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AstraZeneca & PreScouter

Advanced Data Analytics Landscape
Quantum Computing

Research Support Service

October 2021

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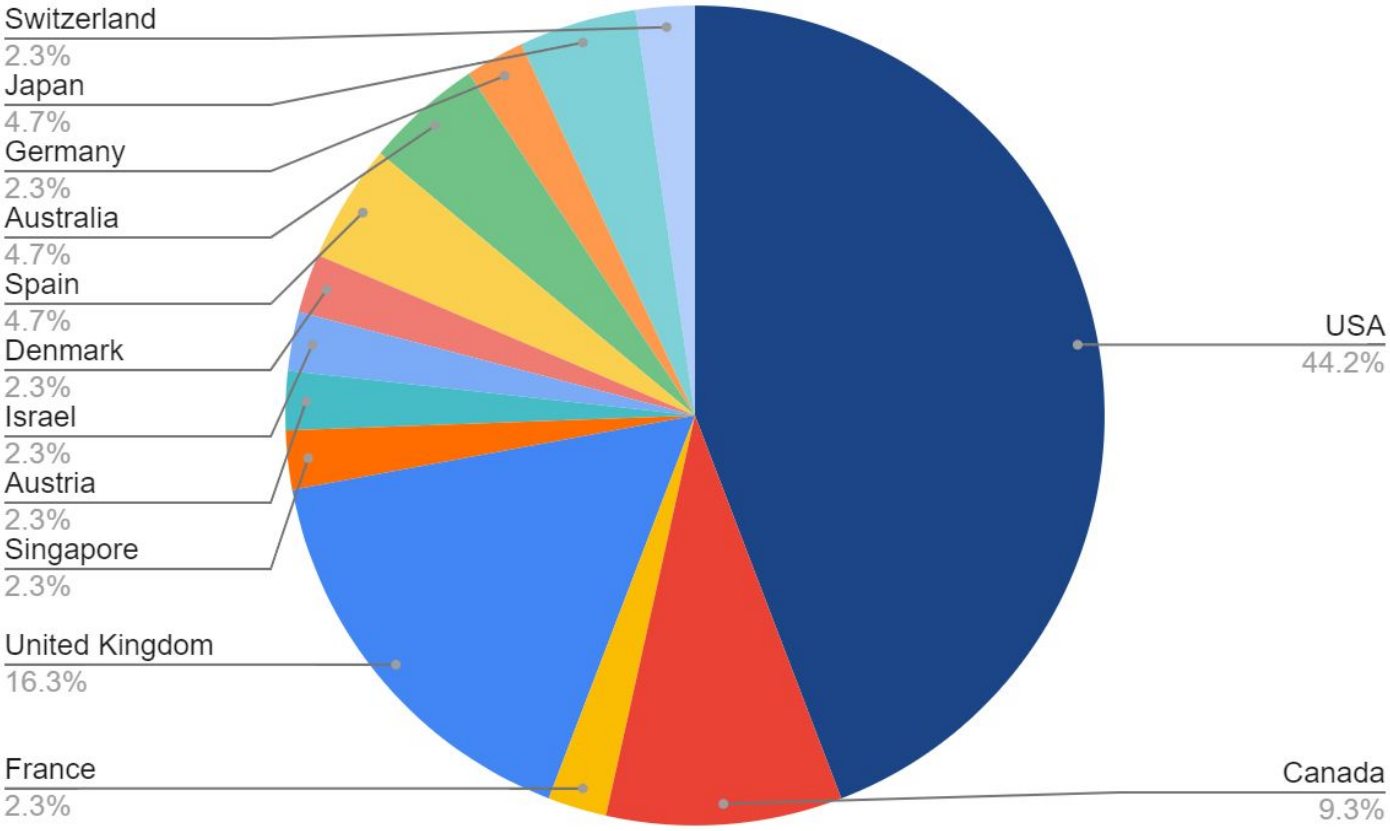
Executive Summary

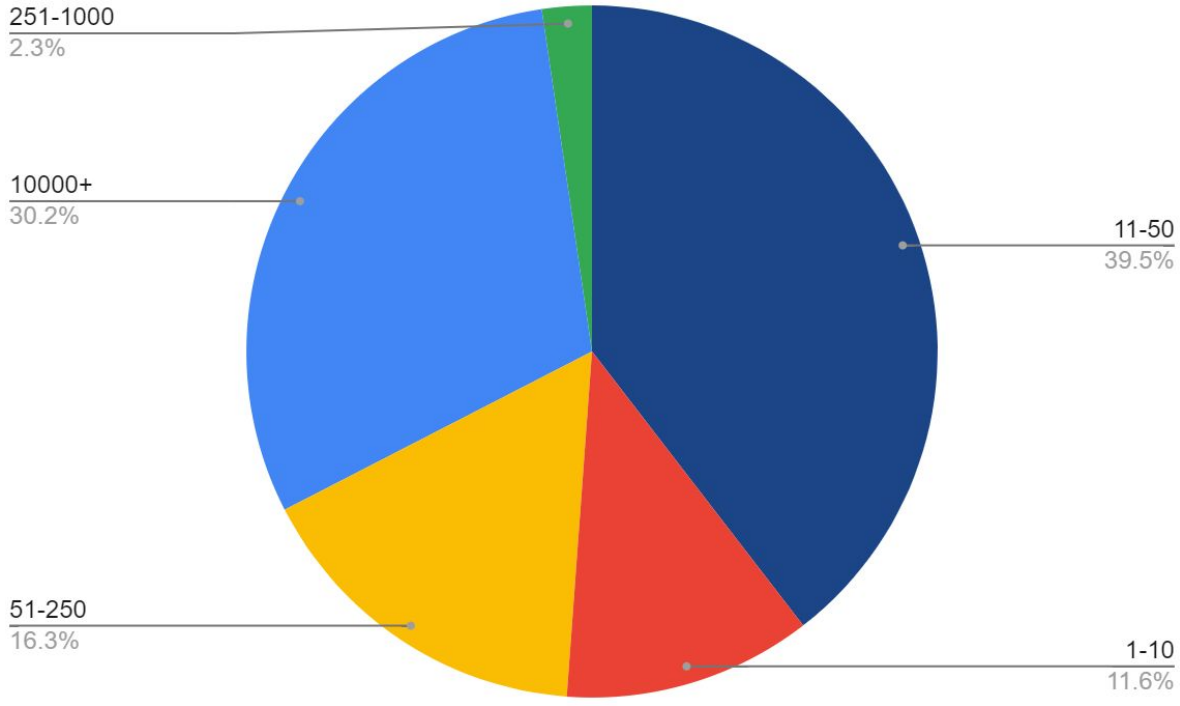
Executive Summary

Location of the profiled quantum computing companies

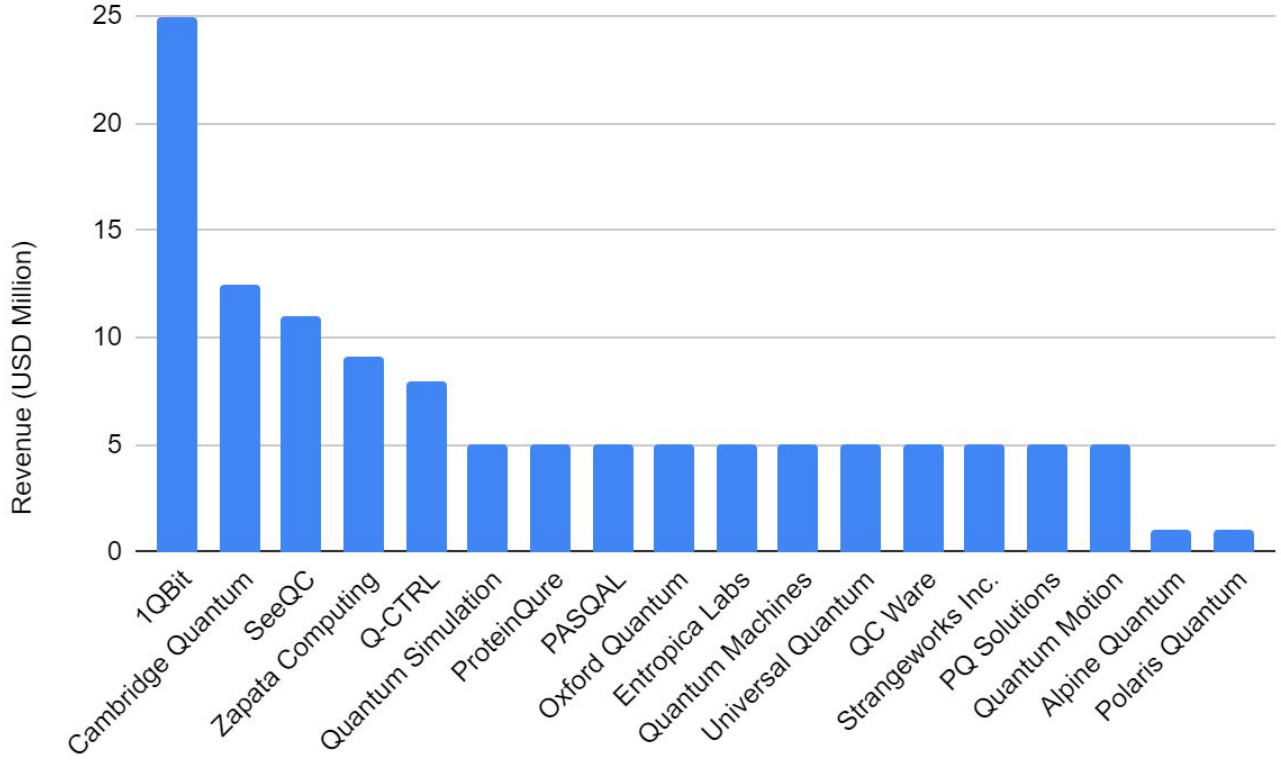


Executive Summary

Profiled players segmented by number of employees

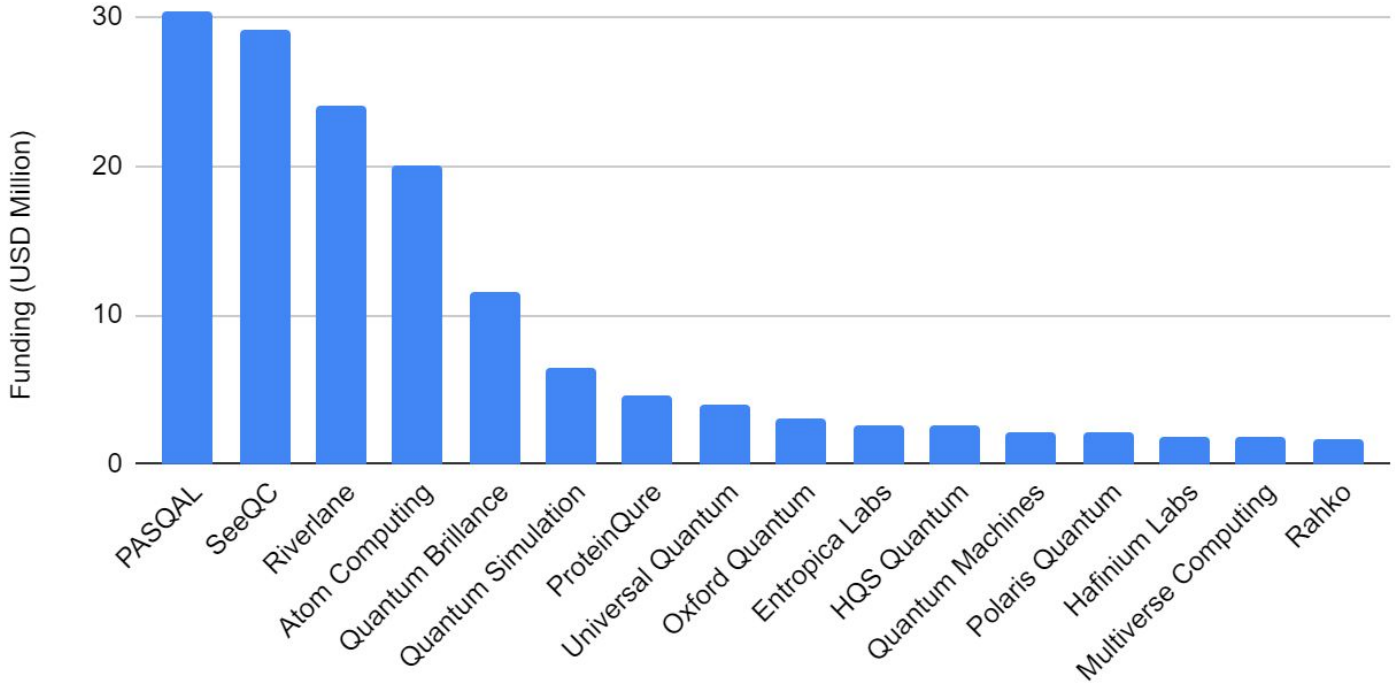


Revenue of profiled startups in quantum computing



Executive Summary

Funding of profiled startups in quantum computing*



**Startups without revenue information were excluded from this report. Startups with revenues >$40M were excluded from this report. Please refer to Spreadsheet for full list*

Overview

Overview

Quantum computing (QC) is ruled by the laws of quantum mechanics. In quantum mechanics, a particle can behave as a particle as well as behaving as a wave. This is a physical theory that governs matter at the molecular and subatomic levels. In quantum computing, this concept translates to the properties of qubits. In contrast to classical bits with a value of either 0 or 1, qubits are not restricted and can be found on different states at the same time [1]. The technology has many potential applications across industries, but the general opinion states that it is still at an early development stage, especially since hardware development is catching up to allow scalability to the many of the proposed practical uses (particularly in pharmaceutical industry) [2]. Nonetheless, recent data strongly indicates a serious interest to develop QC applications in the pharmaceutical industry [3]. The estimated growth of the QC market by 2026 is at a CARG of 30.2% [4].

Technical Details

QC differs from classical binary computing system by using quantum bits (qubits) as their main units. The fact that qubits can have multiple states at one time facilitates an exponentially higher computing power (Fig. 1). This power translates into a significantly advanced processing for simulation, optimization and machine learning algorithms [4]. To put it in perspective, classical computing would fail in a task where the number of atoms added to a molecule reached a number of combinations potentially higher than the number of atoms in the universe. This scenario can potentially be reached in tasks looking at protein folding or binding affinity [3].

In practical terms, the complexity of QC can be reduced to having the advantages of being exponentially faster and achieving an exponentially larger information density. QC speedups can reach a level that some tasks using classical computing would not be able to complete in time less than the age of the universe [2, 3]. For example, penicillin modeling with classical computing would require 10^{86} bits, whereas quantum computing would require 286 qubits [2].

Technical Details

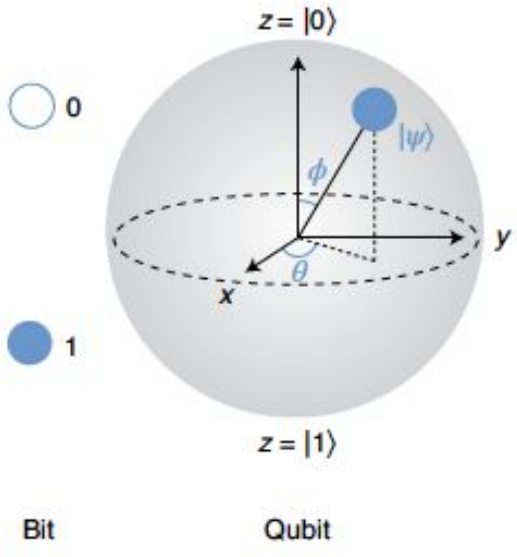


Figure 1. A classical bit (classical computing) can only have a value of 0 (white dot) or 1 (blue dot). A qubit can be represented by a point not restricted to either of these binary values (an area in the sphere) [5].

Currently, QC applications appear to be under development across different industry sectors. Some examples of industries interested in QC include: machine learning and artificial intelligence, computational chemistry, cybersecurity & cryptography, financial modelling, logistics and optimisation, weather forecasting, marketing, pharmaceutical and healthcare industries [6, 7]. All of these applications would be benefited by being able to integrate and process immense amounts of data to model scenarios out of the classical computing capabilities.

Nonetheless, to reach the full potential of QC, there is a need of hardware technology with appropriate technical specifications to match the power of the software. These computers are more difficult to manufacture and current quantum computers have around 50-100 qubits [3].

To note, companies such as Google and IBM have built QC hardware without a particular application in mind. In both instances, the companies have claimed ”quantum supremacy”, which means that their quantum computers undertook tasks that a classical computer could not replicate [4]. Nonetheless, from a practical point of view, it has been argued that these achievements are not relevant given that they were made on theoretical problems rather than real-world problems [3].

Technical Details

Some examples for proposed real world applications for QC include [7]:

-Finance: automatic triggering of share dealings (algorithm trading) and fraud detection (pattern recognition).

-Marketing: Big data analytics on consumer data would allow precise consumer targeting.

-Meteorology: Pattern recognition from multiple variables involved in weather prediction.

-Logistics: data analysis and modelling to optimize supply-chain workflows.

-Pharmaceutical industry: In the pharmaceutical industry, QC applications range from research and development stages to production, logistics, supply chain and marketing (Fig. 2) [8].

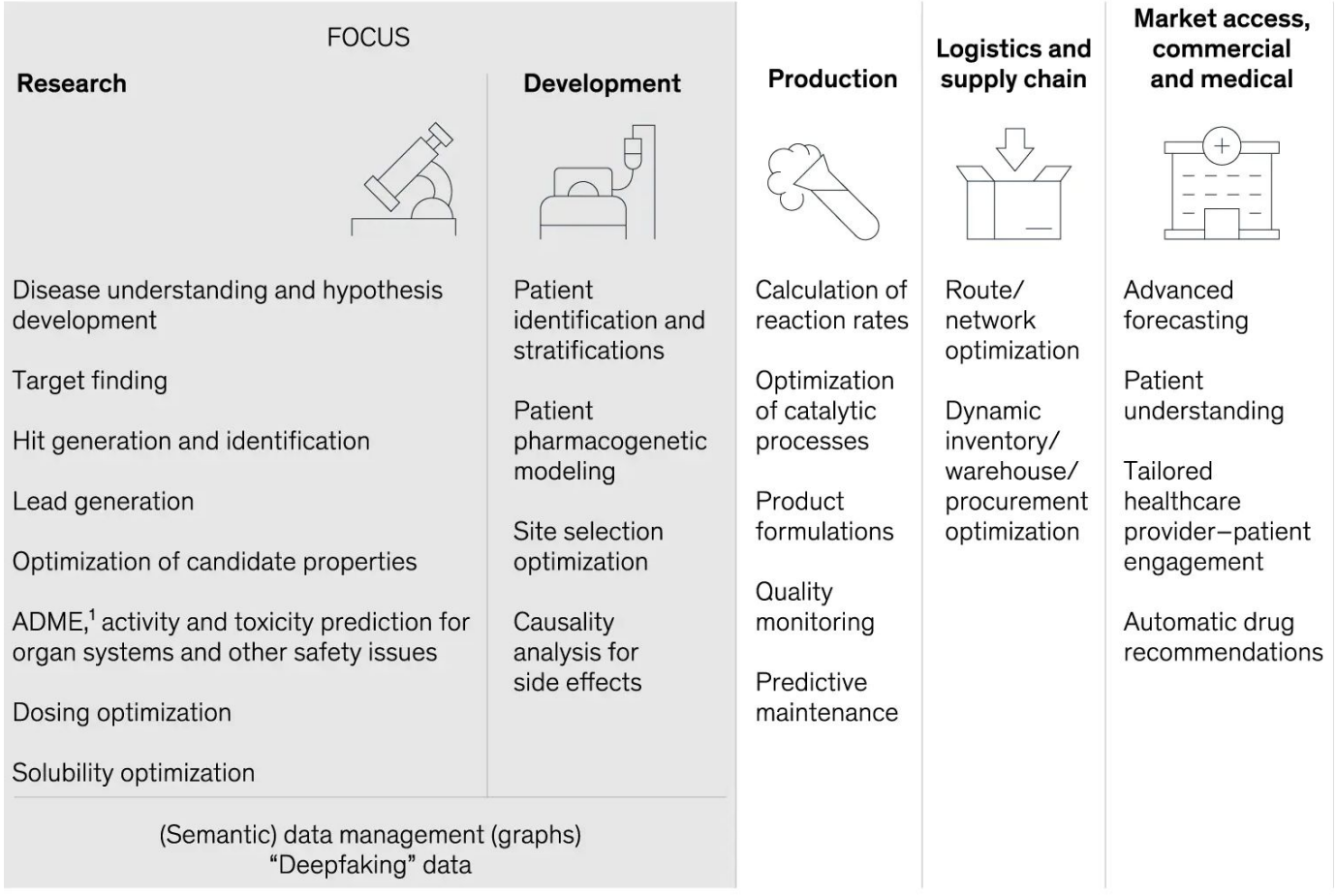


Figure 2. Quantum computing use cases in the pharmaceutical industry value chain [8].

Technical Details

A recent review has described the landscape of QC uses for drug discovery. Their findings indicate that stakeholders (including pharmaceutical companies, startups, and academia) have serious considerations to develop and adopt QC (Figure 3) [3]. Nonetheless, these efforts have not gone beyond a "use case development" stage, meaning that their technologies have not shown to be superior to classical computing (Fig. 4). Furthermore, the authors note that (drug development) applications using QC are likely many years ahead from being developed.

