Begin <> Quantum

A brief overview + Demo

Far from being a perfect lecture!

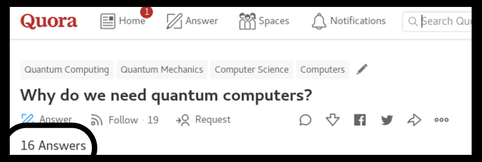
Karim 20220331

Time breakdown!

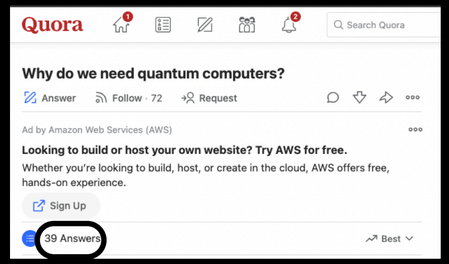
- ~20 min intro
- ~20 min hands-on
- ~20 min discussions

Why quantum?

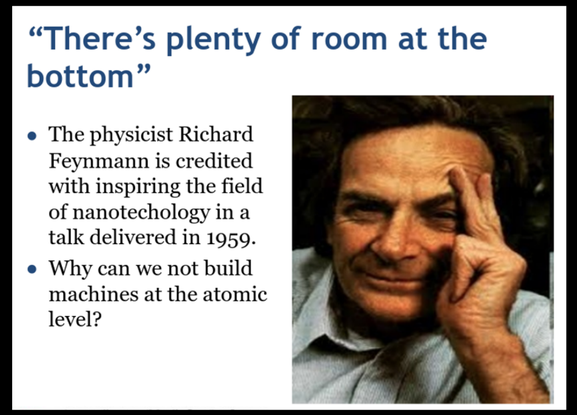
Classical computers are super good already! What about encryption?



Feb 2020



Mar 2022

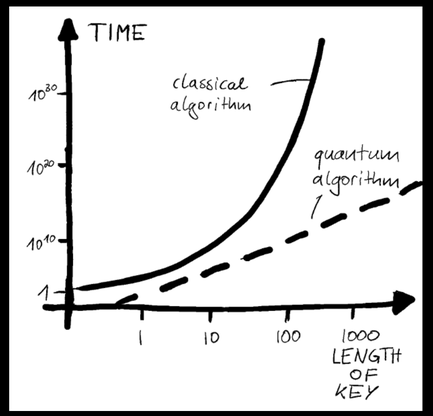


? X ? =21
? X ? = 121
? X ? 8713

Shor's algorithms, a quantum algorithm can find those numbers

? X ? = 188,538,889,076,768,372,354,881,165,818,173,073,829

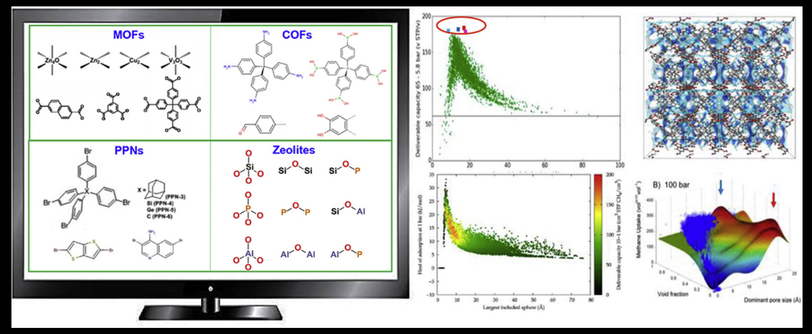
A result of 2 prime numbers with 20 digit each



