Quantum Computing

Our journey so far

Henry Yuen
Assistant Professor
of Computer Science and Mathematics
University of Toronto

TIME

Solutions That Matter

SIGN IN | SUBSCRIBE

SOLUTIONS ... MAGAZINE VIDEOS

Solutions That Matter


9 Ways Quantum Computing Will Change Everything


Watch How Researchers Are Ensuring the Future of America's Livestock


See How Kids Are Getting 3D-printed Hands for Free

BREAKTHROUGH

9 Ways Quantum Computing Will Change Everything

Matt Vella @mattvella | Feb. 6, 2014

Computers built on the principles of quantum physics—as opposed to 'classical' physics—promise a revolution on the order of the invention of the microprocessor or the splitting of the atom. D-Wave, a small Canadian company backed by Jeff Bezos, NASA, and the CIA among others, is the first firm to sell a so-called quantum computer —at roughly $10 million a pop. The vast increase in power could

What will NASA be doing with its new quantum

AINER

47.3K 96 23

7 awesome ways quantum comp world


Kelly Dickerson

Apr. 21, 2015, 4:04 PM 30,904 6

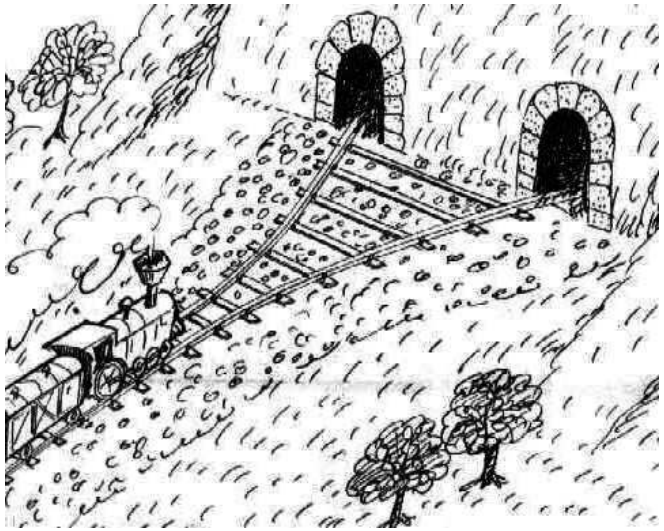
FACEBOOK LINKEDIN TWITTER EMAIL PRINT

Superfast computers built on the

Earlier this year, NASA, in partnership with Google, acquired the world's largest

Quantum mechanics is weird

Wave/particle duality



Uncertainty principle

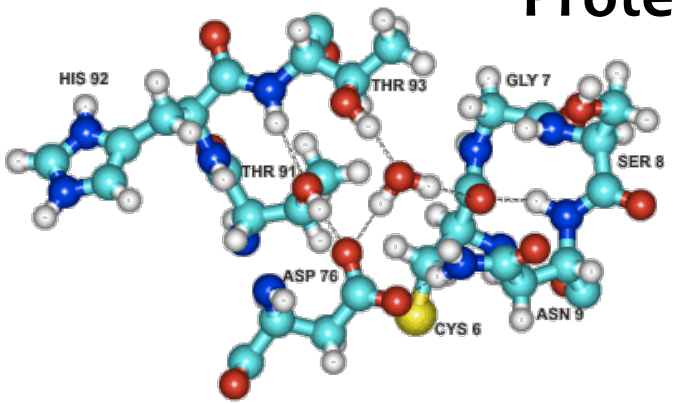
$$\Delta\chi\Delta\rho \geq \frac{\hbar}{2}$$

