Quantum Computing

Brief overview + introductory hands-on

Karim Elgammal

Who am I?

- Researcher at KTH
- PhD from KTH as well!

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

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

$$+ \underbrace{\frac{1}{2}\sum_{i\neq j}\frac{e^2}{4\pi\epsilon_0 \left|\mathbf{r_i}-\mathbf{r_j}\right|}}_{\text{Electron-Electron Interaction}} - \underbrace{\sum_{i,I}\frac{Z_I e^2}{4\pi\epsilon_0 \left|\mathbf{r_i}-\mathbf{R_I}\right|}}_{\text{Electron-Nucleus Interaction}}$$

Time management:

~25 min introduction

~25 min hands-on

Quora Home 1 Answer Spaces Notifications Search Qu

Quantum Computing | Quantum Mechanics | Computer Science | Computers

Why do we need quantum computers?

Answer Follow · 19 Request

16 Answers

Faster solutions?

- ? x ? = 21
- ? x ? = 121
- ? x ? = 8713

Applications

? X ? =

546787410548678745488161461324657681657246168451682342349702394821387462
138472384729471294710410473875294194012489027490146712904721904710461920
472904729047242133626342844244215645454123511315213152115212512551351655
815691656135513561551150045454551112221424645635548651545463565212562815
346635413655125643451534251348613455612358345135513256351351904721904710
461920472904729047242133626342844244215645454123511315213152115212512551
351655815691656135513561551150045454551112221424645635548651545463565212
562815346635413655125641384723847294712947104104738752941940124890274901
467129047219047104619204729047290472421336263428442442156454541235113152
131521152122221424645635548651545463565212562815346635413655125641384723
847294712947104104738752941940124890274901467129047219047104619204729047
290472421336263428442442156454541235113152121384723847294712947104104738
752941940124890274901467129047219047104902749014671290472190471046192047
290472904724213362634284424421564545412351131521213847238472947129471041
047387529419401248902749014671290472190471046192047290472904724213362634
284424421564545412351131881654664179522123512121112251822400985675705685
671808556678614613246576816572461684516823423497023948213874621384723847
294678741054867874548816146132465768165724616845168234234970239671290472
190471046192047290472904724213362634284424421564545412351131521213847238
472947129471041047387529419401248902749014671290472190471046192047290472
904724213362634284424421564545412351131881614613246576816572461684516823
423497023948213428442442156454541235113152121384723847294712947104104738
752941940124890274901467129047219047104619204729047290472421336263428442
442156454541235113188161461324657681657246168451682342349702394821387462
138472384729467874105486787454881614613246576816572461684516823423497023
967129047219047104619204787462138472384729467874105486787454881614613246

Applications

SCAN ME

Respond at **PollEv.com/karimelgamma778**

To find the prime factors of 2048 bit number (which is 617 digit-long), how long does it take for a real large scale quantum computer (if ever found!) with billions of qubits?

~100 years

~100 days

~100 hours

~100 seconds

~100 milliseconds

Quantum computer will hang-up! And will never be able to solve it either!

Applications

Solvable using 'Shor's algorithm' a quantum algorithm

SCAN ME

Respond at **PollEv.com/karimelgamma778**

To find the prime factors of 2048 bit number (which is 617 digit-long), how long does it take for a real large scale quantum computer (if ever found!) with billions of qubits?

- ~100 years
- ~100 days
- ~100 hours
- ~100 seconds
- ~100 milliseconds
- Quantum computer will hang-up! And will never be able to solve it either!

Poll Everywhere

Answers to this poll are anonymous

Application?

From coincentral

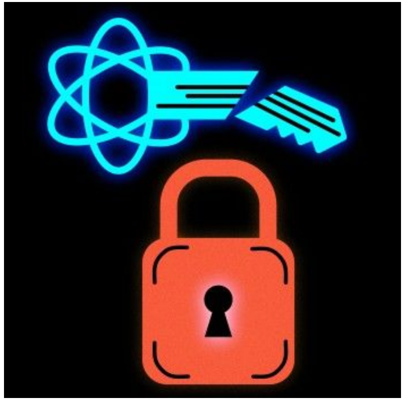
Application?

