end{bmatrix}$$

$$\begin{bmatrix} a & c \\ b & d \end{bmatrix}$$

… it looks like this.

It’s not this …

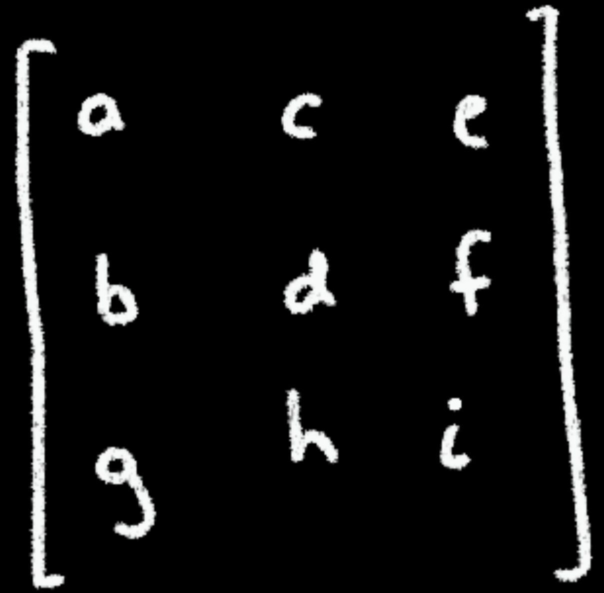
$$\begin{bmatrix} a \\ b \end{bmatrix} \begin{bmatrix} c \\ d \end{bmatrix} \begin{bmatrix} e \\ f \end{bmatrix}$$

$$\begin{bmatrix} a & c & e \\ b & d & f \\ g & h & i \end{bmatrix}$$

….it’s this.

we all know from software development, handling big problems is **hard** unless ...

... we can break them down into small problems



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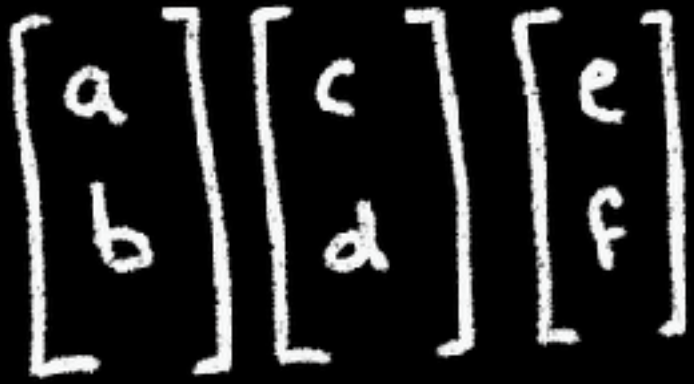
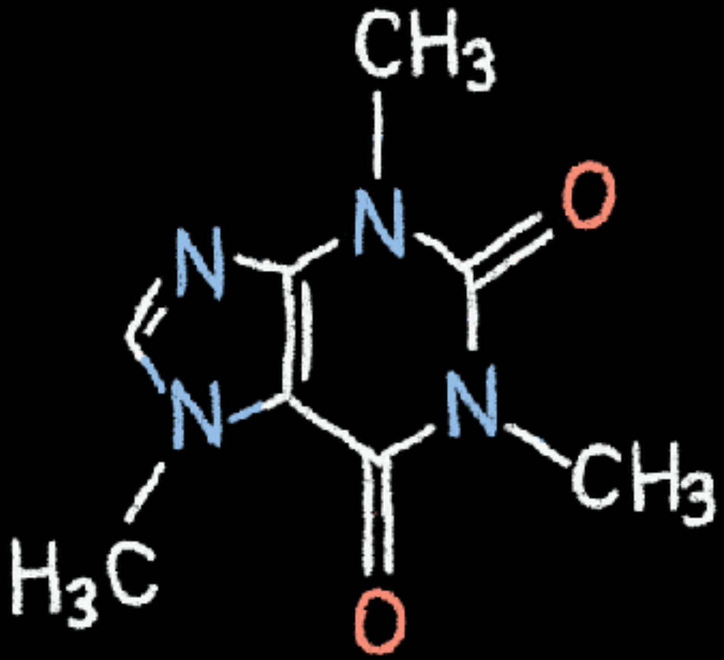


Modelling this needs

10^{48}

bits.



1,000,000,000,000,0
00,000,000,000,000,
000,000,000,000,000
,000,000 bits

If

If

1 bit == 1 atom

If

1 bit == 1 atom

...

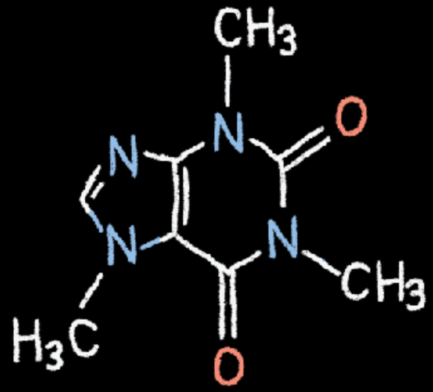
If

1 bit == 1 atom

...

We would use 1-10% of the **earth**.

How can something so **small** be so **hard**?



$$O(2^n)$$

$$O(2^n)$$

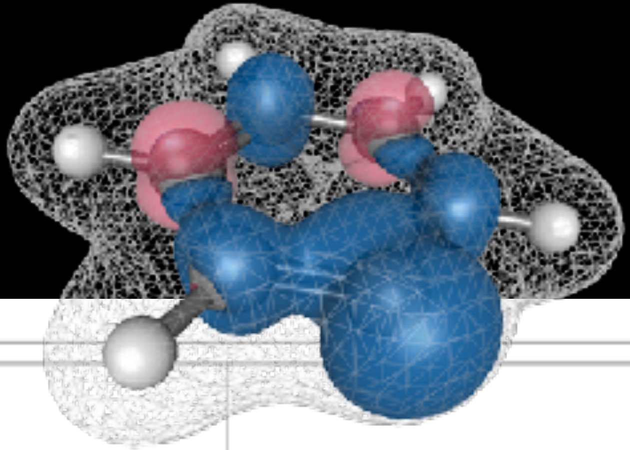
exponential growth

The **best** supercomputer in the world can accurately simulate a **40-50** electron system.

So we

approximate.

How good are the approximations?



Species	Name	Bond Length (Å)		
		Experimental	Calculated	Difference
CaF	Calcium monofluoride	1.967	4.079	2.112
Na_2	Sodium diatomic	3.079	2.379	-0.700

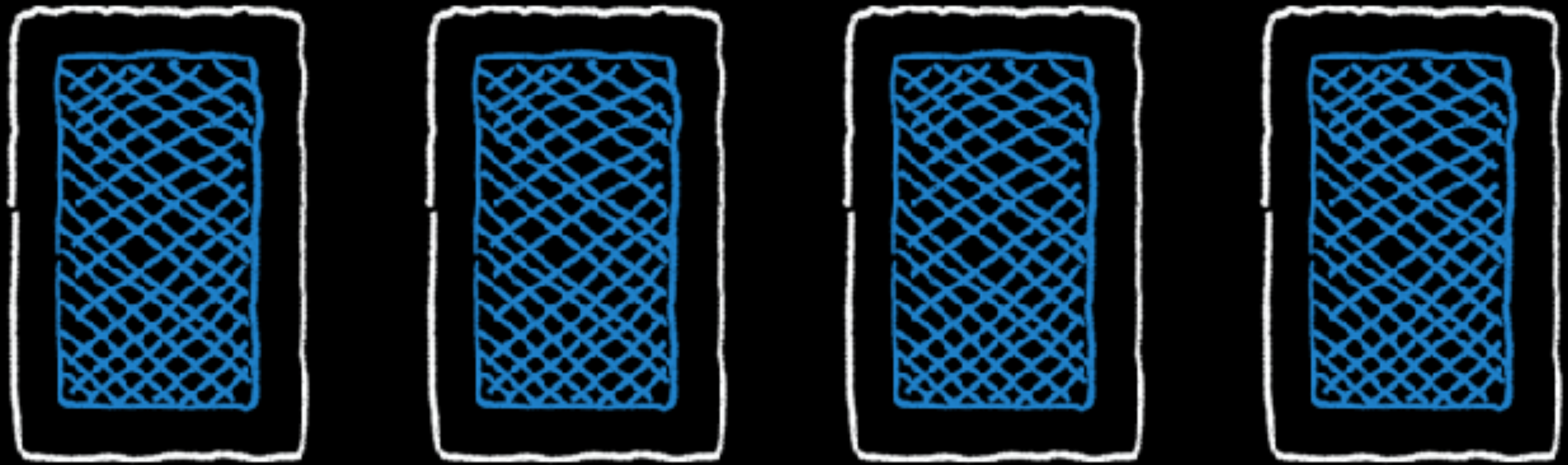
Source: http://cccbdb.nist.gov

If **nature** has a lot of computational complexity, can we use it for computations?

yes

(for some categories of problems)