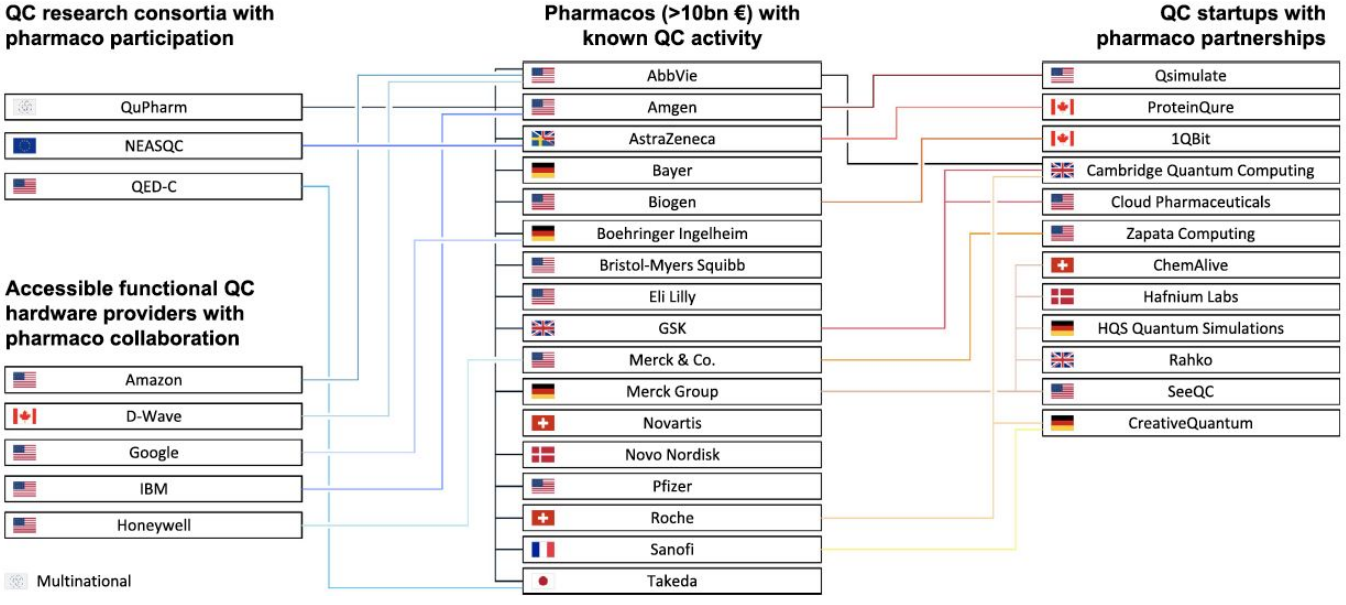


Figure 3. Companies and partnerships in the QC-Pharmaceutical industry area. 17 of the 21 largest companies have activities in the QC space publicly documented. 38 startups out of 260 startups in the QC space are focusing on pharmaceutical problems, from which 12 are directly engaged in partnerships with big pharmaceutical players. Hardware providers and research consortia are also included in the figure as they have established collaborations in the pharmaceutical industry space [3].

Technical Details

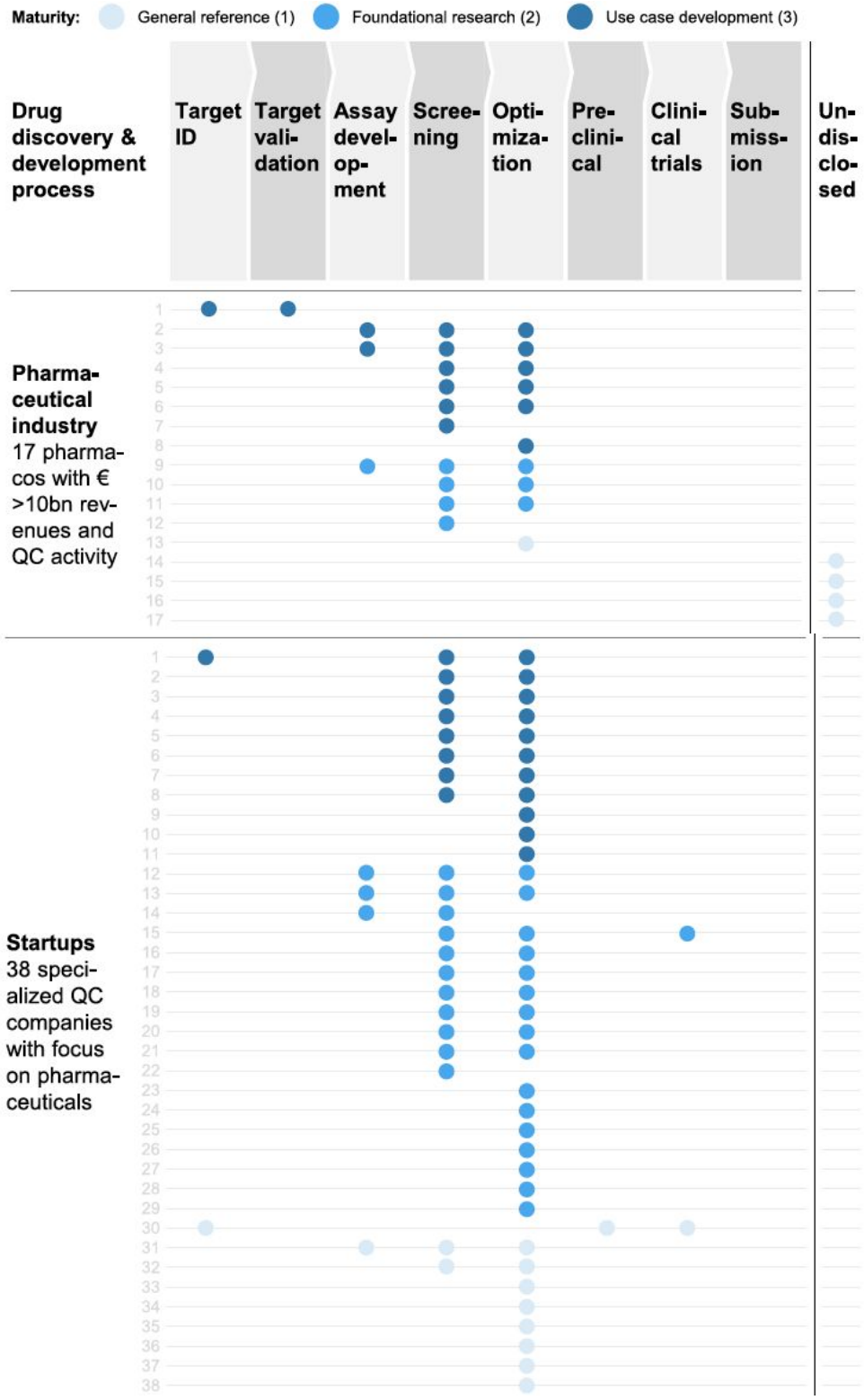
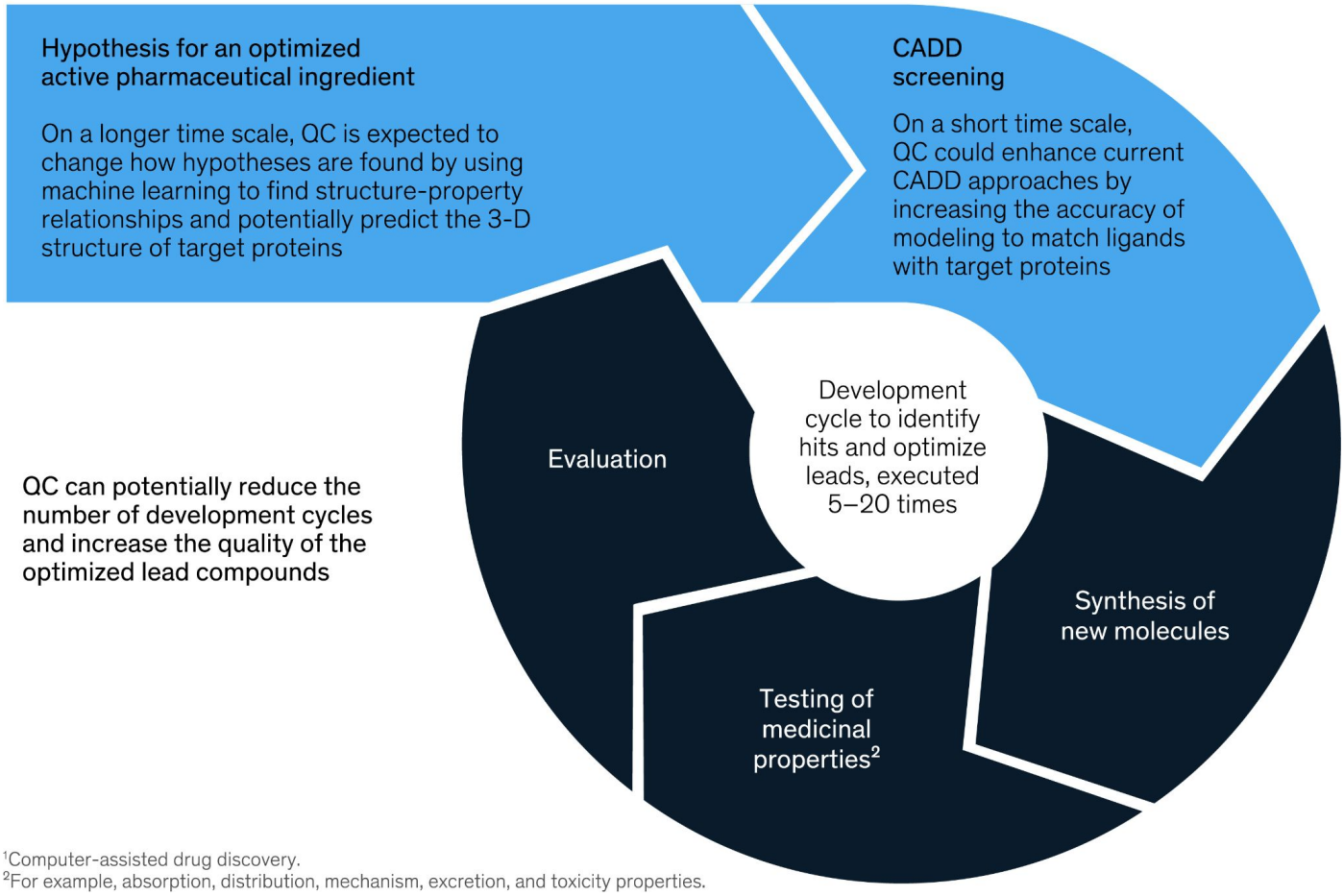


Figure 4. QC applications under development in the pharmaceutical industry. Most stakeholders (17 big companies and 38 startups) are focusing their efforts on lead optimization and compound screening. The highest level of maturity for any application being developed is "use case development", meaning that none of these players have shown that their technology is more advantageous than classical computing.

Technical Details

Industry level reports agree with the above-mentioned findings, in that compound screening can be reached earlier as a real-world application for QC. It is thought that computer-assisted drug screening (CADD), which is currently limited to basic calculations to predict medium-size molecules` behavior, could be exponentially enhanced by QC (Fig. 5) [8].

Effects of quantum computing (QC) on CADD[1]



[1]Computer-assisted drug discovery.
[2]For example, absorption, distribution, mechanism, excretion, and toxicity properties.

Figure 5. CADD could be one of the first real-world applications for QC in the pharmaceutical industry [8].

Technical Details

As mentioned before, real-world applications in the pharmaceutical industry are not in the near-term future. A recent report by McKinsey suggests a gradual transition taking place over the next decades. It can be argued that we are still at the level of incubation, with low maturity. And QC technology is expected to reach early commercial levels this decade (2020-30) at a level described as "not fully error-corrected". Beyond 2020, the technology maturity is expected to reach "fully error-corrected QC", in which QC could be implemented at scale and where chemical players could create value using QC (Fig. 6) [8].

Value creation through quantum computing in the pharmaceuticals industry is expected to start by 2030.

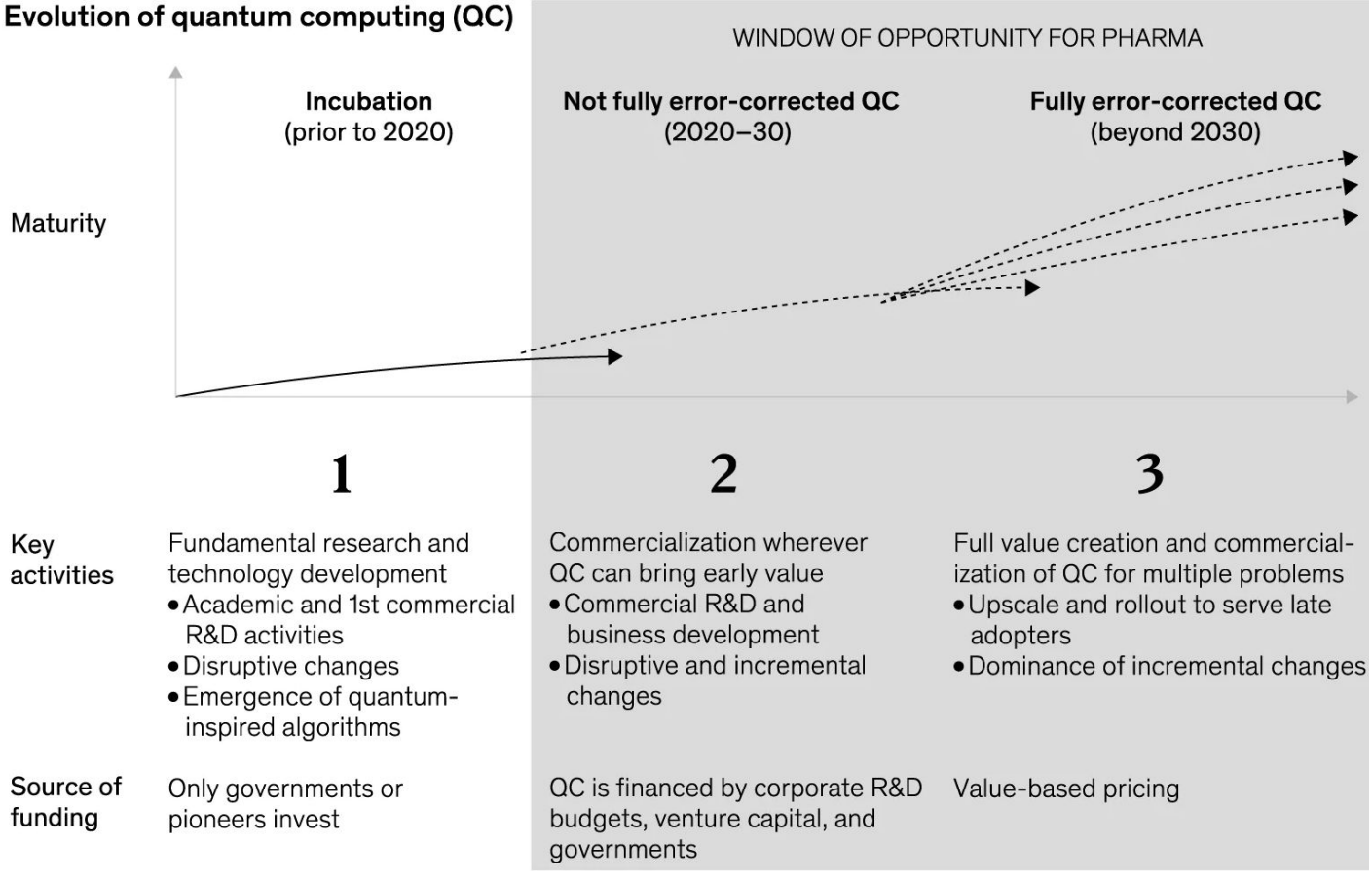


Figure 6. Evolution and timeline of QC in the pharmaceutical industry.

Technical Details

Challenges for Quantum Computing

Quantum computing biggest challenge is the hardware. There is a need to built powerful computers In order to run a powerful computation exponentially more complex than classic computing. However, there are important challenges in the fabrication, verification and architecture of quantum computers [9].

Fabrication must be precise to accommodate fragile quantum states, and must operate at low temperatures. However, a complete state cannot be currently measured with precision, making verification difficult. In addition, because errors are more common than in classic computing, correcting the error ends up being a big task that needs to be handled correctly by the quantum architecture [9].

In addition, technological and economic challenges need to be considered to integrate into industry processes. For instance, in the chemical industry, it has been pointed out that early integration to operating systems (often heterogeneous) should be addressed to allow scalability in a production environment. As for the economic challenge, companies would face the decision of building their own systems, or buying third party services (which may in turn create further issues in data privacy) [10].

Technical Details

Pharmaceutical companies and startups developing QC applications for drug discovery [3].

Pharma companies > 10bn revenue	
Abbvie	Amgen
Astrazeneca	Bayer
Biogen	Boehringer ingelheim
Bristol-Myers	Eli-Lilly
GSK	Merck Group
Merck & Co.	Novartis
Novo Nordisk	Pfizer
Roche	Sanofi
	Takeda

Startups	
Qsimulate	ChemAlive
ProteinQure	Hafinium Labs
1QBit	HQS Quantum Simulations
Cambridge Quantum Computing	Rahko
Cloud Pharmaceuticals	SeeQC
Zapata Computing	CreativeQuantum

References

1. https://www.nature.com/articles/s41592-020-01004-3.pdf
2. https://www.bcg.com/publications/2019/quantum-computing-transform-biopharma-research-development
3. https://doi.org/10.1016/j.drudis.2021.06.003
4. https://www.globenewswire.com/news-release/2021/02/16/2176140/0/en/Global-Quantum-Computing-Market-2020-to-2026-Technological-Advancements-in-Quantum-Computing-Presents-Opportunities.html
5. https://doi.org/10.1038/s41592-020-01004-3
6. https://analyticsindiamag.com/top-applications-of-quantum-computing-everyone-should-know-about/
7. https://www.idquantique.com/quantum-safe-security/quantum-computing/real-world-applications/
8. https://www.mckinsey.com/industries/pharmaceuticals-and-medical-products/our-insights/pharmas-digital-rx-quantum-computing-in-drug-research-and-development#
9. https://doi.org/10.1007/1-4020-8068-9_8
10. https://www.prescouter.com/inquiry/quantum-computing-in-the-chemical-industry/

Landscape

Quantum Simulation Technologies: QSimulate

Quantum Simulation Technologies, Inc.
Headquarters: Cambridge, Massachusetts, USA
Website: https://qsimulate.com/
Contact: info@qsimulate.com

TRL 5

Overview

Quantum Simulation Technologies (11-50 employees) was founded in 2018. Their offices are located in Cambridge MA, Berkeley CA, and Ghent, Belgium [5]. The company provides a simulation platform, QSimulate, that solves computational problems for the chemical and pharmaceutical industries [3]. The company has raised a total of $6.5M in funding [3] and their revenue is less than $5M [4]. Headquartered in Cambridge, Massachusetts, QSimulate focuses on integrating next-generation quantum tools into AI/MI-fueled discovery. It is also working to improve ligand/protein scoring for drug discovery and is collaborating with some of the world's largest developers of quantum computing platforms [6].

Product Description [2]

QSimulate claims to allow the customers to scale their **quantum mechanical simulations** to thousands of molecules per day and achieve high throughput. The platform automates the workflow and claims to take the advantage of low-cost options available in the cloud, such as AWS's spot pricing. The application scope ranges from creating an AI model in Materials Informatics to screening small molecules in drug discovery processes.

The proprietary QSimulate-QM program claims to have realized, high-accuracy quantum mechanical (QM) simulations of thousands of atoms with realistic turnaround time and costs **(~30 minutes and $10)**, utilizing vast computing resources in the cloud. This opens up a possibility, for example, of using QM for ligand-protein scoring.

Quantum Simulation Technologies: QSimulate

Product Description

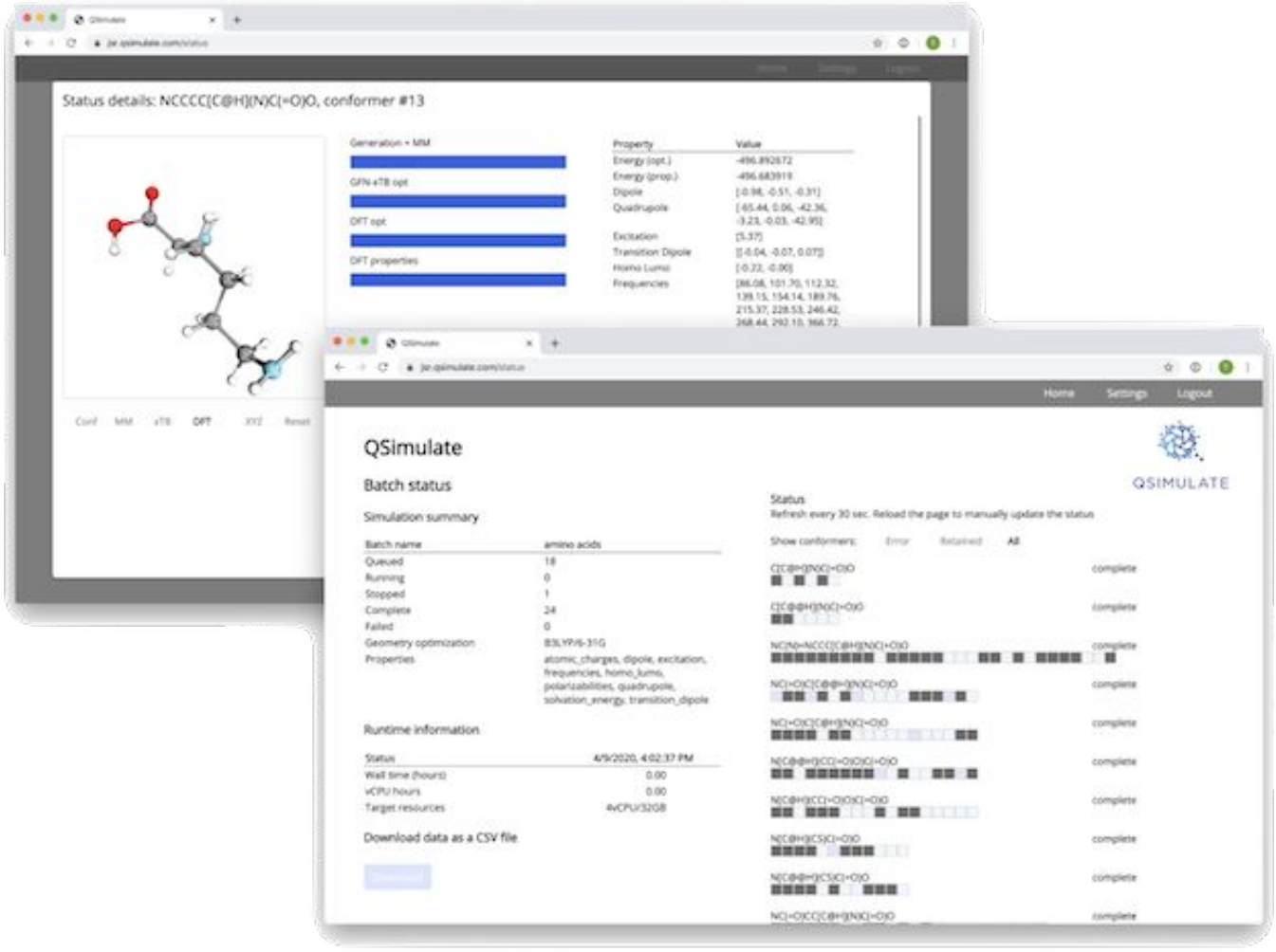


Figure: QSimulate platform snapshot

Case Study/White Paper

1) QSimulate powers high-throughput quantum simulation for materials informatics at JSR [6]

JSR Corporation is a Tokyo-based multinational company employing more than 9,000 people worldwide and a research-oriented organization that pursues close collaborations with leading innovators in a number of industries that are a key to the present and future welfare of human society: life-sciences, synthetic rubbers, electronic materials, display and optical materials. JSR has also been known for cross-organizational efforts to promote digital transformation in R&D based on AI/ML.