QC in natural sciences

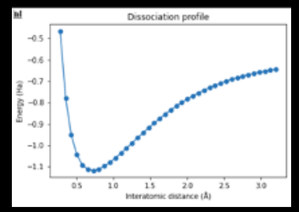
Material science, pharmaceuticals

- Nature is already quantum, thus, we can use a quantum system (quantum computer) to simulate a quantum system (nature)



$$\hat{\mathcal{H}}\Psi = E\Psi$$

$$\hat{H} = \overbrace{-\frac{\hbar^2}{2}\sum_I \frac{\nabla_I^2}{M_I}}^{\text{Nuclei K.E.}} + \overbrace{\frac{1}{2}\sum_{I\neq J}\frac{Z_I Z_J e^2}{4\pi\epsilon_0\,|\mathbf{R_I}-\mathbf{R_J}|}}^{\text{Nucleus-Nucleus Interaction}} - \overbrace{\frac{\hbar^2}{2m}\sum_i \nabla_i^2}^{\text{Electrons K.E.}} + \underbrace{\frac{1}{2}\sum_{i\neq j}\frac{e^2}{4\pi\epsilon_0\,|\mathbf{r_i}-\mathbf{r_j}|}}_{\text{Electron-Electron Interaction}} - \underbrace{\sum_{i,I}\frac{Z_I e^2}{4\pi\epsilon_0\,|\mathbf{r_i}-\mathbf{R_I}|}}_{\text{Electron-Nucleus Interaction}}$$



- For better understanding of interactions
- For better suggestion of new materials
- For accurate description of interactions

Quantum machine learning & optimisation!

A robust number of implemented algorithms is available

I believe this has allot of use cases for various Northvolt areas

nature

Review Article | Published: 14 September 2017

Quantum machine learning

Jacob Biamonte ✉, Peter Wittek, Nicola Pancotti, Patrick Rebentrost, Nathan Wiebe & Seth Lloyd

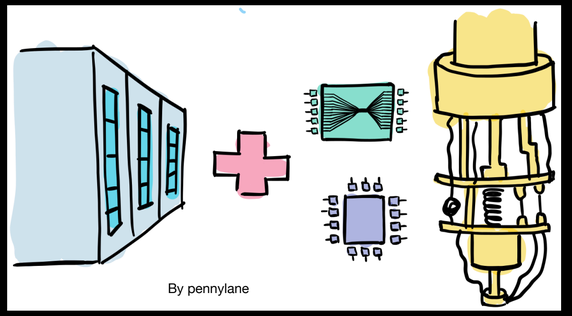
Nature **549**, 195–202(2017) | Cite this article

18k Accesses | **276** Citations | **383** Altmetric | Metrics

Abstract

Fuelled by increasing computer power and algorithmic advances, machine learning techniques have become powerful tools for finding patterns in data. Quantum systems produce atypical patterns that classical systems are thought not to produce efficiently, so it is reasonable to postulate that quantum computers may outperform classical computers on machine learning tasks. The field of quantum machine learning explores how to devise and implement quantum software that could enable machine learning that is faster than that of classical computers. Recent work has produced quantum algorithms that could act as the building blocks of machine learning programs, but the hardware and software challenges are still considerable.

Method	Speedup	Amplitude amplification	HHL	Adiabatic	qRAM
Bayesian inference[106,107]	$O(\sqrt{N})$	Yes	Yes	No	No
Online perceptron[108]	$O(\sqrt{N})$	Yes	No	No	Optional
Least-squares fitting[9]	$O(\log N)$*	Yes	Yes	No	Yes
Classical Boltzmann machine[20]	$O(\sqrt{N})$	Yes/No	Optional/No	No/Yes	Optional
Quantum Boltzmann machine[22,61]	$O(\log N)$*	Optional/No	No	No/Yes	No
Quantum PCA[11]	$O(\log N)$*	No	Yes	No	Optional
Quantum support vector machine[13]	$O(\log N)$*	No	Yes	No	Yes
Quantum reinforcement learning[30]	$O(\sqrt{N})$	Yes	No	No	No



Classical algorithm	Quantum implementation
fourier transform	Quantum fourier transform (QFT)
Linear differential equation solvers, traveling salesman problem	HHL, QAOA, Quantum PCA…
k-means clustering	Quantum k-means
optimization using, simulated annealing	Quantum k-means Quantum Approximate Optimization Algorithm QAOA Variational quantum eigensolver VQE
State Vector Machines SVM	Quantum SVM
Database search	Grover's algorithm