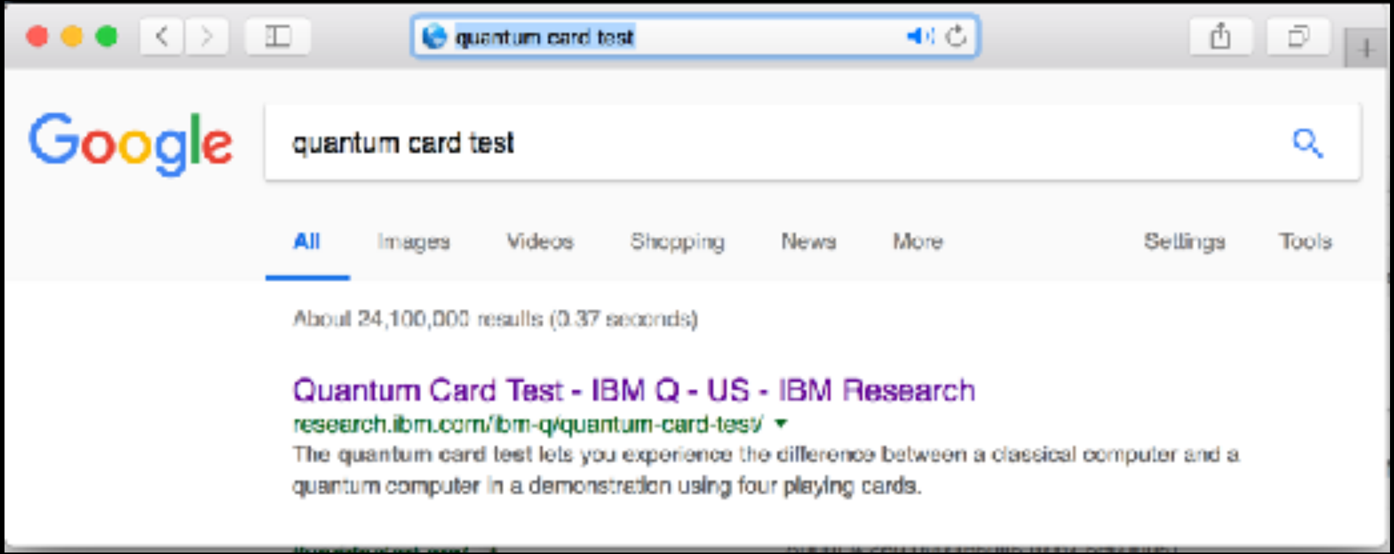

0581 236891



Where's the Queen?

Where's the Queen?

$O(n)$



quantum card test
Google
quantum card test
All
Images
Videos
Shopping
News
More
Settings
Tools
About 24,100,000 results (0.37 seconds)
Quantum Card Test - IBM Q - US - IBM Research
research.ibm.com/ibm-q/quantum-card-test/
The quantum card test lets you experience the difference between a classical computer and a quantum computer in a demonstration using four playing cards.

$$O(\sqrt{n})$$

We can search for an **answer** to a problem

as long as it's quick to verify correctness.

how do quantum computers work?

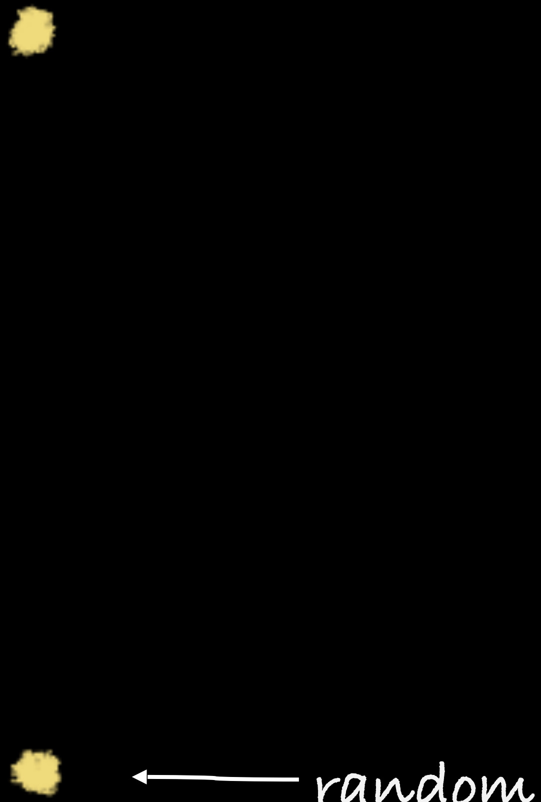
superposition

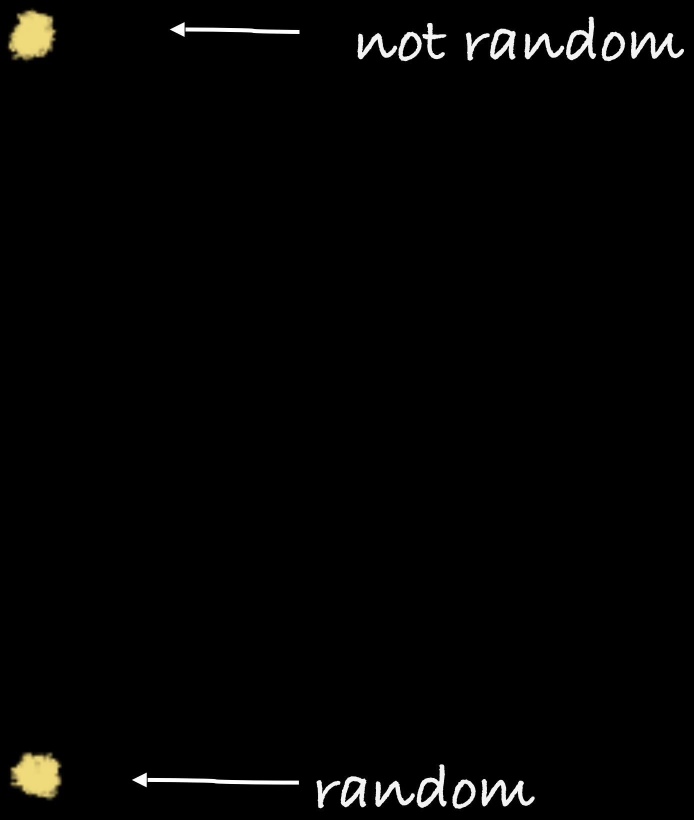
superposition

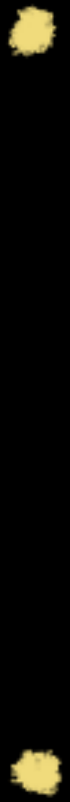
(“being two opposite things at the same time”)

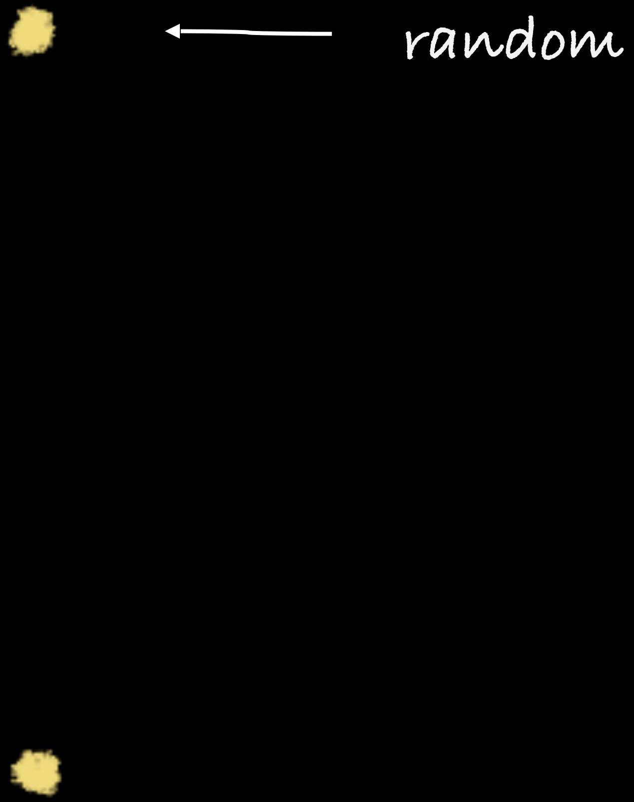
Schrödinger's famous cat

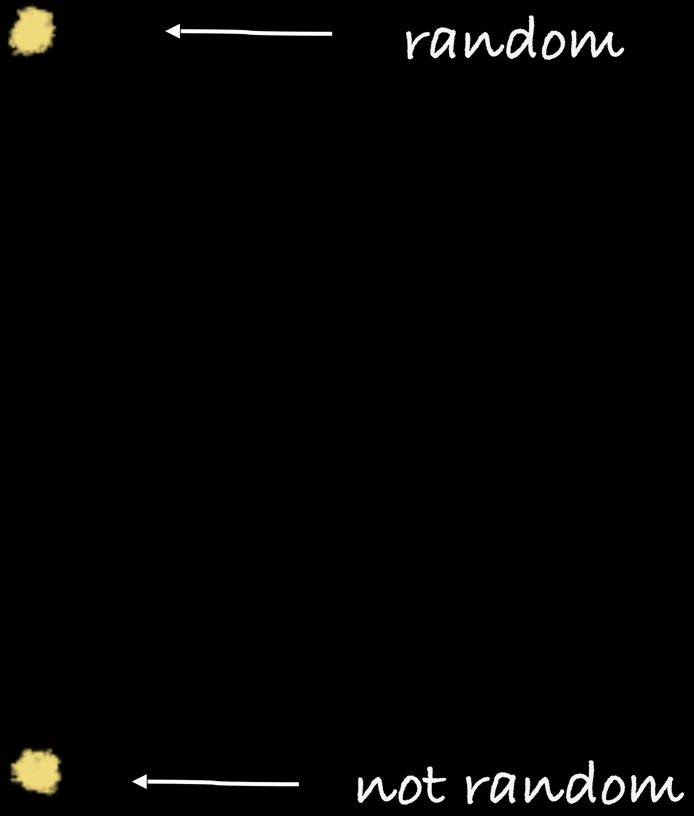
entanglement


random


not random
random




random


random
not random

random

How can one particle **know** we measured the other one?

not random

A physical state that is in a definite state can still behave randomly.

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Two systems that are too far apart to influence each other can still behave in ways that, although individually random, are still strongly correlated.