Superposition

Quantum mechanics governs everything from the mundane…

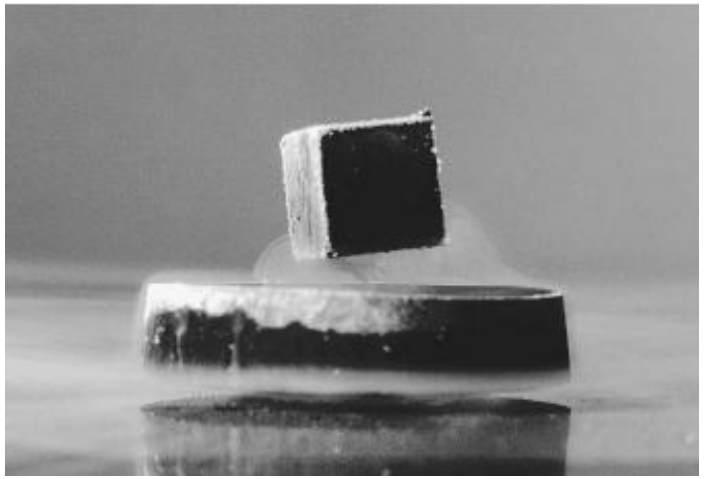
Photosynthesis

Protein folding

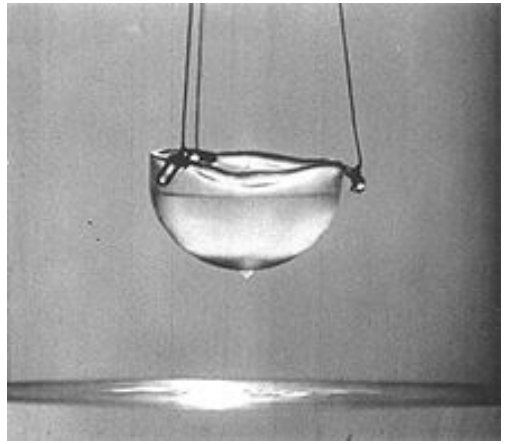


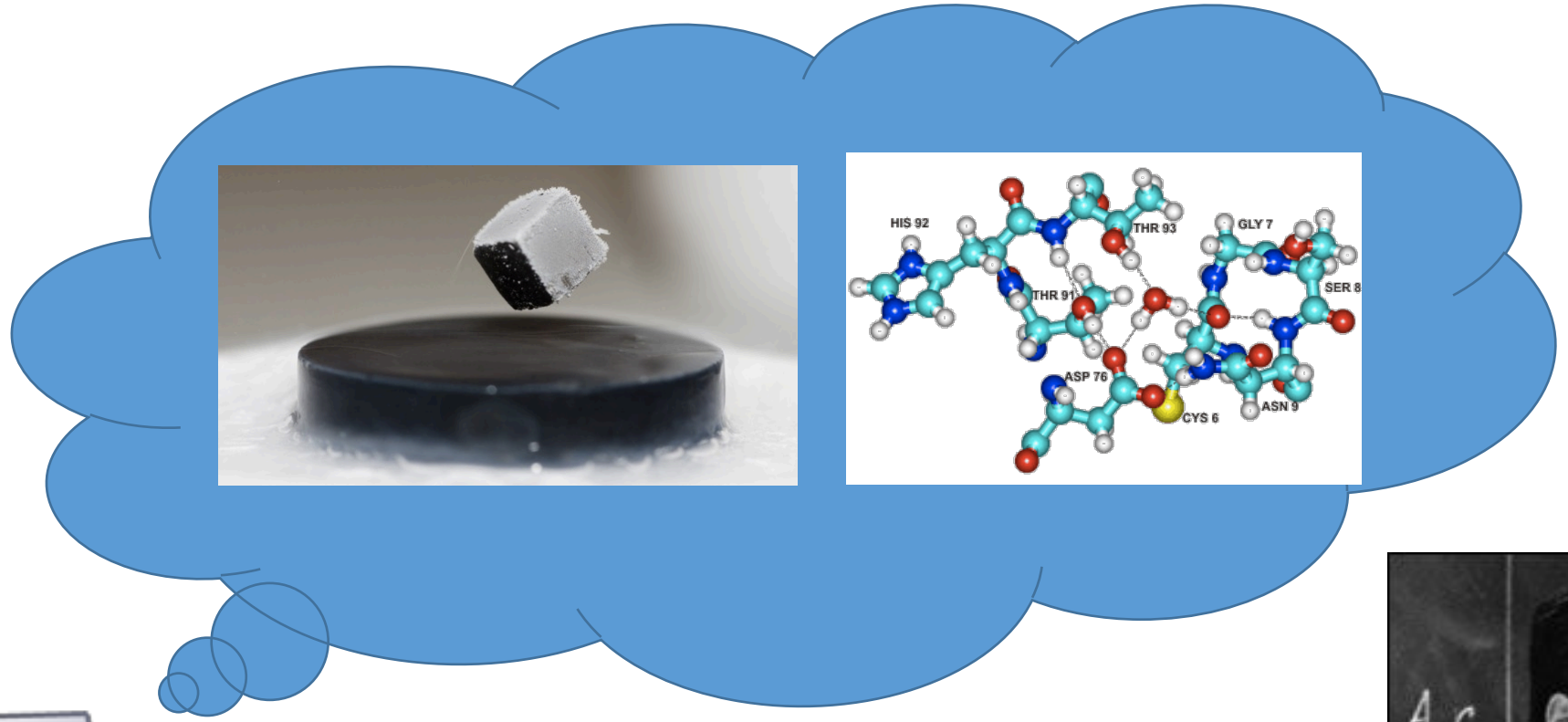
…to exotic physical phenomena

Superconductivity



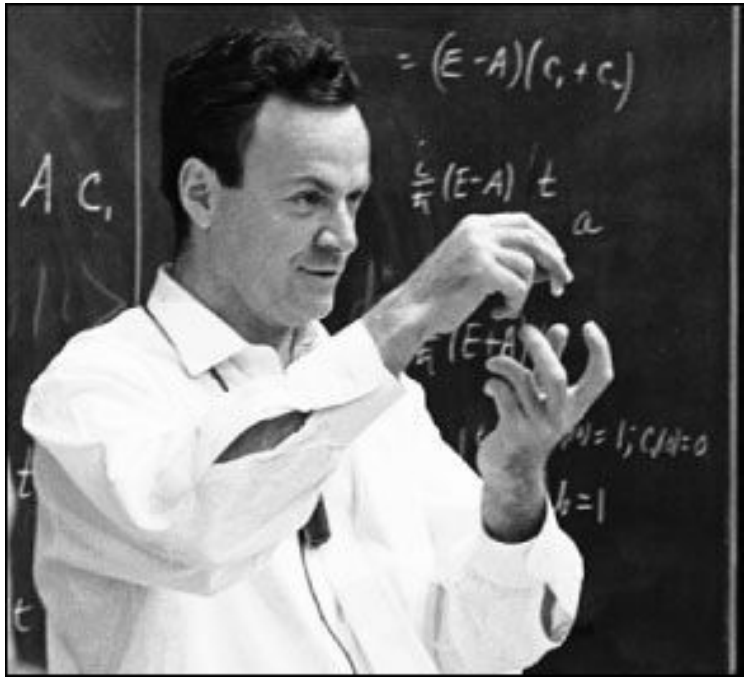
Superfluidity



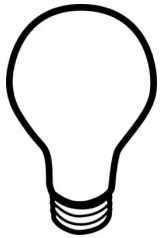


Richard Feynman (1982):

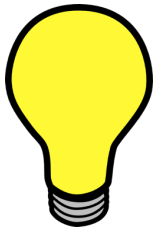
Q: Can a computer simulate this?
A: Not very easily!