Theory

Bloch sphere and quantum gates

The X quantum gate

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

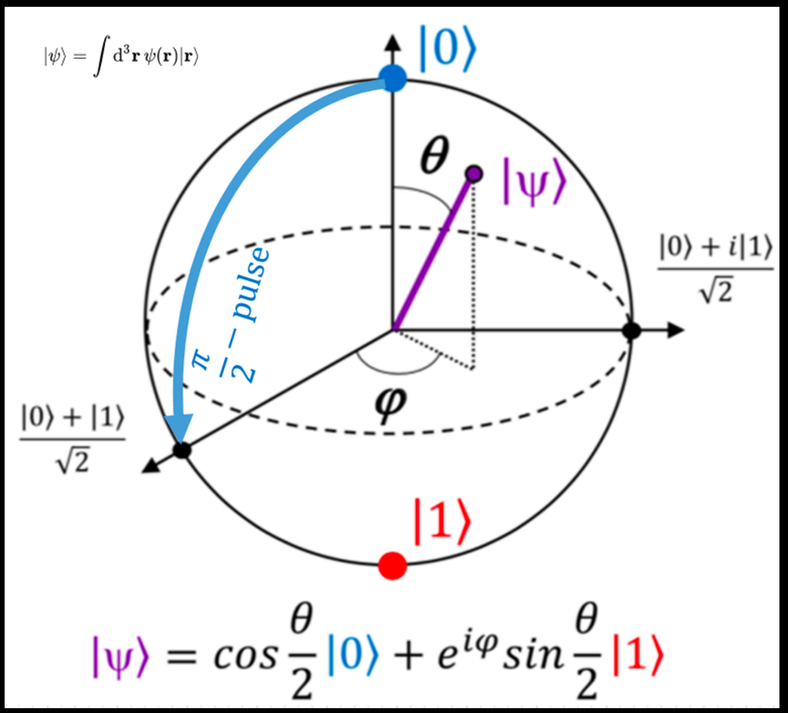
The Z quantum gate

$$A|0\rangle + B|1\rangle \;\text{—}\boxed{Z}\text{—}\; A|0\rangle - B|1\rangle$$

The Hadamard quantum gate

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

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



$$|\Psi\rangle = A|0\rangle + B|1\rangle$$

$$|0\rangle = 1|0\rangle + 0|1\rangle$$

$$|1\rangle = 0|0\rangle + 1|1\rangle$$

Programing quantum computing

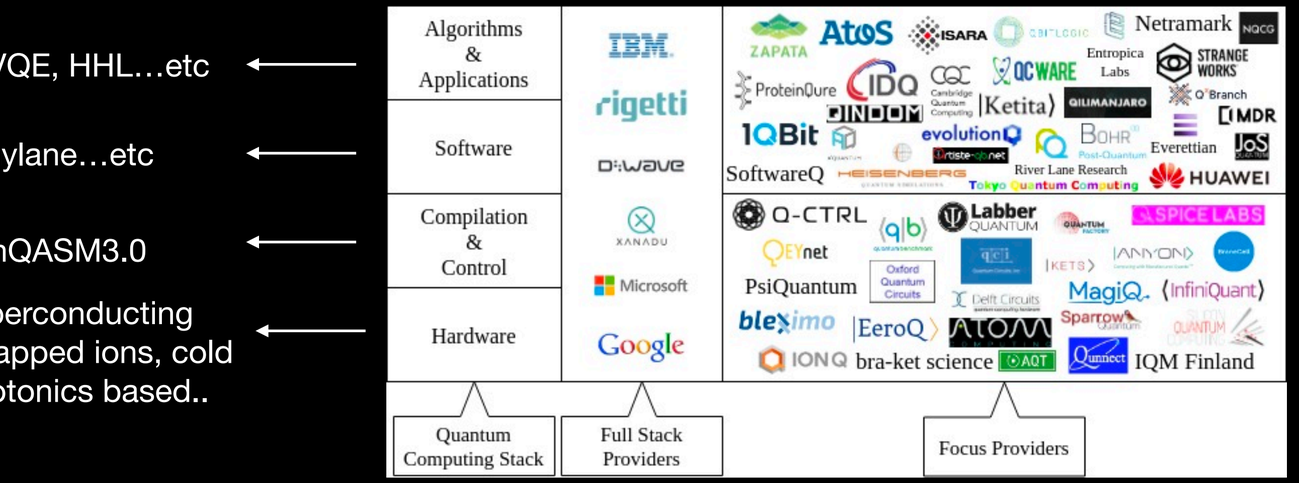
Quantum stack, how big is the real thing?

