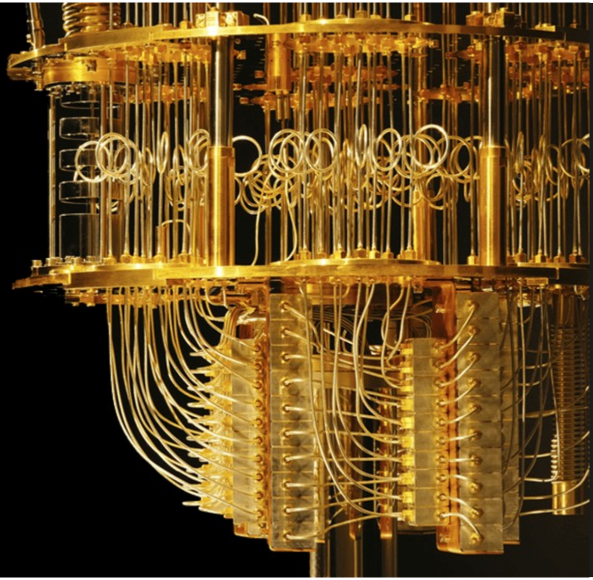

IBM quantum computer

Introduction
What is quantum computing
Quantum tech landscape
Fundamental principles
Developing quantum solutions
Quantum computing in action
Benefits, challenges and opportunities
Summary, reflections and questions

Business Applications of Quantum Computing:
Some Promises and Words of Caution

Honorary Assoc. Prof. Jacob L. Cybulski
School of IT, SEBE, Deakin University

10 November 2022

Quantum technology landscape

What is Quantum Technology?

provides theoretical foundations for all quantum technology

Quantum mechanics
is the area of science dealing with the behaviour of matter and light on the atomic and subatomic scale (Britannica.com, 2020)

Quantum computing and
Quantum information science
are the study of the information processing tasks that can be accomplished using quantum mechanical systems (Nielsen and Chuang, 2010)

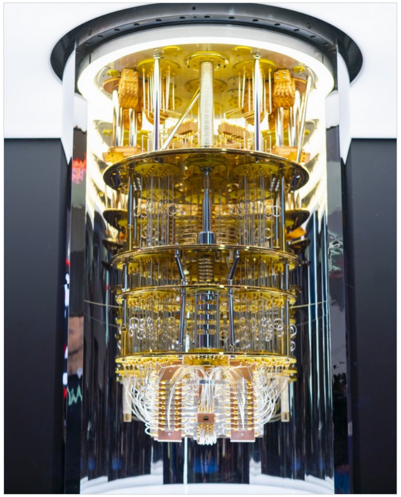
suit complex problems with little data

Quantum machine learning,
Quantum optimisation,
Quantum cryptography,
Quantum communication
are IT-related quantum technology sub-fields

suit complex problems with lots of data

Quantum engineering
building quantum devices

attracts the majority of global effort in quantum technology



IBM superconducting quantum machine (127 qubits on cloud)

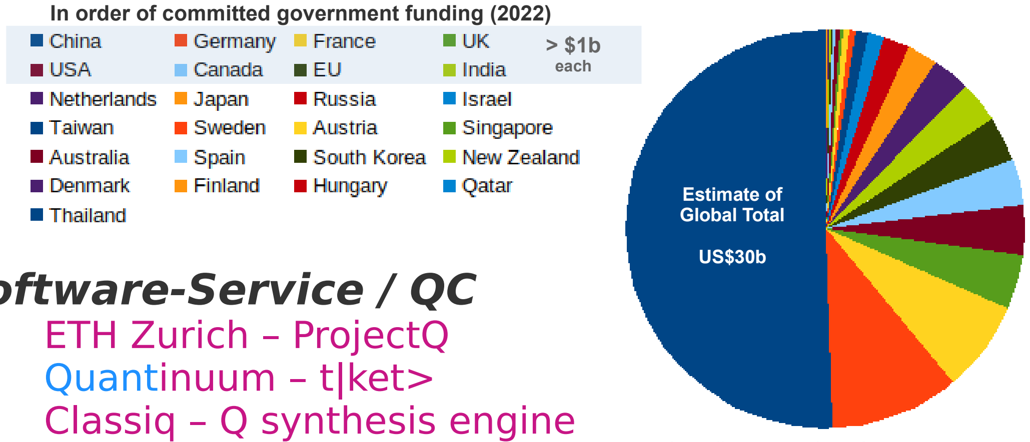
Quantum Brilliance NV diamond quantum machine (“a few” qubits)

ATOS Quantum Learning Machine (HPC simulator, 41 qubits)

Qubit (or quantum bit) is the fundamental model of quantum information and its manipulation

Quantum circuit is a model of quantum computation, involving qubits and operations on them

Quantum Tech Worldwide (2021-2022)



https://qureca.com/overview-on-quantum-initiatives-worldwide-update-2022/

Universal / Gate-Based Machines

- IBM (Superconducting / Cooper pair)
- Google (Superconducting)
- Rigetti (Superconducting)
- IonQ (Trapped ion)
- Quantinuum (Trapped ion, Honeywell+CQC)
- Microsoft (Hybrid+Topological)
- AQT - Alpine Quantum Tech (Trapped ion)
- CEA Leti (Spin - Silicon / Photonics)
- Quantum Brilliance (Carbon / Room Temp)
- Xanadu (Photonics / Room Temp)
- Baidu (Superconducting)

Quantum Annealing Machines

- D-Wave (Q Annealing+…Gate based)

Simulators / Quantum Inspired

- Atos (GPU, 41 qubits)
- Alibaba (Cloud QPD)
- Fujitsu (Digital Annealing)

Software-Service / QC

- ETH Zurich – ProjectQ
- Quantinuum – t|ket>
- Classiq – Q synthesis engine
- IBM Quantum – Qiskit
- Google Quantum AI - Cirq
- Microsoft Azure Quantum – QD Kit/Q#
- AWS Braket - Amazon Braket SDK

Providers

- Quantinuum
- IonQ
- QCI
- Rigetti
- Pasqal
- 1QBit
- Microsoft QIO
- Toshiba

Providers

- IonQ
- Rigetti
- OQC
- Xanadu
- Q-Wave
- QuEra (soon)

Software-Service / QML

- IBM Quantum / Qiskit – Qiskit ML
- Tensorflow – TFQ (+Cirq)
- Xanadu – PennyLane (+SF)
- Atos – QLM

Applications / Users

- NASA, BASF, Boeing, VW, …
- Accenture (Business)
- Zapata (Business)
- 1QBit (Medical / Finance)

US-based quantum companies
Non-US quantum companies

Trends and timelines

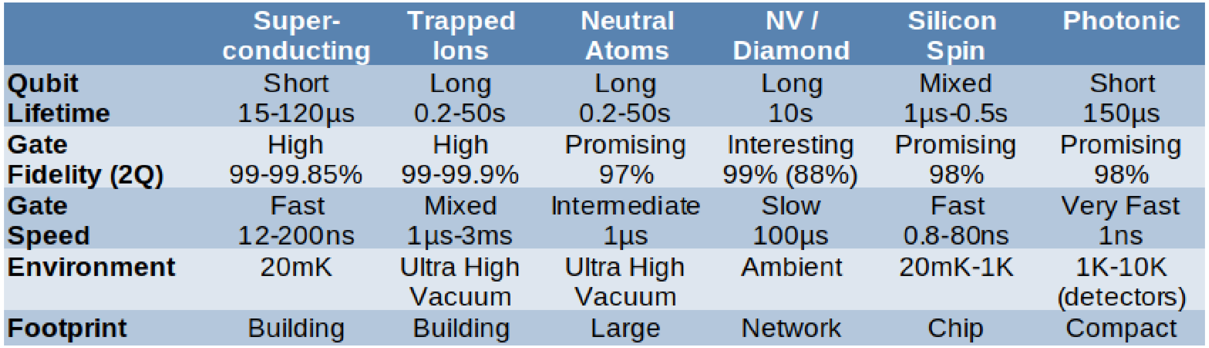
Quantum Roadmaps

Quantum technologies are difficult to compare directly

- Quantum machine vendors use different standards to measure their products
- It is common to measure the power and utility of a quantum machine in terms of *the number of qubits*
- However, different types of qubits have different life-time, speed and fidelity
- It also takes several hardware qubits to make one high-quality logical qubit
- Equally important is the utility of the quantum machine by the enclosing technology (hardware and software)
- As a result, it is very hard to compare the vendor claims as to their product features, plans, timelines and roadmaps