The QSimulate quantum simulation platform that enables unprecedented high throughput, QSimulate-MI, has been enlisted by JSR Corporation, one of the major players in the semiconductor, display, optical, and polymer materials market, to enable the discovery of novel materials using Materials Informatics (MI) approaches. In this partnership, **QSimulate has provided JSR access to its unique automated QM tools on the cloud**, making it possible to run high accuracy quantum calculations for thousands of molecules on a daily basis. This, in turn, provides a superior dataset for Materials Informatics, as well as the ability to efficiently supplant that training set as required.

Once an AI/MI model is successfully trained, JSR scientists hope to apply it to such tasks as identifying new materials with desirable properties, replacing old materials with new ones that avoid costly or dangerous reagents, and creating materials better able to hold up under adverse environmental conditions.

2) QSimulate Announces Partnership and Contract with Google AI Quantum Lab [7]

In April 2020, QSimulate announced delivery of phases I and II of its contract with Google AI Quantum Lab.

> *"We are very happy to partner with QSimulate, a leading developer of HPC based quantum software, as we move towards products for the emerging quantum market", says Ryan Babbush, Head of Quantum Algorithms at Google Quantum. "Our partnership with Google further advances our position in this area and will open up new audiences for our unique technologies", said Toru Shiozaki, CEO of QSimulate. (April 2nd, 2020)*

Case Study/White Paper

3) QSimulate and Amgen collaborate to integrate large-scale, accurate quantum mechanics with drug discovery [8]

On April 21st 2020, QSimulate announced a collaboration with Amgen focused on integrating large scale, high accuracy, quantum mechanics calculations (QM) into the drug discovery pipeline. The impetus for the new collaboration is the development by QSimulate of a novel implementation of density functional theory, a variant of QM, that allows these calculations to be run with discovery-relevant throughput on realistic ligand/protein models for the first time by taking full advantage of cloud resources.

Intellectual Property

N/A

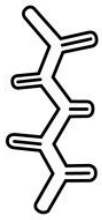
Investors/Funding Partners

QSimulate has raised a total of $6.5M in funding over 4 rounds. Their latest funding was raised on Apr 12, 2021 from a Seed round. QSimulate is funded by 3 investors: Embark Ventures, Abies Ventures and IT-Farm. Embark Ventures and Abies Ventures invested total $5.75M and Pre-seed round raised $750K. IT-Farm's investment is not disclosed [3]

References

1. https://qsimulate.com/
2. https://qsimulate.com/technology.html
3. https://www.crunchbase.com/organization/qsimulate
4. https://www.zoominfo.com/c/quantum-simulation-technologies-inc/483373473
5. https://www.linkedin.com/company/qsimulate/about/
6. https://qsimulate.com/e66d68cc04f77c352f59cb3bed7909ea.html
7. https://qsimulate.com/588cfe6a191ddc23bd08e0c8de1c183d.html
8. https://qsimulate.com/a9052a02cc42cb464464c024dce400f7.html

ProteinQure



ProteinQure
Headquarters: Toronto, Ontario, Canada
Website: https://www.proteinqure.com/
Contact: team@proteinqure.com

TRL 5

Overview

Founded in 2017, ProteinQure (11-50 employees) is a Toronto-based startup building a computational platform for design of protein therapeutics. ProteinQure claims to be a **revenue-generating software platform for computational protein drug discovery**. They claim to combine molecular simulations, machine learning, and quantum computing to do the structure-based design of drugs [2][4]. The company has raised a total funding of $4.6M [2] and has a revenue of less than $5M [3].

Product Description [1]

ProteinQure is a computational platform for protein drug discovery. The company partners with pharma to deliver experimentally validated novel chemical matter. They claim to combine molecular simulations, machine learning and high performance computing algorithms to perform structure-based drug design.

ProteinQure can obtain structures for protein therapeutics and drug targets (up to ~100 amino acids). Their integrative models can use external data (sequence, structure, and functional measurements) to increase the speed and accuracy of our predictions. This approach has shown strong agreement to experimental structures in blind protein folding challenges (CASP).

ProteinQure is applying these methods to develop a novel class of peptide-mimetic polymers with SRI International. These molecules have shown high binding affinity to well-established drug targets involved in cell signalling (cytokines, nucleotide-binding proteins). By modelling the combinatorial space containing non-natural amino acids, we support rational drug design and optimization of these peptides for stability and binding affinity.

Product Description

Their partnerships involve wet lab validation and areas where data availability is often a challenge (GPCR and intracellular targets, non-natural amino acids etc.). They focus on novel peptides optimized for binding, specificity and other pharmacokinetic properties. In addition they engineer proteins to incorporate multiple binding domains.

Figure: ProteinQure Applications

Case Study/White Paper

Molecular Docking with Gaussian Boson Sampling (Published in Feb, 2019) [5]

Gaussian Boson Samplers are **photonic quantum devices** with the potential to perform tasks that are intractable for classical systems. As with other near-term quantum technologies, an outstanding challenge is to identify specific problems of practical interest where these quantum devices can prove useful.

The authors show that Gaussian Boson Samplers can be used to **predict** molecular docking configurations: the spatial orientations that molecules assume when they bind to larger proteins. Molecular docking is a central problem for pharmaceutical drug design, where docking configurations must be predicted for large numbers of candidate molecules. They develop a vertex-weighted binding interaction graph approach, where the molecular docking problem is reduced to finding the maximum weighted clique in a graph. They show that Gaussian Boson Samplers can be programmed to sample large-weight cliques, i.e., stable docking configurations, with high probability, even in the presence of photon loss. They also describe how outputs from the device can be used to enhance the performance of classical algorithms and increase their success rate of finding the molecular binding pose. To benchmark our approach, they predict the binding mode of a small molecule ligand to the tumor necrosis factor-α converting enzyme, a target linked to immune system diseases and cancer.

Molecular docking is a computational tool for rational structure-based drug discovery. Docking algorithms predict non-covalent interactions between a drug molecule (ligand) and a target macromolecule (receptor) starting from unbound three-dimensional structures of both components. The output of such algorithms are predicted three-dimensional orientations of the ligand with respect to the receptor binding site and the respective score for each orientation. Reliable determination of the most probable ligand orientation, and its ranking within a series of compounds, requires accurate scoring functions and efficient search algorithms.

Case Study/White Paper

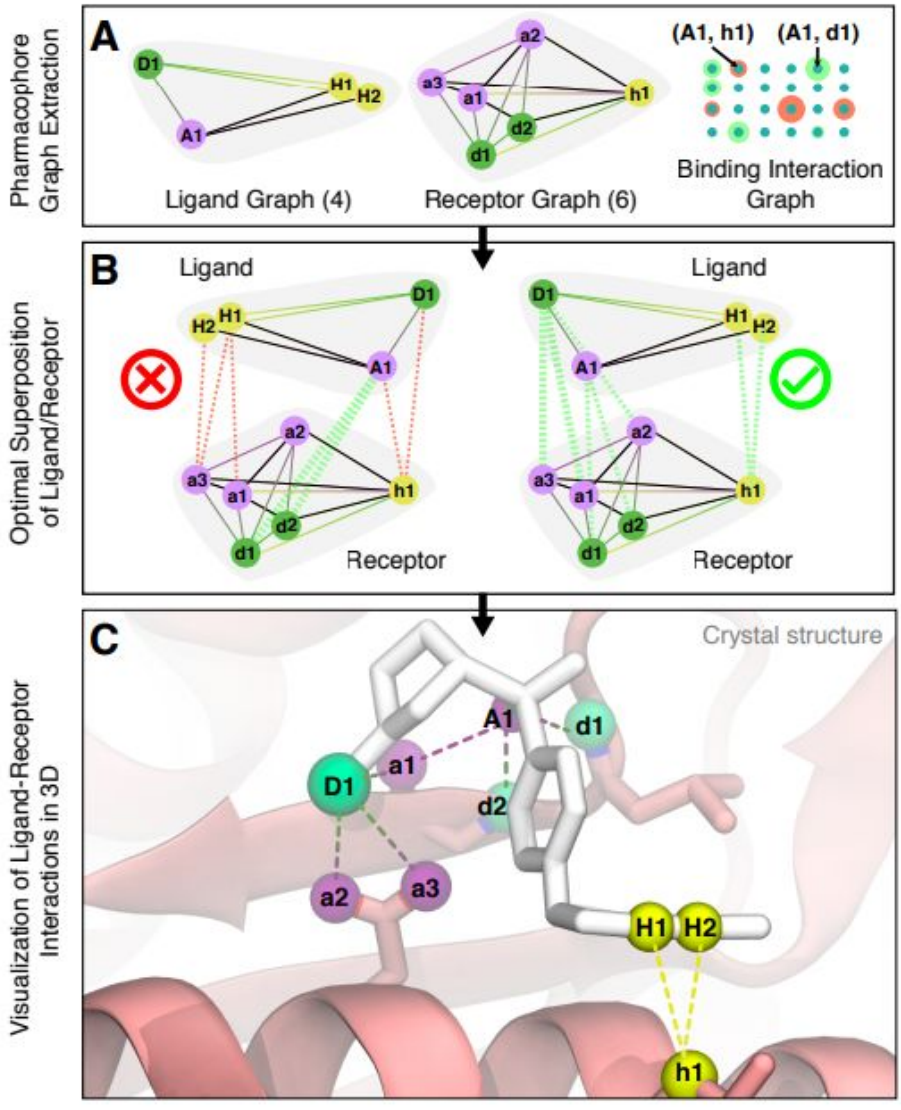


Figure: Graph-based molecular docking of an aryl sulfonamide compound to TACE. Panel A shows the two labelled distance graphs – one for the aryl sulfonamide compound and one for the TACE receptor – and the resulting TACE-AS binding interaction graph. Pharmacophore points on the ligand and receptor are labelled with upper- and lowercase letters, respectively. The search for the maximum vertex-weighted clique within the TACE-AS graph is illustrated in Panel B. Each clique in the TACE-AS graph correspond to a different superposition of the ligand molecule and the TACE receptor. The correct ligand-receptor superposition corresponding to the maximum weighted clique in the TACE-AS graph is shown on the right. Panel C visualizes the crystallographic structure of the TACE-AS complex with optimal ligand-receptor interactions correctly predicted by the maximum weighted clique. We omit the metal cofactor in the enzyme active site for visual clarity, as it was not considered as a pharmacophore point under our procedure.

Intellectual Property

N/A

Investors/Funding Partners

ProteinQure has raised a total of $4.6M in funding over 3 rounds. Their latest funding was raised on Jul 1, 2019 from a Seed round. ProteinQure is funded by 8 investors. Inovia Capital and Tom Williams are the most recent investors [2].

Investor Name	Lead Investor	Funding Round	Partners
Inovia Capital	–	Seed Round - ProteinQure	–
Tom Williams	–	Seed Round - ProteinQure	–
8VC	–	Seed Round - ProteinQure	–
Felicis Ventures	Yes	Seed Round - ProteinQure	Wesley Chan
Golden Ventures	–	Seed Round - ProteinQure	–
Global Founders Capital	–	Seed Round - ProteinQure	–
Tom Williams	–	Pre Seed Round - ProteinQure	–
Ramen Ventures	–	Pre Seed Round - ProteinQure	–
Creative Destruction Lab (CDL)	Yes	Pre Seed Round - ProteinQure	–

References

1. https://www.proteinqure.com/
2. https://www.crunchbase.com/organization/proteinqure
3. https://www.zoominfo.com/c/proteinqure-inc/450534118
4. https://www.linkedin.com/company/proteinqure/about/
5. https://arxiv.org/abs/1902.00462

PASQAL: Full-Stack Quantum Computer

PASQAL
Headquarters: Palaiseau, Ile-de-France, France
Website: https://pasqal.io/
Contact: https://pasqal.io/contact/

TRL 5

Overview

Founded in 2019, PASQAL (2-10 employees) is developing a full-stack quantum computer that will be used to simulate complex phenomena for scientific discovery and to address general problems such as optimization, drug discovery, and machine learning. The company's quantum processing units are made up of hundreds of atomic qubits in 2D and 3D arrays, and their programming environment, to address our customers' needs in quantum computing and simulation [2][4]. The company has raised $30.4M in funding [2] and has a revenue of $5M [3].

Product Description

Application of Pasqal's QPU is Quantum Simulation, where the quantum processor is used to gain knowledge over a quantum system of interest. Beyond the simulation of scientific processes, Pasqal processors can already be used to solve hard computational problems, for which classical computers are inefficient. One important example is the native resolution of a well-known graph problem, Maximum Independent Set (MIS). This problem, which has various direct applications in network design or finance, becomes hard to solve on a classical computer when the size of the graph grows.

In an undirected graph composed of a set of vertices connected by unweighted edges, an independent set is a subset of vertices where no pair is connected by an edge. The objective of the MIS problem is to find the largest of such subsets.

The MIS problem can be tackled by using an ensemble of interacting cold neutral atoms as a quantum resource, where each atom represents a vertex of the graph under study. Interestingly, the physical interactions encoded in the Hamiltonian constrain the dynamics to only explore independent sets of the graph under study, then leading to an efficient search in the set of possible solutions.

Product Description

Figure: Pasqal processors [5]

Case Study/White Paper

Crédit Agricole CIB explores quantum computing applications in partnership with Pasqal and Multiverse Computing (June 28, 2021) [6]

Crédit Agricole CIB and Pasqal and Multiverse Computing announced a partnership to design and implement new approaches running on classical and quantum computers in order to outperform state of the art algorithms for capital markets and risk management.

Crédit Agricole CIB has teamed up with the two quantum technology companies to apply quantum computing to real world finance applications. French company Pasqal is developing a quantum computer based on neutral atoms arrays, a state-of-the-art technology currently being trialled to build industrial quantum computers. Spanish company Multiverse Computing specialises in quantum algorithms which can be run both on quantum and classical computers. A advantage in terms of **shortening** the time-to-market.

Intellectual Property

N/A

Investors/Funding Partners

PASQAL has raised a total of $30.4M in funding over 3 rounds. Their latest funding was raised on Jun 8, 2021 from a Series A round. PASQAL is funded by 7 investors. Eni Next and Runa Capital are the most recent investors [2].

Investor Name	Lead Investor	Funding Round	Partners
Eni Next	–	Series A - PASQAL	Gabriele Franceschini
Runa Capital	–	Series A - PASQAL	Dmitry Galperin
Daphni	–	Series A - PASQAL	–
European Innovation Council	–	Series A - PASQAL	–
Bpifrance	Yes	Series A - PASQAL	Nicolas Dufourcq
Quantonation	Yes	Series A - PASQAL	Christophe Jurczak
TPY Capital	Yes	Seed Round - PASQAL	–
Quantonation	–	Seed Round - PASQAL	–

Figure: Investors list [2]

References

1. https://pasqal.io/technology/
2. https://www.crunchbase.com/organization/pasqal
3. https://www.zoominfo.com/c/pasqal/535355298
4. https://www.linkedin.com/company/pasqal/about/
5. https://venturebeat.com/2021/06/09/pasqals-neutral-atom-tech-promises-200-qubits-of-quantum-processing-power/
6. https://pasqal.io/2021/06/28/credit-agricole-cib-explores-quantum-computing-applications-in-partnership-with-pasqal-and-multiverse-computing/

SeeQC: Digital Quantum Management (DQM) System-on-a-Chip

SeeQC
Headquarters: Elmsford, New York, United States
Website: https://seeqc.com/
Contact: info@seeqc.com

TRL 5

Overview

Founded in 2019, Seeqc is developing a digital digital quantum computing platform for global businesses. Seeqc combines classical and quantum technologies to address the efficiency, stability and cost issues endemic to quantum computing systems. Seeqc's DQM System-on-a-Chip is the linkage that binds quantum hardware with quantum algorithms and applications. By integrating critical management functions on a chip, it claims to bring a new level of scale and cost-effectiveness, and enabling new functionalities to quantum computing.Seeqc's quantum system provides the energy and cost-efficiency, speed and digital control required to make quantum computing useful and bring the first commercially-scalable, problem-specific quantum computing applications to market [2][6]. SeeQC has raised a total of $29.2M in funding over 2 rounds [4] and has a revenue of $11M [5].

Product Description [2]

Seeqc's DQM System-on-a-Chip is the linkage that binds quantum hardware with quantum algorithms and applications. By integrating critical management functions on a chip, it brings a new level of scale and cost-effectiveness, and enabling new functionalities to quantum computing.

Seeqc's patented Single Flux Quantum (SFQuClass) processors will perform digital qubit control, readout and classical data processing functions, as well as being a platform for error correction. They are proximally co-located and integrated with qubit chips in a cryo-cooled environment to drastically reduce the complexity of input/output connections and maximize the benefits of fast, precise, low-noise digital control and readout, and energy-efficient classical co-processing. Seeqc's DQM System-on-a-Chip claims to have the potential to work across multiple quantum hardware designs.

SeeQC: Digital Quantum Management (DQM) System-on-a-Chip

Product Description

Seeqc owns and operates a multi-layer superconductive electronics chip fabrication facility. The foundry enables them to continuously improve and rigorously test their SFQ and SFQuClass chips. It also provides the specialized equipment and processes to fabricate application-specific circuits and combine them with the DQM System-on-a-Chip and qubit hardware to create 3D multi-chip systems.

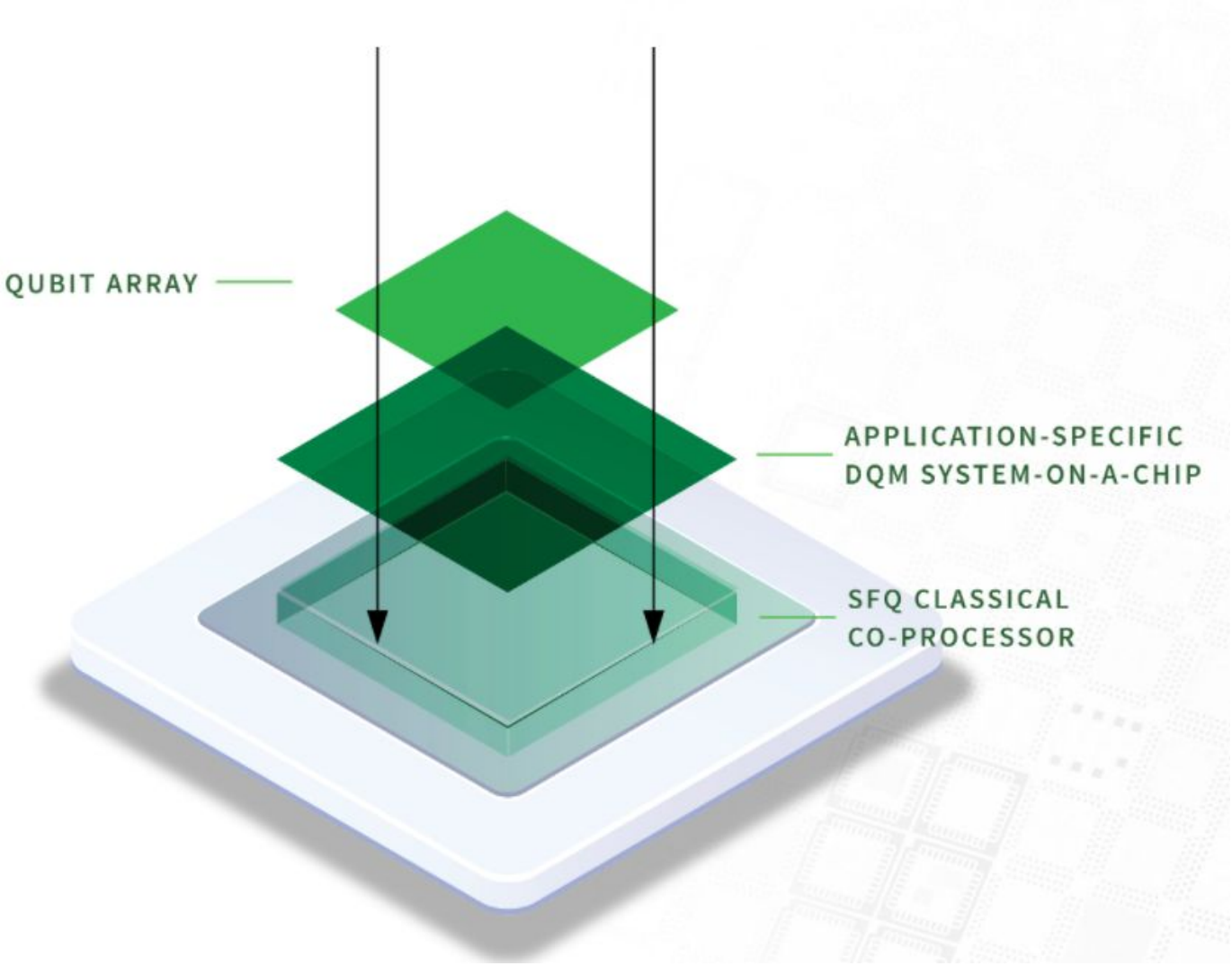


Figure: Digital Quantum Management (DQM) System-on-a-Chip

Case Study/White Paper

N/A

Intellectual Property

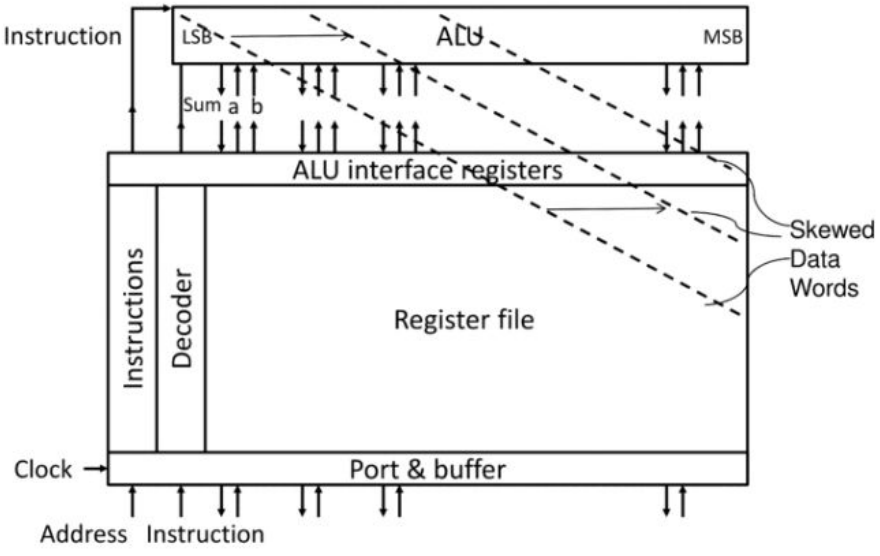
Patent Name/Title: System and method for cryogenic hybrid technology computing and memory [3]

Patent No: US10460796B1

Status: Granted in October 2019.