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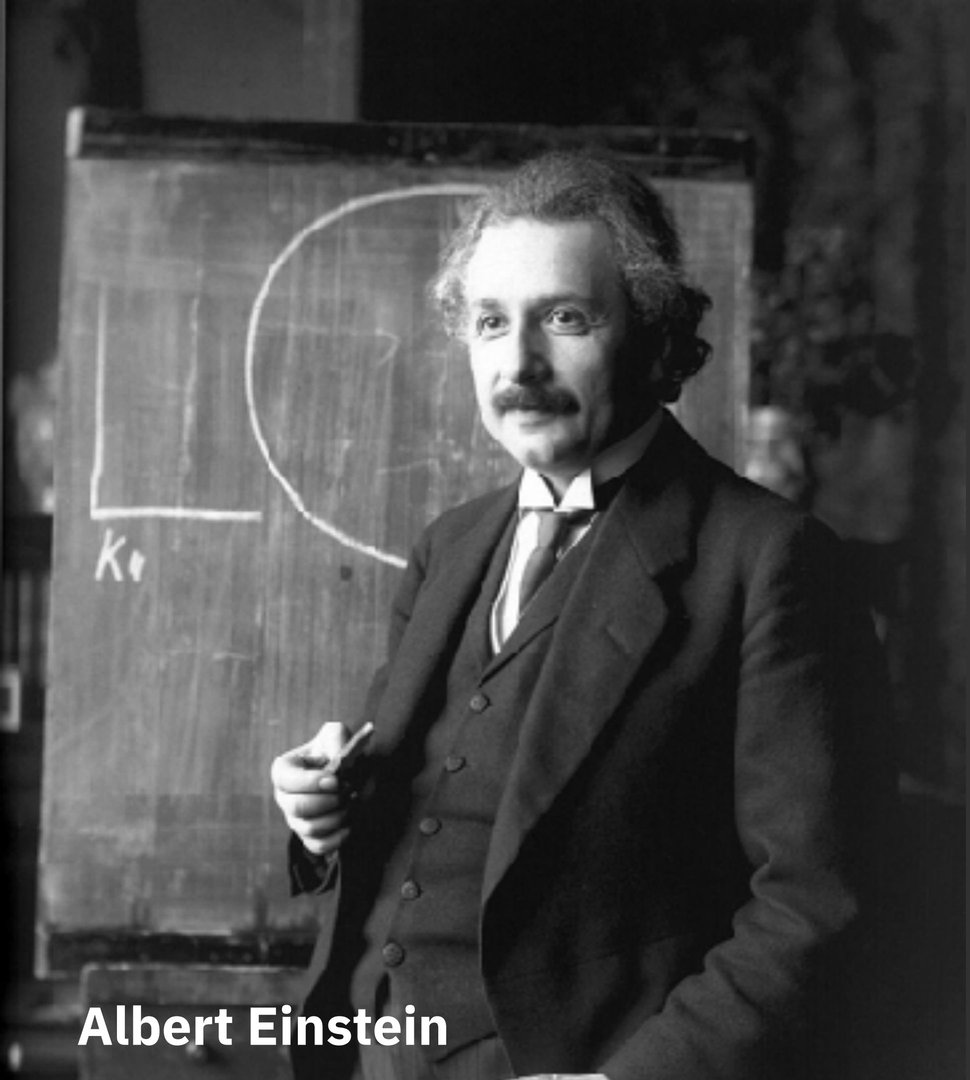
Quantum computing is about working out how to **use** these two principles for a new model of computation.

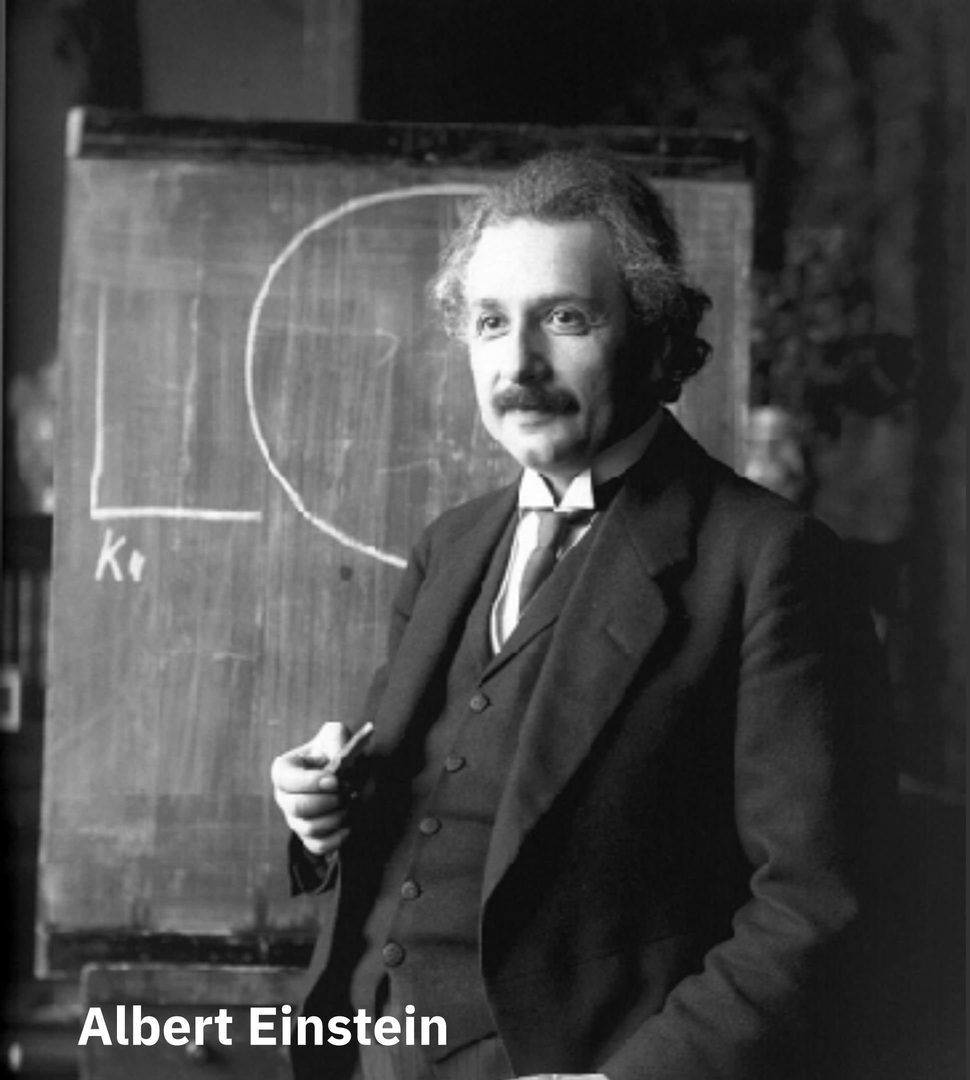
If you find this confusing, you **should**.

The physicists who discovered this were **totally** confused.

“You surely must understand that the whole idea of quantum **jumps** necessarily leads to **nonsense.**”



“God does **not** play dice.”



Albert Einstein

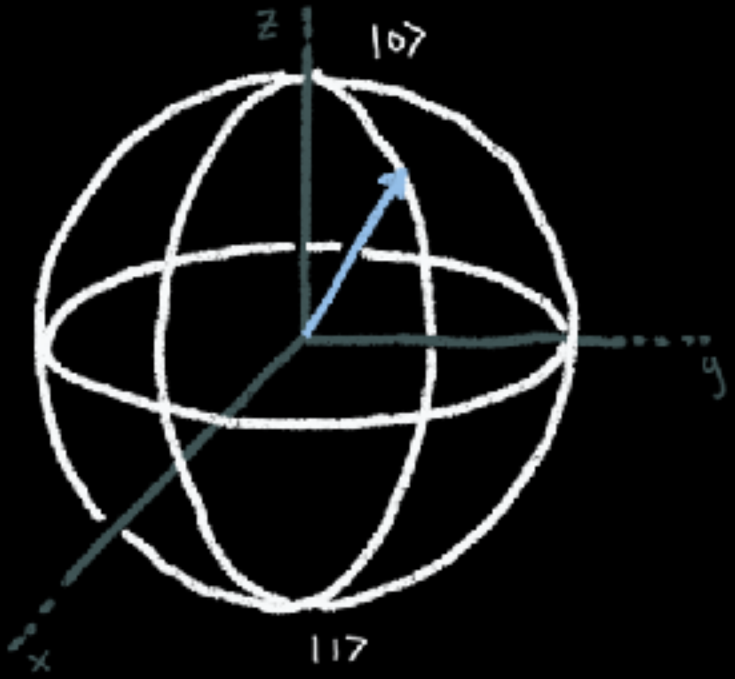
"… physics should represent a reality in time and space, free from **spooky** actions at a **distance**."