David Shaw., Quantum Business Europe, Fact Based Insight, 2021,
URL: https://www.factbasedinsight.com/quantum-hardware-platforms-a-brief-overview/

Platform	Player	2020	2021	2022	2023	2024	2025 to 2030
Superconducting	Google	**53Q**	100Q		10^3Q		10^4Q - 10^4Q - 1MQ
Superconducting	IBM	**65Q**	127Q	433Q	1121Q		path to 1MQ
Superconducting	Rigetti	**32Q**	4x32Q				
Trapped Ion	Honeywell	**H1**		H2	H3		H4 H5
Trapped Ion	IonQ	22AQ		29AQ		256AQ	1024AQ
Neutral Atom	ColdQuanta		100Q	300Q		1000Q	
Silicon	CEA Leti		6Q		100Q		
Silicon	SQC			10Q			100Q
Photonic	QuiX		12Qm	50Qm			
Photonic	PsiQ						1MQ
Photonic	Xanadu	X24	X40	X80	XD80		1MQ



	Super-conducting	Trapped Ions	Neutral Atoms	NV / Diamond	Silicon Spin	Photonic
Qubit Lifetime	Short 15-120µs	Long 0.2-50s	Long 0.2-50s	Long 10s	Mixed 1µs-0.5s	Short 150µs
Gate Fidelity (2Q)	High 99-99.85%	High 99-99.9%	Promising 97%	Interesting 99% (88%)	Promising 98%	Promising 98%
Gate Speed	Fast 12-200ns	Mixed 1µs-3ms	Intermediate 1µs	Slow 100µs	Fast 0.8-80ns	Very Fast 1ns
Environment	20mK	Ultra High Vacuum	Ultra High Vacuum	Ambient	20mK-1K	1K-10K (detectors)
Footprint	Building	Building	Large	Network	Chip	Compact

Fundamentals

Working with Quantum Tech

- You can enter the field from many different areas of expertise, e.g.
  - Physics / Science / Engineering
  - Computer Science / Data Science
  - Software Engineering
  - Business / Law / Defence
  - Arts / Journalism ...
- You can contribute to the quantum field in many different ways, e.g.
  - Work on new quantum hardware
  - Develop new quantum algorithms
  - Solve problems with existing tech
  - Teach / promote quantum tech
  - Specialise in one of the aspects
  - Manage a quantum team ...
- The most important trait of people in quantum tech is their enthusiasm and commitment

Domain	Skill/Knowledge	**Naive** Experiments with quantum concepts	**Basic** Writes simple quantum programs	**Medium** Takes part in quantum challenges	**Advanced** Has a technical job in quantum technology	**Expert** Other people in quantum think they are super
Mathematics	Complex Numbers	✓	✓	✓✓	✓✓	✓✓
	Linear Algebra		✓	✓✓	✓✓	✓✓✓
	Calculus			✓	✓✓	✓✓✓
	Differential Equations				✓	✓✓
	Partial Differential Eqs				✓	✓✓
	Fourier Transforms				✓	✓
	Probability Theory	✓	✓	✓✓	✓✓	✓✓
	Statistics	✓	✓	✓	✓✓	✓✓
Data Science	Programming (Python)		✓	✓✓	✓✓	✓✓
	Optimisation Techniques			✓✓	✓✓	✓✓
	Machine Learning			✓✓	✓✓	✓✓
Quantum Computing	Foundations (Bell State)	✓	✓	✓✓	✓✓✓	✓✓✓
	Circuits, Qubits, Gates, Bloch Sphere	✓	✓	✓✓	✓✓✓	✓✓✓
	Quantum Circuit Simulators	✓	✓	✓	✓✓	✓✓
	Circuit Execution	✓	✓	✓✓	✓✓✓	✓✓✓
	Results Interpretation / Visualisation	✓	✓	✓✓	✓✓✓	✓✓✓
	Algorithms (Grover, Shor, …)		✓	✓✓	✓✓✓	✓✓✓
	Simple Error Mitigation		✓	✓✓	✓✓✓	✓✓✓
Quantum Machine Learning	Variational Quantum Algorithms			✓	✓✓	✓✓✓
	Data Encoding			✓	✓✓	✓✓✓
	Result Interpretation			✓	✓✓	✓✓✓
	Quantum Optimisation			✓	✓✓	✓✓✓
	Quantum Linear Models			✓	✓✓	✓✓✓
	Quantum Neural Networks			✓	✓✓	✓✓✓
	Quantum Kernel Methods			✓	✓✓	✓✓✓
	Quantum Probabilistic Models				✓	✓✓
	Quantum Annealing				✓	✓✓
Quantum Hardware	Configuration				✓	✓✓
	Calibration			✓	✓	✓✓
	Complex Error Mitigation			✓	✓	✓✓

How qubits work

In a simplified way!

Qubit is often “implemented” as a single elementary particle, e.g. electron

Qubit represents a state of such a particle, e.g. an electron spin, which can be up or down.

Qubits are in a state of *superposition*, or a combination, of its *basis states* up and down, e.g.

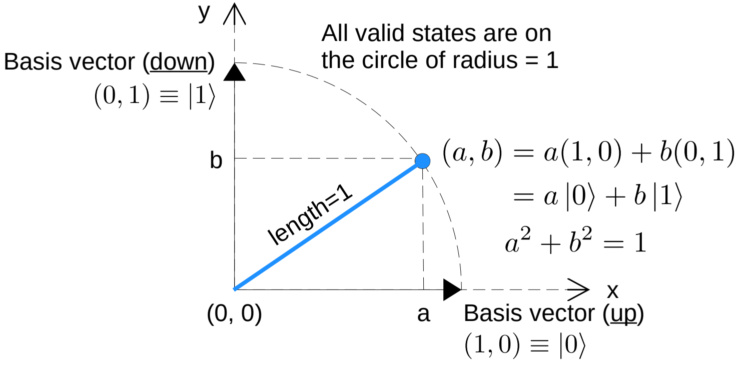
$$\frac{\sqrt{3}}{2} \times \underline{up} + \frac{1}{2} \times \underline{down}$$

A qubit state can be thought of as a *vector* in a space spanned by the *basis vectors*, up and down.

The *qubit state space* has its own coordinate system, defined by the basis vectors, which are orthogonal unit vectors (of length=1), e.g. vectors (1, 0) and (0, 1), denoted as |0> and |1>.

When we *measure* the qubit, its state collapses probabilistically into one of its basis states up or down, measured as simple values, e.g.

0 or 1 for up or down in electrons



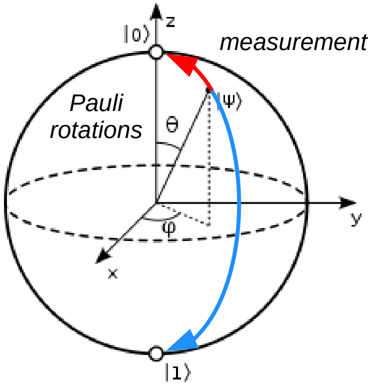
|0> and |1> are vectors, not values 0 and 1, which is what we observe on qubit measurement

Measurement of a qubit in state (a, b) returns 0 or 1, with probability a^2 and b^2 respectively

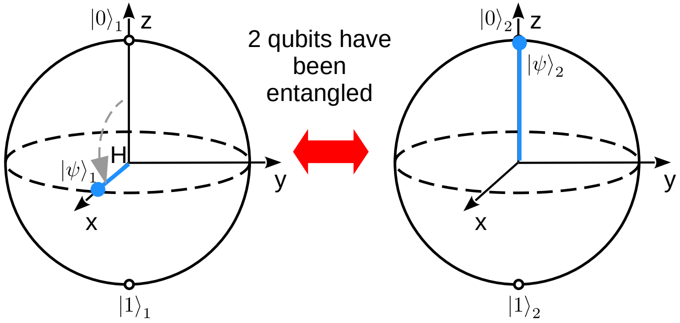
When measurements are repeated we can calculate expectation values of observing 0 or 1

As we can see, any vector (a, b) is a *superposition* . (linear combination) of the basis vectors (1, 0) and (0, 1).