Brief description:

- A system and method for high-speed, low-power cryogenic computing are presented, comprising ultrafast energy-efficient RSFQ superconducting computing circuits, and hybrid magnetic/superconducting memory arrays and interface circuits, operating together in the same cryogenic environment. An arithmetic logic unit and register file with an ultrafast asynchronous wave-pipelined datapath is also provided. The superconducting circuits may comprise inductive elements fabricated using both a high-inductance layer and a low-inductance layer.
- The memory cells may comprise superconducting tunnel junctions that incorporate magnetic layers. Alternatively, the memory cells may comprise superconducting spin transfer magnetic devices (such as orthogonal spin transfer and spin-Hall effect devices). Together, these technologies may enable the **production of an advanced superconducting computer that operates at clock speeds up to 100 GHz**.



Investors/Funding Partners

SeeQC has raised a total of $29.2M in funding over 2 rounds. Their latest funding was raised on Sep 16, 2020 from a Series A round. SeeQC is funded by 8 investors. LG Technology Ventures and EQT Ventures are the most recent investors [4].

Investor Name	Lead Investor	Funding Round	Partners
LG Technology Ventures	–	Series A - SeeQC	Dong-Su Kim
EQT Ventures	Yes	Series A - SeeQC	Ted Persson
Newlab	–	Series A - SeeQC	–
FAM AB	–	Series A - SeeQC	–
BlueYard Capital	–	Series A - SeeQC	–
M Ventures	Yes	Series A - SeeQC	Owen Lozman
Partnership Fund for New York City	–	Series A - SeeQC	–
Cambium Capital Partners	–	Seed Round - SeeQC	–
Partnership Fund for New York City	–	Seed Round - SeeQC	–
BlueYard Capital	–	Seed Round - SeeQC	–

Figure: Investors list [4]

References

1. https://seeqc.com/
2. https://seeqc.com/innovation/dqm-system-on-a-chip/
3. http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&p=1&u=/netahtml/PTO/srchnum.html&r=1&f=G&l=50&d=PALL&s1=10460796.PN.
4. https://www.crunchbase.com/organization/seeqc
5. https://www.zoominfo.com/c/seeqc-inc/452474666
6. https://www.linkedin.com/company/seeqc-us/about/

Oxford Quantum Circuits: Quantum Computing-as-a-Service (QCaaS) Platform

Oxford Quantum Circuits
Headquarters: Oxford, Oxfordshire, United Kingdom
Website: https://oxfordquantumcircuits.com/
Contact: hello@oxfordquantumcircuits.com

TRL 6

Overview

Founded in June 2017 by Dr Peter Leek, OQC developed its first technology at the University of Oxford and its world-leading physics department. There he developed OQC's core IP – the Coaxmon – a quantum bit (qubit) developed from first principles with commercial scalability in mind and liberated from the constraints of 2D technology. OQC spun-out of the University of Oxford, raising an initial Seed of £2M. OQC's Quantum Computing-as-a-Service (QCaaS) platform, the first in the UK and in Europe, is built entirely using their proprietary technology [1]. The company has a revenue of less than $5M [5].

Product Description [1]

OQC's Quantum Computing-as-a-Service (QCaaS) platform, claimed as the first in the UK and in Europe, is built entirely using a proprietary technology. With its private Quantum Computing-as-a-Service platform, OQC claims to enable strategic partners and customers to make breakthrough discoveries. Businesses invited to join OQC's beta list will be able to test OQC's systems in streamlining or enhancing their business processes, and model and experiment with new approaches.

Oxford Quantum Circuits: Quantum Computing-as-a-Service (QCaaS) Platform

Product Description

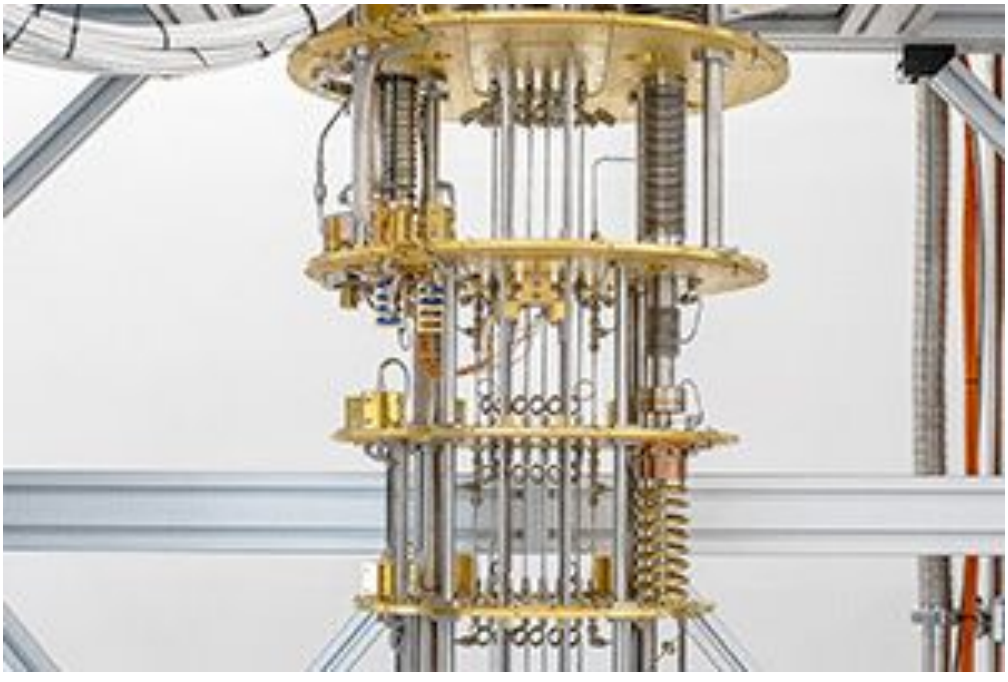


Figure: A close view of 'Sophia', one of OQC's systems.

Figure: OQC's laboratory is the first commercial quantum computing facility in the UK

Case Study/White Paper

OQC delivers Europe's first Quantum Computing as-a-Service (7 July 2021) [5]

OQC's Quantum Computing-as-a-Service platform takes its proprietary quantum technology to the market through a private cloud, where it will be used by strategic partners and customers to further experiment with quantum until ultimately they make breakthrough discoveries and tackle some of the world's most intractable problems.

OQC's partner, Cambridge Quantum, **will be the first to be given access to the private cloud to demonstrate its IronBridge cybersecurity platform**, which extracts perfect certified entropy from quantum computers to generate unhackable cryptographic keys. To achieve this milestone — of national strategic importance — Cambridge Quantum will have access to one of OQC's systems, "Sophia", hosted at the company's state-of-the-art lab in the UK. The facility, which was built last year amid the global pandemic, is the first commercial quantum computing laboratory in the country.

Intellectual Property

Patent Name/Title: Control method for a distributed processing system including a quantum information processor [6]

Patent No: WO2021165639A1

Status: Published in August 2021.

Brief description:

The classical-quantum hybrid program includes a function to be executed by the quantum information processor. The method comprises parsing the classical-quantum hybrid program to generate an intermediate representation of the classical-quantum hybrid program, the intermediate representation comprising a series of basic blocks, each basic block comprising a sequence of instructions. The method comprises identifying basic blocks for which the sequence of instructions comprises one or more stream operation instructions, the one or more stream operation instructions configured to control interactions with the quantum information processor. A computer-readable medium, a distributed system controller, and a distributed processing system are also mentioned.

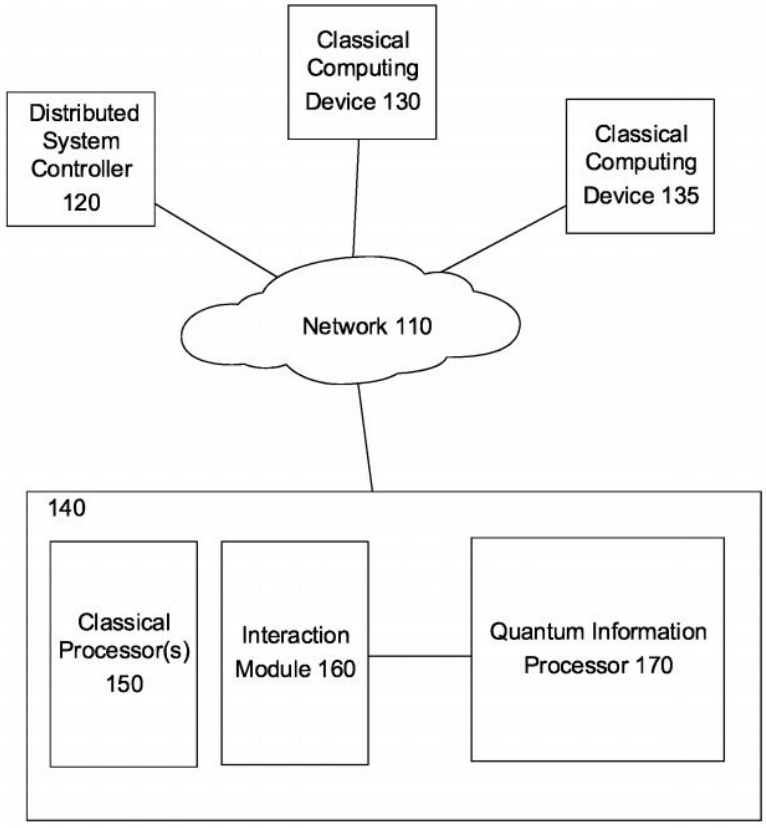


Figure 1 from the patent shows a distributed processing system including a quantum information processor.

Investors/Funding Partners

Oxford Quantum Circuits has raised a total of — in funding over 1 round. This was a Series A round raised on Sep 8, 2017. Oxford Quantum Circuits is funded by 2 investors: Oxford Sciences Innovation and Parkwalk Advisors [2].

References

1. https://oxfordquantumcircuits.com/
2. https://www.crunchbase.com/organization/oxford-quantum-circuits
3. https://www.zoominfo.com/c/oxford-quantum-circuits-ltd/463879160
4. https://www.linkedin.com/company/oqc/about/
5. https://oxfordquantumcircuits.com/oqc-delivers-first-eu-qcaas
6. https://worldwide.espacenet.com/patent/search/family/070108324/publication/WO2021165639A1?q=pn%3DWO2021165639A1

1QLOUD; QEMIST; MSM; XrAI : 1QBit

1QB Information Technologies, Inc. (1QBit)
Headquarters: Vancouver, Canada
Website: https://1qbit.com/
Contact: info@1qbit.com or +1 (646) 820–8865

TRL 7

Overview

Founded in 2012, 1QB Information Technologies, Inc. (1QBit) is a quantum computing software company based in Vancouver, British Columbia. 1QBit develops general purpose algorithms for quantum computing hardware, the organization is primarily focused on computational finance, materials science, quantum chemistry, and the life sciences. It has established hardware partnerships with Microsoft, IBM, Fujitsu and D-Wave Systems. 1QBit also has a hardware innovation lab at the University of Waterloo in Waterloo, Ontario. [1]

Product Description

1QBit has multiple products naming: 1QLOUD, QEMIST, Market Sentiment Meter (MSM) and XrAI :AI “co-pilot” for clinicians interpreting chest X-rays.

1QLOUD™ [2]

1Qloud platform is a computational bridge that connects intractable industry problems to novel quantum-inspired optimization solutions that utilize the most advanced hardware. The platform focuses on optimization including reformulating optimization problems into the quadratic unconstrained binary optimization (QUBO) format necessary to compute with quantum annealing processors and similar devices from organizations such as Fujitsu, D-Wave, Hitachi and NTT.

Product Description

The 1Qloud platform is a computational bridge that connects intractable industry problems to novel quantum-inspired optimization solutions that utilize the most advanced hardware. Its hardware-agnostic approach enables operations researchers, data scientists, and developers to harness the power of advanced computing resources and novel algorithms without the need to learn the intricacies of each individual hardware platform or to manage complex and expensive computing infrastructure.

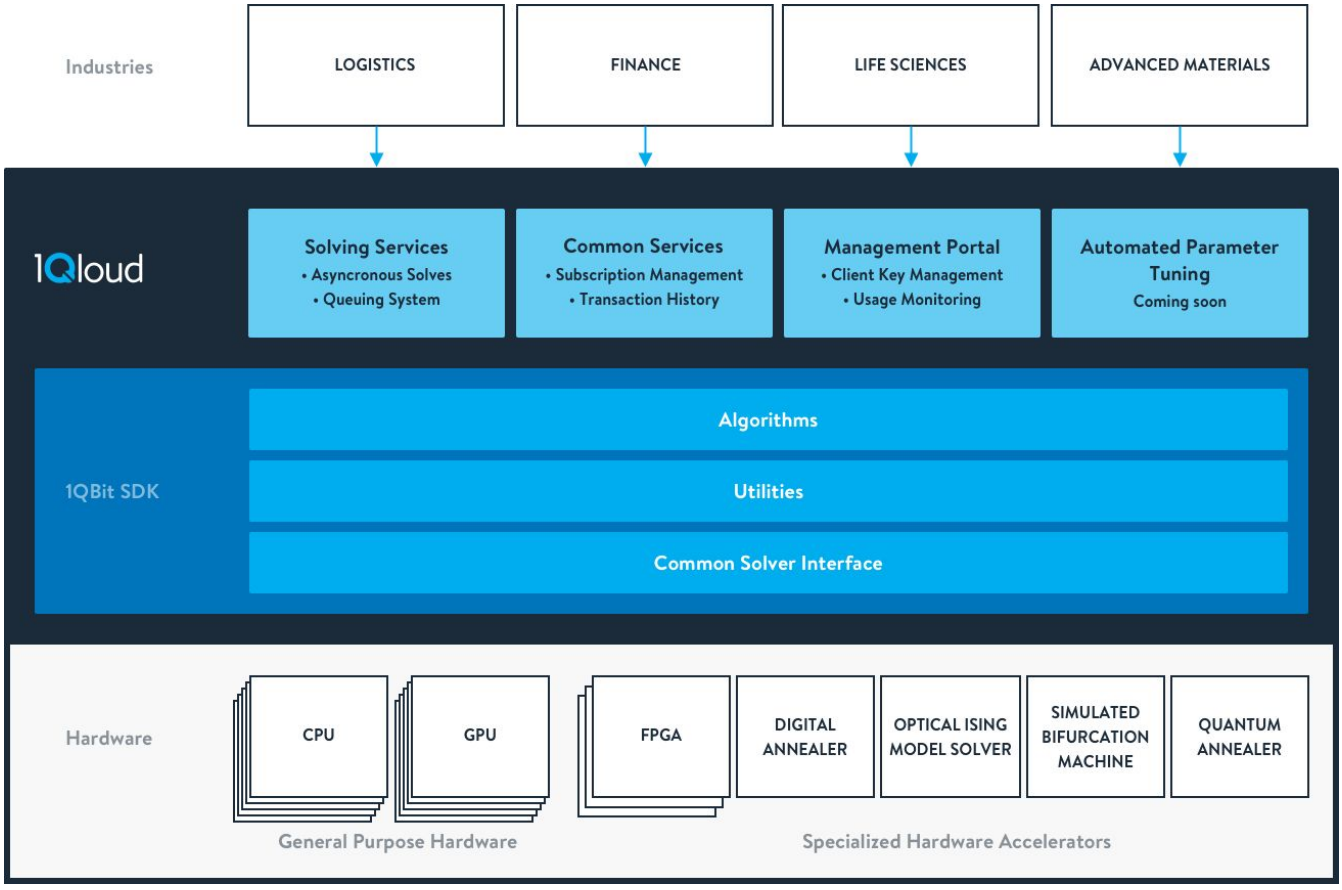


Figure 1. 1Qloud platform

Product Description

What 1QLOUD™ Can be used for?

1. Discover New Drugs

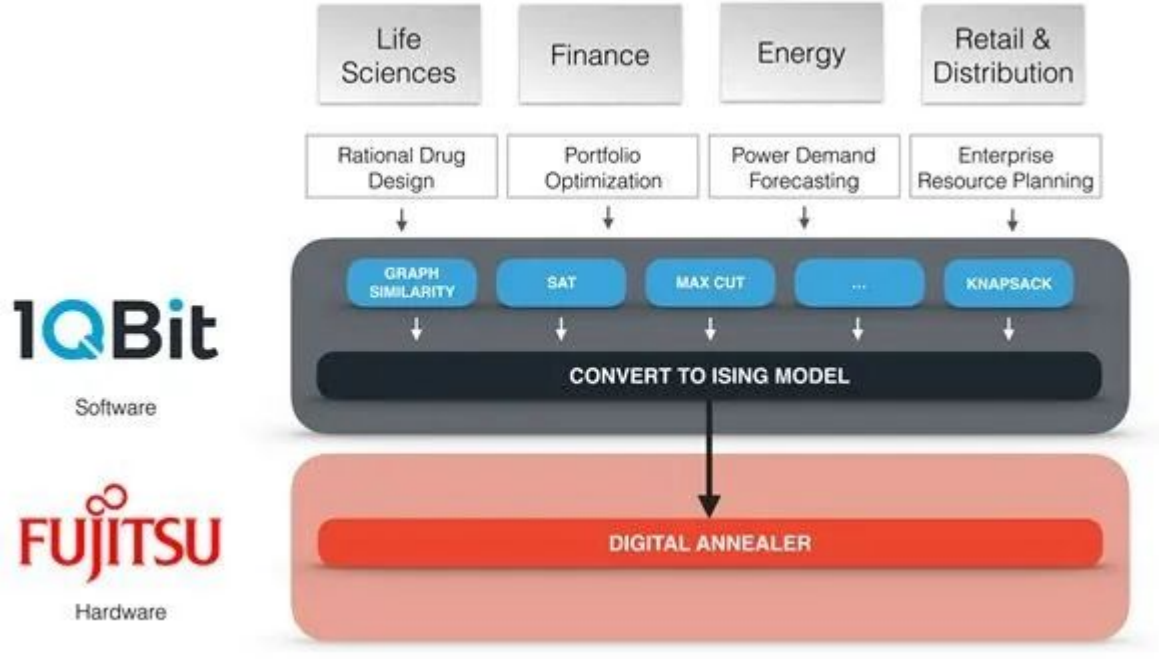
   The 1QBit Graph-Based Molecular Similarity (GMS) tool is being used by pharmaceutical companies to perform virtual screening and assist in drug discovery. This tool outperforms current techniques, such as fingerprints, in achieving higher retrieval rates in virtual screening.

2. Optimize Portfolios

   1QBit Quantum-Inspired Hierarchical Risk Parity (QHRP) method is used for optimizing portfolios, which uses quantum-inspired technology and advanced hardware accelerators to outperform conventional methods with respect to a variety of risk measures in addition to lowering susceptibility to inaccuracies in the input data.

3. Route and Schedule

   1QBit's Advanced Routing and Scheduling Platform helps to harness quantum-inspired hardware and novel formulations to solve complex mobility problems, optimize the manufacturing tasks, or improve home healthcare scheduling.



Product Description

1QLOUD™ Platform Benefits

1. High-performance cloud-based solution that scales up to meet the computational demands, and allow to reduce the need to manage complex and expensive computing infrastructure in the data centre.
2. Novel quantum-inspired optimization solvers developed by a world-leading team of optimization experts with an in-depth knowledge of classical and quantum computers and algorithms. Modular and extensible architecture allows to easily add new and powerful algorithms as they get rigorously benchmarked by the research team and validated using real-world problems from the customers.
3. Seamless integration with special-purpose hardware accelerators. It allows removing the need to commit to one particular hardware technology in this rapidly evolving hardware landscape in the post Moore's law era, future-proofing your business and preparing it for the quantum computing revolution.
4. The platform makes quantum and quantum-inspired technology accessible. Intuitive and easy to use Python SDK, gRPC, and REST API interfaces, comprehensive documentation, and interactive notebooks allow ones to get started in no time and rapidly progress towards more advanced scenarios.
5. Hyperparameter Optimization and Benchmarking Framework. The in-progress intelligent, automated parameter tuning, and benchmarking framework guarantees that optimization problems are solved in the most efficient way.