From datavirtualizationblog

Research area: Post quantum cryptography

From MIT

Research area: Post quantum cryptography



From MIT

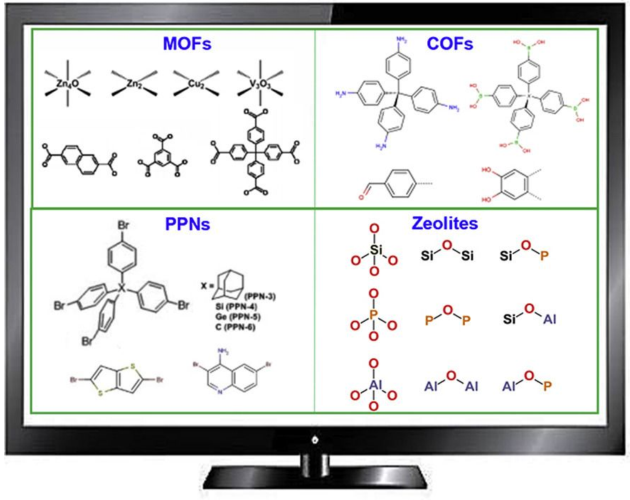
Application: simulating and understanding quantum system

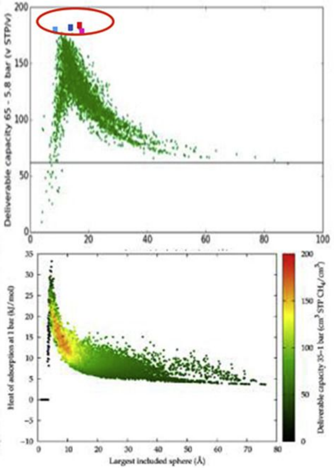
Use a quantum system (quantum computer)

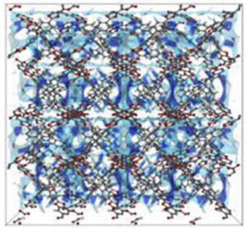
To simulate

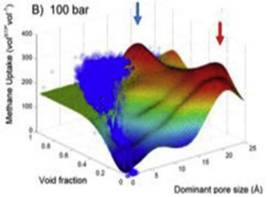
a Quantum system (nature)