In reality, qubit states are described by two *complex numbers*, making it 4 numbers, which can be “projected” onto a *Bloch sphere* (see right).



The states of two *independent qubits* are: $\{|00\rangle\,,\ |01\rangle\,,\ |10\rangle\,,\ |11\rangle\}$



Entangled qubits act in unison and some of their states cannot be accessed, e.g.

$\{|00\rangle\,,\ |\cancel{01}\rangle\,,\ |\cancel{10}\rangle\,,\ |11\rangle\}$

QC program & its results

Quantum solutions

Quantum circuits are the essence of any quantum solution, however, they can be defined in many different ways, which could then be translated into a form executable on a quantum machine

e.g. consider a Grover Algorithm

Mathematical model

Oracle

$$O|x\rangle = (-1)^{f(x)}\,|x\rangle$$

Oracle matrix

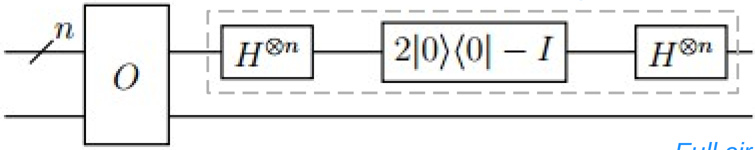
$$O\,|x\rangle = \begin{bmatrix} (-1)^{f(0)} & 0 & \cdots & 0 \\ 0 & (-1)^{f(1)} & \cdots & 0 \\ \vdots & 0 & \ddots & \vdots \\ 0 & 0 & \cdots & (-1)^{f(2^n-1)} \end{bmatrix} \begin{bmatrix} x_0 \\ x_1 \\ \vdots \\ x_{2^n-1} \end{bmatrix}$$

Grover operator

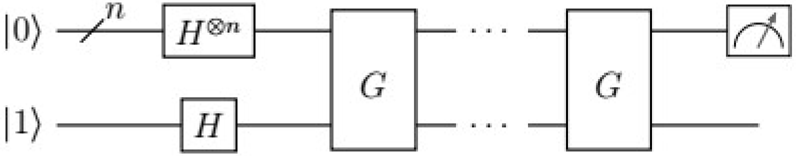
$$G = (H^{\otimes n}(2\,|0\rangle\,\langle 0| - I)H^{\otimes n})O$$

Conceptual circuit diagram

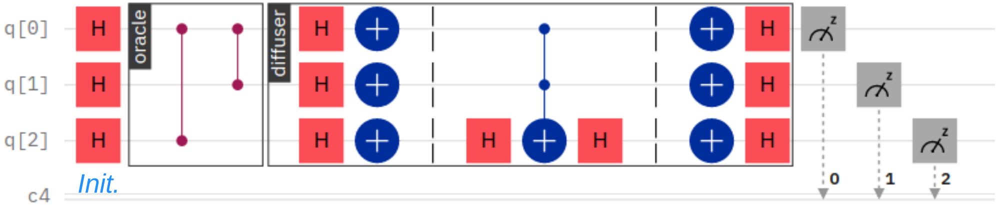
Grover operator (Oracle + Diffuser)



Full circuit with repeated Grover operator



Note: no acilla bit, super-gates and barriers included for readability only!



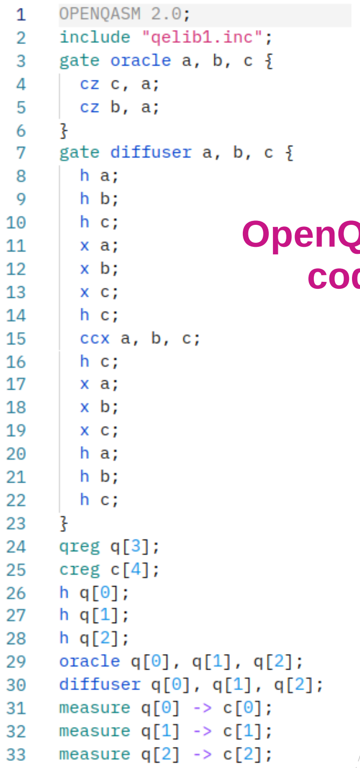
Init.

Oracle encoding two numbers

Diffuser amplifying the solution

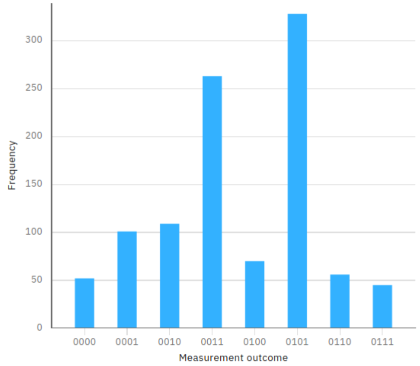
Executable circuit diagram

OpenQASM code



```
OPENQASM 2.0;
include "qelib1.inc";
gate oracle a, b, c {
  cz c, a;
  cz b, a;
}
gate diffuser a, b, c {
  h a;
  h b;
  h c;
  x a;
  x b;
  x c;
  h c;
  ccx a, b, c;
  h c;
  x a;
  x b;
  x c;
  h a;
  h b;
  h c;
}
qreg q[3];
creg c[4];
h q[0];
h q[1];
h q[2];
oracle q[0], q[1], q[2];
diffuser q[0], q[1], q[2];
measure q[0] -> c[0];
measure q[1] -> c[1];
measure q[2] -> c[2];
```

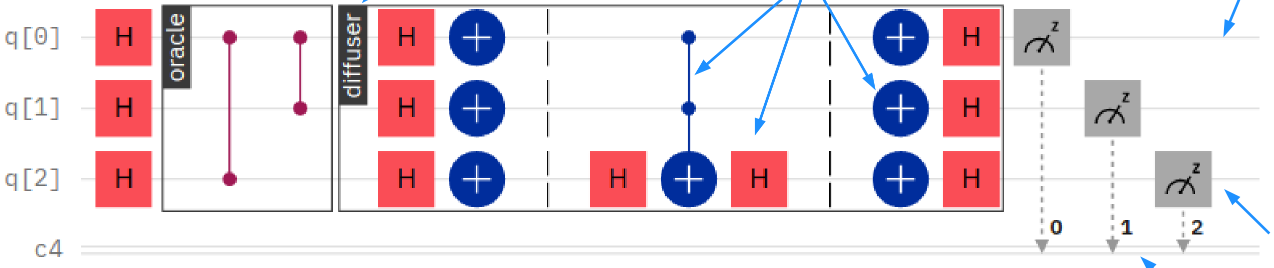
Circuit Execution



Results obtained on a NISQ machine

Building a quantum solution

Logical structure of a circuit



Init.