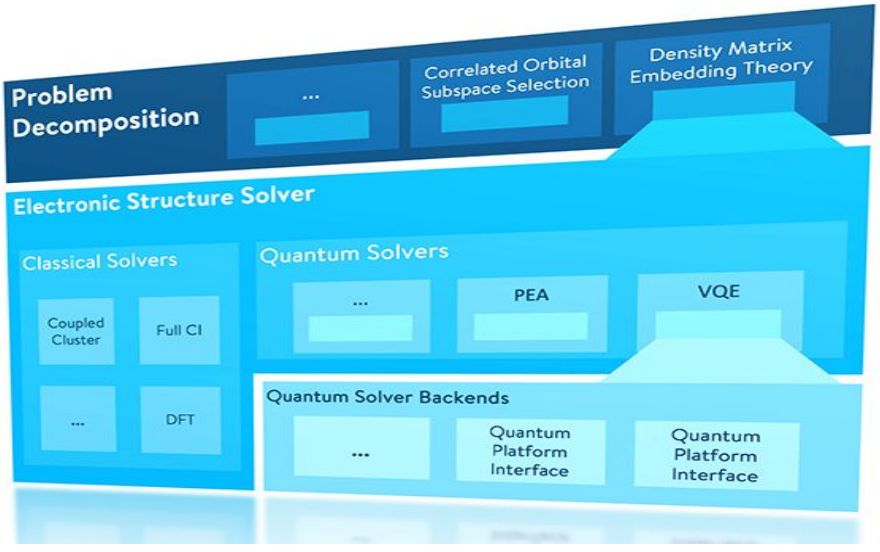
Product Description

QEMIST [3]

Quantum-Enabled Molecular ab Initio Simulation Toolkit, or QEMIST, is a solution to the fundamental and intractable problem in chemistry: ab initio simulation of molecules. The QEMIST platform focuses on advanced materials and quantum chemistry research with universal quantum computing processors. The accurate prediction of the electronic structure of a molecule is key to the design of new materials, such as drug compounds and catalyst molecules, by helping to anticipate a material's properties before its synthesis in the lab. However, obtaining this information using classical computers is computationally intensive, and the resources required for an exact solution scale exponentially with the size of the problem. Attempts to provide approximate approaches to this problem on classical computers have been to date either limited to small-sized systems or compromising on the accuracy of the simulation.

A Modular, Platform-Agnostic Design

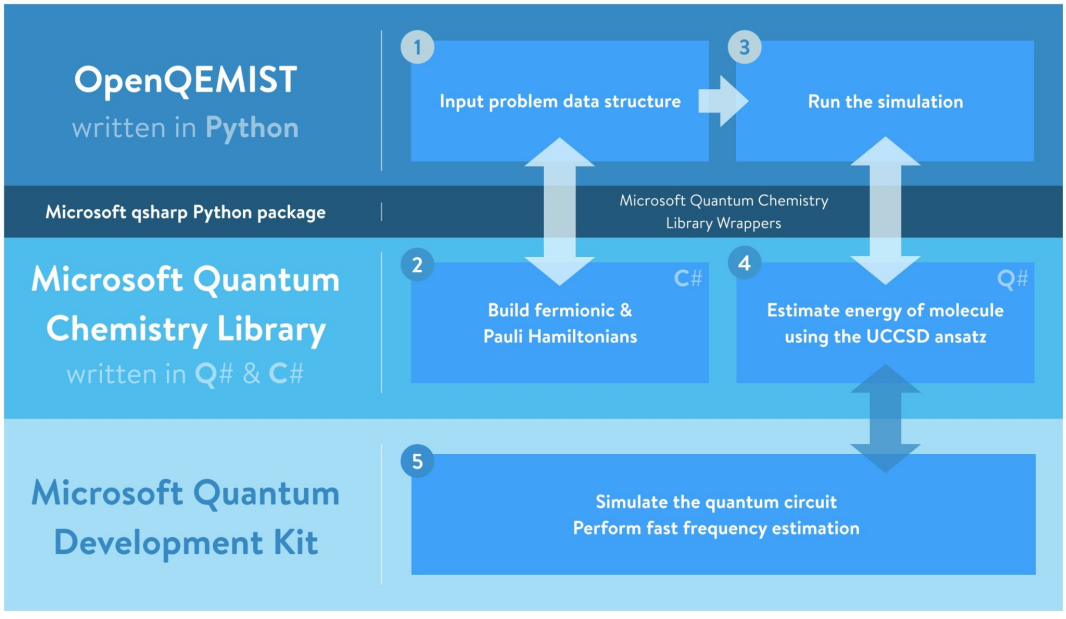
QEMIST is designed to enable the accurate calculation of molecular properties by leveraging advanced problem decomposition (PD) techniques and quantum computing. The variety of PD techniques implemented in QEMIST enables massively parallel simulations by breaking down a computational chemistry task into smaller, independent subproblems. These subproblems can use a combination of interfaces to various classical and quantum solvers to achieve a higher level of accuracy for large-scale, practical molecular simulations.



Product Description

The Microsoft and 1QBit Collaboration [4]

In 2019, Microsoft and 1QBit collaborated and developed an implementation of the variational quantum eigensolver (VQE) algorithm that works with Python and Q# and demonstrated the integration of the QDK with QEMIST through an example of density matrix embedding theory (DMET) for resource-efficient, larger-scale quantum simulations.



The Microsoft Quantum Development Kit provides a scalable end-to-end quantum development environment and leverages the Q# quantum programming language, which enables users to perform quantum algorithm design, compilation, and simulation. These functions are augmented by domain-specific libraries (such as the Microsoft Quantum Chemistry Library), and can be used in Python through the qsharp PyPI package. 1QBit has been working closely with the quantum team at Microsoft to connect the OpenQEMIST platform and the Quantum Development Kit using this package.

Product Description

CME Market Sentiment Meter (MSM) [11]

The CME Market Sentiment Meter (MSM) was created by 1QBit and the CME Group. It offers new trading insights by putting numbers to market expectations.

The MSM uses settlement data on eight major futures and options markets to estimate the likelihood of price movements. The MSM is based on money-at-risk in the open market, not just chatter and fake news.

Knowing what people are trading far out the curve adds another dimension to analyzing a market. The MSM is a metric with better forecasting and statistics that you can use to make more money from algorithmic trading.

How Does the MSM Work?

The overall attitude of traders toward a particular market—known as market sentiment—is calculated using futures and options settlement data.

Market sentiment is quantified using risk-return curves, which give the probability of price movement. The wider the curve, the more risk there is on the return, and the more anxiety there is in the market.

There is always more than one school of thought by investors toward a given market, especially leading up to big events with uncertain outcomes. Conventional approaches may not take multiple schools of thought into account—missing out on the whole story. The MSM is able to capture market sentiment states that are rare or short-lived yet extremely important to recognize.

The MSM begins with the assumption that multiple schools of thought will always be present, and that most of the time they are similar. When they are different, though, the MSM detects this and infers a risk-return distribution that departs from the conventional bell curve shape.

Product Description

XrAI: An AI "co-pilot" for clinicians interpreting chest X-rays [10]

XrAI is a quality-control and clinical-decision support tool that uses deep learning to expedite the way frontline care workers identify lung-related abnormalities by highlighting regions of abnormality in chest X-ray images. This tool was developed as a "co-pilot" for clinicians to improve the accuracy and timeliness of diagnosing lung and pleural abnormalities on chest radiographs.

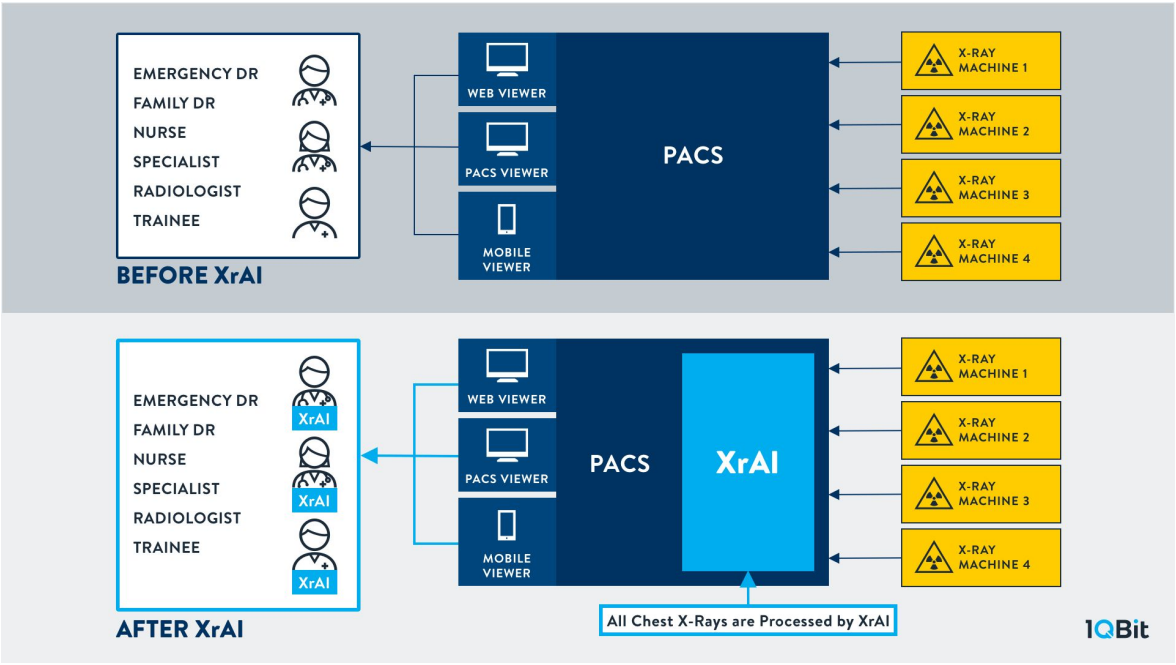
The solution empowers clinicians by providing immediate analysis of a chest radiograph, enhancing their ability to form an accurate diagnosis at the time treatment is prescribed.

XrAI has been validated in clinical trials in Canada and is the first AI tool for radiology to be authorized by Health Canada as a Class III Certified Medical Device. The landmark clinical trial was dramatically accelerated and prioritized by the health care community in response to the COVID-19 pandemic. After seeing the impact this tool has for optimizing patient care, health care organizations across Canada and internationally mobilized to get XrAI into the hands of clinicians.

How XrAI works?

1. **Responsible AI:** Rather than employing a traditional black box system, XrAI provides physicians with transparency into the conclusions made by the underlying algorithm and an intuitive interface to view accurate results and inform their final diagnoses.
2. **Confidence Dial:** The confidence dial, which allows clinicians to increase or decrease the confidence level in the identified potential abnormalities, is unique to XrAI and has been widely praised by users as a critical feature that is intuitive to the way radiologists share their opinions with other medical professionals.
3. **Intuitive Integration:** XrAI integrates into existing clinical information systems with no workflow disruption and little to no training required. The results of XrAI's analysis are made available within a clinician's standard X-ray viewer, displaying the machine learning algorithm's findings along with its level of confidence in the provided results.

Product Description

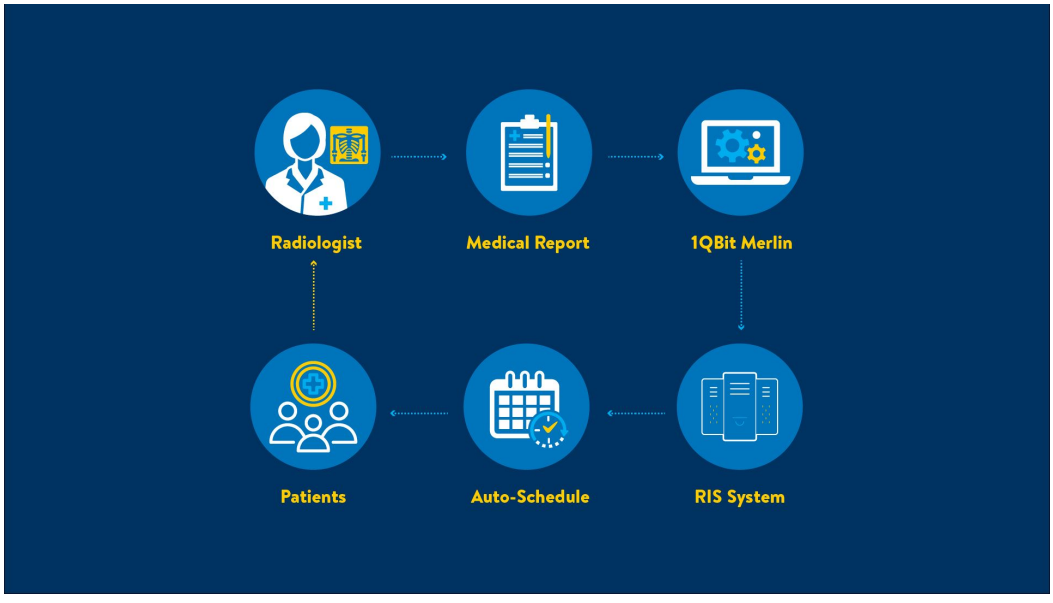


What is Merlin?

Follow-up management can be overwhelming. Losing track of follow-up recommendations is not only dangerous for patient outcomes—it can damage the important relationship between a health care provider and a patient. 1QBit has developed and validated an easy, intuitive way to minimize these kinds of errors using state-of-the-art natural language understanding (NLU) methods. Merlin is a quality-assurance and workflow enhancement tool that automatically detects recommendations for follow-ups in radiologists' reports.

Combining binary classification and entity-extraction models for follow-up identification, Merlin detects whether a radiologist recommended a follow-up, and, if so, recognizes the type of follow-up exam, the part of the body concerned, and the recommended date for the exam. Merlin has been validated in its ability to interpret proposed follow-up durations and detect and understand recommended exam types. Merlin is now available for purchase and deployment, ready to improve clinical workflow.

Product Description



Workflow Impact

Merlin has capabilities to directly integrate into Radiology Information Systems (RIS). This has been shown with Konica Minolta's EXA RIS-PACS integration, resulting in dramatic improvements in workflow. Radiology reports, once generated by a radiologist, are instantaneously routed to Merlin, where an analysis is performed in search of follow-up recommendations. If such a recommendation is detected, a scheduling queue is automatically populated with the follow-up details, including the modality, body type, and time frame. This is an important step toward enhancing the quality of care that radiology practices can provide to their patients and referring clinicians.

NLU in Health Care Improves Outcomes

Natural language understanding uses neural net–based models for training and understanding the context of the text being processed. Natural language understanding models are able to analyze and understand an entire radiology report and produce an accurate result that will help clinicians provide world-class care and improve patient outcomes. Negations, uncertainty, and irrelevant summarization are not a problem for Merlin, which identifies recommendations in the report and presents findings using standardized labels. Merlin, a trusted partner in radiology, ensures that patients receive the follow-up care they need by identifying whether a follow-up is recommended and extracting the relevant information.

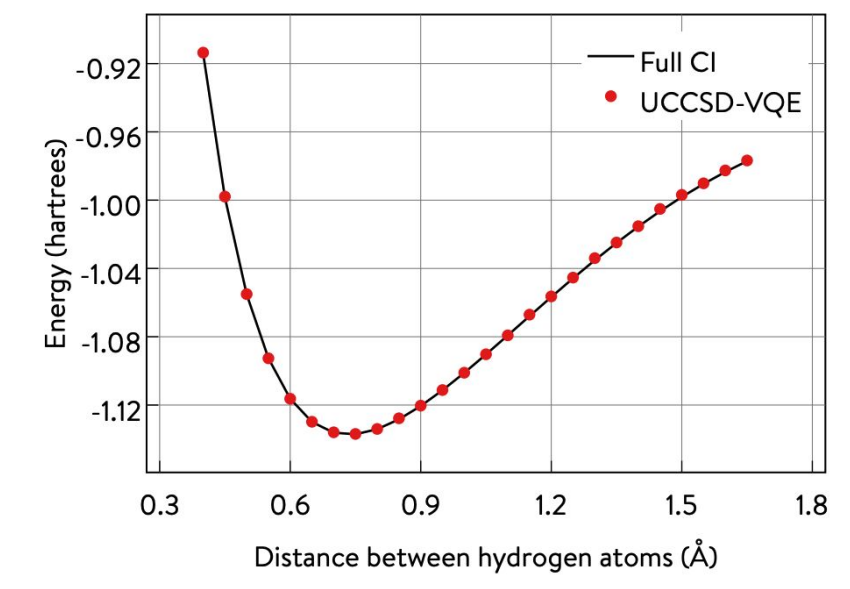
Case Study/White Paper

A Sample of Hybrid Quantum–Classical Computing [4][5]

Currently, performing quantum chemistry simulations on near-term quantum computing platforms remains restricted to systems consisting of only a few atoms, due to the limited number of available qubits and gate operations, as well as the need for quantum error correction. Hybrid quantum–classical algorithms mitigate these restrictions by offloading well-suited computational tasks to existing classical approaches.

The recently developed implementation of the VQE algorithm demonstrates this combination of classical and quantum components. By combining quantum circuits with a classically controlled variational approach, it can perform electronic structure calculations while requiring a shallower circuit than other purely quantum algorithms.

A simple hydrogen bond dissociation experiment demonstrates the implementation of this hybrid algorithm. In addition, a detailed explanation and interactive sample of this hybrid approach is available, which also provides detailed information on how we used Python and Q# to implement this algorithm.

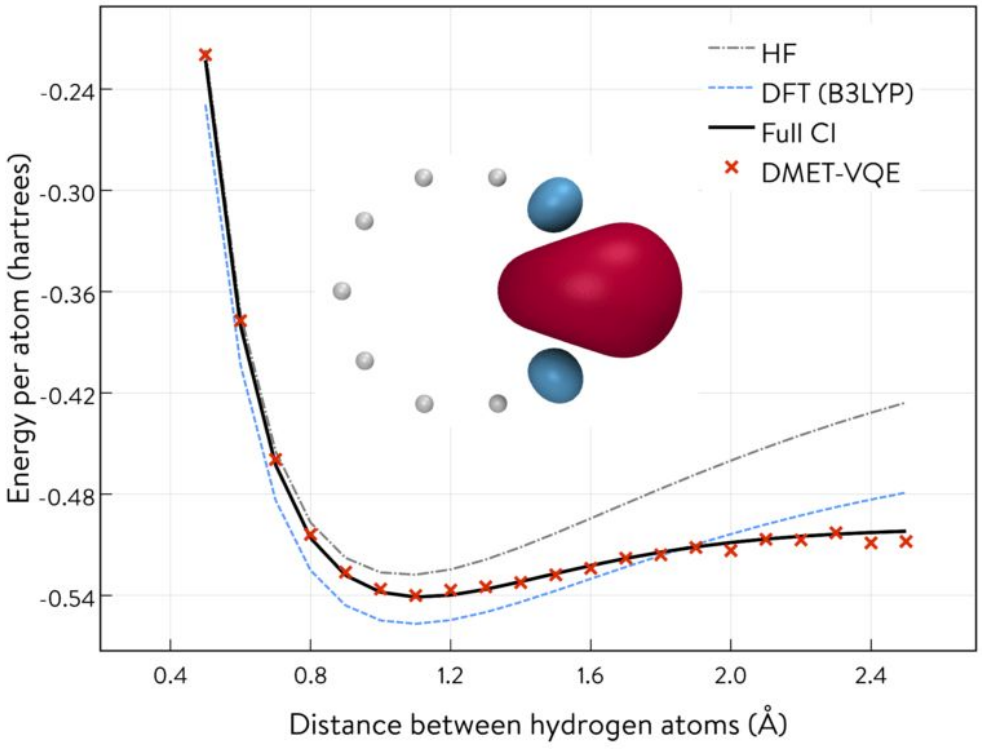


Case Study/White Paper

Problem Decomposition Techniques to Scale Up Hybrid Quantum–Classical Computing

After implementing the VQE algorithm, we can integrate this tool with QEMIST to leverage PD techniques and solve larger simulation problems. As mentioned, 1QBit has been exploring PD techniques that have the potential to scale up the size of molecules for quantum-enabled materials simulation by reducing the required quantum resources while maintaining the accuracy of the electronic structure calculation.

QEMIST is equipped with a variety of PD techniques and can intelligently select the most-appropriate techniques for a given molecular target. OpenQEMIST features DMET as a PD technique. It divides a molecule into fragments and determines the electronic structure of each subsystem using an accurate calculation method.



Case Study/White Paper

1QBit developed the DMET-VQE algorithm using the Microsoft Quantum Development Kit. It guides users through the construction of the potential energy curve of the "symmetric stretching" (i.e., changing the distance between the atoms homogeneously) of a ring of 10 hydrogen atoms.

The calculated results for DMET-VQE almost coincide with the Full CI calculation (i.e., the exact value) without using DMET on a classical computer. Running a VQE simulation of 10 hydrogen atoms without employing DMET requires 20 qubits with a minimal basis set. However, DMET-VQE uses only four qubits while maintaining the accuracy of the electronic structure calculation. Note that the other conventional quantum chemistry methods, the Hartree–Fock method (HF) and density functional theory (DFT) with the B3LYP functional, failed to reproduce the correct potential energy curve.

1QBit is a member of the Microsoft Quantum Network, and this successful demonstration of DMET-VQE, using Open QEMIST and the Microsoft Quantum Development Kit, is a promising beginning to 1QBit and Microsoft's collaboration efforts in materials design, paving the road toward practical quantum-enabled simulation to further accelerate progress in this area.

Case Study/White Paper

Using AI and Social Media to Analyze the Economy [6]

Text sentiment analysis uses a machine learning framework called natural language processing (NLP). In NLP, data is pre-processed to extract grammatical structure and to identify how words relate to each other with respect to syntax and semantics. Text is transformed into an array of numbers used by computer algorithms.