Application: simulating quantum system

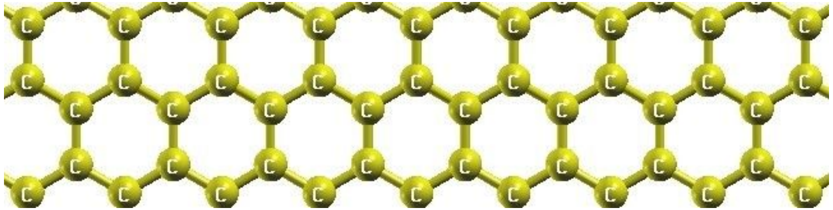






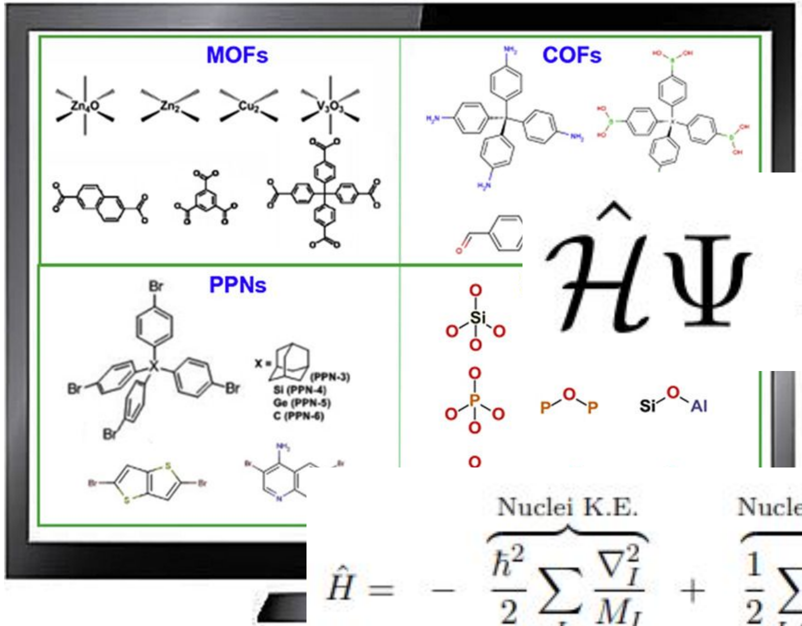


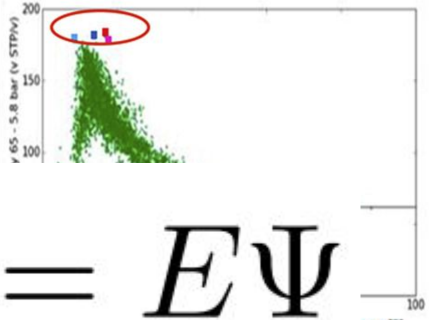
Pharmaceutical industry & medecine

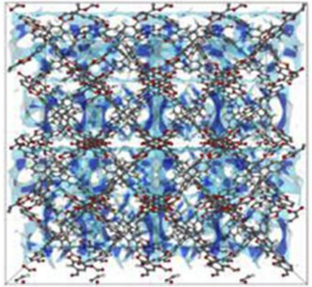


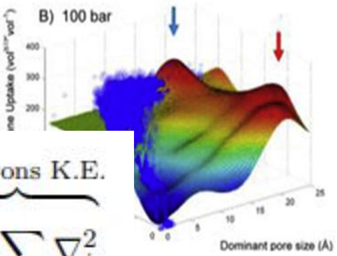
Application: Pharmaceutical industry & medecine

Application: simulating quantum system





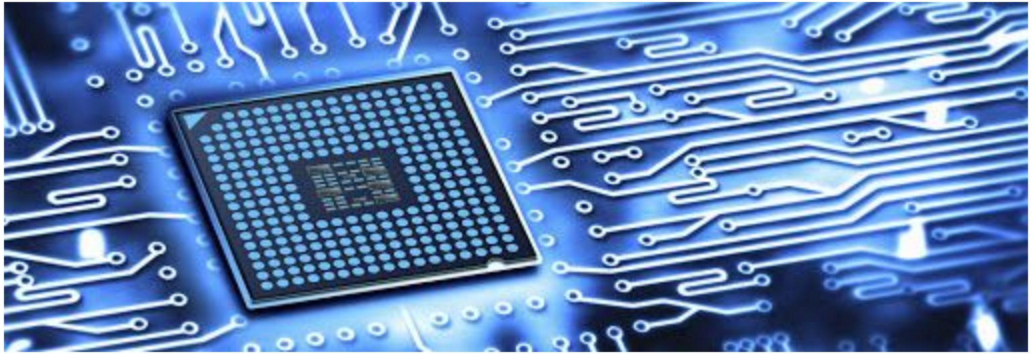




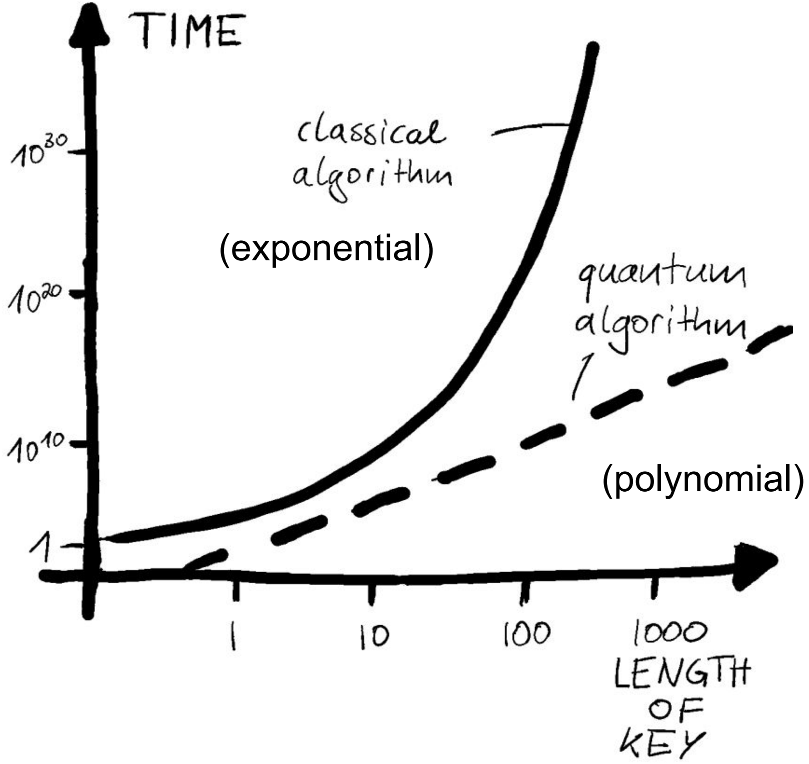
$$\hat{\mathcal{H}}\Psi = E\Psi$$

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

Application: accelerate inventing new materials



Speed up


TIME
classical algorithm
(exponential)
quantum algorithm
(polynomial)
10^{30}
10^{20}
10^{10}
1
1
10
100
1000
LENGTH OF KEY

Quantum machine learning!