Input Preparation

user-defined gates

Processing

gates
(or operations)

Output Measurement

quantum registers
(or qubits)

measurement
operations

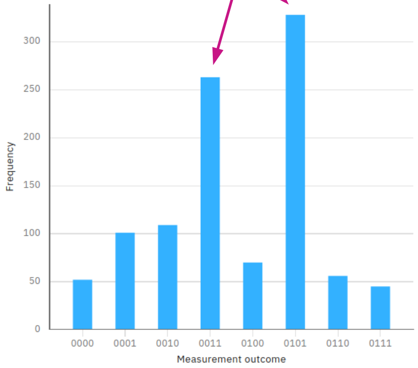
classical registers
with qubit state measured as 0 or 1

Circuit depth (# of gates across)

A circuit is typically generated by a program, e.g. in Python

Result of repeated measurement

Two most likely results



Results need to be interpreted

In the process of quantum circuit design, we usually perform four tasks (opt. alternating and repeated), i.e.

1) Initialisation of quantum registers, often left at default |0>
2) Preparation of quantum information, which involves setting each qubit to a specific state based on input data
3) Processing of quantum information, which applies inter-related gates to these qubits, changing their states
4) Measurement of qubits to obtain classical information about their state

A circuit can then be executed, however note:

Input data is hard-coded into the circuit!
Different input requires a new circuit, however, circuit templates can be created to reuse circuit logic (as in QML)

Each execution produces a single random result!
A circuit must be executed repeatedly, measurements collected and their distribution analysed

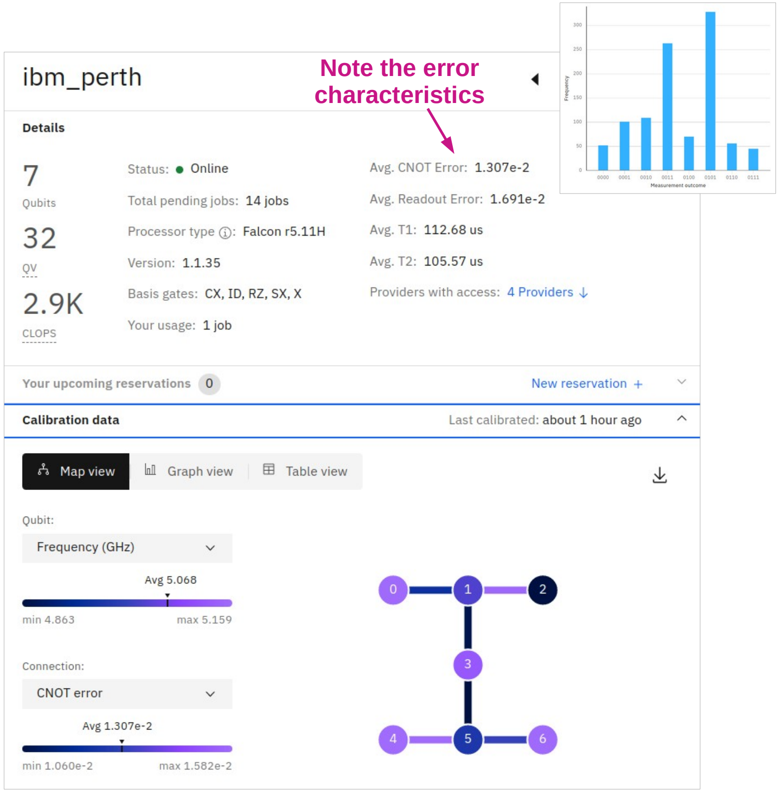
Due to noise, circuits may decohere, leading to errors!
Presence of noise requires detailed analysis of results, error mitigation, and possibly circuit redesign

Circuit transpilation

Note that the previously discussed Grover circuit was executed on the real IBM quantum machine “ibm_perth” of 7 qubits (see its details right).

The circuit was automatically *transpiled* (translated) to use only the supported gates (such as CX, ID, RZ, SX, and X) and qubit entanglements had to be “rewired” to match their physical connections (e.g. CX involving qubits q0 and q2 are not allowed on “ibm_perth”).

This circuit returns only two possible results on a fault-tolerant simulator, i.e. 0011 and 0101. However, on the “noisy” machine, all possible results can be generated.



ibm_perth

Note the error characteristics

Details

7 Qubits

32 QV

2.9K CLOPS

Status: ● Online

Total pending jobs: 14 jobs

Processor type ⓘ: Falcon r5.11H

Version: 1.1.35

Basis gates: CX, ID, RZ, SX, X

Your usage: 1 job

Avg. CNOT Error: 1.307e-2

Avg. Readout Error: 1.691e-2

Avg. T1: 112.68 us

Avg. T2: 105.57 us

Providers with access: 4 Providers ↓

Your upcoming reservations 0 New reservation +

Calibration data Last calibrated: about 1 hour ago

Map view | Graph view | Table view

Qubit: Frequency (GHz)

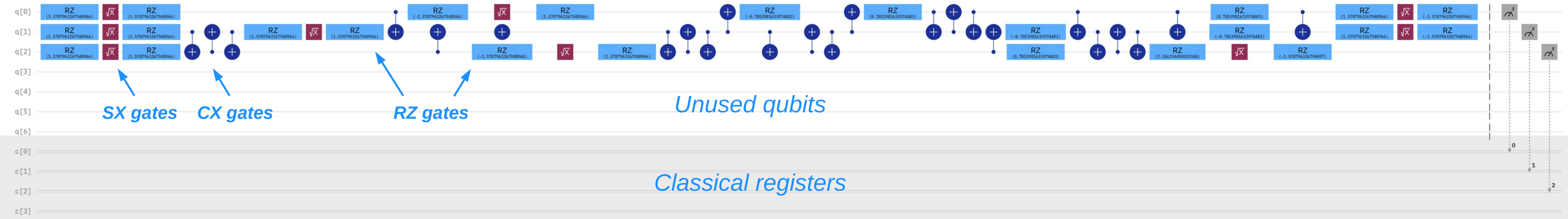
Avg 5.068

min 4.863 max 5.159

Connection: CNOT error

Avg 1.307e-2

min 1.060e-2 max 1.582e-2



Quantum technology in action

Chemistry, Finance, Logistics, Optimisation, Weather, etc.

Major players in quantum application

- Defence Systems – Cryptography, planning, control, sensing, etc.
- Rigetti – Weather forecasts
  https://thequantuminsider.com/2021/12/07/quantum-machine-learning-may-improve-weather-forecasting/
- NASA (QuAIL) – Mission control, space vehicle / rover design and coordination, air traffic management, planning and scheduling, fault diagnosis, etc.
  https://www.sciencedirect.com/science/article/pii/S0167819116301326
- Accenture – Financial, logistics, communications and security services
  https://www.accenture.com/au-en/services/technology/quantum-computing-services
- BASF – Quantum chemical computations: new catalysts and polymers
  https://www.qutac.de/basf-how-quantum-computing-can-help-develop-chemical-catalysts/?lang=en
- Ford / VW / BMW – Traffic, batteries, financials, materials, production opt
  https://spectrum.ieee.org/ford-signs-up-to-use-nasas-quantum-computers
  https://www.volkswagenag.com/en/news/stories/2021/08/volkswagen-takes-quantum-computing-from-the-lab-to-the-factory.html
  https://www.zdnet.com/article/bmw-explores-quantum-computing-to-boost-supply-chain-efficiencies/
- Boeing / Airbus – Manufacturing, materials, logistics, aerospace, flight dynamics
  https://www.ibm.com/blogs/research/2020/09/quantum-industry/
- Goldman Sach / JPMorgan – Financial: derivatives, simulations, pricing, etc.
  https://www.efinancialcareers.com.au/news/2020/12/quantum-computing-at-goldman-sachs-and-jpmorgan
- Boehringer Ingelheim – Medical molecular dynamics
  https://www.boehringer-ingelheim.com/press-release/partnering-google-quantum-computing

Selected areas of
Quantum applications

Most successful quantum computing applications can be found in disciplines such as: *Science* & *Finance* using *Quantum Optimisation* & *Quantum Machine Learning*

Organisations & Society

People

Discovery & Knowledge

Economy

Environment

Networks & Security
- Quantum info & comms
- Encryption
- Quantum repeaters
- Key distribution

Quantum Sensors
- *Measurement*
- *Instruments*
- *Timing*
- *Seismology*
- *Navigation*
- *Microscopy*
- *Imaging*
- *Radars*