Machine learning algorithms are used for training a computer to 'understand' the interpretation of words. With enough data, statistical methods build 'knowledge' to discern the most meaningful features in the text data—like positive or negative sentiment.

How is sentiment analysis used in finance?

Constructing a reliable and consistent trading strategy is a keystone for investors. Automated trading strategies perform better with more robust input that indicates shifts or unusual activity within a market.

Text sentiment may have potential in estimating price movements. Input is taken from relevant social media and news feeds to calculate polarity scores, quantifying sentiment as positive, negative, or neutral.

Market sentiment is another type of sentiment analysis that quantifies the overall attitude of traders toward a particular market. It is calculated from actual market data, based on futures and options settlement data.

Both types of sentiment analysis were applied in a case study of the year 2020 regarding the US Treasury 10-Year Note futures (TYF). The year brought large fluctuations in the US economy due to the COVID-19 pandemic. The US Federal Reserve acted by adding more cash into circulation, more colloquially referred to as 'quantitative easing, or 'printing money'. Other major events include the UN Security Council Resolution 2532 regarding a global ceasefire and the US presidential election.

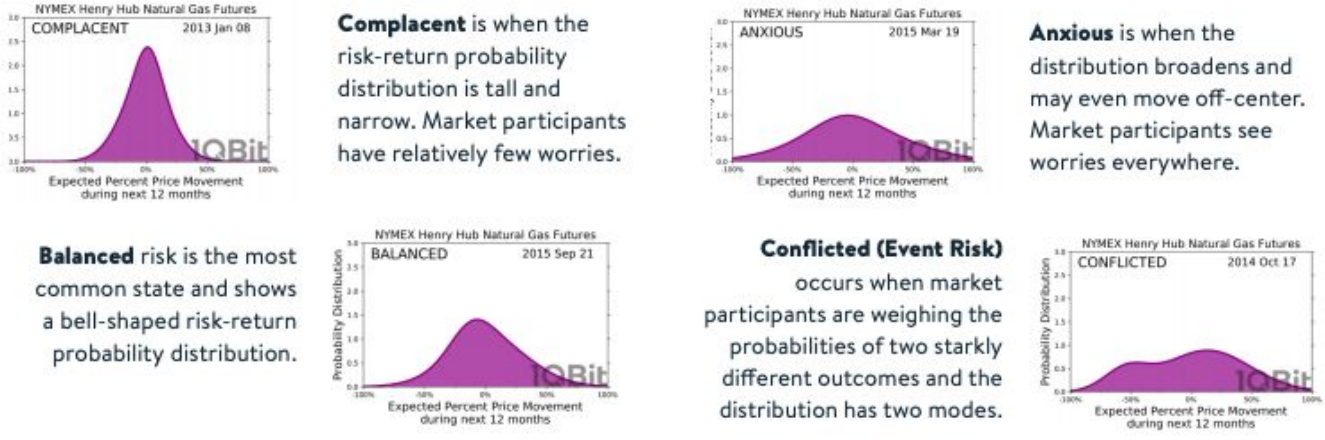
Case Study/White Paper

For the market sentiment, the CME Market Sentiment Meter (MSM) was used to calculate different market sentiment states across the same time period. MSM is delivered as a "Third-Party Dataset" on the CME DataMine platform. At the end of each trading day, a Curated Data File is calculated from the prices, volumes, open interests and intraday activity.

The MSM showed that the market was in an anxious state during the printing money period, resulting in a sharp spike in standard deviation, indicating a higher degree of risk for traders. The standard deviation quantifies risk: when it is larger, there is a higher chance of a larger price movement.

During the time of UN Resolution 2532, the MSM indicated the market was in a complacent state with a decrease in standard deviation. During the time of the US presidential election, the MSM indicated the market was in a conflicted state which preceded a rapid increase followed by a decrease in standard deviation.

In short, the MSM mixture distribution standard deviation shifted earlier than the polarity score found through the VADER analysis.



Text sentiment analysis, or opinion mining, is a popular technique that uses artificial intelligence (AI). Model Classifications of MSM.

Intellectual Property

N/A

Investors/Funding Partners

1QBit was founded as the first dedicated quantum computing software company in 2012. In 2013, 1QBit raised seed funding from US and Canadian angel investors, before closing a Series A financing round led by the Chicago Mercantile Exchange in 2014. On August 5, 2015 the World Economic Forum announced 1QBit as a recipient of the 2015 Technology Pioneer Award recognizing 1QBit as a leader among the world's most promising technology companies. In 2017, 1QBit raised a $45M Series B financing round led by Fujitsu with participation from Allianz, Accenture, The Royal Bank of Scotland and The Chicago Mercantile Exchange. In April 2018, 1QBit joined the IBM Q Network, a global community of leading Fortune 500 companies, academic institutions, startups, and national research labs designed to explore practical applications for quantum computing. [1]

References

[1] https://en.wikipedia.org/wiki/1QBit
[2] https://ml2quantum.com/1qloud/
[3] https://1qbit.com/qemist/
[4] https://1qbit.com/news/microsoft-1qbit-collaborate-disrupt-materials-innovation-1qbit-openqemist-platform-microsoft-quantum-development-kit/
[5] https://cloudblogs.microsoft.com/quantum/2019/05/06/new-plans-to-open-source-more-of-the-quantum-development-kit/
[6] https://1qbit.com/blog/market-sentiment-meter-msm/using-ai-and-social-media-to-analyze-the-economy/
[7] https://15ghc9mhpvs48me3o4drqanw-wpengine.netdna-ssl.com/files/msm/MSM_One_Pager.pdf
[8] https://cifar.ca/cifarnews/2020/09/28/ai-radiology-tool-supports-real-time-diagnosis-of-covid-19-related-pneumonia/
[9] https://www.digitalsupercluster.ca/covid-19-program-page/xrai/
[10] https://1qbit.com/xrai/
[11] https://1qbit.com/market-sentiment-meter-msm/
[12] https://1qbit.com/blog/quantum-computing/learn-how-quantum-inspired-algorithms-can-help-you-make-safer-investments/

t|ket>:Cambridge Quantum Computing

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TRL 5

Overview

Founded in 2014, Cambridge Quantum Computing (CQC) is an independent quantum computing company, based in Cambridge, England. CQC builds tools for the commercialization of quantum technologies with a focus on quantum software and quantum cybersecurity. CQC has developed an architecture agnostic quantum software development platform, t|ket>, around which the company has built enterprise applications for quantum cryptography, quantum chemistry, quantum machine learning and Quantum artificial intelligence. [1]

Product Description

t|ket> is an architecture agnostic quantum software development platform that enables quantum software developers to optimize large circuits for general purpose quantum algorithms. t|ket>'s routing and scheduling protocol translates machine independent algorithms into executable circuits by optimizing for physical qubit layout while reducing the number of required operations. t|ket>'s Python module, pytket, allows any Python user with access to a quantum computer to deploy the tket> SDK in any context, including commercially. [2]

t|ket> Q-SDK is designed to maximize the performance of quantum algorithms when executing on quantum computing hardware, and to accelerate the development of quantum computing applications across multiple industry sectors. The latest version extends the number of supported quantum hardware devices while enhancing circuit optimization and noise mitigation. [3]

Product Description

t|ket⟩works across virtually all quantum hardware devices and quantum programming languages and can be easily migrated between devices by changing just a single line of code to connect devices across a developer's research program. The Q-SDK is used by many quantum hardware providers as well as major companies worldwide. [9]

Following are details on the new features included in the 0.6 version of t|ket>: [9]

Extends the number of supported devices, simulators and development frameworks. Quantum researchers and developers can now test their applications on multiple high-performance simulators and, when ready, execute their circuit on quantum devices of choice via Amazon Braket, including IonQ and Rigetti. The latest version of t|ket⟩also features direct support for IonQ trapped-ion quantum computers in addition to its existing support for devices from IBM, Honeywell, Rigetti and AQT.

Enhances circuit optimization and noise mitigation techniques developed from proprietary research, including Cambridge Quantum Computing's extensive research on ZX Calculus. This feature set allows t|ket⟩developers to optimize large circuits for general purpose quantum algorithms.

Extends operating systems support. Users can now choose to develop quantum applications on their framework of choice — Microsoft Windows, Linux or Apple macOS.

Improves support for Qiskit, IBM's open-source framework for quantum computing. Quantum application developers can use high-level quantum libraries which provide cross-domain algorithms upon which domain-specific applications can be built, dramatically reducing development time.

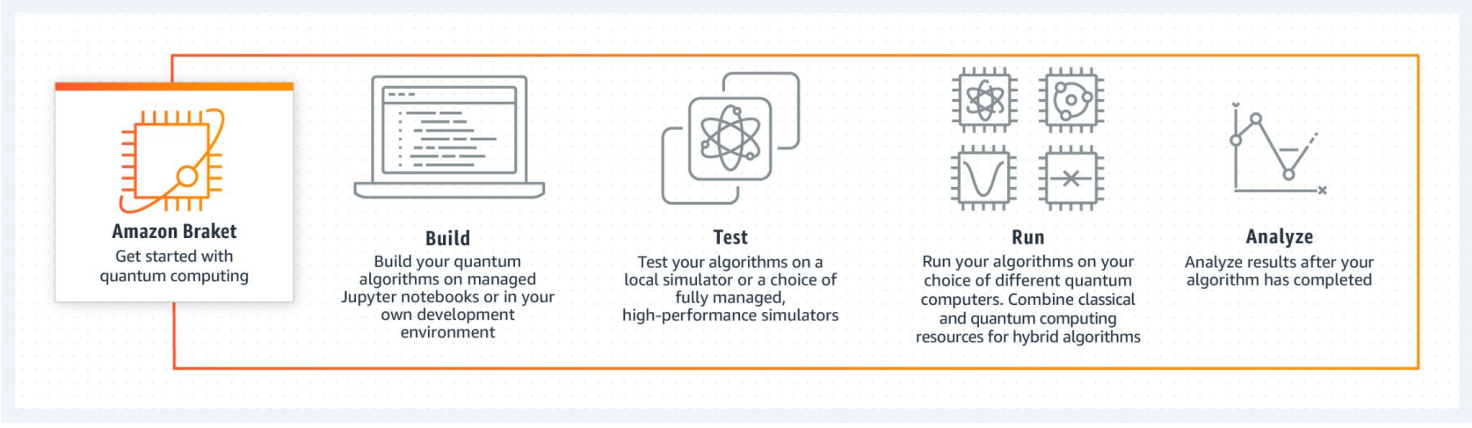
t|ket⟩is also used as a fundamental building block for EUMEN, CQC's quantum computational chemistry platform, and the company's Quantum Machine Learning framework. Standalone commercial support (via joint development or not) is also available.

This high-performance quantum software development kit (Q-SDK), which now enables quantum circuit execution on Amazon Braket, a fully managed quantum computing service from Amazon Web Services (AWS), and IonQ quantum computers as well as application development on the Windows operating system.

Case Study/White Paper

Generating quantum randomness with Amazon Braket [4] [5] [6] [7]

Amazon Braket is a fully managed quantum computing service designed to help speed up scientific research and software development for quantum computing.



It has three modules, Build, Test, and Run. The Build module centers around managed Jupyter notebooks pre-configured with sample algorithms, resources, and developer tools, including the Amazon Braket SDK. The Test module provides access to managed, high-performance, quantum circuit simulators. The Run module provides secure, on-demand access to different types of quantum computers (QPUs): gate-based quantum computers from IonQ and Rigetti, and a quantum annealer from D-Wave.

Intellectual Property

n/a

Investors/Funding Partners

Cambridge Quantum Computing has raised a total of $72.8M in funding over 7 rounds. Summaries is listed below: [10]

1. Jul 2, 2014 - $1.6M
2. Aug 1, 2015 - $3.3M
3. Mar 1, 2017 - $3.9M
4. Jul 20, 2018 - $10M from JSR Corp.
5. Jun 15, 2019 - $4M from JSR Corp.
6. Jul 1, 2020 - $5M
7. Dec 8, 2020 - $45M - Honeywell Ventures, IBM Ventures, JSR Corporation, Serendipity Capital, Alvarium Investments, and Talipot Holdings.

References

[1] https://en.wikipedia.org/wiki/Cambridge_Quantum_Computing
[2] https://cambridgequantum.com/cambridge-quantum-computing-announces-update-to-tket%E2%9F%A9-quantum-software-development-kit-q-sdk/
[3] https://thequantumdaily.com/2020/03/27/cqcs-press-release-tket-a-retargetable-compiler-for-nisq-devices/
[4] https://www.infoworld.com/article/3573372/amazon-braket-get-started-with-quantum-computing.html
[5] https://press.aboutamazon.com/news-releases/news-release-details/aws-announces-general-availability-amazon-braket
[6] https://www.geekwire.com/2019/aws-launches-amazon-braket-service-part-broad-quantum-computing-initiative/
[7] https://aws.amazon.com/braket/
[8] https://aws.amazon.com/blogs/quantum-computing/generating-quantum-randomness-with-amazon-braket/
[9] https://www.newswire.ca/news-releases/cambridge-quantum-computing-announces-update-to-t-ket-tm-quantum-software-development-kit-q-sdk--806200322.html
[10] https://www.crunchbase.com/organization/cambridge-quantum-computing-limited/company_financials

Entropica Quantum Services: Entropica Labs

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Contact: n/a

TRL 5

Overview

Founded in 2018, Entropica Labs is a Singapore-based company, spin-off of Singapore's Centre for Quantum Technologies (NUS). The company creates algorithms, software tools, methods and models using quantum computers. Entropica Labs is a company developing quantum computing and AI tools for bioinformatics and genomics. The current focus of Entropica is quantum optimisation and machine learning, supporting enterprise customers to understand and integrate quantum computing.

Product Description

Entropica Labs is a Singapore-based team of physicists and computer scientists developing tools and applications for near-term quantum computing for enterprise customers that express interests in the system.[2] They design software to work on the leading cloud quantum computing platforms, to ensure a smooth integration, testing and benchmarking across models, computing systems and workflows.[2]

Case Study/White Paper [3]

In 2019, Entropica Labs released a free and open source software package implementing the quantum approximate optimisation algorithm (QAOA) named EntropicaQAOA. QAOA is an algorithm designed for near-term quantum computers, and has applications to both machine learning and discrete optimisation. The EntropicaQAOA package integrates fully with their partner, Rigetti's Quantum Cloud Services™ (QCS).

The basic goal of QAOA is to find a set of parameters that, when fed to specific operations in a quantum circuit, output the desired solution to the problem. In EntropicaQAOA, multiple options for parameterizing QAOA were provided to facilitate prototyping and testing of different approaches.

Several different ways of initialising parameters are included, and it is very easy to switch from one classical optimiser to another. If Scipy's methods are inadequate, one can easily import tools from other optimisation libraries such as NLopt, scikit-optimize, or use their own custom-built code.

A range of utility functions are also provided to allow easy integration with, and problem translation from, popular data analysis packages such as Pandas and NetworkX.

Case Study/White Paper [4]

BMW is partnering with Entropica Labs to develop and run a benchmark for near-term quantum optimization on the H1 hardware.

Entropica Labs used the Recursive Quantum Approximate Optimization Algorithm (R-QAOA) to tackle number partitioning, a classic combinatorial problem that is an entry point to many logistics and supply chain problems of industrial interest. The work leveraged three key features of the Honeywell H1 hardware: full qubit connectivity, high fidelity operations and high angular resolution of the quantum gates.

The results showed the performance of the H1 to be competitive with a simulator incorporating only shot noise resulting from the finite number of measurements. On the algorithmic side, for the small problem instances studied, the depth-1 R-QAOA has a performance that is comparable to the classical Karmarkar-Karp (KK) heuristic. Future work will explore whether higher-depth versions of R-QAOA are able to outperform the KK algorithm.

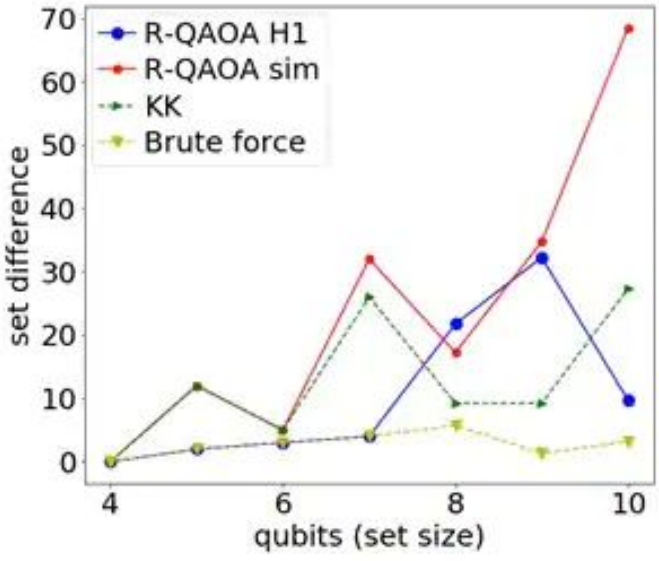

Figure 1: Experimental data taken on the Honeywell System Model H1 demonstrating the performance of the R-QAOA vs. the classical KK heuristic, and the brute force answer (smaller set difference is better). For both H1 (blue) and the simulator (red), 200 shots were taken.

Intellectual Property

N/A

Investors/Funding Partners [5], [6]

The start-up of Entropica was established with funding from Singapore's Entrepreneur First programme and as of 2018 has support from SG Innovate (Singapore) and the Creative Destruction Lab (Toronto, Canada). Entropica partnered with Rigetti, a US hardware company in 2018, which gives them access to advanced quantum processors.

In 2020, Entropica Labs raises a $1,959,314 seed round from Elev8.VC, Entrepreneur First, Lim Teck Lee, SGInnovate, TIS Japan and Wavemaker Partners.

Entropica collaborates and works with major quantum hardware manufacturers, including Rigetti Computing, IBM and Microsoft.

References

[1] https://www.linkedin.com/company/entropica-labs/about/
[2] https://www.entropicalabs.com/
[3] https://entropicalabs.medium.com/entropica-labs-releases-qaoa-package-for-rigettis-quantum-cloud-service-12ea71019436
[4] https://www.honeywell.com/us/en/news/2021/01/exploring-supply-chain-solutions-with-quantum-computing
[5] https://golden.com/wiki/Entropica_Labs-AMB3VRX
[6] https://www.techinasia.com/entropica-labs-seed-funding

Orquestra®: Zapata Computing

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TRL 7

Overview

Zapata Computing was founded in 2017 as a spun out of Harvard, and currently has 51-100 employees, with $67.4M in total funding amount [1] and $9.1M in annual revenue [2]. The company focuses on developing quantum software and algorithms for business. They claim to provide hardware-agnostic solutions for simulation, optimization, and machine learning applications in chemistry, finance, logistics, pharmaceuticals, engineering, and materials.

Product Description

Zapata Computing is builds computing software for companies and industries. For that, the company first evaluates the business, to adapt the software and resources needed. Then, they develop workflows and algorithms for commercial use, and integrate everything in their Orquesta Platform [3].

Orchestra first compose quantum workflows. It creates tools to design the workflows in the YAML-compatible Zapata Quantum Workflow Language (ZQWL). Then, the Orquestra Quantum Engine (OQE) servers via REST API, conduct workflows across quantum and classical hardware. Lastly, the results are recorded and saved in a packaged database by the Orquestra Data Correlation Service (ODCS). Data can be exported to be analyzed to Excel, a Jupyter notebook, or Tableau [3].

Orquestra®: Zapata Computing

Product Description

The Orquesta platform does not run entirely on all the quantum hardware. The company only use Orquesta to allow best performance from quantum devices. Thy claim to have algorithms that enable to upgrade the strengths of each device across the quantum technologies, such as:

- Quantum-inspired classical: the company claims that “Orquestra, is built to run enterprise workloads that utilize classical computing techniques”.
- Quantum annealing
- Quantum gate model: the company claims they have expertise in gate model algorithms and physics.

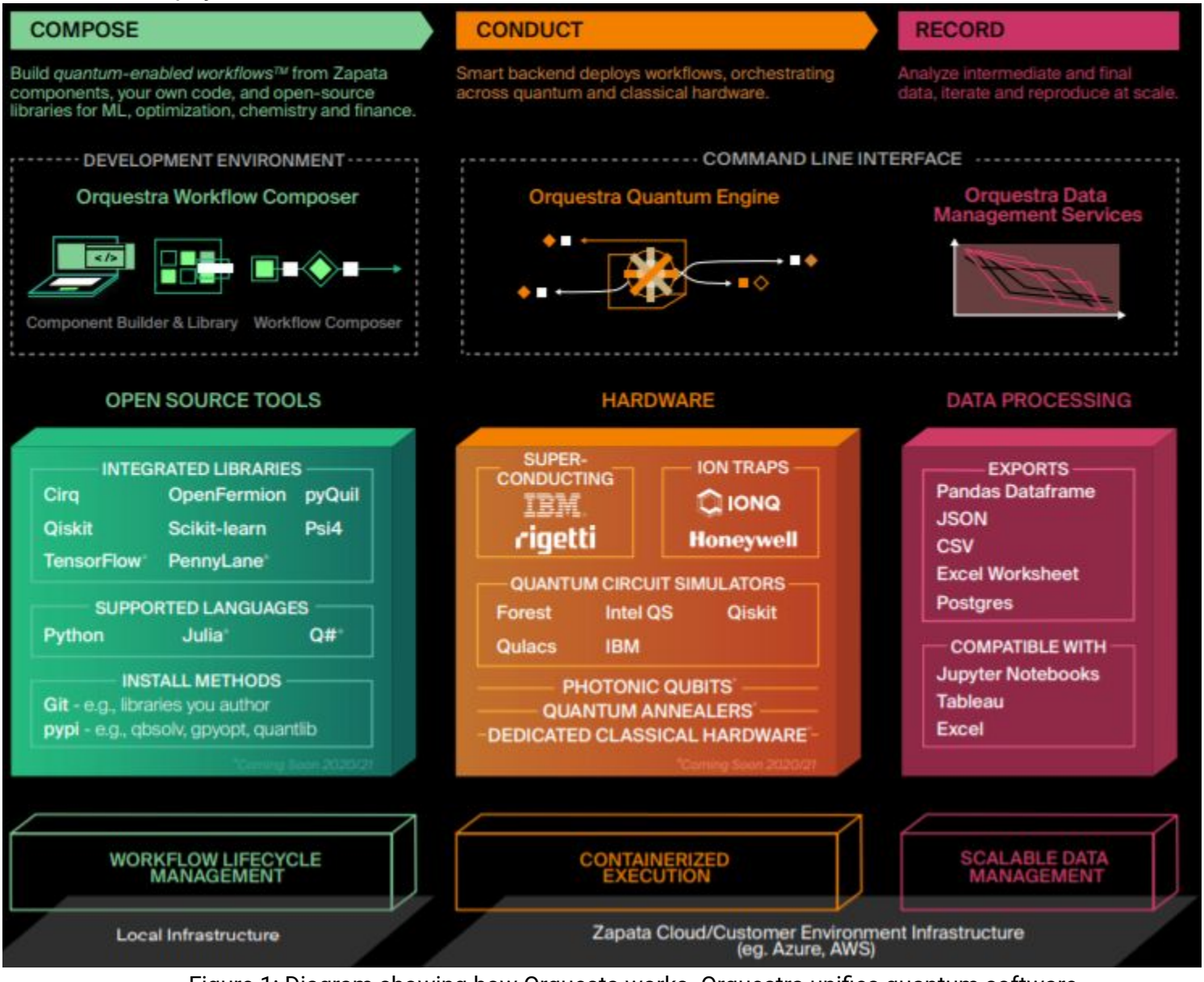

Figure 1: Diagram showing how Orquesta works. Orquestra unifies quantum software libraries and hardware back ends in one modular, workflow based toolset.