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

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.

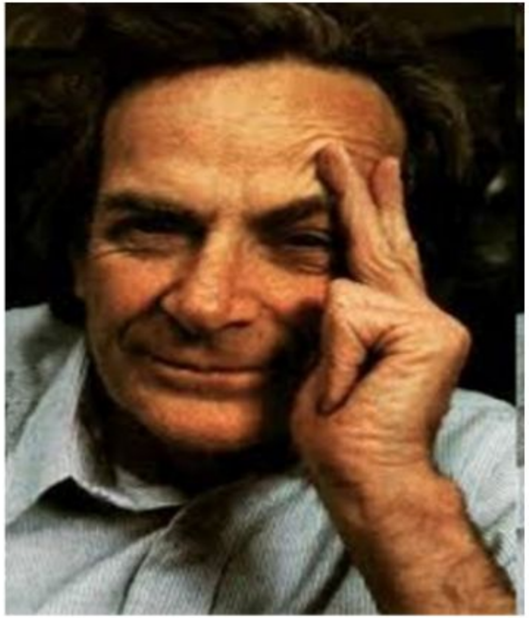
Method	Speedup	Amplitude amplification	HHL	Adiabatic	qRAM
Bayesian inference[106,107]	$O(\sqrt{N})$	Yes	Yes	No	No
Online perceptron[108]	$O(\sqrt{N})$	Yes	No	No	Optional
Least-squares fitting[9]	$O(\log N)$*	Yes	Yes	No	Yes
Classical Boltzmann machine[20]	$O(\sqrt{N})$	Yes/No	Optional/No	No/Yes	Optional
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

Theory!

"There's plenty of room at the bottom"

- The physicist Richard Feynmann is credited with inspiring the field of nanotechology in a talk delivered in 1959.
- Why can we not build machines at the atomic level?

1981



From univ. Of HK

Theory!

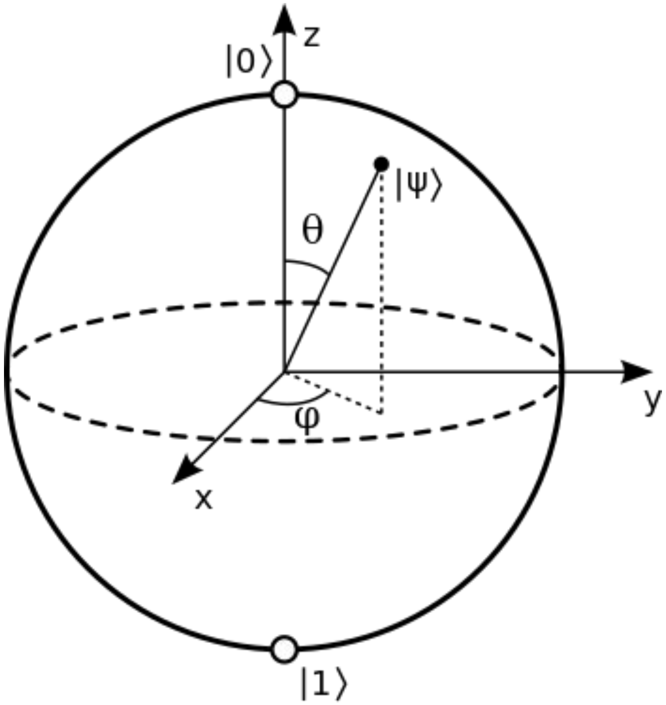
Qubits and Superposition

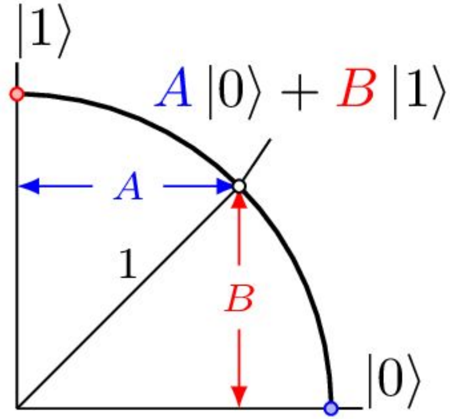
$$|\psi\rangle = \int d^3\mathbf{r}\, \psi(\mathbf{r})|\mathbf{r}\rangle$$

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

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

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





The Bloch Sphere by Smite-Meister - Own work, CC BY-SA 3.0

Theory!