you can completely **ignore** the physics

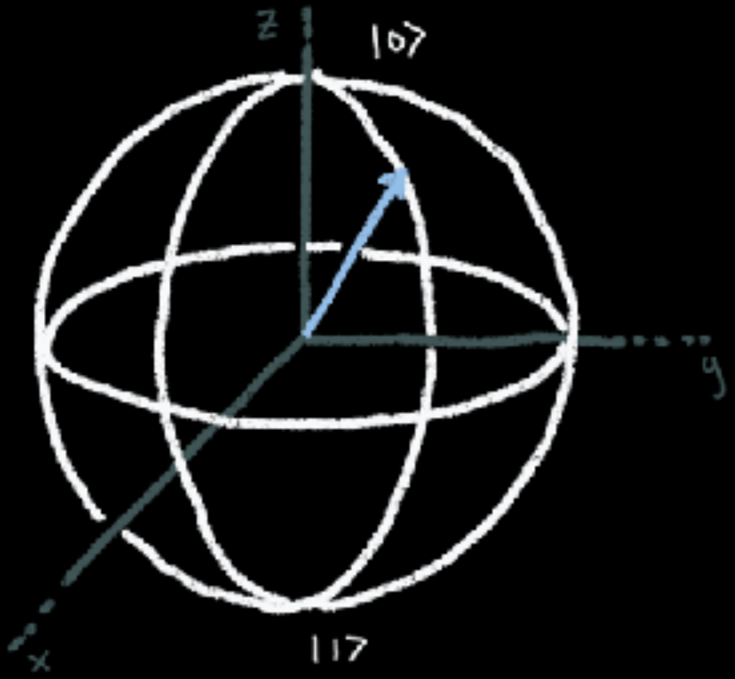
quantum information

a classical bit

a quantum bit

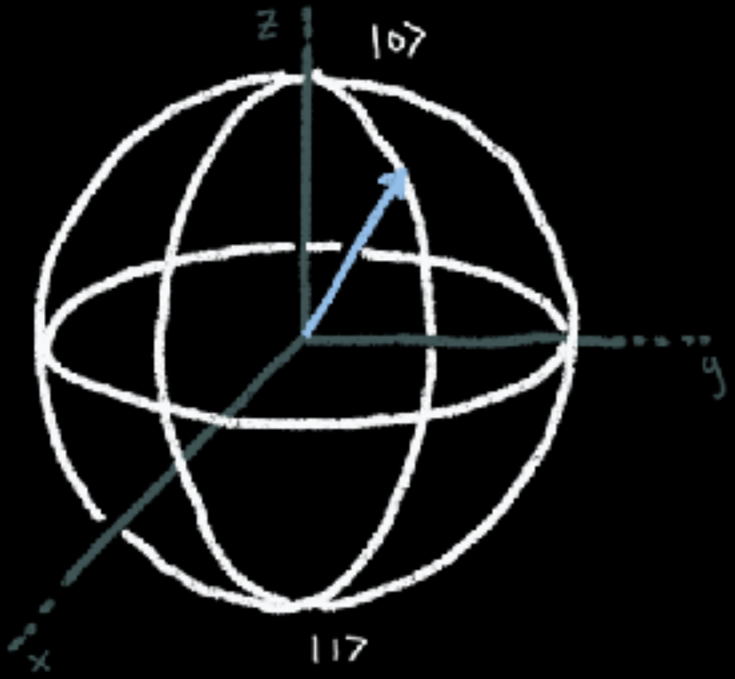


a qubit

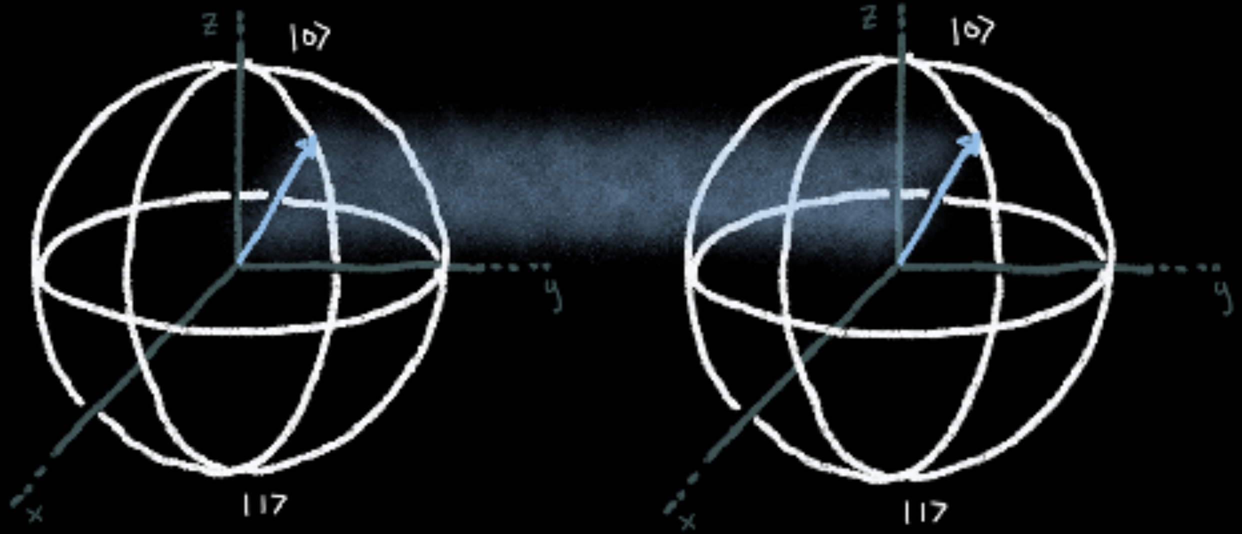


a qubit

a **superposition** of 0 and 1

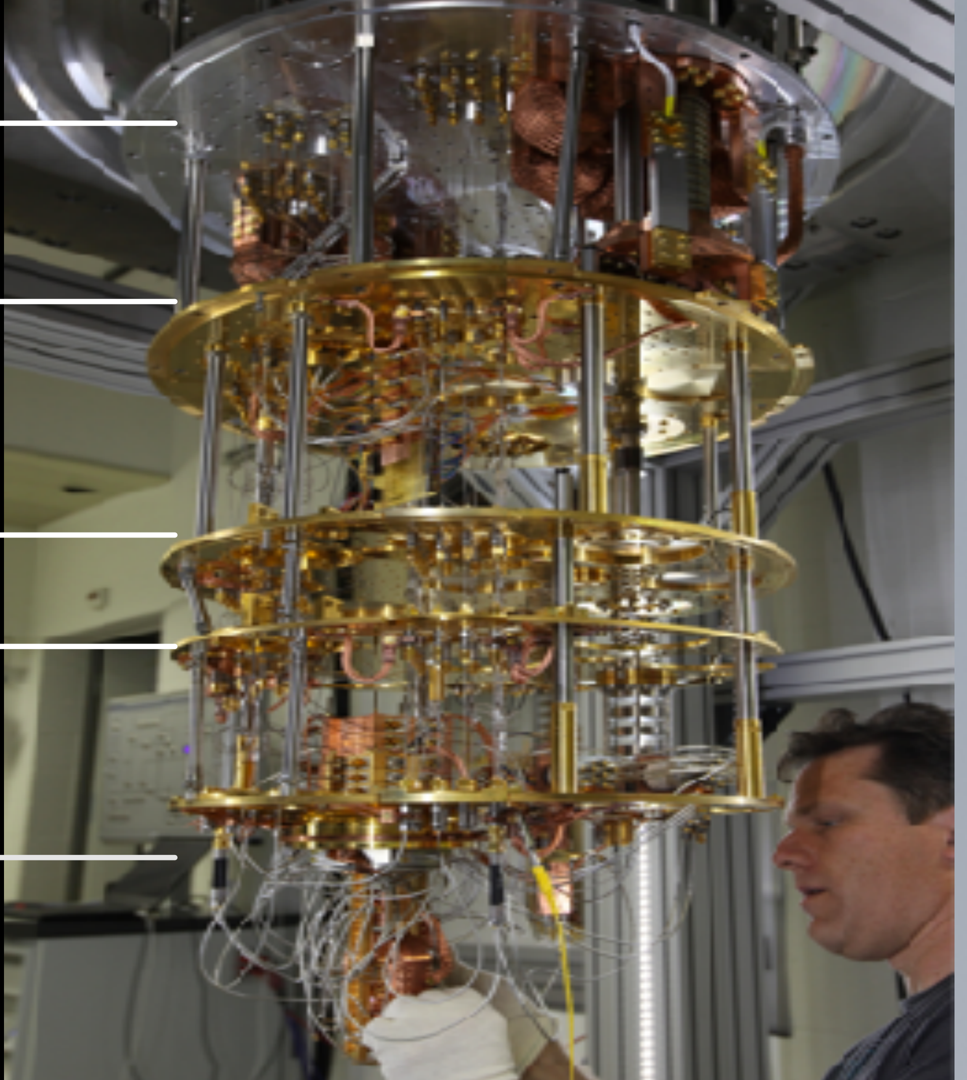


entangled qubits



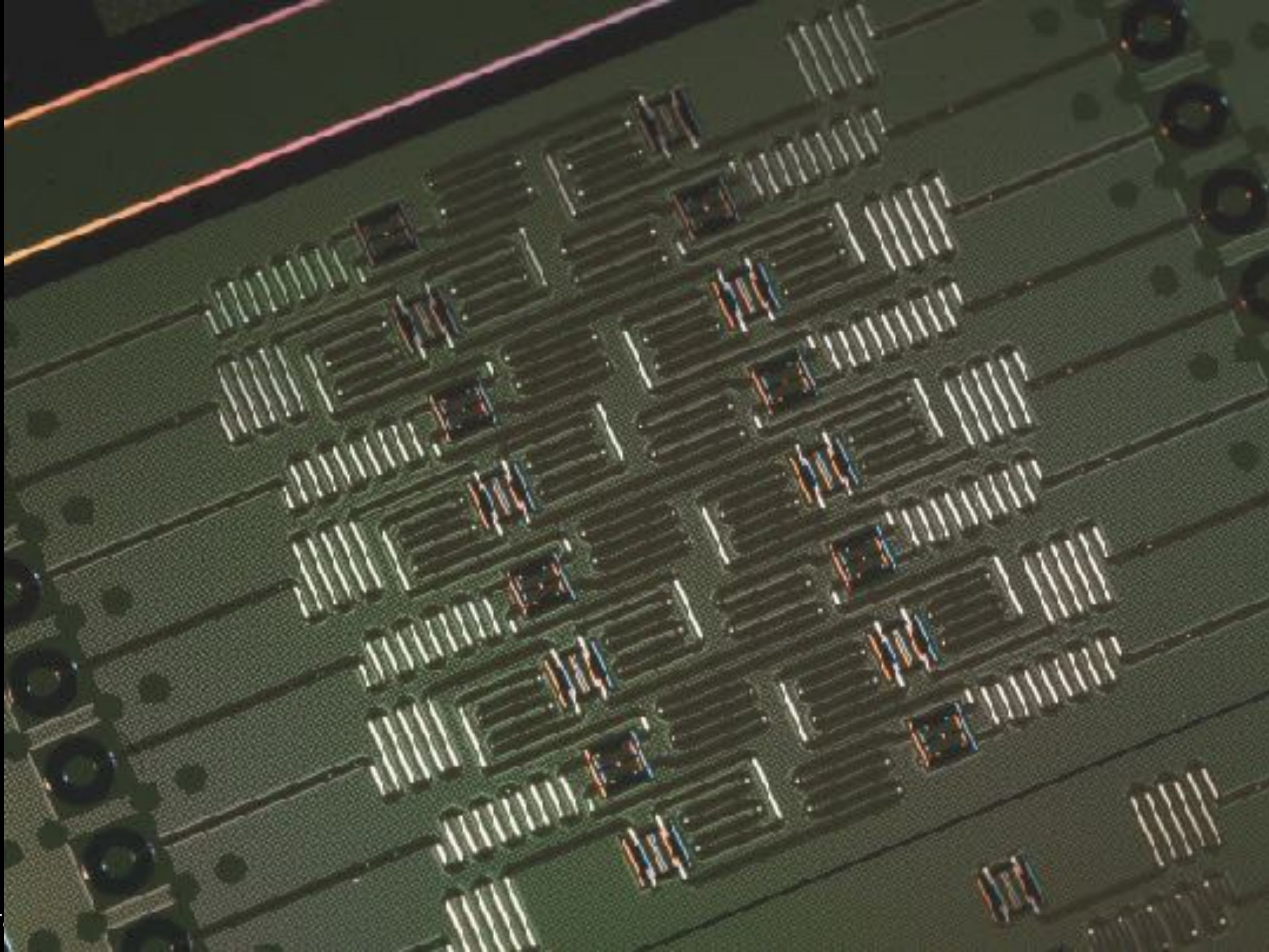
What does a quantum computer look like?