Classical computer



0

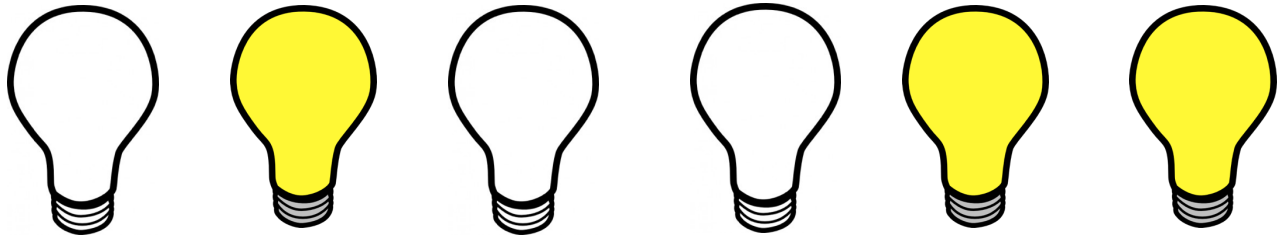


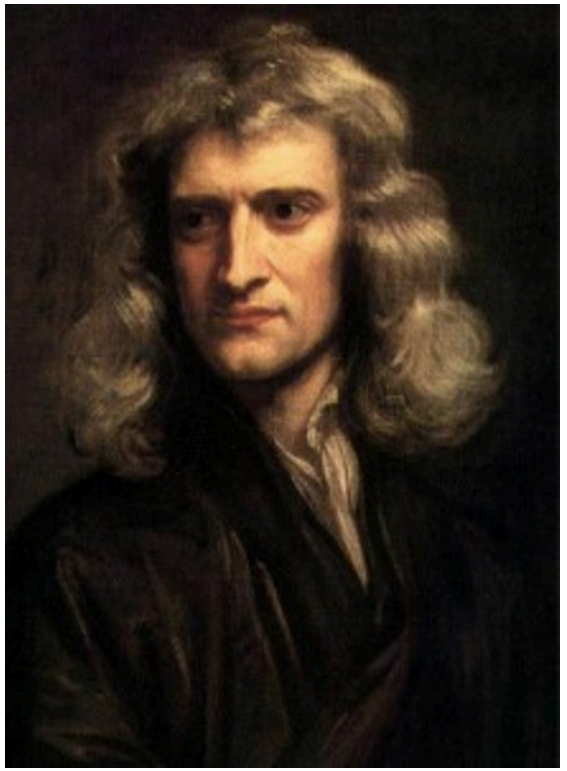
1

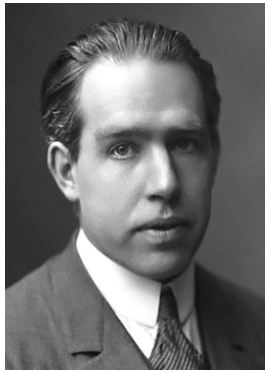
Bit

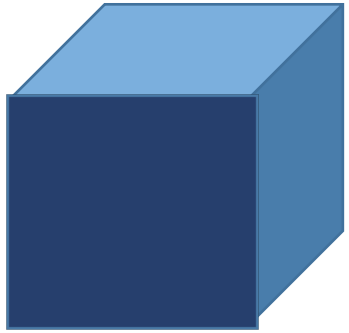
Classical computer

Classical bit

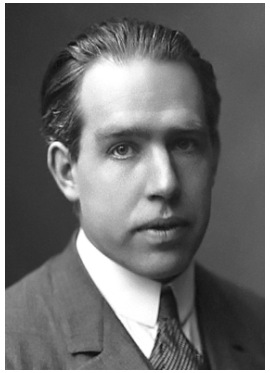


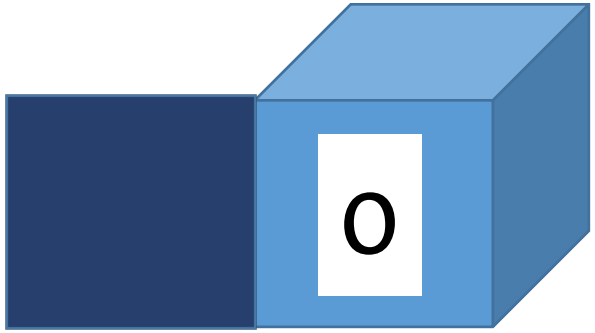




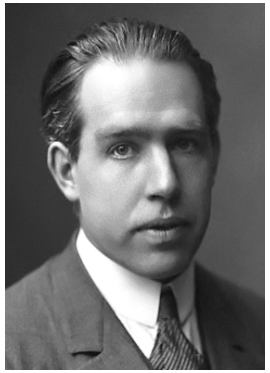


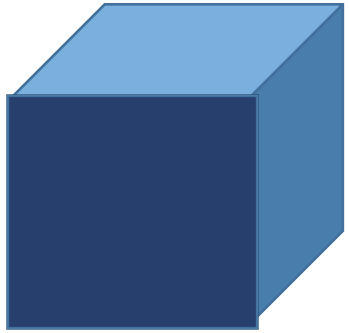
Qubit



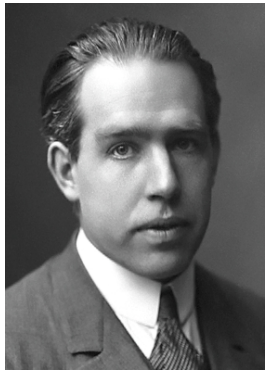


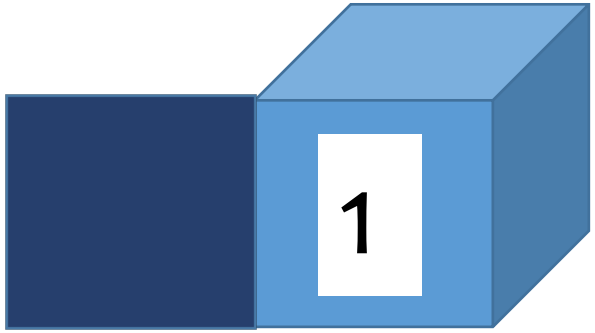
Qubit



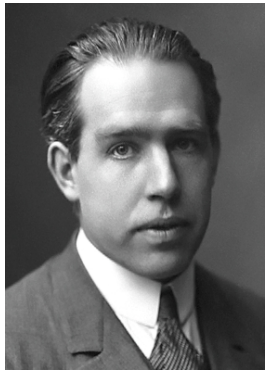


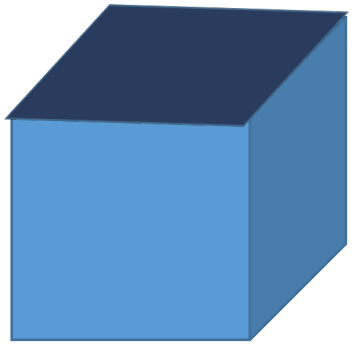
Qubit