Quantum gates

The X quantum gate

$$A|0\rangle + B|1\rangle \;-\!\boxed{X}\!-\; B|0\rangle + A|1\rangle$$

The Z quantum gate

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

The H Hadamard gate

$$|0\rangle \;-\!\boxed{H}\!-\; \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

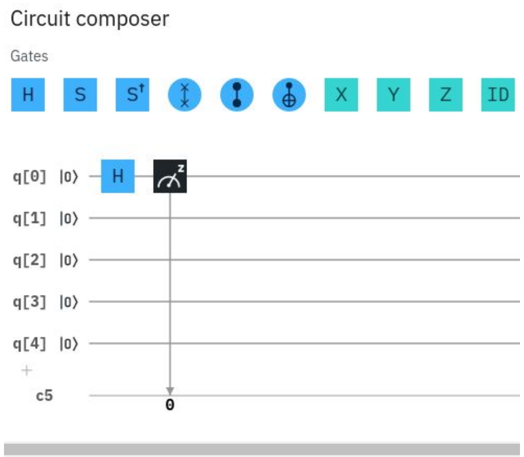
$$|1\rangle \;-\!\boxed{H}\!-\; \frac{1}{\sqrt{2}}|0\rangle - \frac{1}{\sqrt{2}}|1\rangle$$

When poll is active, respond at **PollEv.com/karimelgamma778**

Q: How many measurable classical bits in a 100 Qubit quantum computer operation?

- ~10^{30}
- ~100
- ~10^{100}
- ~100^{100}
- 200
- none of the above!

Programing on a quantum computer



Cirq

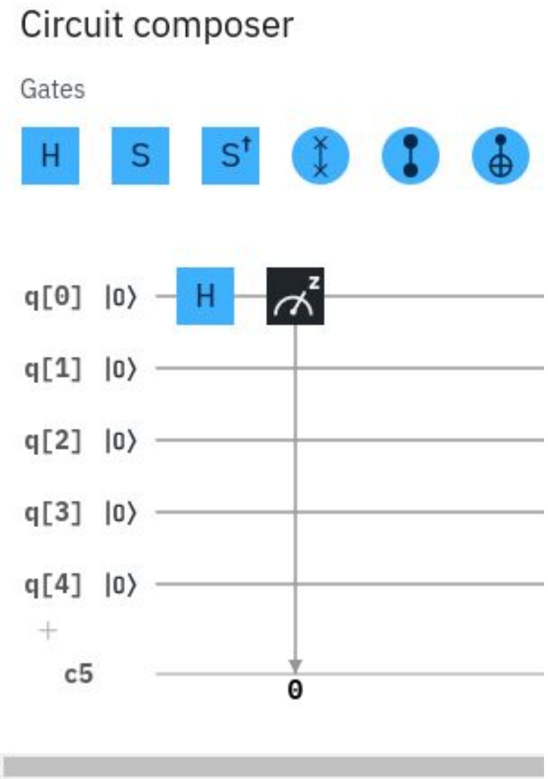
strange build passing

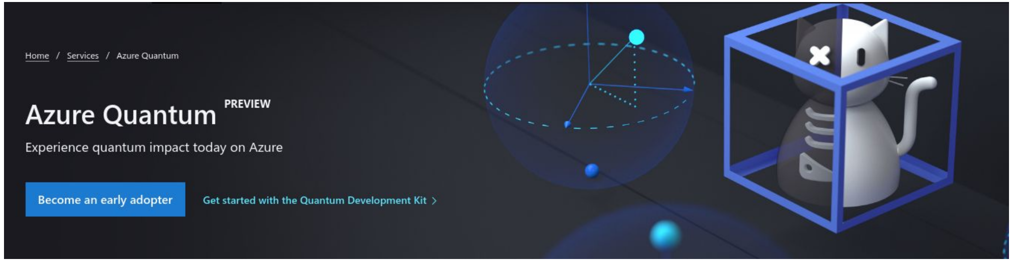
Quantum Computing API for Java

<Q#>

Hardware of Quantum Computers

Cloud platforms






```
import qiskit
from qiskit import *
from qiskit.tools.visualization import *
from qiskit.tools.monitor import job_monitor
from qiskit import IBMQ
%matplotlib inline
```

```
with open('tocken.txt', 'r') as file:
    myTocken = file.read().replace('\n', '')
IBMQ.save_account(myTocken,overwrite=True)
IBMQ.load_account()
```

Quantum developers?