This is the fridge and supporting electronics.

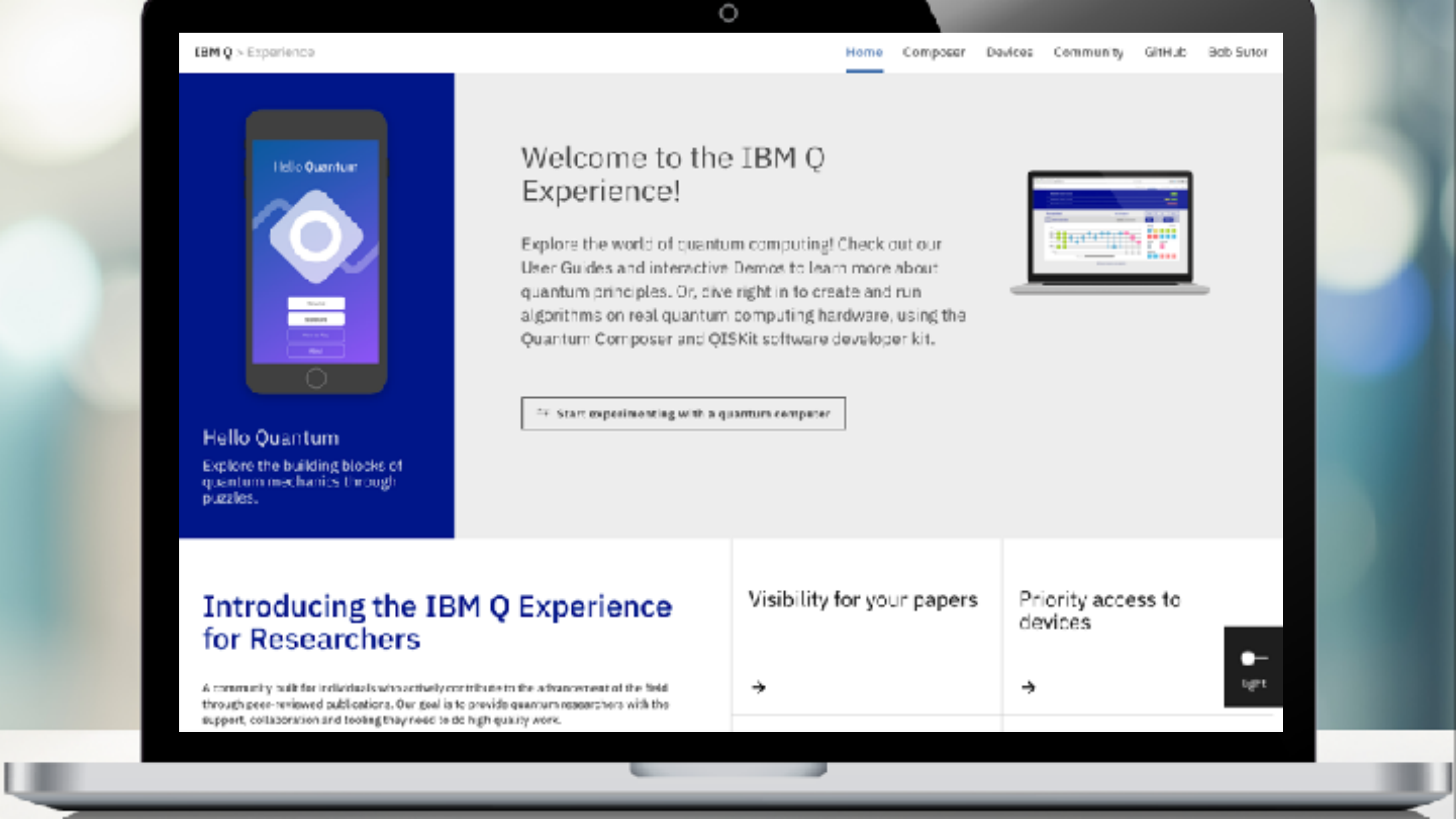


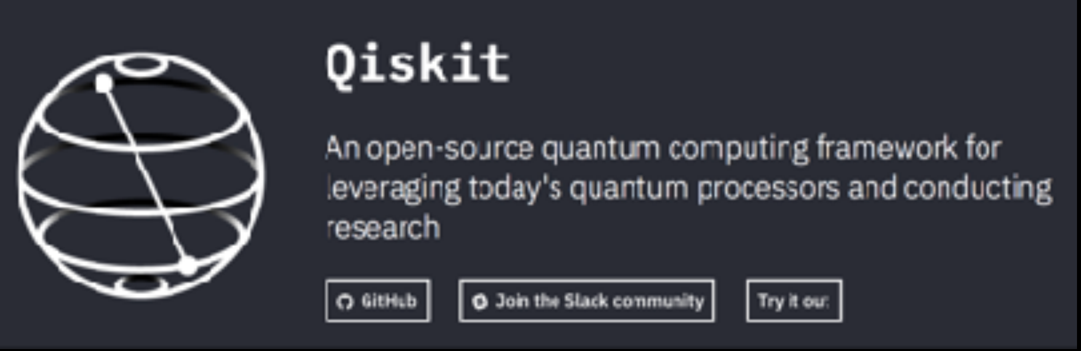
The fridge is
surprisingly pretty.

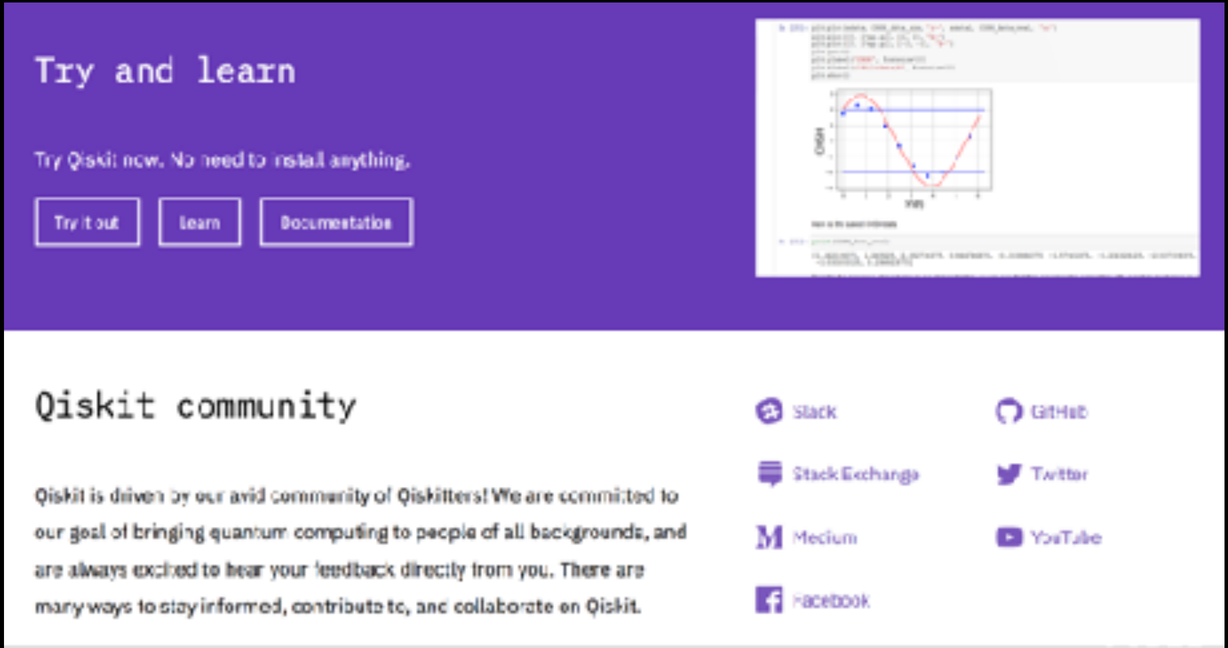
This circuit contains the qubits.



IBM had the first quantum computers on the cloud.