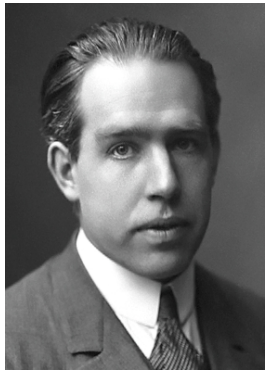


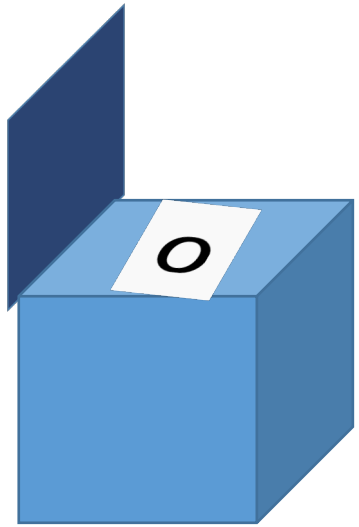
Qubit



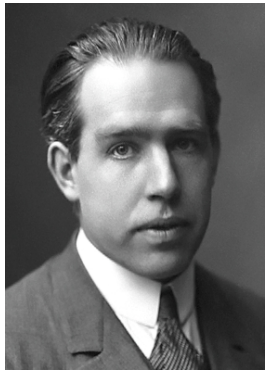


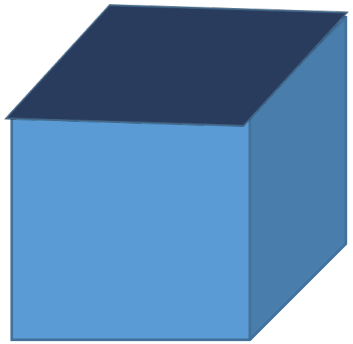
Qubit



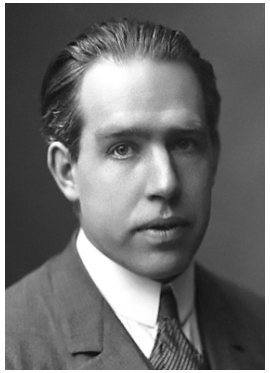


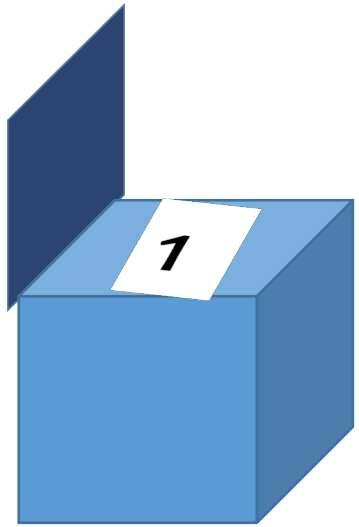
Qubit



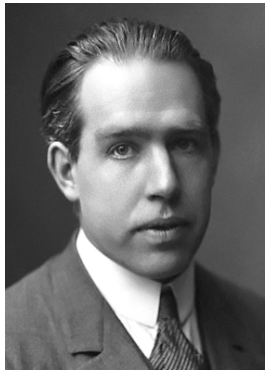


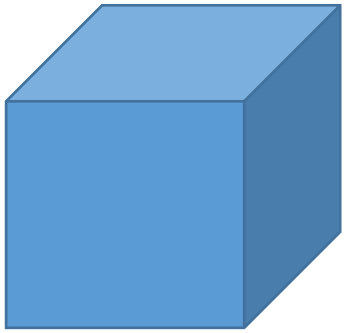
Qubit

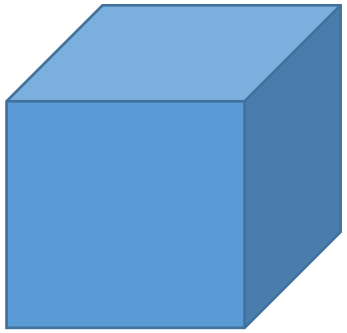


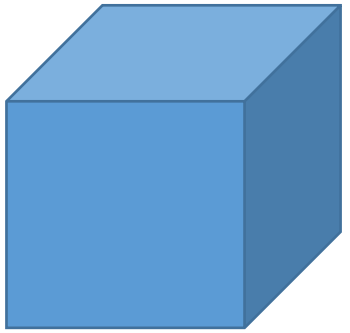


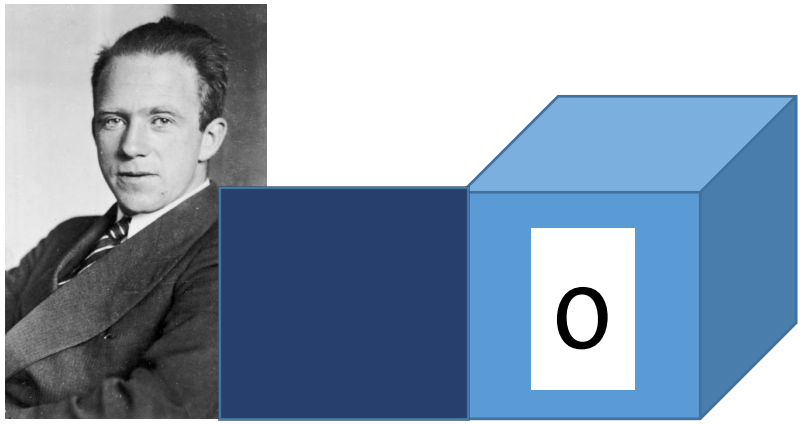
Qubit

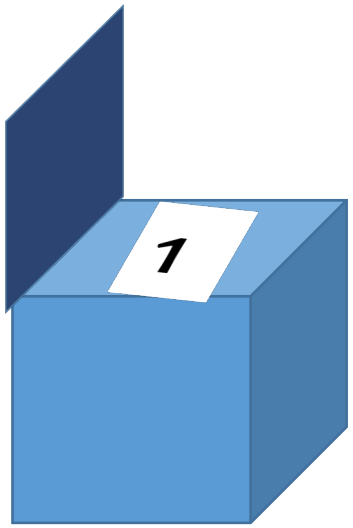


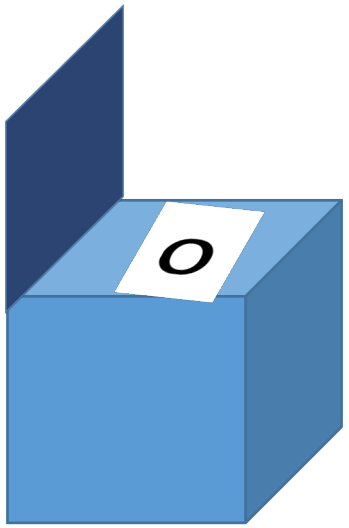