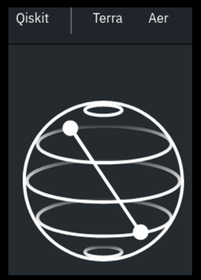
Shor's factoring, grover, VQE, HHL…etc

Qiskit, Cirq, Q#, pennylane…etc

OpenQASM2.0, openQASM3.0

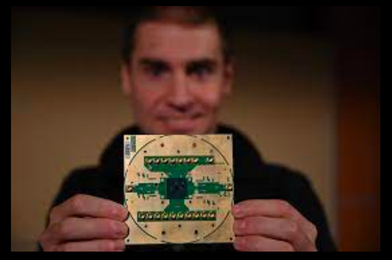
Quantum annealers, superconducting
Quantum universal gate, trapped ions, cold atoms, silicon based, photonics based..

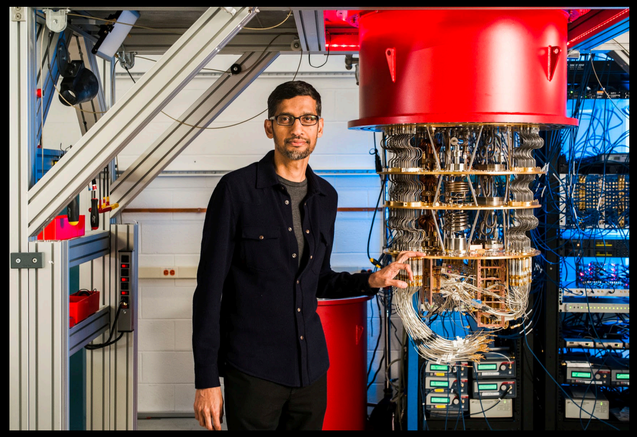




I totally encourage to start with qiskit

Cirq





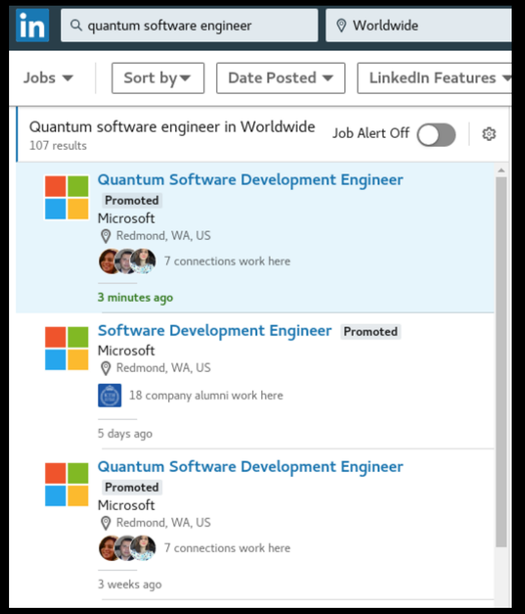
Common questions

- Do I need a PhD to use, do quantum programming or have a career in quantum computing?
  - No, the tools are getting more abstract by time evolving

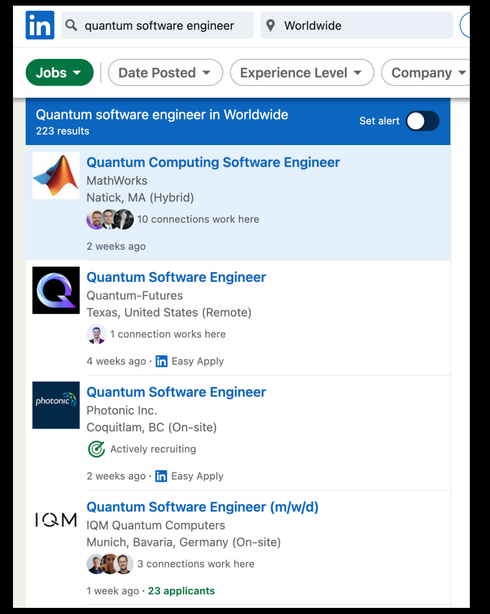
- Can it be a personal computer?
  - Maybe yes, maybe no, but why would you need it
- Can we mine crypto on it?
    - Cost!