IBM Q > Experience
Home
Composer
Devices
Community
GitHub
Bob Sutor
Hello Quantum
Welcome to the IBM Q Experience!
Explore the world of quantum computing! Check out our User Guides and interactive Demos to learn more about quantum principles. Or, dive right in to create and run algorithms on real quantum computing hardware, using the Quantum Composer and QISKit software developer kit.
Start experimenting with a quantum computer
Hello Quantum
Explore the building blocks of quantum mechanics through puzzles.
Introducing the IBM Q Experience for Researchers
Visibility for your papers
Priority access to devices


Qiskit
An open-source quantum computing framework for leveraging today's quantum processors and conducting research
GitHub
Join the Slack community
Try it out


Try and learn
Try Qiskit now. No need to install anything.
Try it out
Learn
Documentation
Qiskit community
Qiskit is driven by our avid community of Qiskitters! We are committed to our goal of bringing quantum computing to people of all backgrounds, and are always excited to hear your feedback directly from you. There are many ways to stay informed, contribute to, and collaborate on Qiskit.
Slack
GitHub
Stack Exchange
Twitter
Medium
YouTube
Facebook

demo-time


jupyter
quantum_emoticon
Logout
File
Edit
View
Insert
Cell
Kernel
Widgets
Help
Trusted
Python 3
Run
Markdown
QISKit
Quantum Emoticon
Adapted from a notebook on https://github.com/QISKit/qiskit-tutorial by James R. Wootton, University of Basel and Anna Phan, IBM Research.
We first prepare set up the credentials required to access the devices.
In [ ]:
from qiskit import register, available_backends, get_backend

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#IBMQ #ibmcloudgarage @holly_cummins

The result on the **real** quantum computer

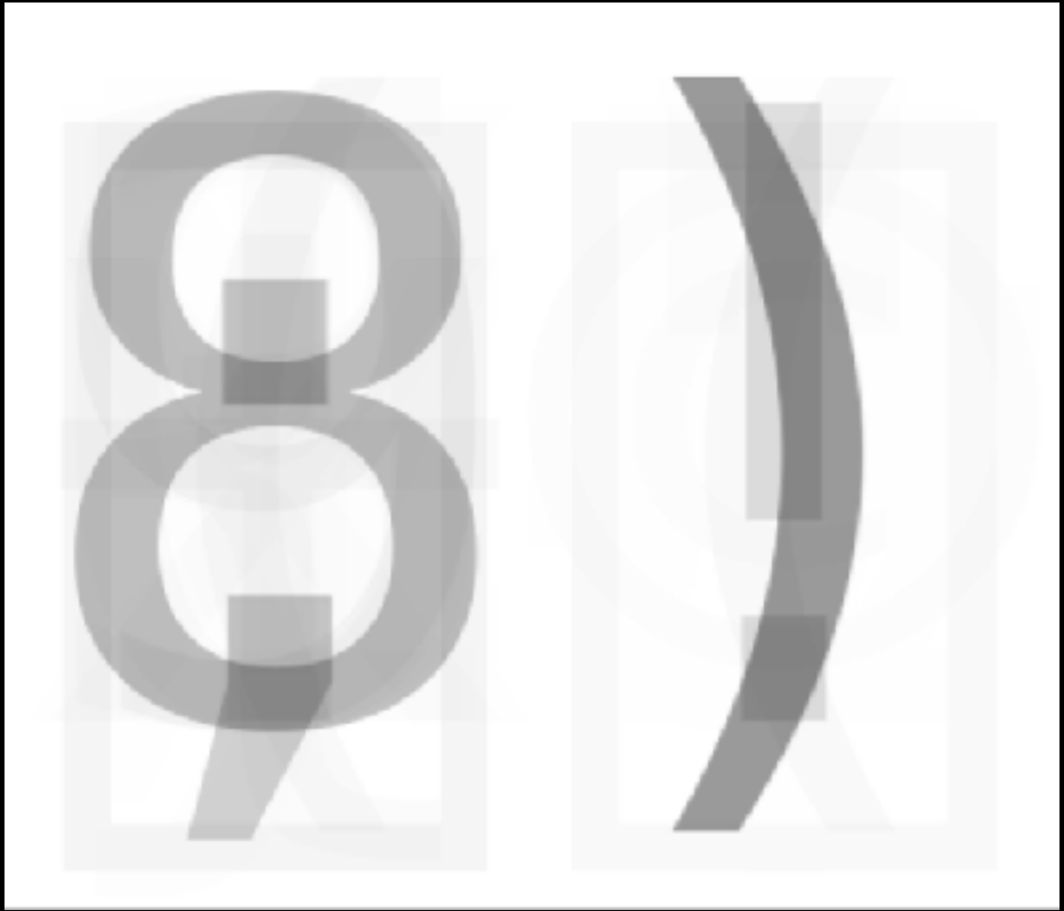
IBM

The result on the **real** quantum computer

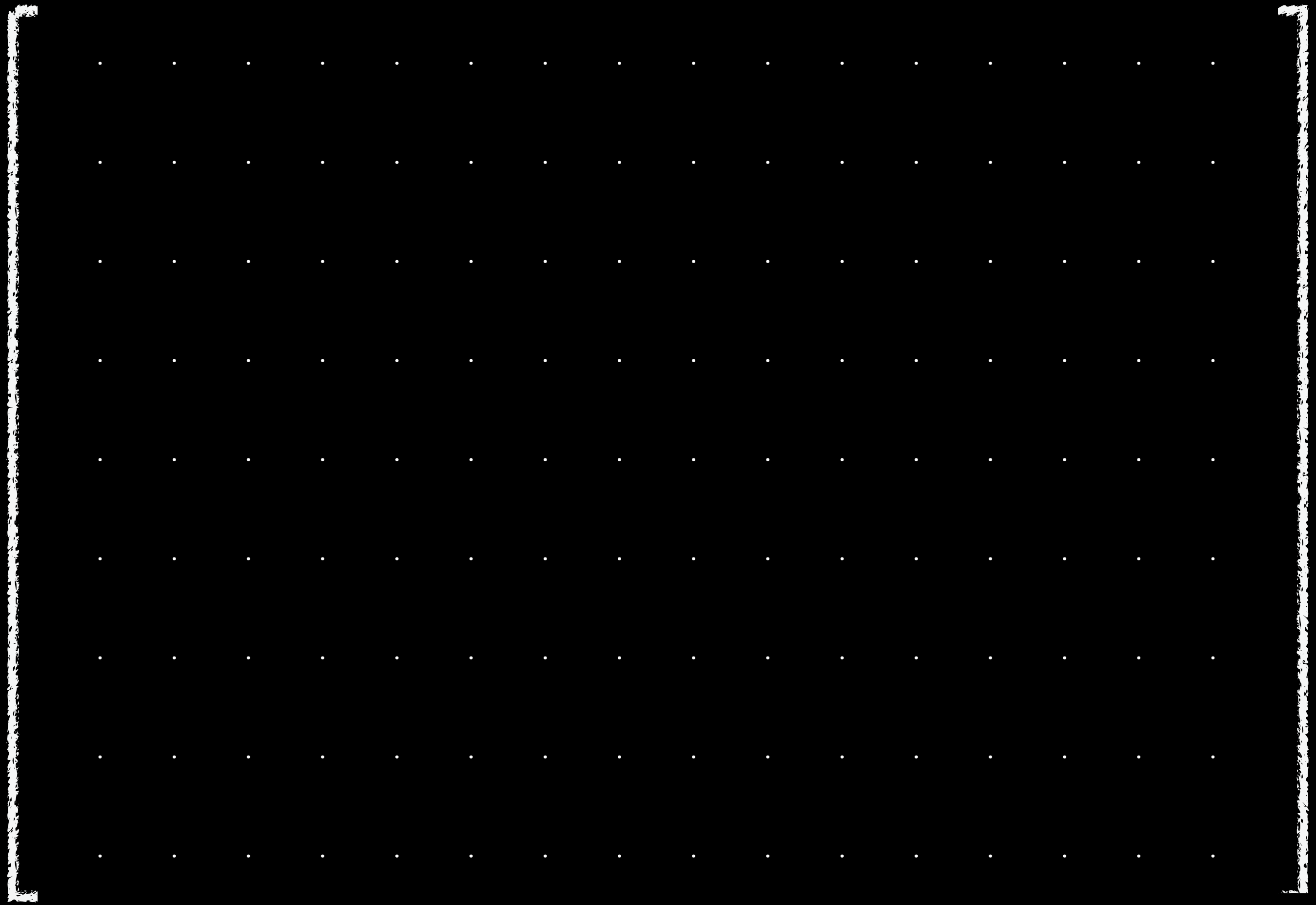
0.06	8!
0.16	8)
0.12	;)