Case Study/White Paper

- Quantum algorithm for credit valuation adjustments (2021) [4].

In this study, the authors aimed to identify challenges and opportunities for quantum algorithms to accelerate Monte Carlo simulations in finance. These simulations are usually performed to obtain credit valuation adjustment and derivative pricing. This study explains a different and novel circuit design, that significantly reduces the resources needed to gain a quantum advantage in derivative calculations. This would allow cut years of the expected timeline established, so the financial institutions can create value from quantum computers.

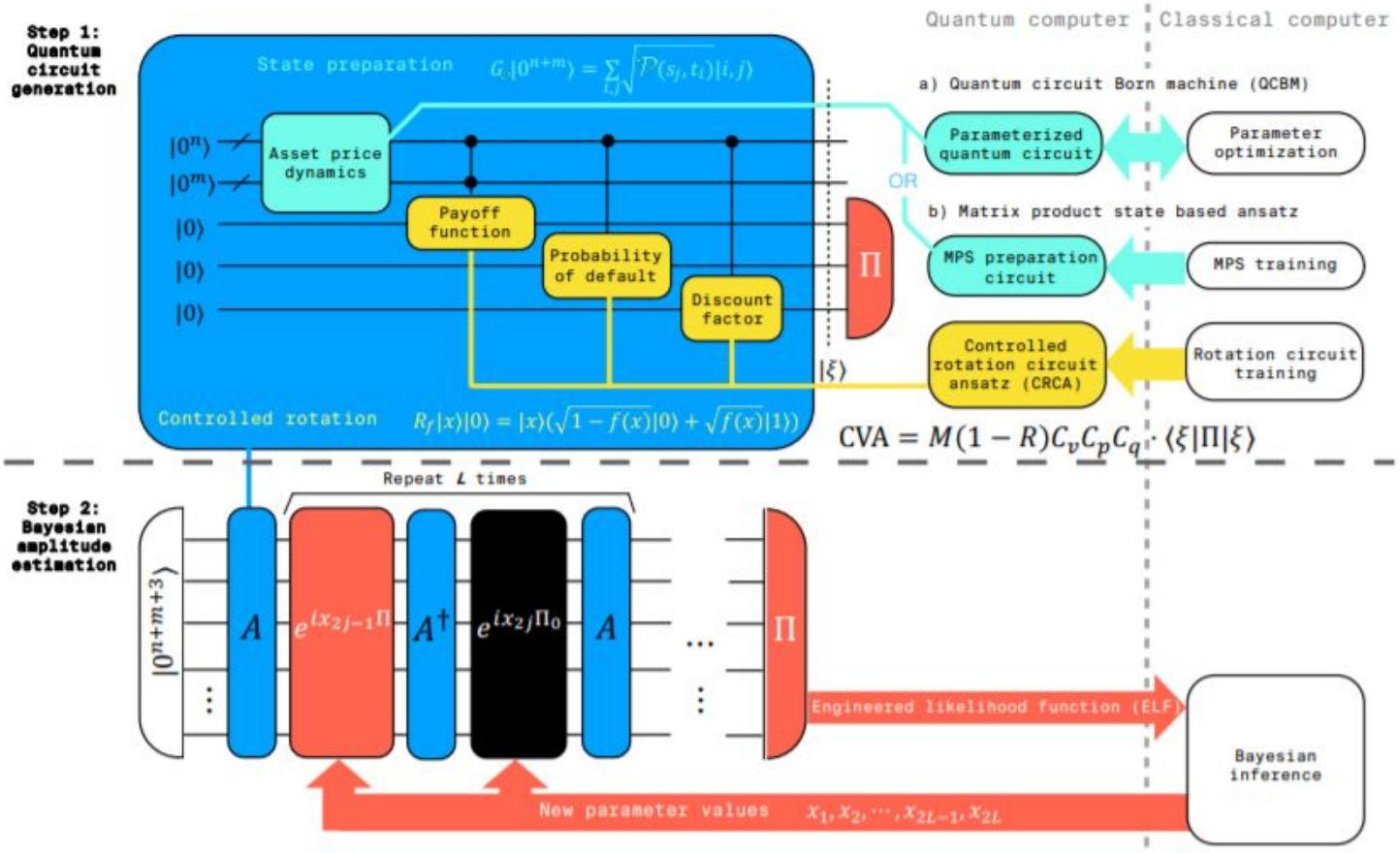

Figure 2: Overview of the quantum approach to credit valuation adjustment proposed

Intellectual Property

The company has several patents, amongst the most recent ones are included the following:

Patent Name/Title: **Computer System and Method for Implementing a Conditional Reflection Operator on a Quantum Compute**r (2020) [5]

Patent No: US20210073668A1

Status: Pending

Brief description: The patent describes a computer system and a method to implement a conditional reflection operator on an ion trap quantum computer.

Patent Name/Title: **Hybrid Quantum-Classical Computer System for Parameter-Efficient Circuit Training** (2020) [6]

Patent No: US20210133617A1

Status: Pending

Brief description: This patent describes a method to improve the techniques used to prepare a quantum computer. These include reducing the number of redundant gates in a quantum circuit, nıby removing gates and re-optimizing the circuit parameters, in order to create a reduced state preparation.

Patent Name/Title: **Quantum Computer System and Method for Partial Differential Equation-Constrained Optimization** (2020) [7]

Patent No: US20210133618A1

Status: Pending

Brief description: This patent describes a quantum computer that can perform PDE-constrained optimization problems. The adjustments made, allow to eliminate the right arrow, and formulate formulate the optimization as a polynomial unconstrained binary optimization (PUBO) problem.

Investors/Funding Partners

Investors in Zapata include Comcast Ventures, BASF Venture Capital, Honeywell Ventures, Itochu Corporation, Merck Global Health and Robert Bosch Venture Capital [8]. In addition, in 2020 Zapata announced it had received $38M in Series B funding [9]. All these investors have participated in the Series B funding:

- Prelude Ventures
- BASF Venture Capital
- Markus Solibieda
- Merck Global Health Innovation Fund
- Pitango Venture Capital
- ITOCHU Corporation
- Ahren Innovation Capital
- Honeywell Venture Capital
- The Engine
- Comcast Ventures
- Alumni Ventures Group

References

1. https://www.crunchbase.com/organization/zapata-computing
2. https://growjo.com/company/Zapata_Computing#:~:text=Estimated%20Revenue%20%26%20Financials,currently%20%249.1M%20per%20year.
3. https://www.zapatacomputing.com/orquestra/
4. https://4627su41pzrvhaad34118k3y-wpengine.netdna-ssl.com/wp-content/uploads/2021/05/2105.12087.pdf
5. https://worldwide.espacenet.com/patent/search/family/072613996/publication/US2021073668A1?q=pn%3DUS2021073668A1
6. https://worldwide.espacenet.com/patent/search/family/075688733/publication/US2021133617A1?q=pn%3DUS2021133617A1
7. https://worldwide.espacenet.com/patent/search/family/075688735/publication/US2021133618A1?q=pn%3DUS2021133618A1
8. https://www.crunchbase.com/organization/zapata-computing/company_financials
9. https://www.zapatacomputing.com/news/series-b/

Quantum information processors: Alpine Quantum Technologies GmbH

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TRL 5

Overview

Alpine Quantum Technologies GmbH (AQT) was founded in 2018 by Prof. Rainer Blatt, Dr. Thomas Monz, and Prof. Peter Zoller. The company currently has 11-50 employees [1], and $217K in annual revenue [2]. The main aim of the company is to commercialize Austrian quantum computer. They are currently working on general-purpose quantum information processors, that will be able to be used in different applications and industries.

Product Description

AQT founders started to utilize what they claimed a “controlled-NOT gate operation – the building block for general-purpose quantum computers”. They also use ion-trap quantum computers. For that, they use electric fields, in which single charged atoms are trapped inside vacuum chambers. Each bit is represented by an ion, and each bit is manipulated and measured by timed laser pulses [2].

So far, AQT has achieved the following goals:

- Scalable Shor algorithm
- Topologically encoded quantum error correction
- Quantum chemistry calculations
- World record on 14-particle entanglement

AQT claims to offer ion-trap technologies to large scale quantum computers, and they provide every step needed, from ion-trap processors, to photonic networks connecting quantum computers.

Quantum information processors: Alpine Quantum Technologies GmbH

Product Description

AQT claims their devices “operate at room temperature in a normal office environment, are installed in standard 19” racks, and are powered from an ordinary wall-mounted power-plug”

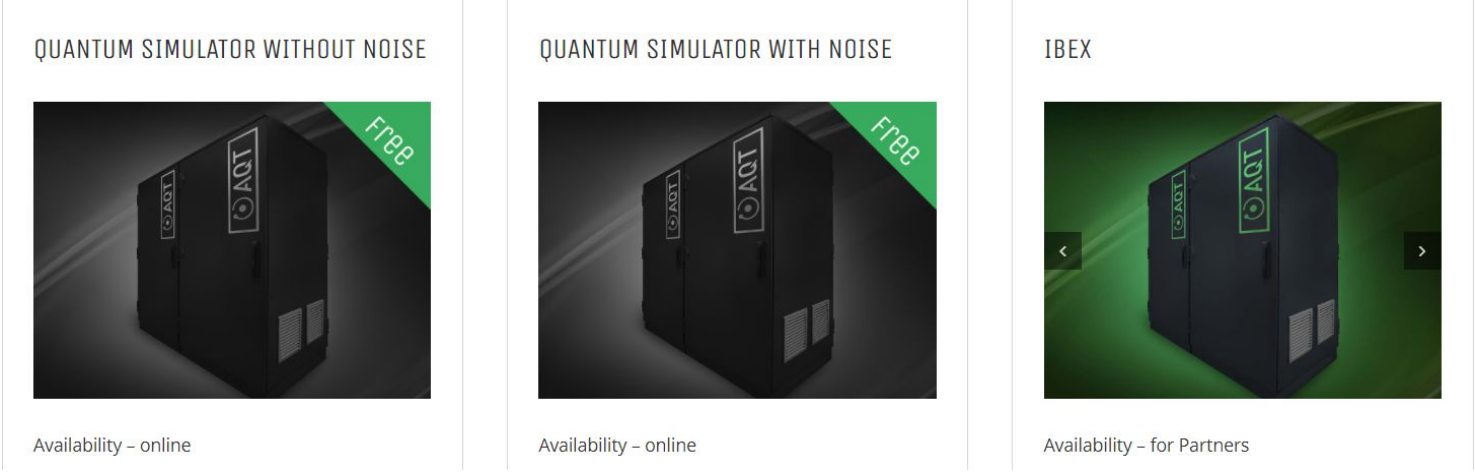

Figure 1: AQT quantum computer devices

Quantum information processors: Alpine Quantum Technologies GmbH

Case Study/White Paper

There were not study cases retrieved.

Intellectual Property

Patent Name/Title: **MEMS-based 3D ion trapping device for using laser penetrating ion trapping structure, and method for manufacturing sam**e (2014) [3]

Patent No: US10242859B2

Status: Active

Brief description: The patent describes a method to manufacture a micro electro mechanical system (MEMS)-based three-dimensional (3D) ion-trap device, to use a laser that penetrates an ion trapping structure

Patent Name/Title: **Ion trap apparatus and method for manufacturing same (**2013) [4].

Patent No: US9548179B2

Status: Active

Brief description: The patent describes a method to manufacture an ion-trapped device and its different components: DC electrode, FR electrode and connectors.

Patent Name/Title: **A method and system for comparing two quantum states** (2019) [5].

Patent No: WO2021110261A1

Status: Filed

Brief description: The patent describes a methodology to compare two different quantum states, particularly when they are in different platforms, separated in physical space or in time.

Patent Name/Title: **Apparatus and method for trapping charged particles and performing controlled interactions between them** (2010) [6]

Patent No: US8426809B2

Status: Active

Brief description: The patent describes an ion-chip surface-electrode for trapping charged particles (ions), and perform controlled interactions between these ions for performing quantum interactions between ions.

Investors/Funding Partners

AQT is supported by the Federation of Austrian Industries Tyrol, the FFG Austrian Research Promotion Agency, and the University of Innsbruck [1].

It is supported by Creative Destruction Lab (CDL) as its lead investor [7].

References

1. https://www.linkedin.com/company/alpine-quantum-technologies-gmbh/
2. https://www.dnb.com/business-directory/company-profiles.alpine_quantum_technologies_gmbh.ae2c9820ad985d4029b9953c9885f9c1.html
3. https://worldwide.espacenet.com/patent/search/family/055857868/publication/US10242859B2?q=pn%3DUS10242859B2
4. https://worldwide.espacenet.com/patent/search/family/052588962/publication/US9548179B2?q=pn%3DUS9548179B2
5. https://worldwide.espacenet.com/patent/search/family/068808364/publication/WO2021110261A1?q=pn%3DWO2021110261A1
6. https://worldwide.espacenet.com/patent/search/family/042470710/publication/US8426809B2?q=pn%3DUS8426809B2
7. https://www.crunchbase.com/organization/alpine-quantum-technologies-gmbh/company_financials

Quantum Orchestration: Quantum Machines

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TRL 5

Overview

Quantum Machines is a start-up founded in 2018, which currently has 11-50 employees, $23 in total funding amount [1], and less than $5M in annual revenue [2]. The company focuses on developing control and operation systems for quantum computers. They also develop software, hardware and electronics, with the science and technology used in the field of quantum computing. They use algorithms, machine learning and quantum physics.

Product Description

The Quantum Orchestration is a hardware and software platform built with the aim to perform complex quantum algorithms and experiments. It is compatible and works with all the quantum technologies: superconducting qubits, quantum dots, VN centers, trapped ions, trapped atoms, mechanical resonators, topological qubits and carbon nanotubes [3]. The platform architecture can be built both in single and multiple machines modes.

The set of features provides all the tools to run complex quantum algorithms and experiments:

- Parametric programming: the platform enables to loop over a wide range of parameters, including intermediate frequencies, amplitudes, phases, delays, integration parameters, measurement axes and more.
- Real-time calculations: the platform enables to program complex calculations in real time, and then integrate and synchronize them into any protocol.
- Control flow: the platform enables to use flow and loop statements, to manipulate the flow of the client programs.

Product Description

- Ultra low feedback latency: the platform uses measurements to influence in real-time decision making.
- Frequency multiplexing: the platform is able to play up to 10 pulses with different intermediate frequencies to a single output (5 in IQ-mode).
- Frequency demultiplexing: the platform is able to demodulate any given input signal with up to 10 different frequencies.
- Synced digital pulses: the platform synchronizes digital pulses which are sent to different control devices with analog pulses.
- Measurement optimization
- Mixer calibration

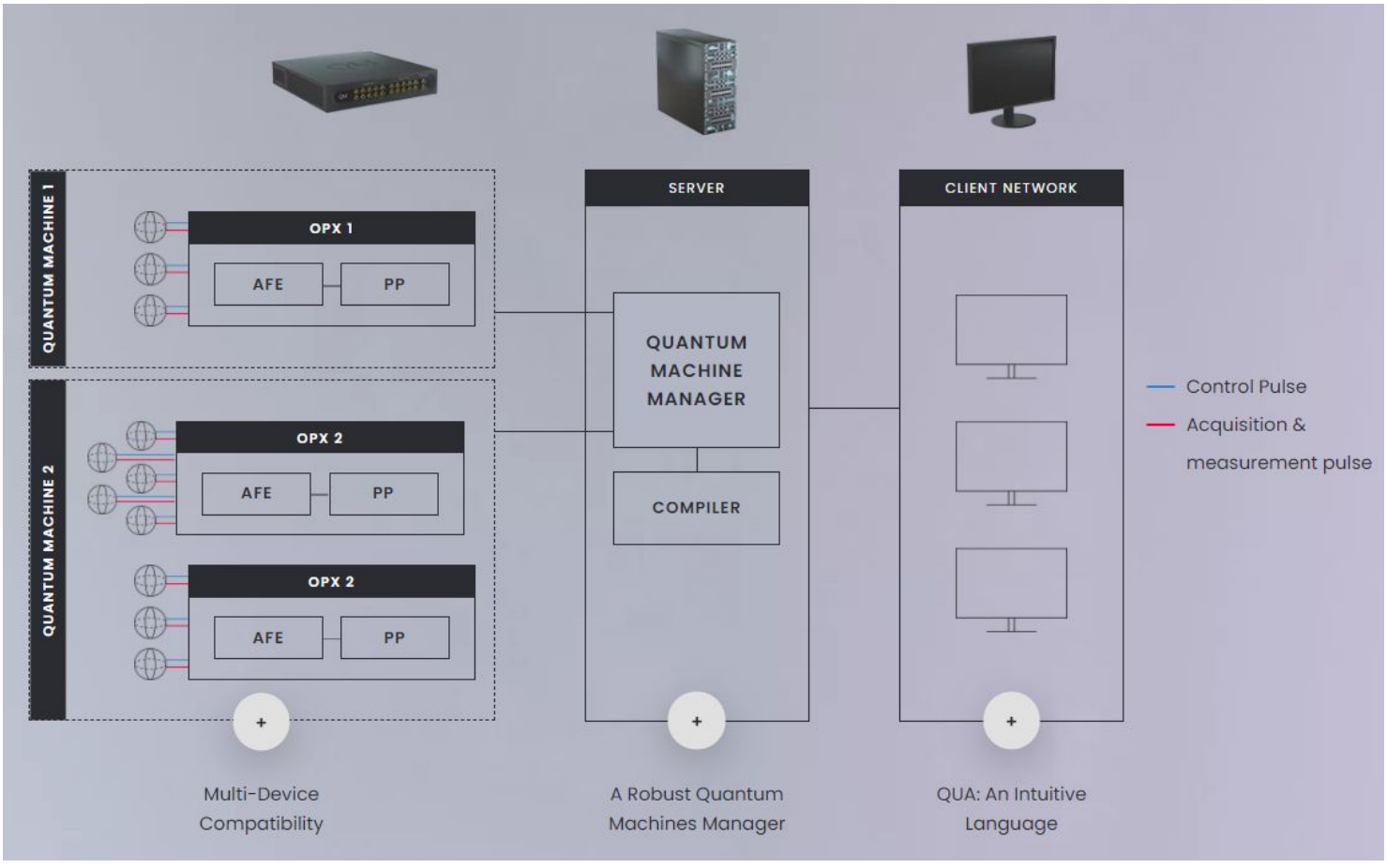

Figure 1: Platform Architecture

Intellectual Property

The company has several published patents, a few of them are the following:

Patent Name/Title: **Quantum controller with modular and dynamic pulse generation and routing** (2018) [4]

Patent No: US10637449B1

Status: Active

Brief description: The patent describes the methodology to build a quantum controller with dynamic pulse routing. The system is composed of an input manager circuitry, raw pulse generation circuitry, pulse modification circuitry, and output manager circuitry.

Patent Name/Title: **Quantum controller with multiple pulse modes** (209) [5]

Patent No: US10985739B2

Status: Active

Brief description: The patent describes a method to develop a quantum controller with multiple pulse modes and an electromagnetic pulse generation system. This electromagnetic pulse generator is composed two single pulse generation circuits and, and a mixing circuit.

Patent Name/Title: **Synchronization in a quantum controller with modular and dynamic pulse generation and routing**(2019) [6]

Patent No: US11088679B2

Status: Active

Brief description: The patent describes the methodology to build a quantum computer control system and systems for synchronization in a quantum controller with dynamic pulse routing. The system would be composed of two single pulse generation circuits and a synchronization management circuitry.

Patent Name/Title: **Software-defined pulse orchestration platform** (2019) [7]

Patent No: US10958253B1

Status: Active

Brief description: The patent describes a method to develop a software-defined pulse orchestration platform, which contains a pulse program compiler and a pulse operation statement

Investors/Funding Partners

In September 2021, Quantum Machines obtained $38M from Series B round funding, led by Red Dot Capital Partners, with the participation of Exor, Claridge Israel, Samsung NEXT, Valor Equity Partners, Atreides Management LP, and joined by TLV Partners, Battery Ventures, Altshuler Shaham and other existing investors [8].

Investors participating in Series A round funding were: Battery Ventures, Harel Insurance Investments and Financial Services, Meron Capital, Avigdor Willenz, TLV Partners, Itzik Parnafes and TLV Partners [9].