Finance / Insurance
- *Portfolio optimisation*
- *Price / option prediction*
- *Fraud indicators*
- *Credit scoring*
- *Financial risk assessment*

Transport / Logistics
- *Traffic control*
- *Supply chain optimisation*
- *Inventory control*
- *Distribution optimisation*
- *Planning & scheduling*

Aerospace / Automotive
- *Vehicle / Spacecraft design*
- *Fault diagnosis*
- *Efficient fuels*
- *Effective assembly*
- *Route planning*

Materials / Manufacturing
- *Machine condition monitoring*
- *Structural analysis*
- *Efficient batteries*
- *Semiconductor chip layout & fault analysis*
- *Electronic circuits for quantum tech*

Energy / Resources
- *Energy distribution & optimisation*
- *Carbon capture*
- *Oil exploration*

Chemistry / Pharmaceutical
- *Simulation of chemical reactions*
- *Computational chemistry*
- *Drug Development*

Bio-Technology
- *Genetics*
- *Omics*
- *Protein folding*
- *Study of genetic diseases*

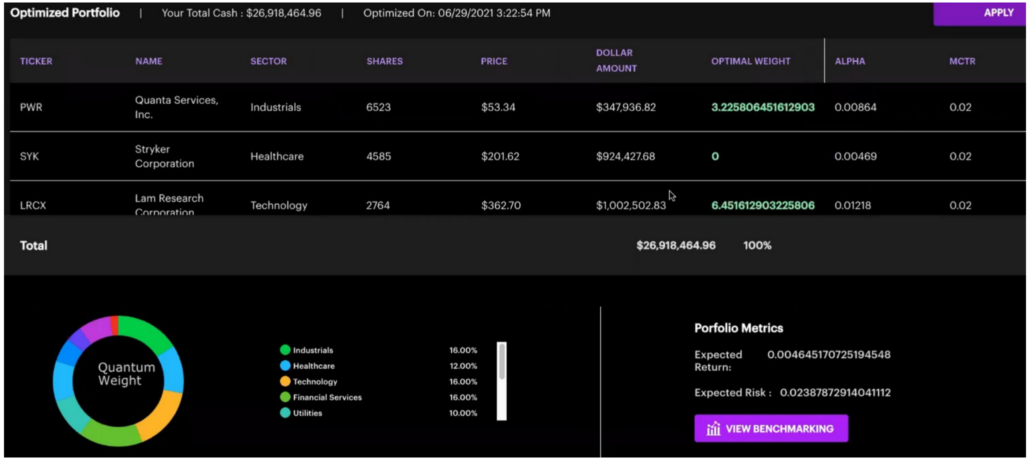
Medical / Healthcare
- *Radiotherapy*
- *Medical imaging*
- *Precision medicine*

Sample Applications

Accenture: Portfolio rebalancing

Quantum Tech 2021 (Sept) one day conference.

- In 2021 *Accenture* presented a demo of portfolio rebalancing in financial services.
- The presented system was running on AWS Braket with D-Wave Leap backend, using 52 weeks of ticker stock data from Yahoo Finance.
- The aim was to minimise the difference between the target and the final portfolio while maximising the return, but also keep the minimum number of stocks and the number of transactions (implied cost) needed to obtain the final portfolio.
- Note that quantum portfolio optimisation has been explored by other companies, e.g. *Multiverse Computing*, *Chicago Quantum*, *KPMG*, *JPMorgan Chase Bank*, etc.



Optimized Portfolio | Your Total Cash : $26,918,464.96 | Optimized On: 06/29/2021 3:22:54 PM

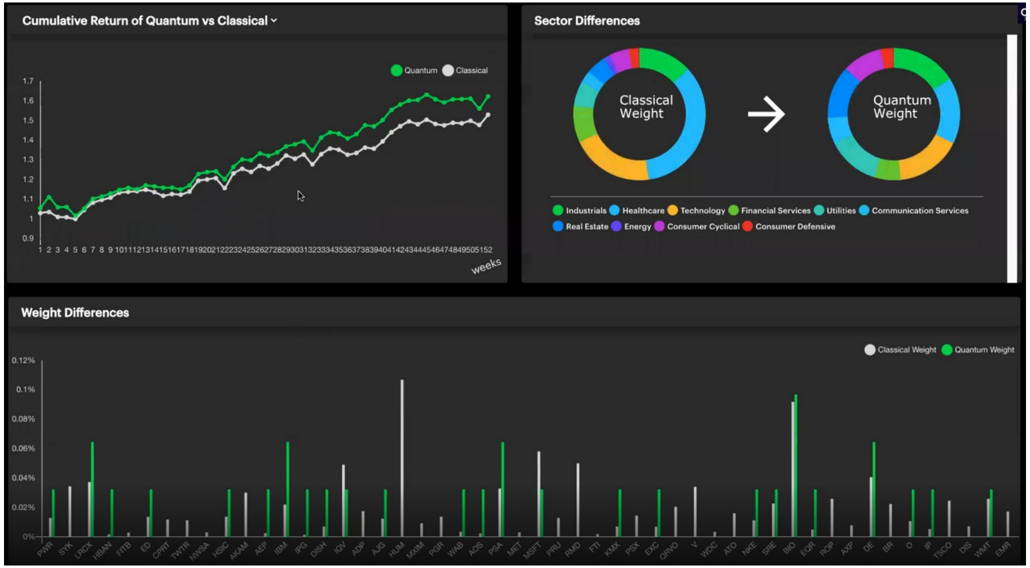
TICKER	NAME	SECTOR	SHARES	PRICE	DOLLAR AMOUNT	OPTIMAL WEIGHT	ALPHA	MCTR
PWR	Quanta Services, Inc.	Industrials	6523	$53.34	$347,936.82	3.225806451612903	0.00864	0.02
SYK	Stryker Corporation	Healthcare	4585	$201.62	$924,427.68	0	0.00469	0.02
LRCX	Lam Research Corporation	Technology	2764	$362.70	$1,002,502.83	6.451612903225806	0.01218	0.02
Total					$26,918,464.96	100%		

Industrials	16.00%
Healthcare	12.00%
Technology	16.00%
Financial Services	16.00%
Utilities	10.00%

Porfolio Metrics

Expected Return: 0.004645170725194548

Expected Risk : 0.0238787291404111 2

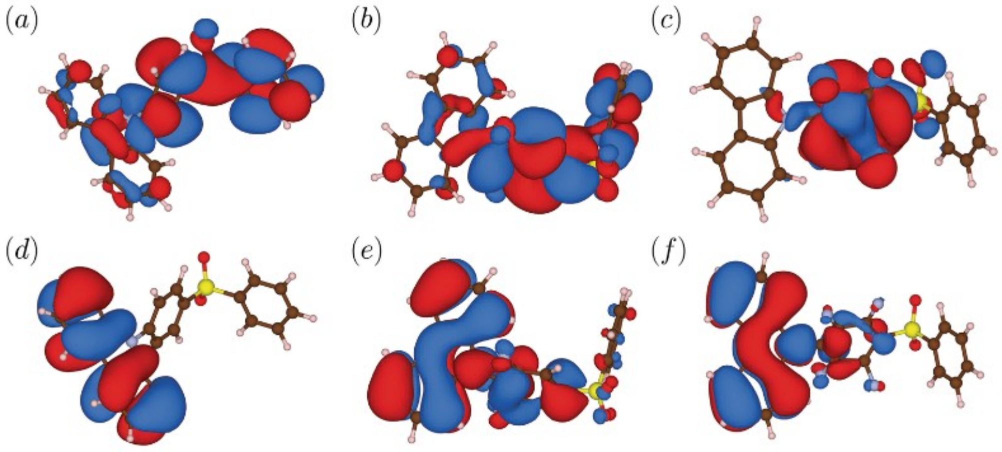


Sample Applications

Mitsubishi, IBM, ...: Chemistry

Gao, Qi, Gavin O. Jones, et al. "Applications of Quantum Computing for Investigations of Electronic Transitions in Phenylsulfonyl-Carbazole TADF Emitters." Npj Computational Materials 7, no. 1 (May 20, 2021): 1–9.