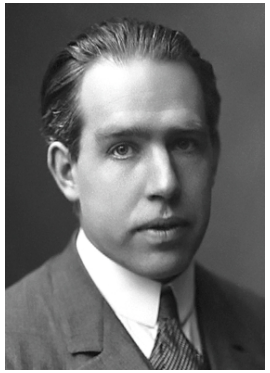


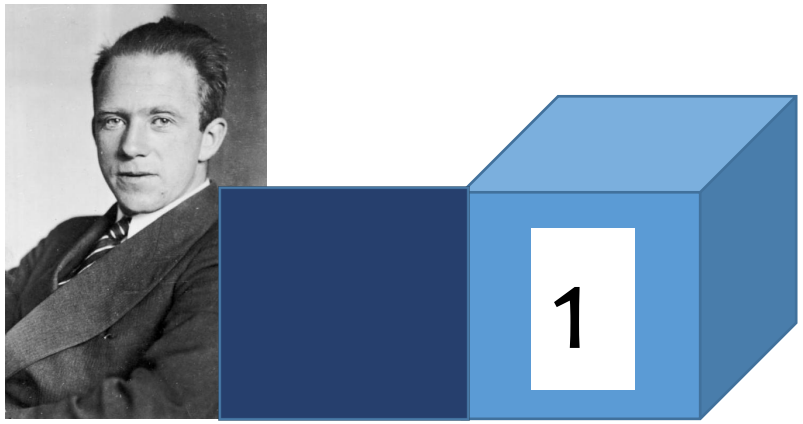


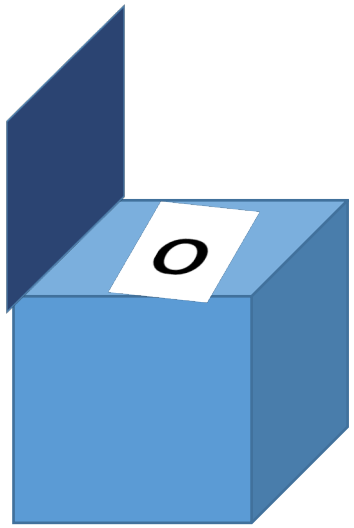

0

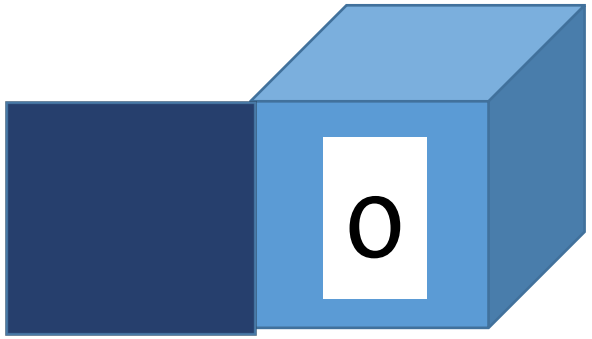

1

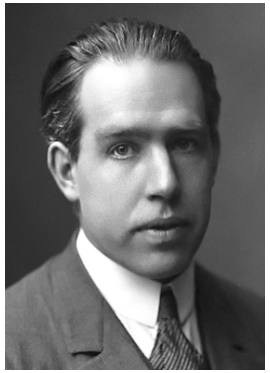

0

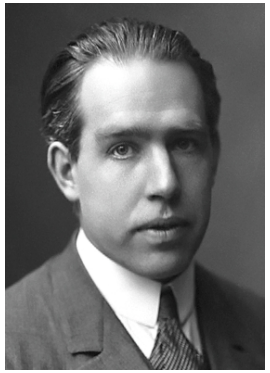



1


0

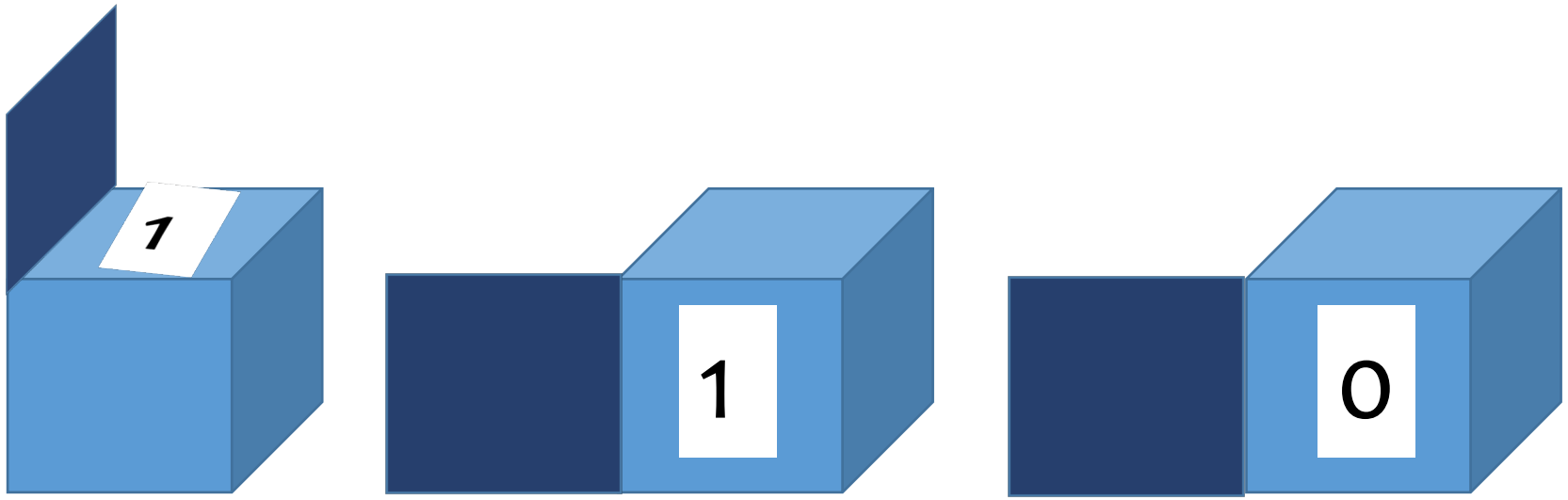

0





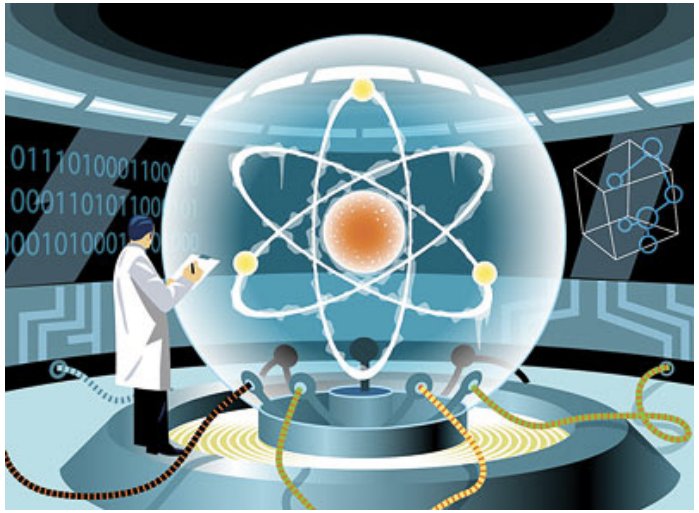
3 qubits: requires 8x3 = 24 classical bits

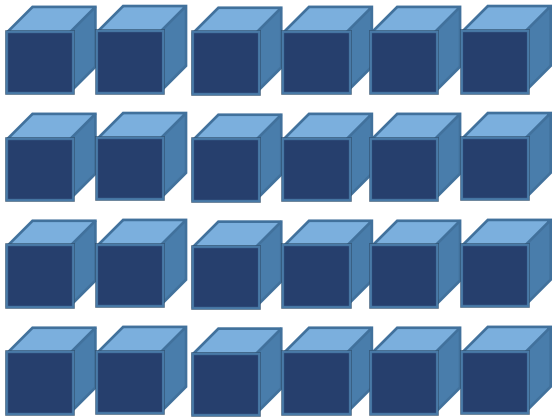
N qubits: requires at least 2^N classical bits!

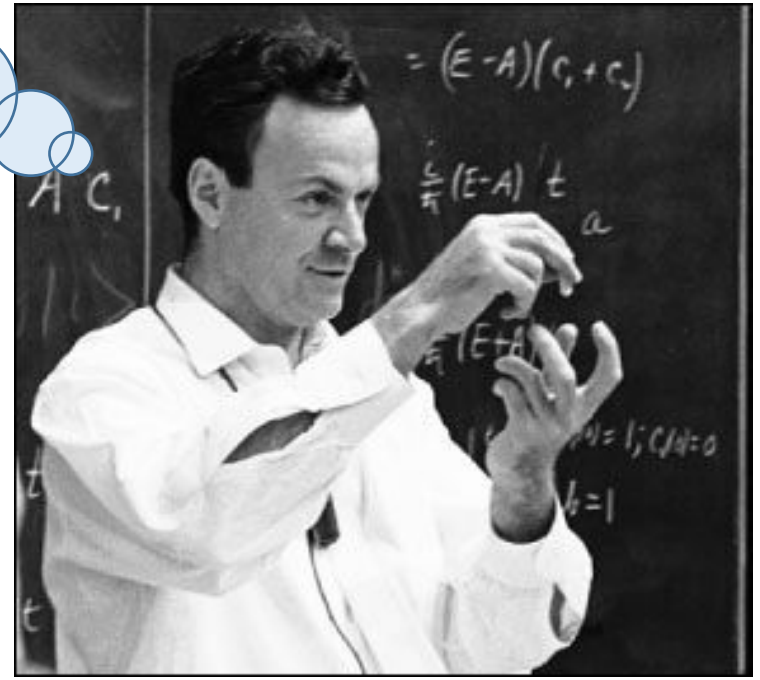


The whole is greater than the sum of its parts!

We need a new kind of computer!