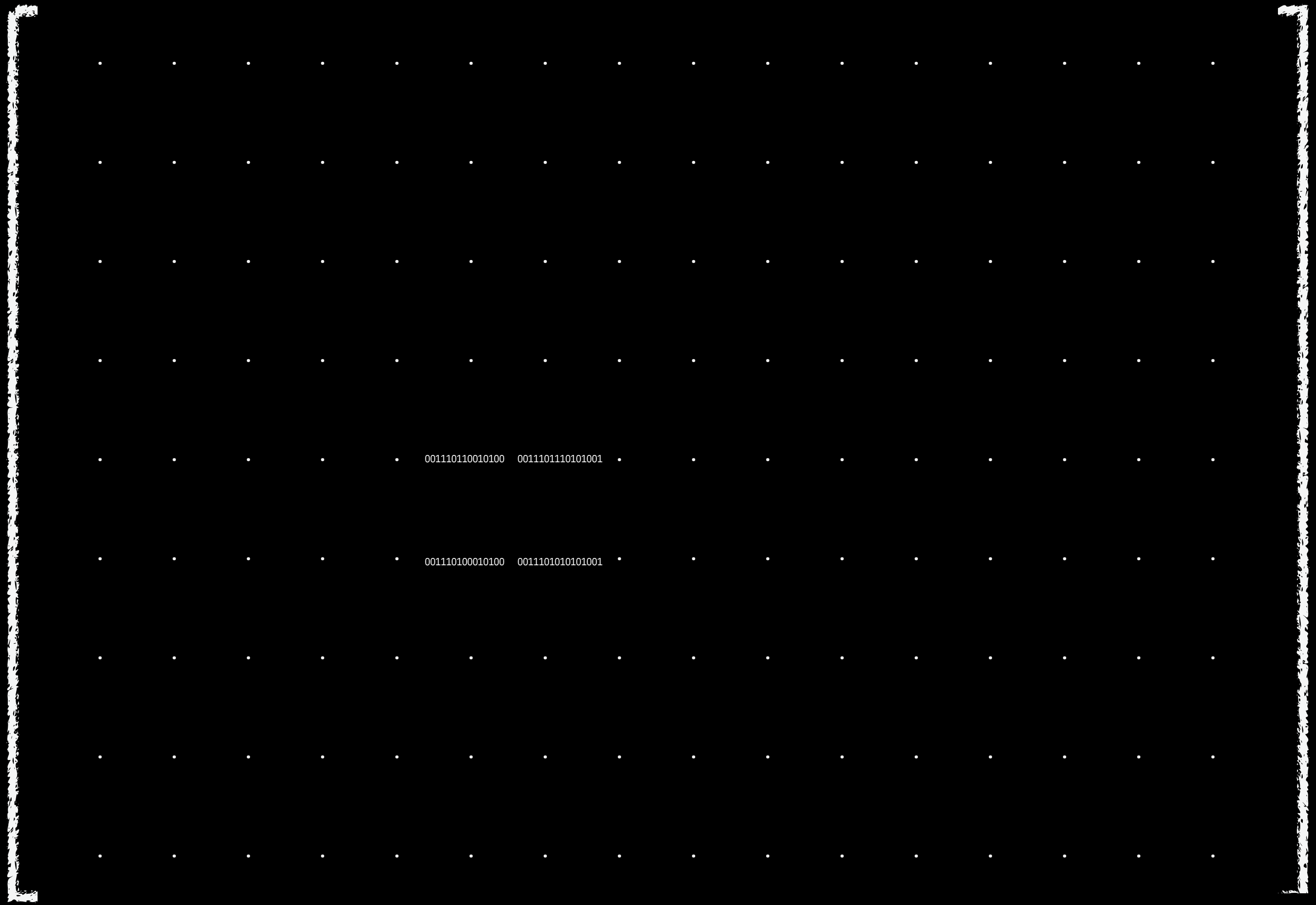
The result on the **real** quantum computer

0.06	8!
0.16	8)
0.12	;)



$$\begin{bmatrix} a \\ b \end{bmatrix} \begin{bmatrix} c \\ d \end{bmatrix} \qquad \begin{bmatrix} a & c \\ b & d \end{bmatrix}$$




001110110010100
0011101110101001
001110100010100
0011101010101001

00	01
10	11

8) 9)

:) ;)

8) ~~9)~~

~~:)~~ ;)

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we can’t represent this system as a product of simpler matrices

8) ~~8)~~

~~;)~~ ;)

we can’t represent this system as a product of simpler matrices

8) ~~9)~~

~~:)~~ ;)

it is computationally **complex**

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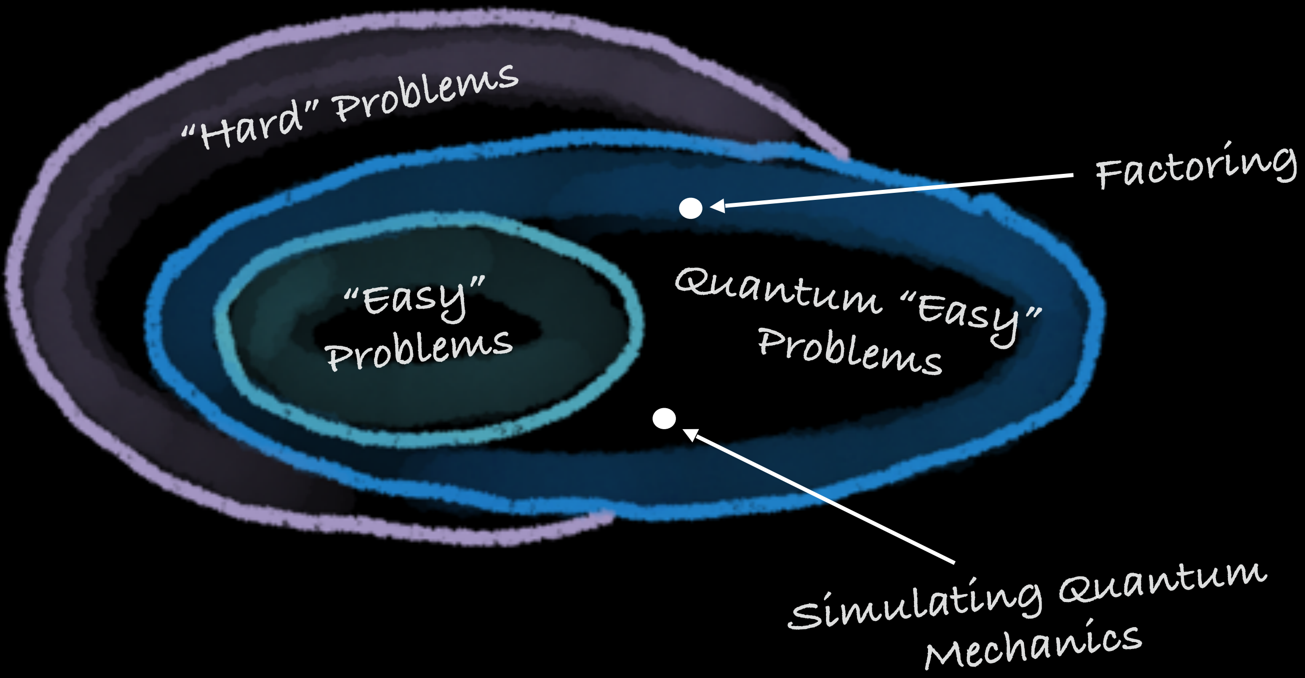
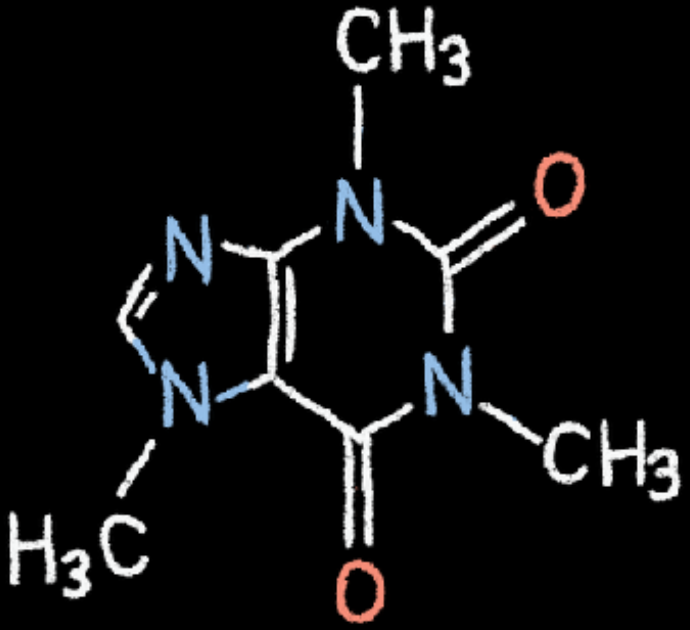
What’s it **good** for?



Quantum computing provides a new path to solve some of the hardest problems in business and science.

simulating chemical molecules

We could model caffeine using 160 qubits.



materials design

potential
new
lifesaving
drugs

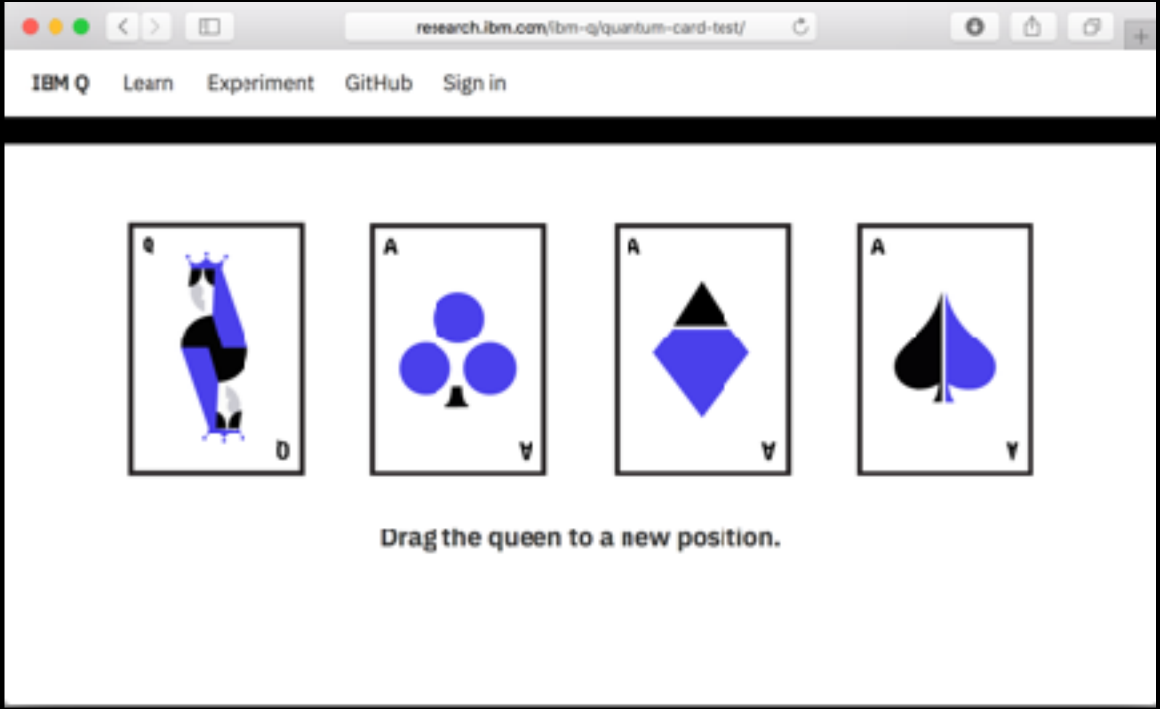
artificial
intelligence
classification
machine
learning
linear algebra