- Organic Light Emitting Diodes (OLED) have become increasingly popular in the fabrication of thin, flexible TV and mobile phone displays that emit light upon application of an electric current.
- Recent studies have been looking at electronic transitions of high energy states in some molecules, which could could potentially produce OLEDs that are 100% efficient. The conventional methods make OLEDs of 25% efficiency.
- A project by *IBM Quantum and partners* was successful in developing quantum methods to improve accuracy for the calculation of excited TADF states for efficient OLEDs, making it the world's first research case of applying quantum computers to the calculation of excited states of commercial materials.
- The project reported (May 2021) methods of calculating the exact values and predicting properties, such as excited states of different materials used in OLED production, by using the currently available NISQ devices with various quantum algorithms and error mitigation schemes.
- Note that the project and its methods were reproduced and tested by the participants of the IBM Quantum Challenge 2021 (November).



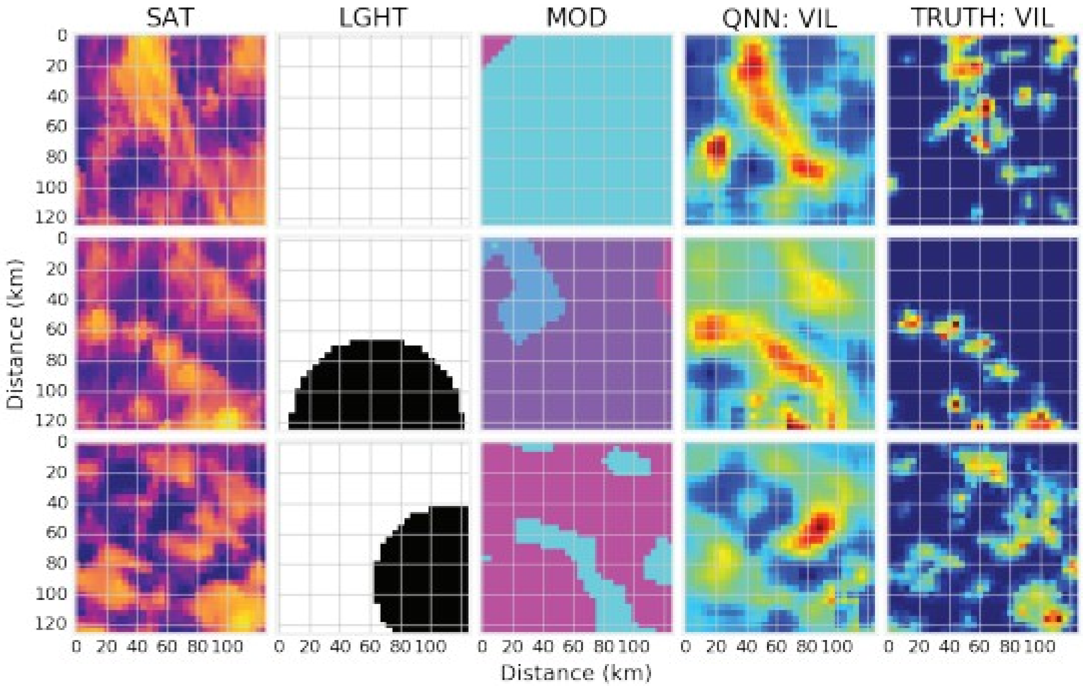
Sample Applications

Rigetti: Weather

Enos, Graham R., Matthew J. Reagor, Maxwell P. Henderson, Christina Young, Kyle Horton, Mandy Birch, and Chad Rigetti. “Synthetic Weather Radar Using Hybrid Quantum-Classical Machine Learning.” arXiv, November 30, 2021. https://doi.org/10.48550/arXiv.2111.15605.

- Global Synthetic Weather Radar (GSWR) is a class of techniques for assimilating diverse meteorological data types, in order to produce synthetic weather radar images (Enos et. al., 2021).
- GSWR models are used in those cases when radar data is not available, e.g. in remote areas or in disaster response.
- *Rigetti Computing* announced in 2021 that it developed a hybrid classical-quantum solution to enhance GSWR weather modelling.
- The approach resulted in high-quality synthetic weather radar data, and was able to improve classical machine learning models for storm prediction.

- Several approaches were developed running on Rigetti’s 32-qubit machine and the best performance was achieved using a Quantum Neural Network.



Benefits, problems, risks and opportunities

Quantum technology ...

Quantum Technology is still Science
rather than Business...

Yet its potential is extremely promising!

Benefits	**vs.**	**Challenges**
Seamless integration of algorithms with maths and physical phenomena	←?→	Difficult to conceptualise, design, develop, execute and understand results
Can handle massive parallelism and randomness (via quantum superposition and measurement)	←?→	Must carefully constrain qubit interaction to get meaningful results (via quantum entanglement)
Quantum algorithms drastically reduce complexity as compared with classical ones	←?→	Quantum advantage can only be demonstrated in niche application areas
Quantum supremacy is possible and exponentially reducing complexity	←?→	Quantum supremacy cannot be proven in general case, also new classical algorithms challenge quantum advantages
By using quantum-classical hybrid approaches quantum machine learning is very effective	←?→	Classical machine learning algorithms do not readily translate to quantum computing, often there is no quantum advantage
There is a lot of free QC learning resources, tutorials, communities, challenges and hackathons	←?→	There is still acute shortage of knowledge, skills and expertise in conceptualising and developing quantum solutions
Recent emergence of high-end specialist QC community	←?→	QC requires highly specialised skills and there is a shortage of QC development tools for “humans” (problem owners)
QC experts have a track record of generating insightful quantum applications	←?→	There are no accepted “software engineering” QC methods ensuring teamwork, repeatable process and quality results
Cloud-based QC lowered access costs with freely available software tools	←?→	Majority of QC development is for proof-of-concept solutions, There are no tools for future quantum machines (1k-1M qubits)
Increased business investment and increased government funding	←?→	There is still no clear path of transitioning quantum proofs of concept to successful business applications

Just 3+3 Opportunities for R&D

Research

- Investigate development of very large quantum circuits / solutions (involving over 1000s qubits)
- Develop new QC dev tools / GUI for non-scientists or business users
- Create novel areas of QC application, e.g. computer vision, epigenetics, space, economics, or fluid mechanics

Development

- Develop high-level cross-platform quantum development environments (CASE / VLSI)
- Establish quantum algorithm reuse repositories and circuit generators
- Develop QC software development methodologies ensuring team work, repeatable process and quality results (eliminate quantum heroes)

Bird-view of quantum computing...
Summary, reflections and questions

Opportunities
for quantum R&D

Global
quantum initiatives

New ways of
solving “impossible”
problems

New quantum tech
products and services

Quantum solutions
for business

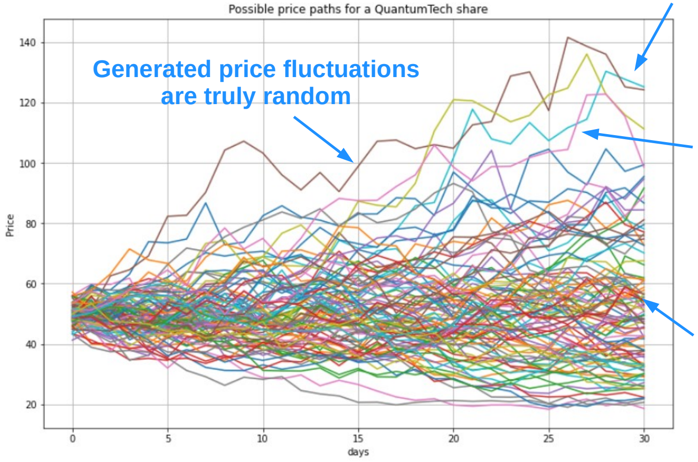
Quantum enabled
discoveries in science

Variety of quantum
tools and methods
for developers

Free quantum
learning resources

More Applications
Qiskit Finance

- Similarly to other quantum platforms, *Qiskit* provides a small library of ready-made Finance tools, which simplify development of financial quantum applications.
- One of such Qiskit tools allows predicting financial option prices. The method replaces the Monte Carlo sampling used in the algorithm based on the Black-Scholes (European) option pricing, with quantum sampling.