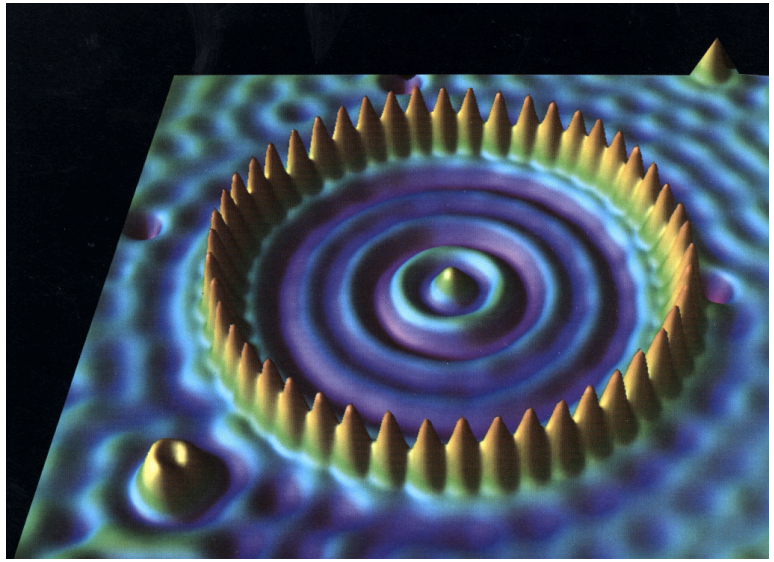


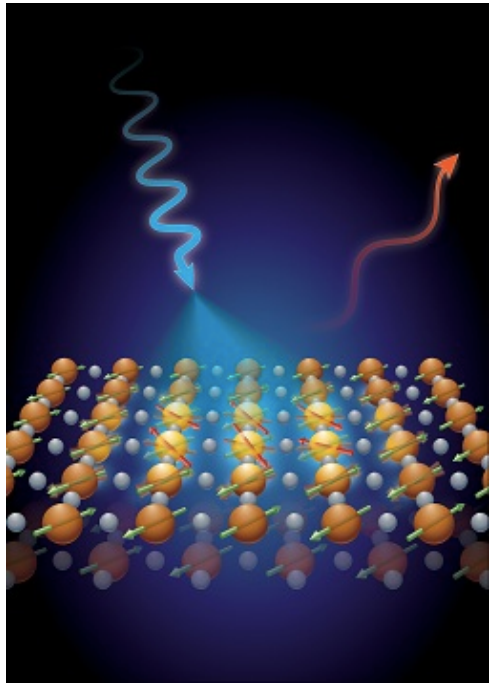


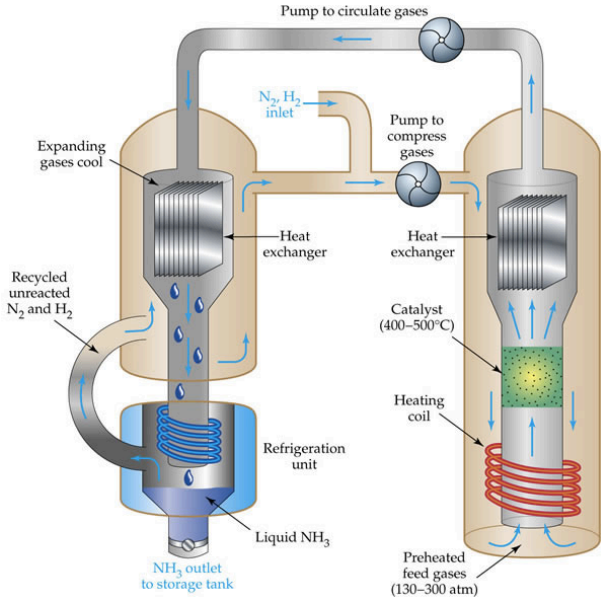


What can a quantum computer do?

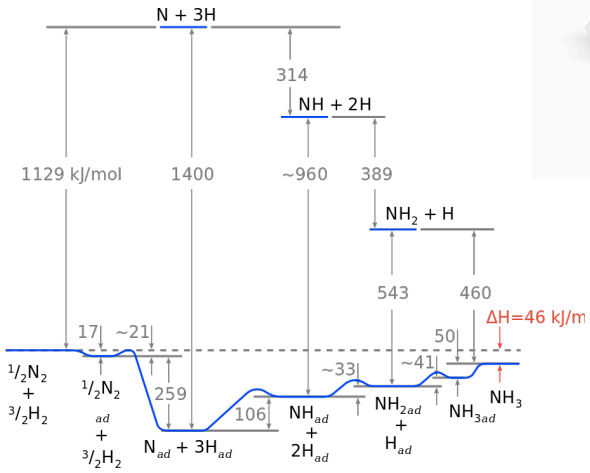
Simulating quantum physics, of course!

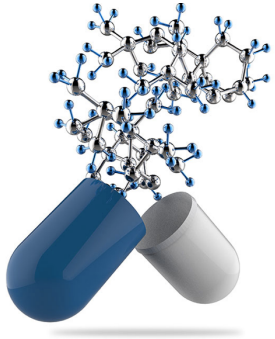






Example:
Artificial nitrogen fixation for fertilizer production (i.e. Haber process)
Consumes > 1% of world's energy output.





Quantum computers could speed up

- finding more efficient reaction pathways
- develop exotic materials
- drug design

$$P = 15904$$

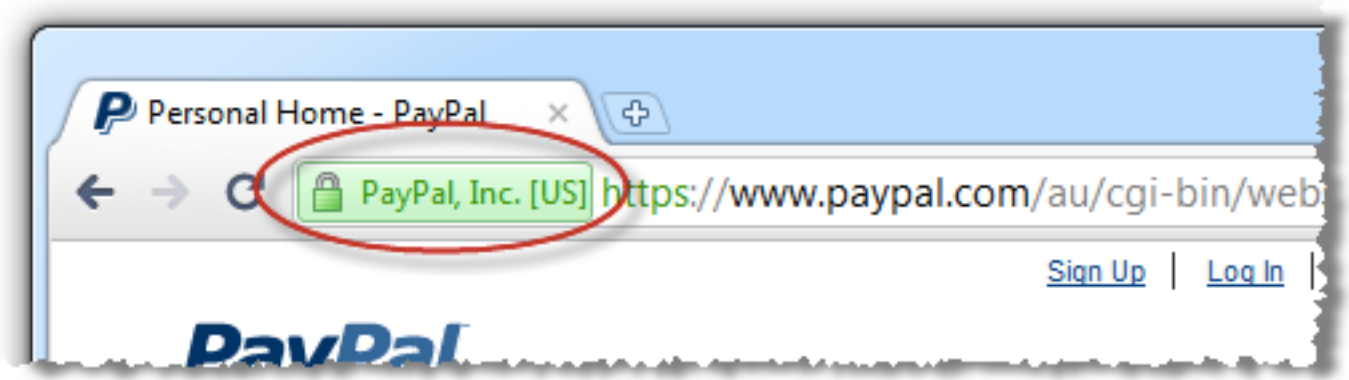
$$Q = 93520$$

$$P \times Q = 1487342080$$

$P = 17449$

$Q = 34253$

$P \times Q = 597680597$



Peter Shor (1994): quantum computers
can factor large numbers very quickly!

Crossroads

Since Shor's algorithm, physicists and computer scientists have been faced with three options:

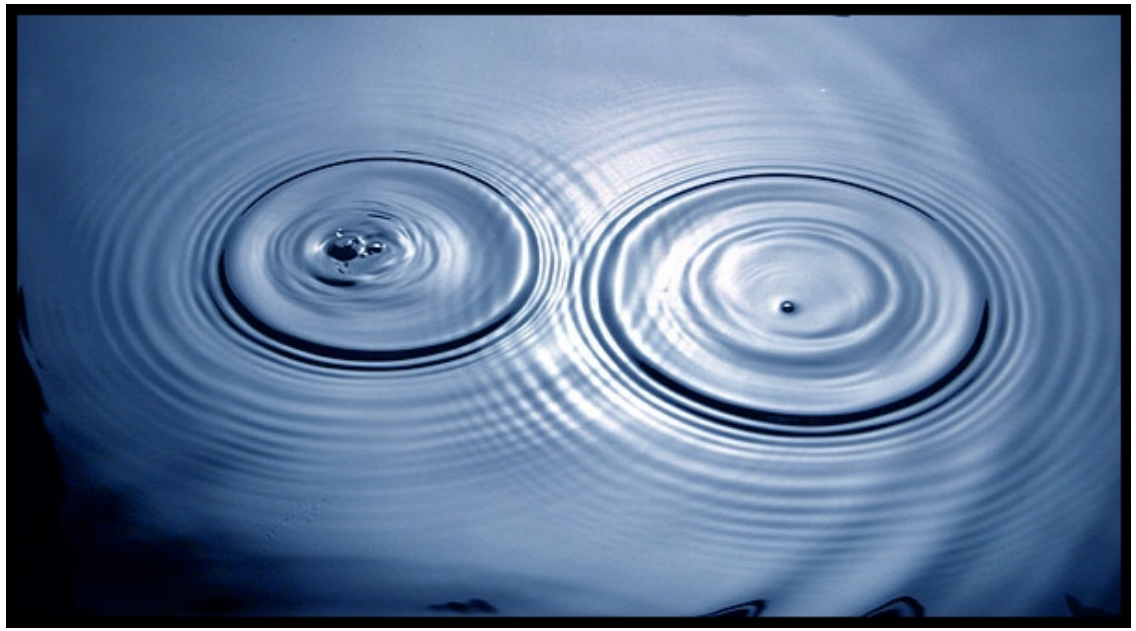
1. Quantum mechanics is wrong.
2. There is a fast classical algorithm for factoring.
3. Quantum computers are more powerful than classical computers.