My take on this!

- Try to bring quantum to your tasks, maybe once quantum advantage is achieved, you can be ready!
- Search for the quantum alternative of the classical method you using and use it
- Maybe we will end up with something different, yet experience counts
- You don’t need access to a quantum hardware in most cases, a simulator can achieve allot



Feb 2020



Mar 2022

Demo and future reading

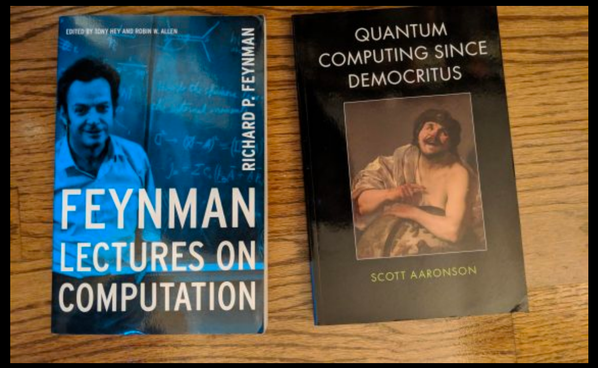
Some suggested resources

```
OPENQASM 2.0;
include "qelib1.inc";

qreg q[2];
creg c[2];

h q[0];
cx q[0],q[1];
measure q[0] -> c[0];
```

- Qiskit textbook https://qiskit.org/textbook/preface.html
- Qiskit's medium https://medium.com/qiskit/learn-quantum-computing-with-these-seven-projects-7478d90d125a
- Qiskit community https://github.com/qiskit-community/qiskit-community-tutorials
- Pennylane with QML https://pennylane.ai/qml/



- Amazon braket: https://github.com/aws/amazon-braket-examples

Braket Tutorials GitHub

Welcome to the primary repository for Amazon Braket tutorials. We provide tutorials on quantum computing, using Amazon Braket. We provide examples for quantum circuits and quantum annealing. We cover canonical routines, such as the Quantum Fourier Transform (QFT), as well as hybrid quantum algorithms, such as the Variational Quantum Eigensolver (VQE).

The repository is structured as follows:

- Getting Started: Simple circuits and algorithms
- Advanced circuits and algorithms
- Hybrid quantum algorithms
- Quantum machine learning and optimization with PennyLane
- Quantum annealing with D-Wave
- Amazon Braket features
- Amazon Braket Hybrid Jobs
- Creating a Conda environment

- An old workshop exercises I gave 2 years ago: https://github.com/KarimElgammal/QuantumComputing/tree/master/Facebook_Developer_Circle_Feb2020_workshop probably won't work, depend on older version, maybe you can pipenv it

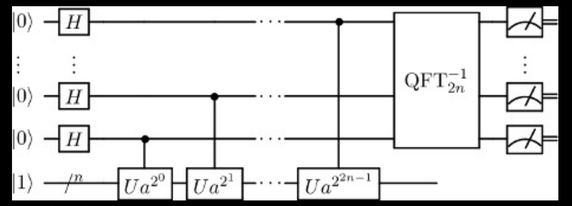
Homework

Implement shorts algorithm using quantum gates and circuits and lets learn it together!

- Full solution here, but of course you can implement it the way you prefer https://github.com/qiskit-community/qiskit-community-tutorials/blob/master/algorithms/shor_algorithm.ipynb old one

$$
\begin{aligned}
x^k &\equiv 1 \pmod N \\
x^k &= qN + 1 \\
x^k - 1 &= qN \\
(x^{k/2} + 1)(x^{k/2} - 1) &= qN
\end{aligned}
$$

- https://qiskit.org/textbook/ch-algorithms/shor.html newer



- https://qiskit.org/documentation/stable/0.26/tutorials/algorithms/09_textbook_algorithms.html