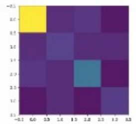
All possible price evolution paths can be considered in parallel

Generated price fluctuations are truly random

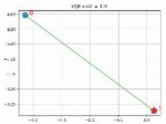
Price evolution can be constrained to the financial model governing the market price behaviour

In the end, the price estimate can be based on the expectation value, the payoff function, etc.

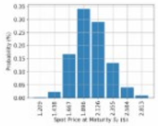
Quantum Amplitude Estimation



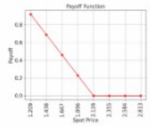
Portfolio Optimization



Portfolio Diversification

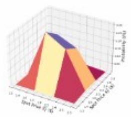


Pricing European Call Options

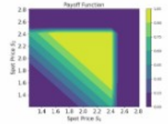


Pricing European Put Options

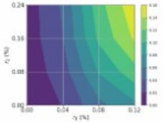
Pricing Bull Spreads



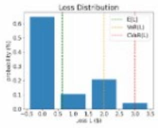
Pricing Basket Options



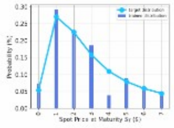
Pricing Asian Barrier Spreads



Pricing Fixed-Income Assets



Credit Risk Analysis



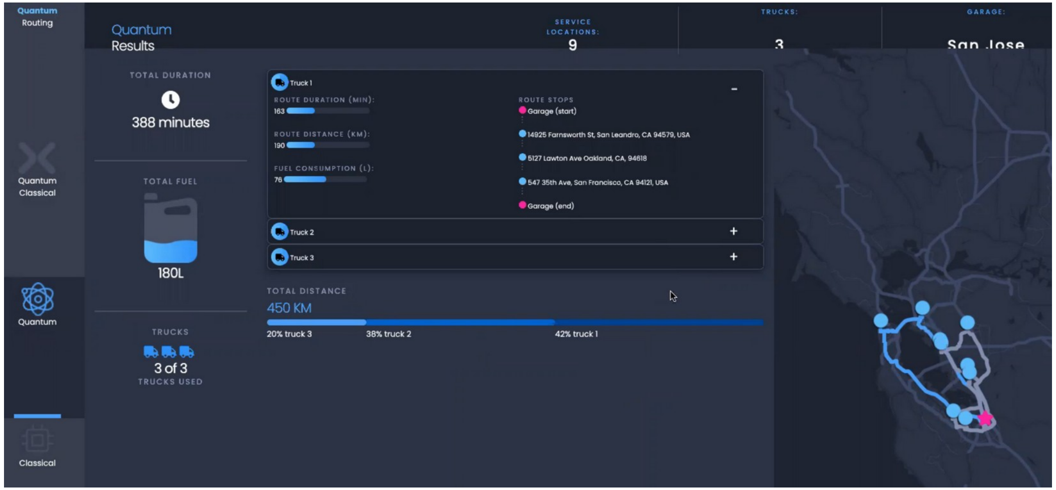
Option Pricing with qGANs

Loading and Processing Stock-Market Time-Series Data

More Applications

Accenture: Vehicle routing

- In 2021 *Accenture* presented a demo of quantum vehicle routing, which was running on IBM Quantum and Qiskit.
- The problem was structured as a complex optimisation, which allowed scheduling of delivery truck route scheduling, while optimising several parameters, such as trip time and usage of petrol.
- The system showed results from various experiments, e.g. using classical methods, quantum simulators and a real quantum machine.
- The effective user interface gave the feel of a complete product ready for deployment.



Quantum Results

SERVICE LOCATIONS: 9

TRUCKS: 3

GARAGE: San Jose

TOTAL DURATION: 388 minutes

TOTAL FUEL: 180L

TRUCKS: 3 of 3 TRUCKS USED

Truck 1

ROUTE DURATION (MIN): 163

ROUTE DISTANCE (KM): 190

FUEL CONSUMPTION (L): 76

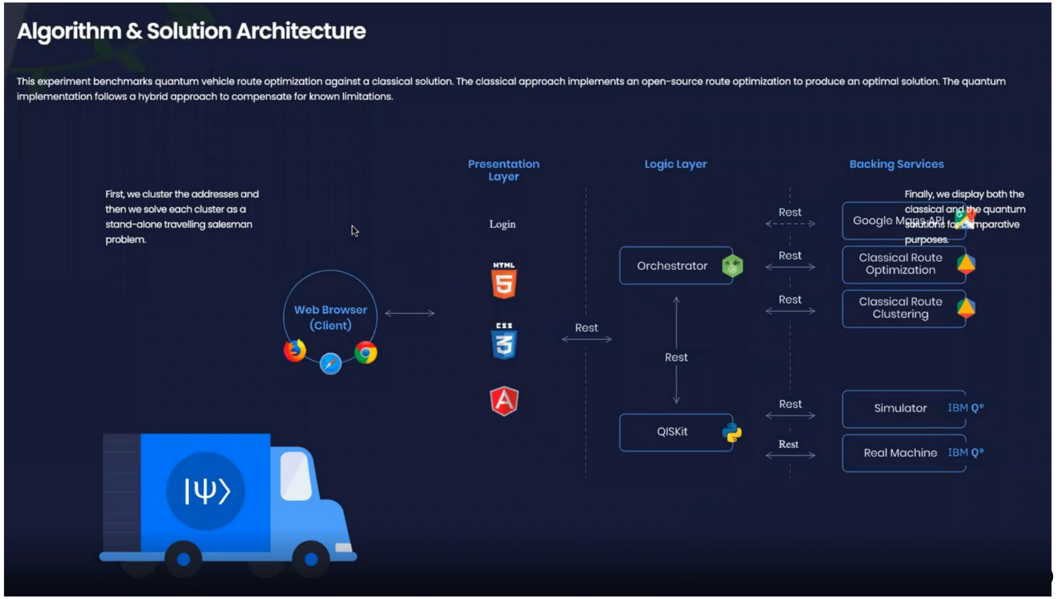
ROUTE STOPS
Garage (start)
14925 Farnsworth St, San Leandro, CA 94579, USA
5127 Lawton Ave Oakland, CA, 94618
547 35th Ave, San Francisco, CA 94121, USA
Garage (end)

Truck 2 +

Truck 3 +

TOTAL DISTANCE: 450 KM

20% truck 3 · 38% truck 2 · 42% truck 1



Algorithm & Solution Architecture

This experiment benchmarks quantum vehicle route optimization against a classical solution. The classical approach implements an open-source route optimization to produce an optimal solution. The quantum implementation follows a hybrid approach to compensate for known limitations.

First, we cluster the addresses and then we solve each cluster as a stand-alone travelling salesman problem.

Finally, we display both the classical and the quantum solutions for comparative purposes.