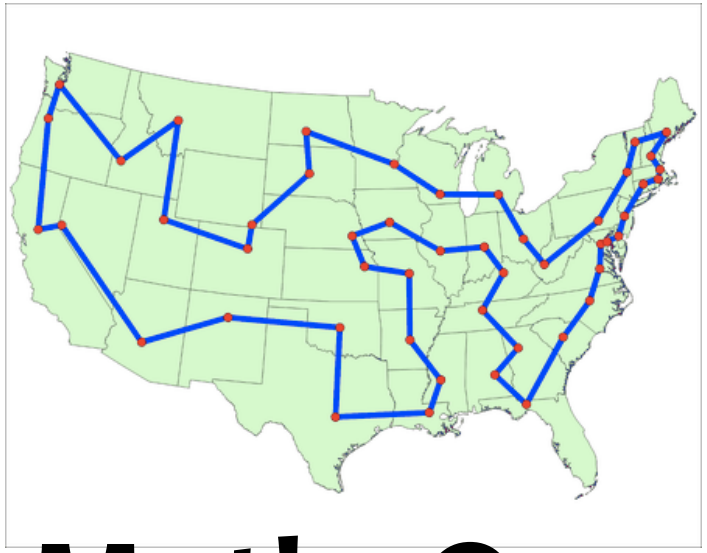
At least one of these must be true!

Public Service Announcement

Myth: Quantum computers solve things by trying every possibility at once.

Fact: Quantum computers can solve certain types of problems faster via *interference patterns*.





Myth: Quantum computers can solve the traveling salesman problem quickly.

FALSE

Fact: Quantum computers *probably* cannot solve TSP quickly.

Quantum computing today

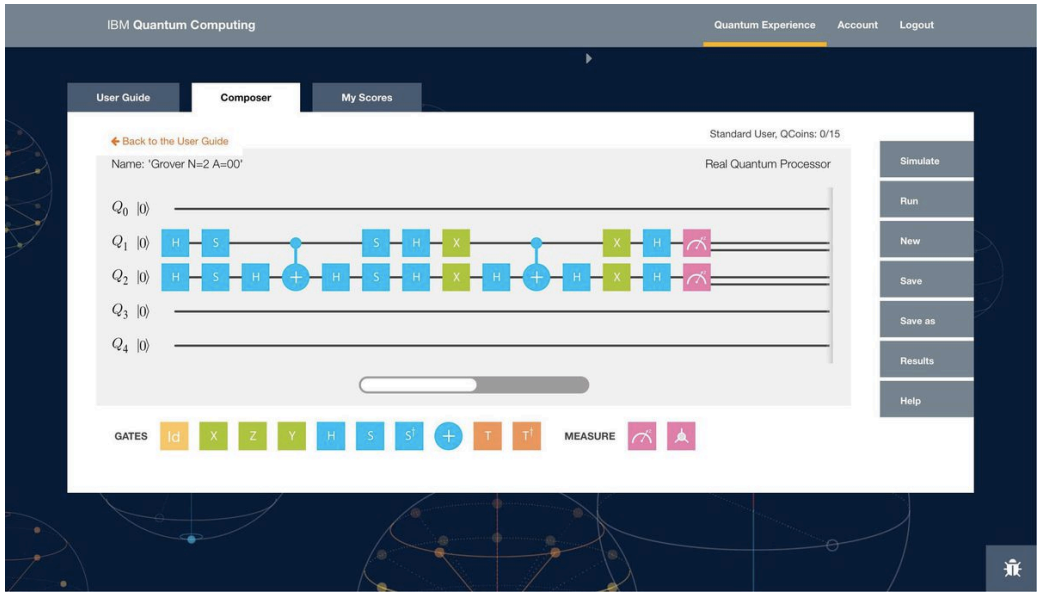
Google

IBM

XANADU

Microsoft

rigetti

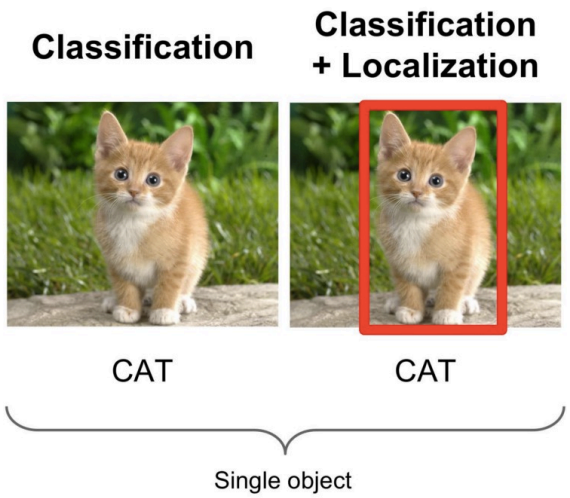


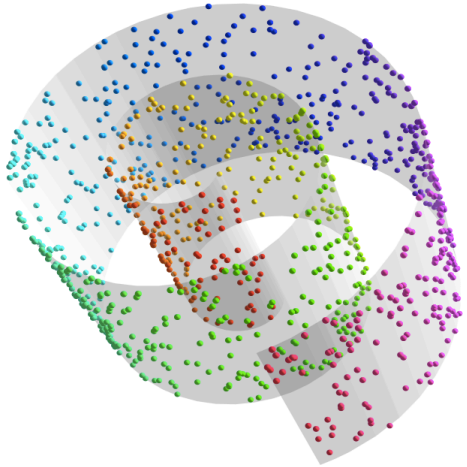
The big questions

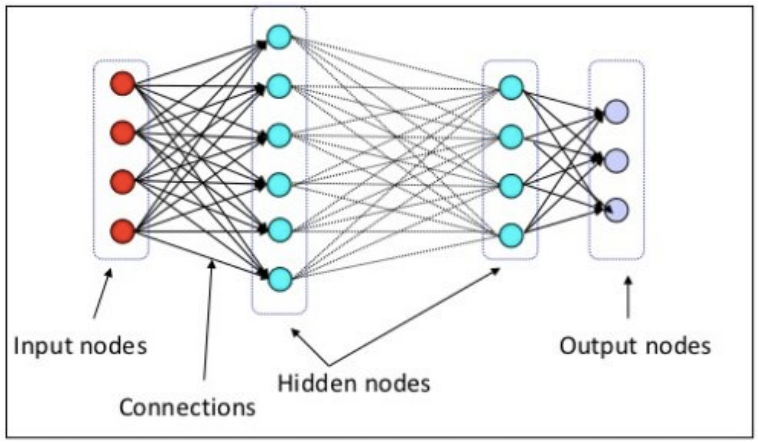
- How will we scale up quantum computers to millions of qubits?
- Are small-scale, rudimentary quantum computers useful for anything?
- What kinds of problems are quantum computers good at solving?
- What can quantum computing tell us about nature?

Quantum Machine Learning?