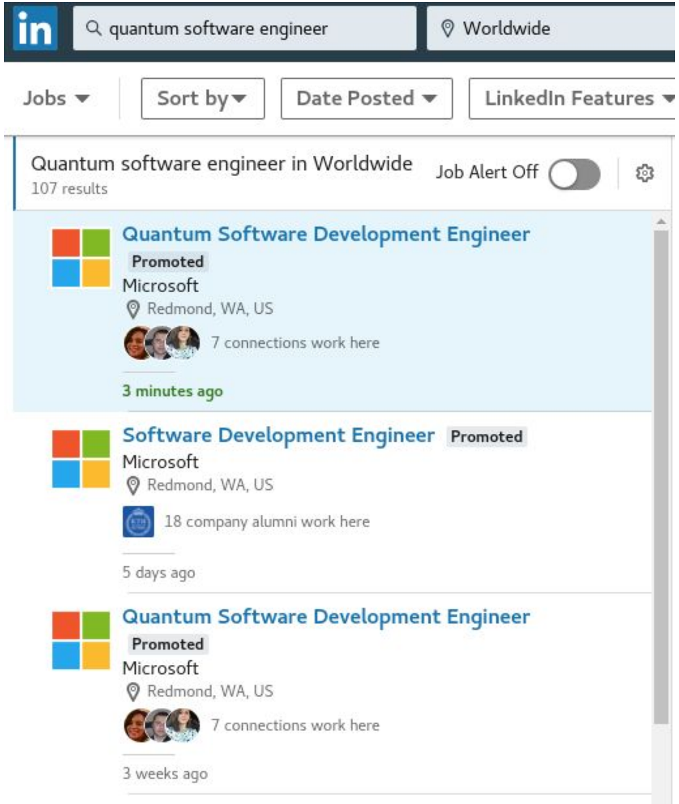
IBM Google Microsoft

rigetti

IONQ

ZAPATA

Startups > 100



Time for hands-on

Update

Check all latest links on

https://github.com/KarimElgammal/QuantumComputing/tree/master/Facebook_Developer_Circle_Feb2020_workshop

Prerequisites:

Jupyter?	pip3 install jupyter
Qiskit?	pip3 install qiskit
Matplotlib?	pip3 install matplotlib
Pipenv?	pipenv shell

Store your token in a file then name it ‘tocken.txt’

Download jupyter file http://bit.ly/39lcmuG for testing purpose

Superposition experiment - flip a coin!

Update your Jupyter notebook implementing H gate on 1 qubit

Fill in: http://bit.ly/3bmXNJ3

Superposition experiment - flip a coin!

Update your Jupyter notebook implementing H gate on 1 qubit

Solution: http://bit.ly/2vh2SIB

2 qubit operations

- Fill the missing gaps in http://bit.ly/2SxNoRV according to the steps
-

2 qubit operations

- Solution: **http://bit.ly/3bperri**

8-sided dice

Follow this jupyter http://bit.ly/2SxNoRV

8-sided dice

Solution: http://bit.ly/2SrjYVu

Quantum random number generator

http://bit.ly/3bsLBGs

Using Shor’s algorithm

http://bit.ly/2St1J28

Homework: implement Shor as detailed in the next slide and compare your result with the proposed solution!