portfolio optimization

logistics

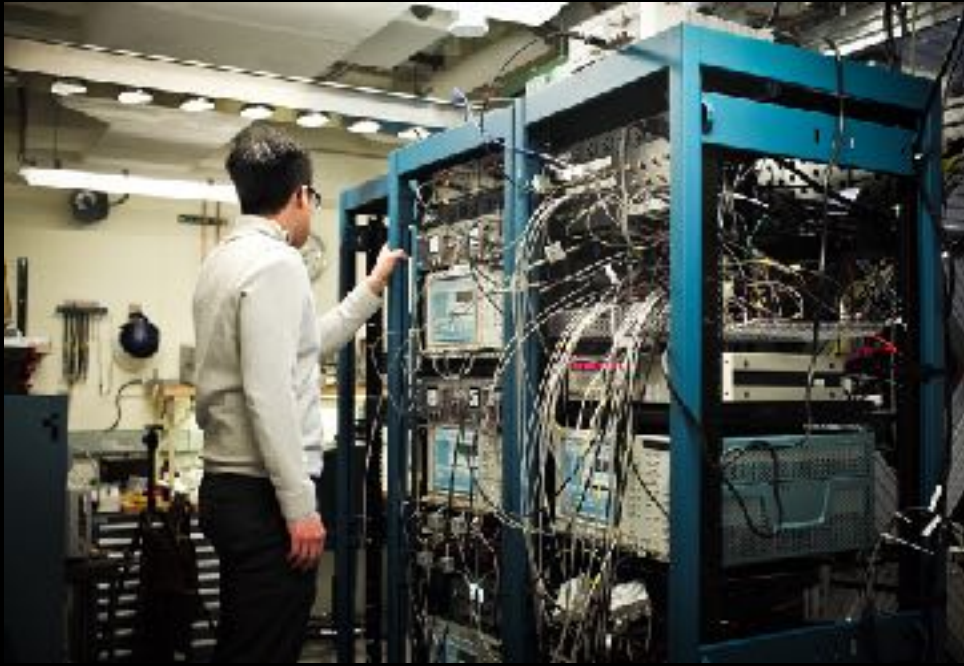
the future

This was **real**.
But it was small.



IBM Q Experience in 2016

First cloud quantum computing device



ENIAC

One of the earliest electronic general-purpose computers in 1946

IBM Q Experience in 2016

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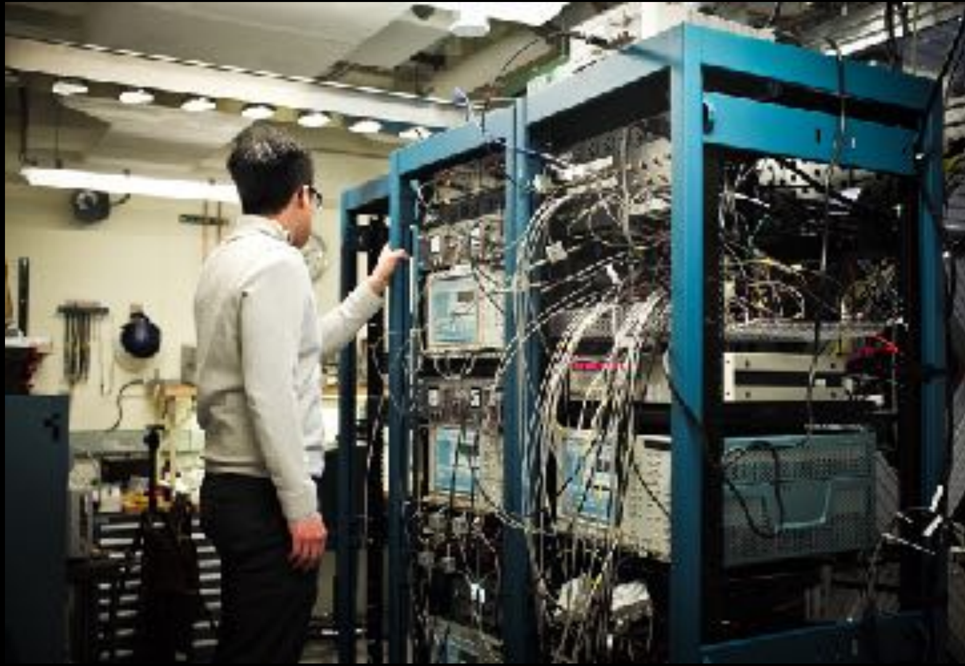

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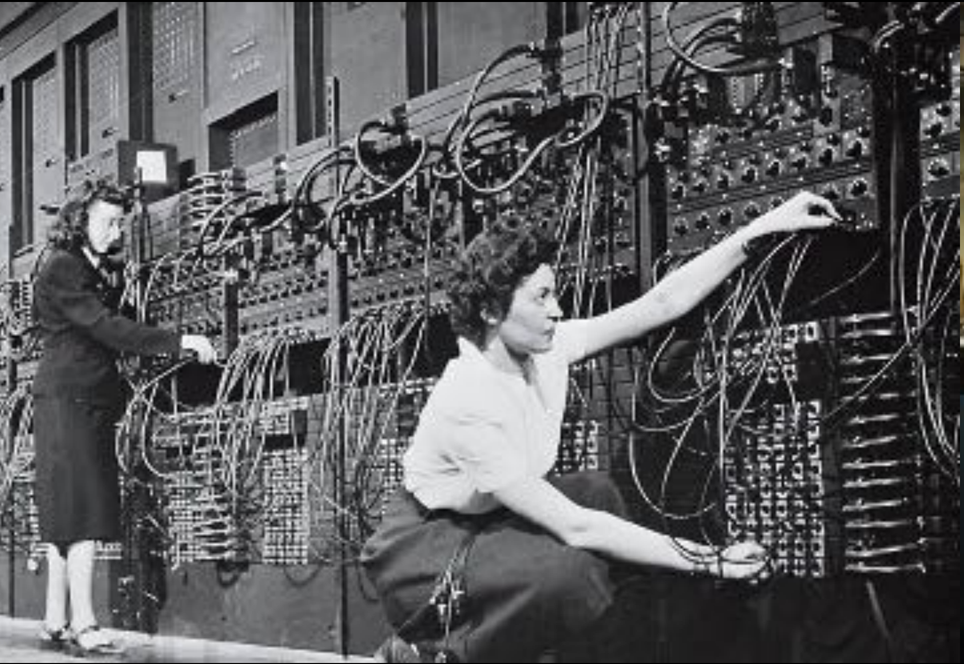

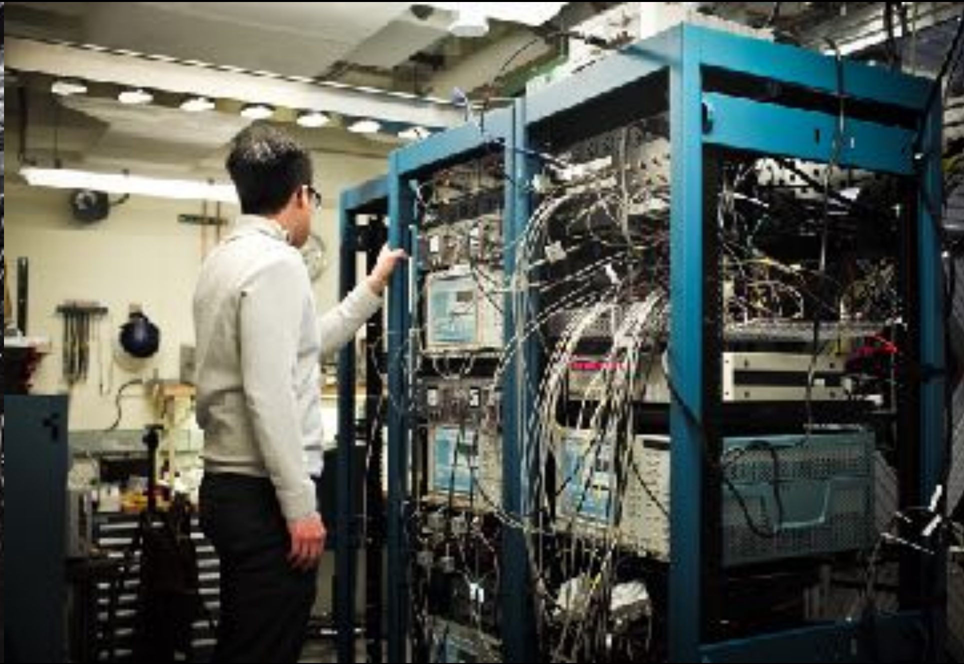

Introducing the **IBM Q System One**

The world’s “first universal approximate quantum computing system installed outside of a research lab”.

Quantum computing will evolve through distinct phases…

Quantum Foundations

Quantum computing as the exclusive domain of research scientists

Quantum Ready

Demonstrations of quantum advantage for use cases of scientific and business value

Quantum Advantage

Extracting direct value out of quantum computing for business and science

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How **many** qubits do we need to see quantum **advantage**?

approximate

\# qubits for advantage (est) · years to advantage (est)

	# qubits for advantage (est)	years to advantage (est)
Quantum chemistry Optimization (specific) Heuristic machine learning	$10^2 \sim 10^3$	< 5 years

universal, fault-tolerant

\# qubits for advantage (est) · years to advantage (est)

	# qubits for advantage (est)	years to advantage (est)
Shor's algorithm (factoring) Big Linear Algebra Programs (FEM)	$>10^8$	10 - 15 years (If possible)

We have built the quantum computation centers of today ...

… and are imagining the computational centers of tomorrow

qiskit.org
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