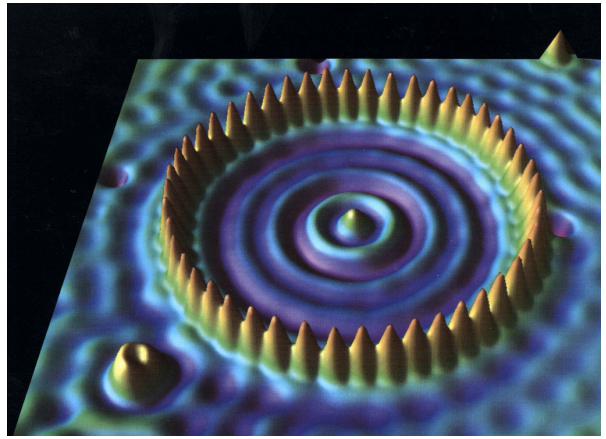
ML for **classical** data

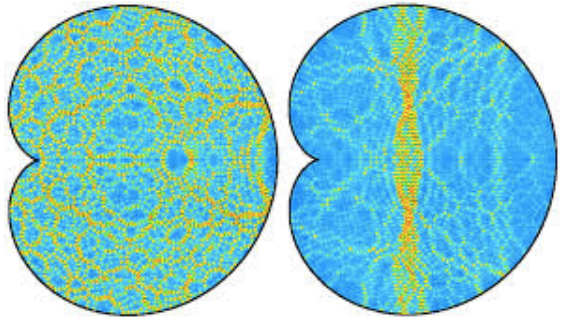


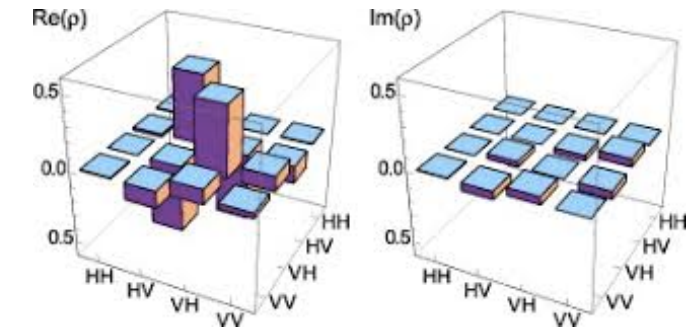


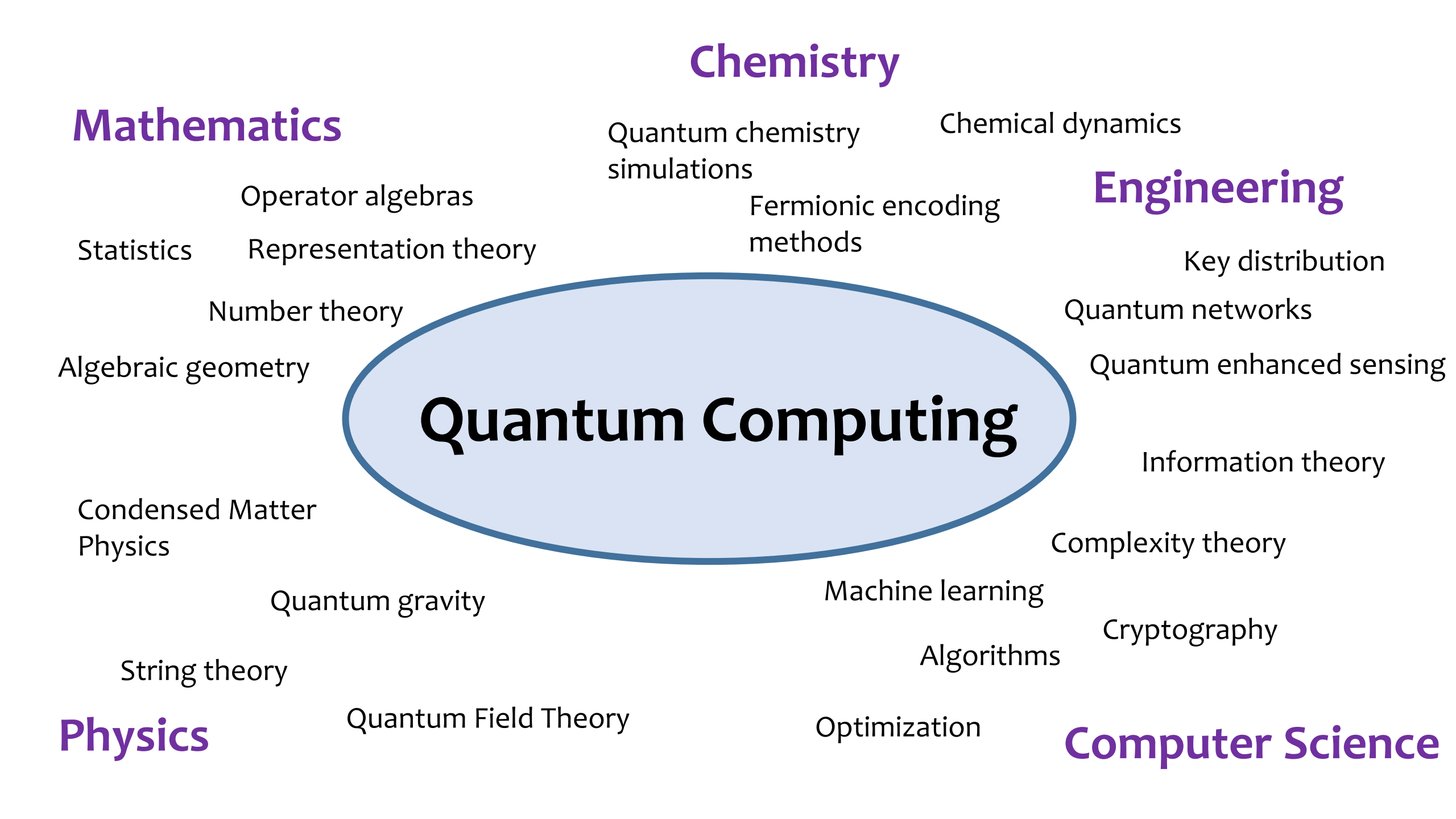


ML for **quantum** data

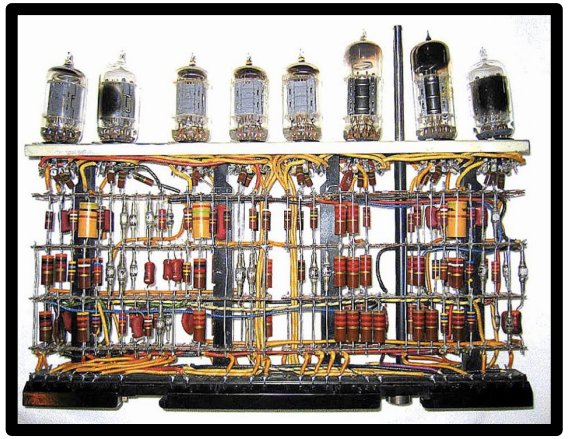







Chemistry
Mathematics
Quantum chemistry simulations
Chemical dynamics
Engineering
Operator algebras
Fermionic encoding methods
Statistics
Representation theory
Key distribution
Number theory
Quantum networks
Algebraic geometry
Quantum enhanced sensing
Quantum Computing
Information theory
Condensed Matter Physics
Complexity theory
Machine learning
Quantum gravity
Cryptography
Algorithms
String theory
Quantum Field Theory
Optimization
Physics
Computer Science

We’re in the early days of quantum computing.



II

Uncharted territory

Thanks!