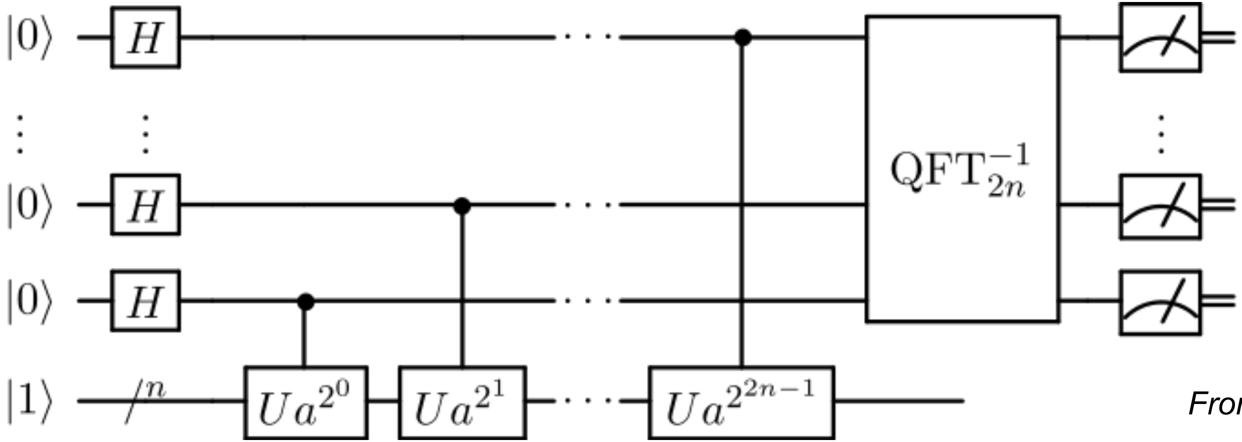
Shor's Algorithm

$$x^k \equiv 1 \pmod{N}$$

$$x^k = qN + 1$$

$$x^k - 1 = qN$$

$$(x^{k/2} + 1)(x^{k/2} - 1) = qN$$



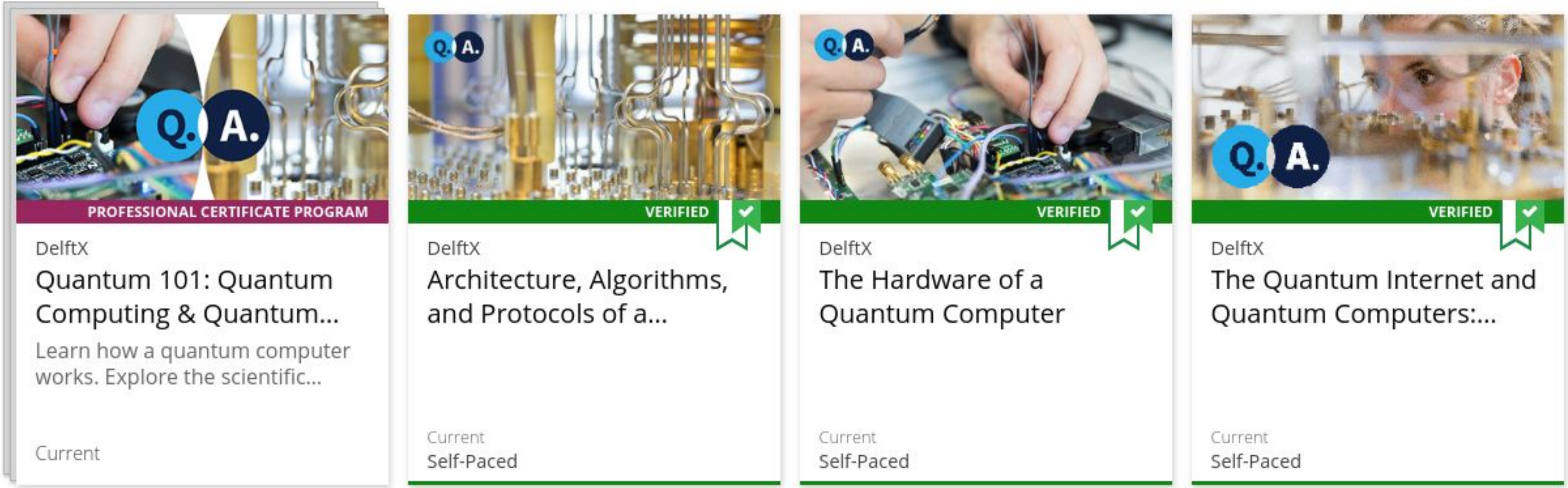
From wikipedia

The github repository

https://github.com/KarimElgammal/QuantumComputing

Refs. and more reading?

- https://quantumcomputingreport.com/
- https://blog.cloudflare.com/the-quantum-menace/
- https://quantum.country/qcvc



Thank you!

Add me on linkedIn

Please answer the feedback questionnaire

SCAN ME