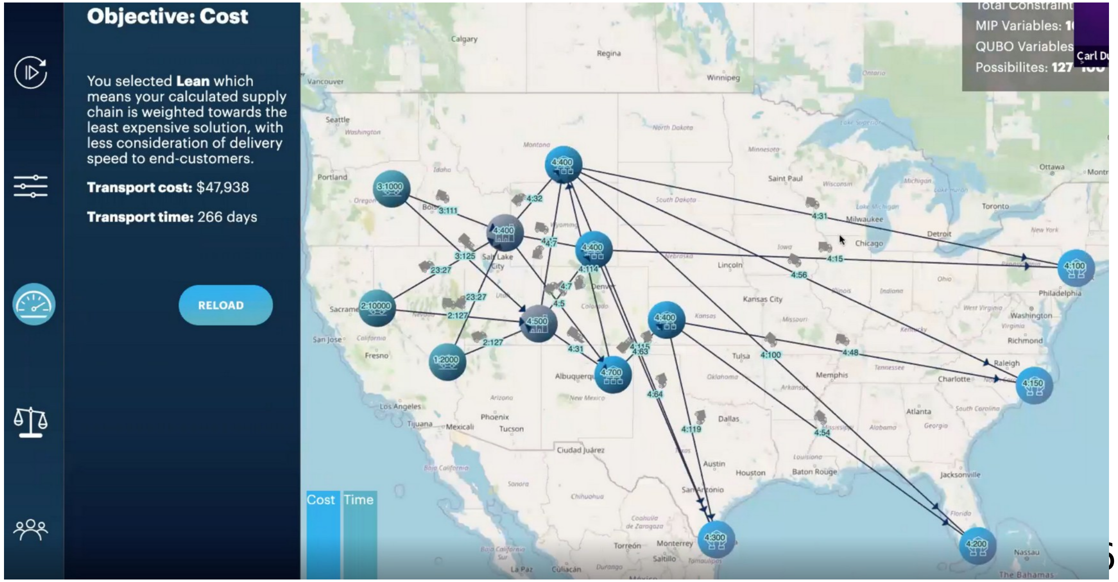
Quantum Tech 2021 (Sept) one day conference.

Quantum Tech 2021 (Sept) one day conference.

More Applications

Accenture: Supply chain optimisation

- In 2021 *Accenture* presented a demo of supply chain optimization using three methods, i.e. a 1QBit classical QUBO optimisation (Azure), 1QBit quantum-inspired digital annealer (Azure), and a true D-Wave Quantum Annealer.
- This example featured warehouses stocked with various products and of different capacity, as well as, delivery routes with products in different amounts, and modes of transportation (land, air, train, etc).
- The supply chain formed a network of constraints, which was optimised using several different objective functions, and different methods of their satisfaction. The entire process was visualised with an interactive map, in which you could explore the results.
- Interestingly, quantum solution not always produces the most optimum results, nor delivered them in the least time.
- However, Accenture was studying the circumstances in which one or the other solution was more effective.



Objective: Cost

You selected **Lean** which means your calculated supply chain is weighted towards the least expensive solution, with less consideration of delivery speed to end-customers.

Transport cost: $47,938

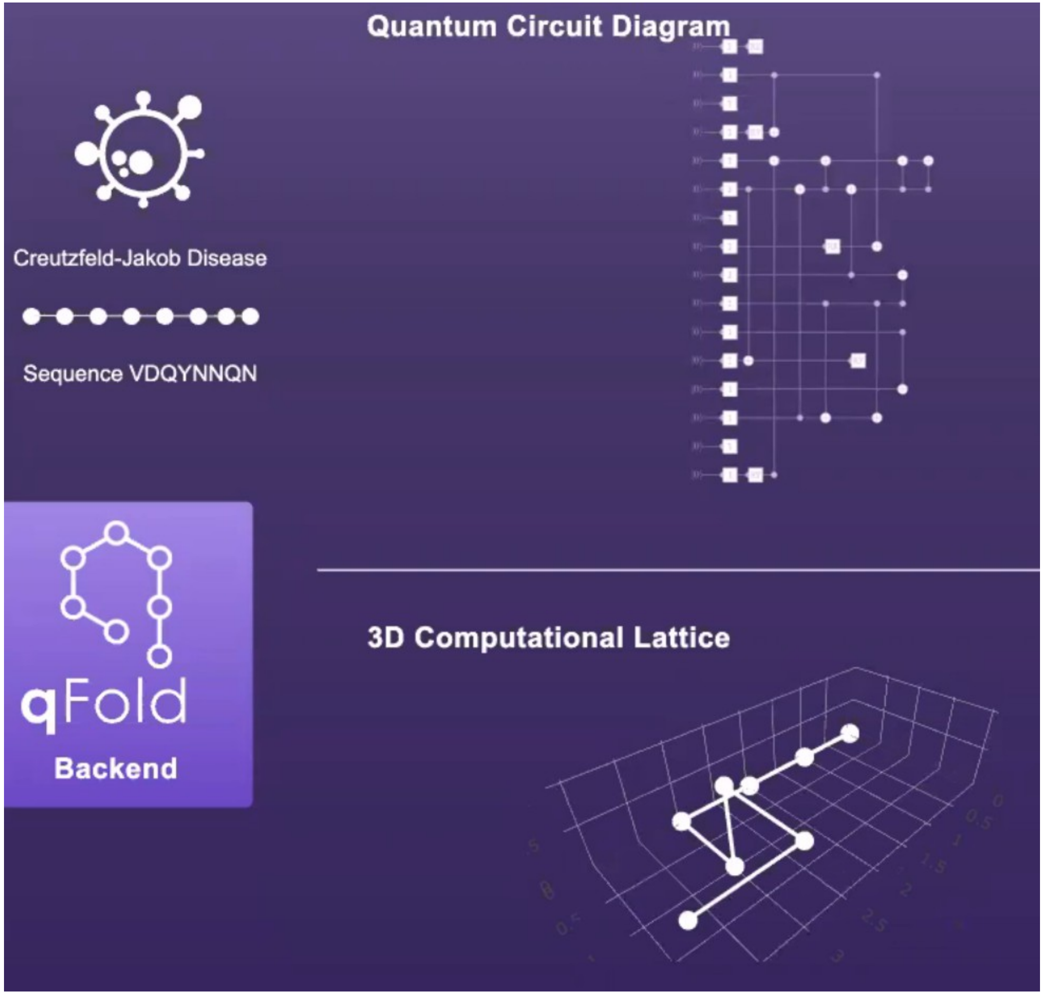
Transport time: 266 days

MIP Variables: **1**
QUBO Variables
Possibilites: **127**

More Applications

Accenture: Protein folding

- In 2021 *Accenture* presented a complex process of 3D protein folding running on Rigetti quantum machines.
- It was demonstrated how to investigate neurodegenarative prion disease caused by incorrectly folded proteins in the brain, which occurs in Greutzfeld-Jakobs disease. The traditional method takes 3-4 weeks, with mixed success.
- The computational methods to protein folding calculate a 3D lattice, which involves solving a classically intractable problem of the "self-avoiding walk" (SAW).
- Accenture solved this by combining quantum computing with reinforcement learning, reducing the overall computational cost.



Quantum Tech 2021 (Sept) one day conference.

Organisations & Society

Networks & Security
- Quantum info & comms
- Encryption
- Quantum repeaters
- Key distribution

Quantum Sensors
- Measurement
- Instruments
- Timing
- Seismology
- Navigation
- Microscopy
- Imaging
- Radars

People

Finance / Insurance
- Portfolio optimisation
- Price / option prediction
- Fraud indicators
- Credit scoring
- Financial risk assessment

Transport / Logistics
- Traffic control
- Supply chain optimisation
- Inventory control
- Distribution optimisation
- Planning & scheduling

Aerospace / Automotive
- Vehicle / Spacecraft design
- Fault diagnosis
- Efficient fuels
- Effective assembly
- Route planning

Materials / Manufacturing
- Machine condition monitoring
- Structural analysis
- Efficient batteries
- Semiconductor chip layout & fault analysis
- Electronic circuits for quantum tech

Discovery & Knowledge

Energy / Resources
- Energy distribution & optimisation
- Carbon capture
- Oil exploration

Chemistry / Pharmaceutical
- Simulation of chemical reactions
- Computational chemistry
- Drug Development

Bio-Technology
- Genetics
- Omics
- Protein folding
- Study of genetic diseases

Medical / Healthcare
- Radiotherapy
- Medical imaging
- Precision medicine

Economy

Environment