References

1. https://www.crunchbase.com/organization/quantum-machines
2. https://www.zoominfo.com/c/quantum-machines/481095576
3. https://www.quantum-machines.co/platform/
4. https://worldwide.espacenet.com/patent/search/family/066996532/publication/US10637449B1?q=pn%3DUS10637449B1
5. https://worldwide.espacenet.com/patent/search/family/068241829/publication/US10985739B2?q=pn%3DUS10985739B2
6. https://worldwide.espacenet.com/patent/search/family/068766365/publication/US11088679B2?q=pn%3DUS11088679B2
7. https://worldwide.espacenet.com/patent/search/family/073653672/publication/US10958253B1?q=pn%3DUS10958253B1
8. https://techcrunch.com/2021/09/05/quantum-machines-plans-to-expand-quantum-orchestration-platform-with-50m-investment/
9. https://www.crunchbase.com/organization/quantum-machines/company_financials

Tachyon: Polaris Quantum Biotech

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TRL 5

Overview

Polaris Quantum Biotech was founded in 2020 as a venture of Cloud Pharmaceuticals. It currently has 2 employees and $45,667 in sales [1]. The company focuses on drug discovery and drug design by using Artificial Intelligence and precision medicine. The company claims they are able to simulate multiple molecules to identify new potential drugs, which can be used to target proteins in specific diseases [2].

Product Description

Polarisqb has developed Tachyon drug design platform. This technology enables to design molecules across the cloud, by an automated process, which allows the company to search big chemical libraries, while also computing parallel projects [3]. The company has developed a proprietary software for quantum systems, that enables to design molecular assets faster and with increased quality. This way, the company claims they are able to deliver novel drug leads faster and at lower costs.

Tachyon platforms has an automated software that is able to optimize multiple molecules in faster runs. In each of the runs, the internal models are update, so that the more projects have been completed, the more effective and efficient the platform becomes. They use machine learning algorithms on their internal data from previous projects, leading to faster developments and new solutions.

The platform is able to analyze billions of molecules in seconds, which constitutes an advantage in drug design. The platform is system agnostic, thus it has flexibility and versatility to work with multiple diseases and treatments.

Product Description

The Tachyon platform is built in several layers, each of them has the ability to increase the accuracy of the calculations. It starts from the 3 dimensional structure of the protein, and it follows exploring the wide chemical space. The platform also uses multi-object optimization to find the best drug candidates.

In the process of molecule design, Tachyon is able to calculate linear interaction energies to different drug targets.. This provides information about treatments and cures for diseases, and conditions that otherwise would be too expensive and time consuming.

Figure 1: Quantum computing example device

Case Study/White Paper

Polaris worked in collaboration with Fujitsu, to use the Digital Annealer, and search molecules in the chemical space [4]. The objective was to identify potential candidates to treat Dengue Fever, which there is no cure for, currently. The company targeted the RNA-dependent RNA polymerase protein in Dengue virus, and build a chemical library of more than one billion molecules. Then, they filter molecules by using AI/ML-based algorithms and calculate binding affinity by QM/MM, after which they end up using 997 potential drug candidates. This process allowed to identify several drugs in a fraction on the time in which it is usually performed, and has the potential to find treatments for diseases that have no cure.

Intellectual Property

There were no patents retrieved

Investors/Funding Partners

Polaris has two investors: Infinity Medical and OurCrowd, which is the lead investor [5].

References

1. https://www.dnb.com/business-directory/company-profiles.polaris_quantum_biotech_inc.c23a27fc3ab67b618108ea8e443c4b90.html
2. https://www.crunchbase.com/organization/polaris-quantum-biotech
3. https://polarisqb.com/tachyon/
4. https://polarisqb.com/tag/polaris-quantum-biotech/page/2/
5. https://www.crunchbase.com/organization/polaris-quantum-biotech/company_financials

Q-Props™: Hafnium Labs

Hafnium Labs
Headquarters: Copenhagen, Denmark
Website: www.hafniumlabs.com
Contact: contact@hafniumlabs.com

TRL 5

Overview

Hafnium labs develop software to obtain physical property data for molecules and mixtures. The company was founded in 2016 and is based in Copenhagen, Denmark and employs 1-10 people. It has received over $1.8M USD in funding [1].

Product Description

Q-props is a tool for decision making from molecular discovery to process optimization through the physical property prediction. Uses [2]:

- Molecular discovery: Identification of compounds with specific physical properties.
- Synthesis: Find optimal solvents and reaction conditions.
- Formulation: Desired formulation properties can be found by finding additives and concentrations.
- Process design: identify risks using thermodynamics.
- Troubleshooting and optimization: faster identification of problems and creation of digital twins.

Case Study/White Paper [3]

Q-props uses data modeling to obtain an accurate property prediction along its uncertainty.

The main problem with computer simulations is that they rely on the accuracy of the physical property data used. In turn, experimental data is usually unavailable and unreliable. Even with quantum methods, there aren't tools to yield accurate predictions and when available, these don't provide information about their reliability.

Q-props aims at solving these problems by selecting and quantifying all available data and applying novel models such as quantum chemistry and molecular simulation. Q-props returns not only a property prediction, but also their specific uncertainty to show how reliable the prediction is.

The study presents an example of obtaining the heat of formation for two compounds: Ethylbenzene and Tert-butanol. The heat formation is predicted by 1) a group's contribution methods, 2) quantum chemistry and 3) Q-props (Table 1).

Method	Heat of formation, 25ºC [kJ/mol]	
	Ethylbenzene	Tert-butanol
Group contribution	28.1	-286.9
Quantum Chemistry	23.1	-313.3
Q-Props™	29.5 ± 2.9	-313.8 ± 3.2
NIST webbook	29.8 ± 0.8 49 ± 4 69.3	-312.6 ± 0.9 -313 ±1.5 -309.7

Table 1. Method comparison

Case Study/White Paper [3]

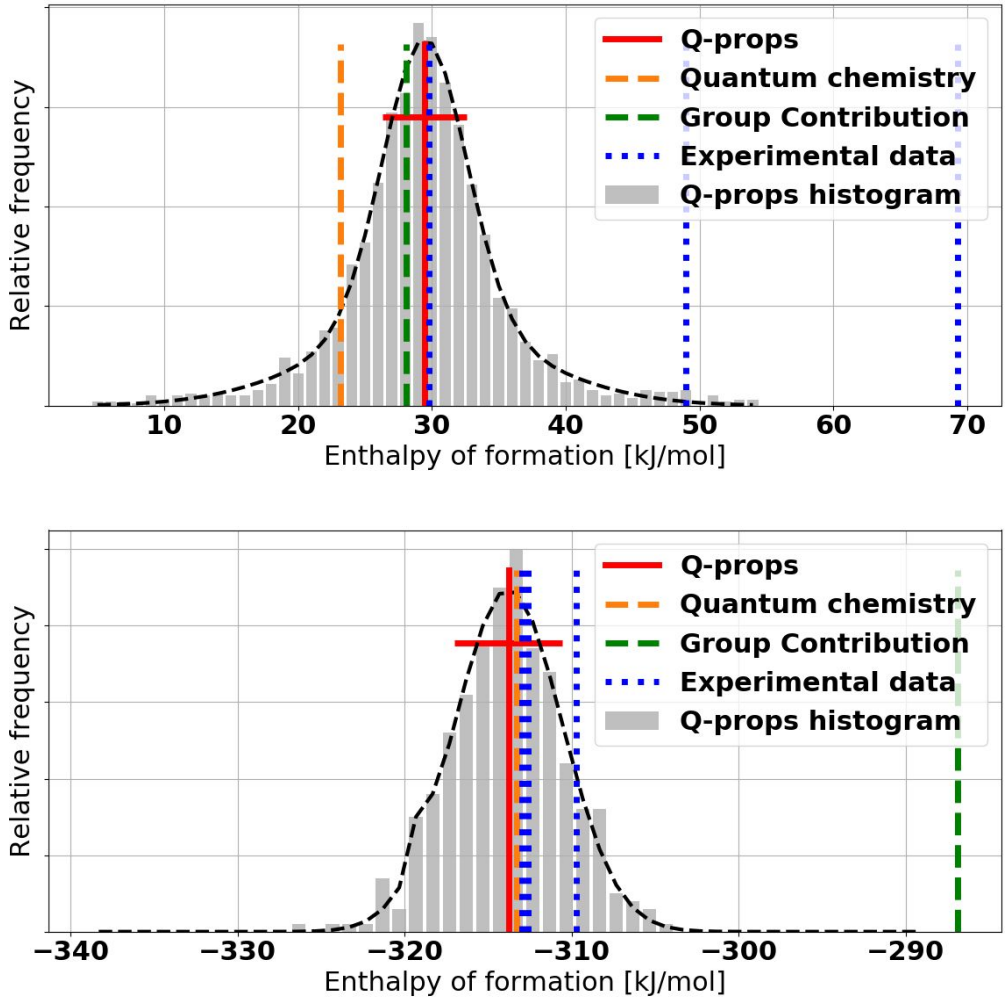

Figure 1. Visualization of Q-Props™ predictions using histograms. Ethylbenzene (upper panel) and Tert-Butanol (Bottom panel).

In both, data histograms (Fig. 1) and table 1, the group contribution and quantum chemical method are off in one of in at least one of the compounds. On the other hand, Q-props™ gives an accurate prediction for both compounds.

Intellectual Property

N/A

Investors/Funding Partners

Hafnium Labs has received funding in two rounds. In 2018 it received a grant from Climate-KIC acceleration programme, IBM and the innovation fund denmark for an undisclosed sum. In 2019, the European Innovation Council funded Hafnium labs with 1.8M USD (1.6M Euros) [1].

References

1. https://www.crunchbase.com/organization/hafnium-labs
2. https://www.hafniumlabs.com/products/
3. https://www.hafniumlabs.com/technology/

DeltaFlow.OS®: Riverlane

Riverlane
Headquarters: Cambridge, Cambridgeshire, UK
Website: www.riverlane.com
Contact: team@riverlane.com

TRL 5

Overview

Riverlane is a startup based in Cambridge, United Kingdom and was founded on 2017. It employs 11-50 people and it has received funding for $24.1M USD. Riverlane is a software developer for quantum computers [1, 2]. Riverlane is the developer of DeltaFlow.OS®, an operating system for quantum computing aimed at increasing performance [2].

Product Description

DeltaFlow.OS® is an operating system that seeks optimal performance by orchestrating classical and quantum computing elements, which is required for quantum error correction [2].

The operating system consists of an heterogeneous architecture, and makes all computing elements in the stack accessible (CPU, FPGAs and qubits), enabling a programmer to perform operation at the right stack level.

Riverlane presents the following advantages of its software [2]:

- Low latency: The software design avoids slowing down the process.
- Accelerated R&D: It provides debugging and emulation tools to easily get gateware onto FPGAs.
- Full stack: Provides a framework to interact with all levels of the stack, which in turn enables developing functions from algorithms to qubit tune-up.

Product Description

DeltaFlow.OS® components:

- Deltalanguage: A programming language that allows to define a graph of all the elements and declare the transport of data between them. The nodes of the graph can be filled with python or migen. Importantly, the operating system is portable across technologies because of a built-in hardware abstraction layer, which standardized which operations can be triggered on qubits.
- Runtime: Runtime executes DeltaFlow® programs, scheduling and system services.
- Applications: Anian® is the library application for DeltaFlow®. Anian® includes proprietary algorithms that help reducing hardware requirements (i.e. accelerated Variational Quantum Eigensolver).

DeltaFlow-on-ARTIQ is an example showing the portability of the operating system [2]. ARTQ (Advanced Real-Time Infrastructure for Quantum Physics) is a control system used for quantum information experiments (Fig. 1) [3].

Deltalanguage allows to define a graph of nodes, the deltasimulator allows to test programs on simulated hardware and the deltamodels connects the deltastumulator to the ARTIQ control system emulator.

Product Description

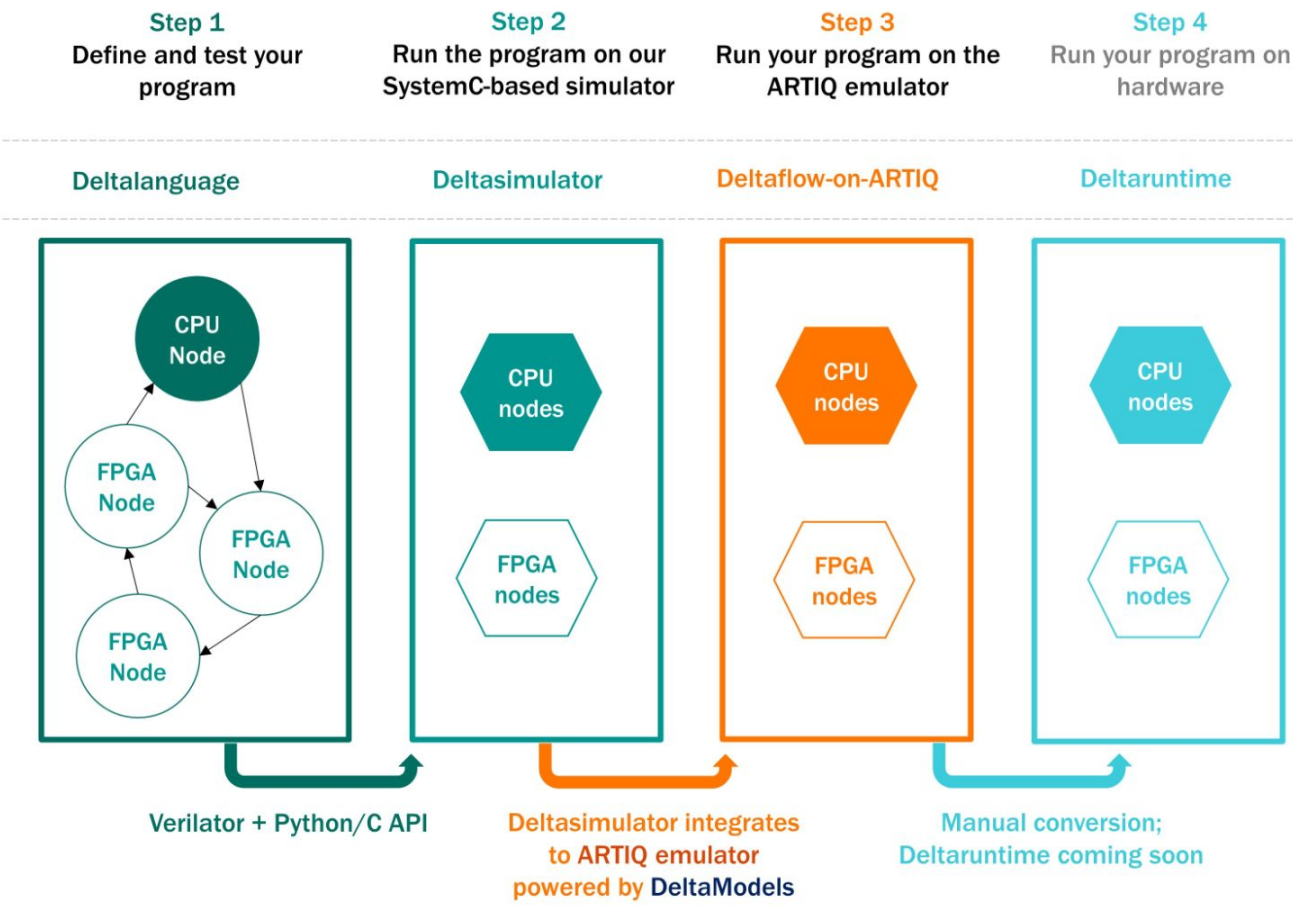

Figure 1. DeltaFlow-on-ARTIQ

Case Study/White Paper

No case study/White paper found.

Intellectual Property

Indicate any patents the company has patented/applied. Please include:

Patent Name/Title: Simultaneous measurement of commuting operators

Patent No: WO2021028680A1

Status: Filed

Brief description: The invention is a method to determine possible eigenstates and energies of a physical system (i.e. molecule or atom). By determining how the energy may change in a molecule upon a perturbation, facilitates finding the molecular properties.

Investors/Funding Partners

Riverlane has received $24.1M USD of funding over 3 rounds of funding according to crunchbase. In the first round (2019), Riverlane received 3.3M USD from Amadeus Capital and Cambridge Innovation Capital. The second funding round received $20M USD on January 2021 and came from Amadeus Capital, Draper Esprit, Cambridge innovation Capital and the University of Cambridge. A third round of funding was held on March 2021 with Parkwalk Advisors being the only funder (undisclosed amount) [5].

References

1. https://www.crunchbase.com/organization/riverlane/company_financials
2. https://www.riverlane.com/products
3. http://m-labs.hk/experiment-control/artiq/
4. WO2021028680A1
5. https://www.crunchbase.com/search/principal.investors/field/funding_round.has_funding_round.forward/num_investors/riverlane-seed--2d507d55

Singularity: Multiverse computing

Multiverse Computing
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Website: www.multiversecomputing.com
Contact: contact@multiversecomputing.com

TRL 6

Overview

Multiverse computing is a Spanish startup based in the Pais Vasco region. The company was founded in 2019 and employs 1-10 people [1]. Multiverse has received $1.8M USD and has developed Singularirty, a quantum computing-based toolbox for finance [1, 2].

Product Description

Singularity is a quantum computing tool characterized by being intuitive, having a simple front-end and with plug ins available for commonly used applications such as Microsoft Excel© [3].

The technology is agnostic, which allows it to be run on different quantum platforms [3]:

- Superconducting
- Photonic
- Ion Traps
- Neutral atoms.

The algorithms that run singularity allows quantum and quantum-inspired optimization, machine learning, monte carlo, among others [3]:

- Tensor Networks
- Digital Annealing
- QI optimization
- Artificial Intelligence

Singularity: Multiverse computing

Product Description

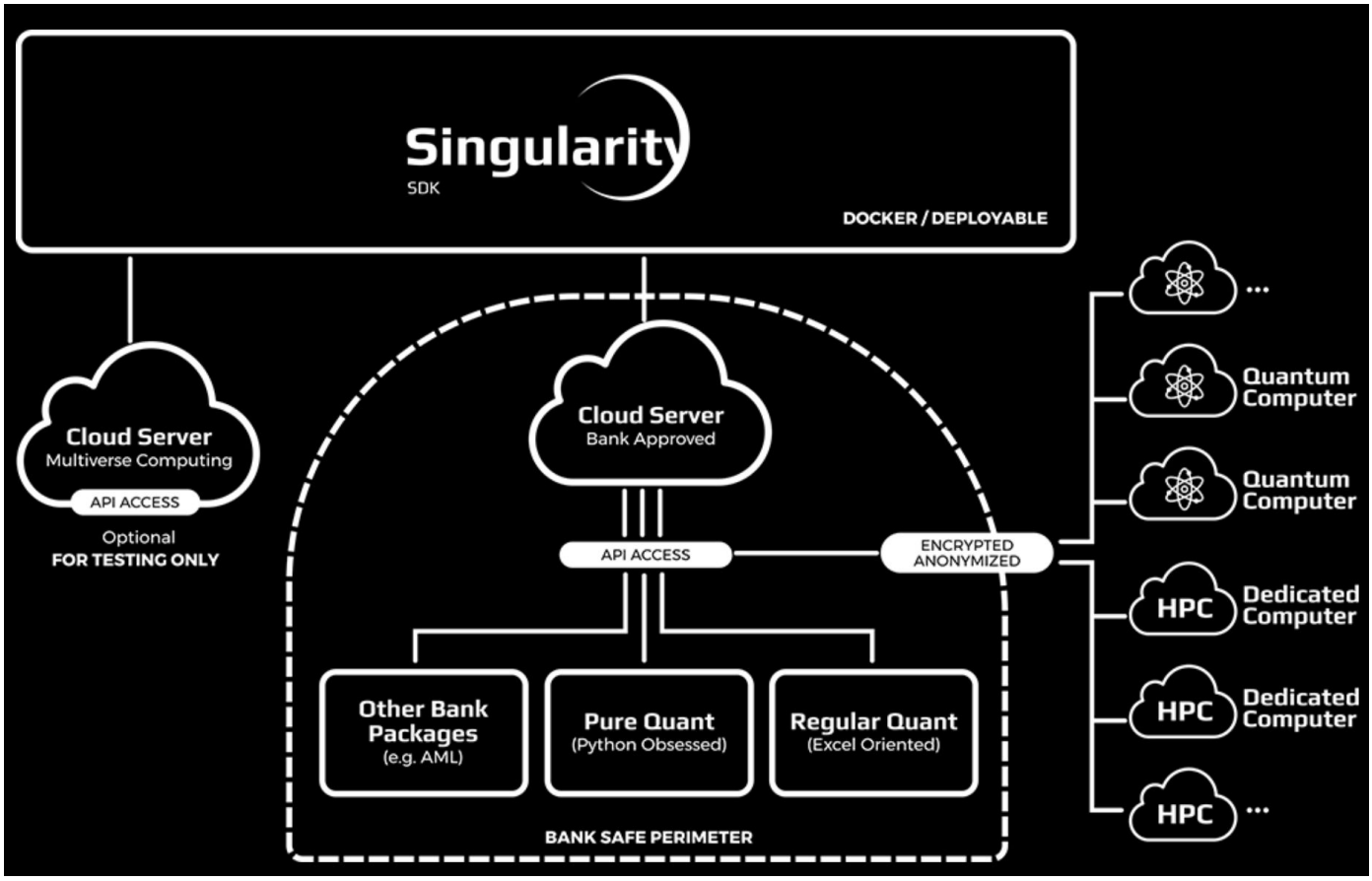

Figure 1. Singularity is a containerized solution which is deployed within the institution (i.e. investor firm) limits. Communication with the outside is encrypted.

Case Study/White Paper [4]

The technology has been tested for dynamic portfolio optimization with minimal holding period.

The algorithm works by sampling near-optimal portfolios at each trading step. It uses a quantum processor and a post-selection algorithm for minimal holding constraint (Fig. 1 and 2). The authors used a dataset of 50 assets in a timespan of 1 year. (Fig. 3)

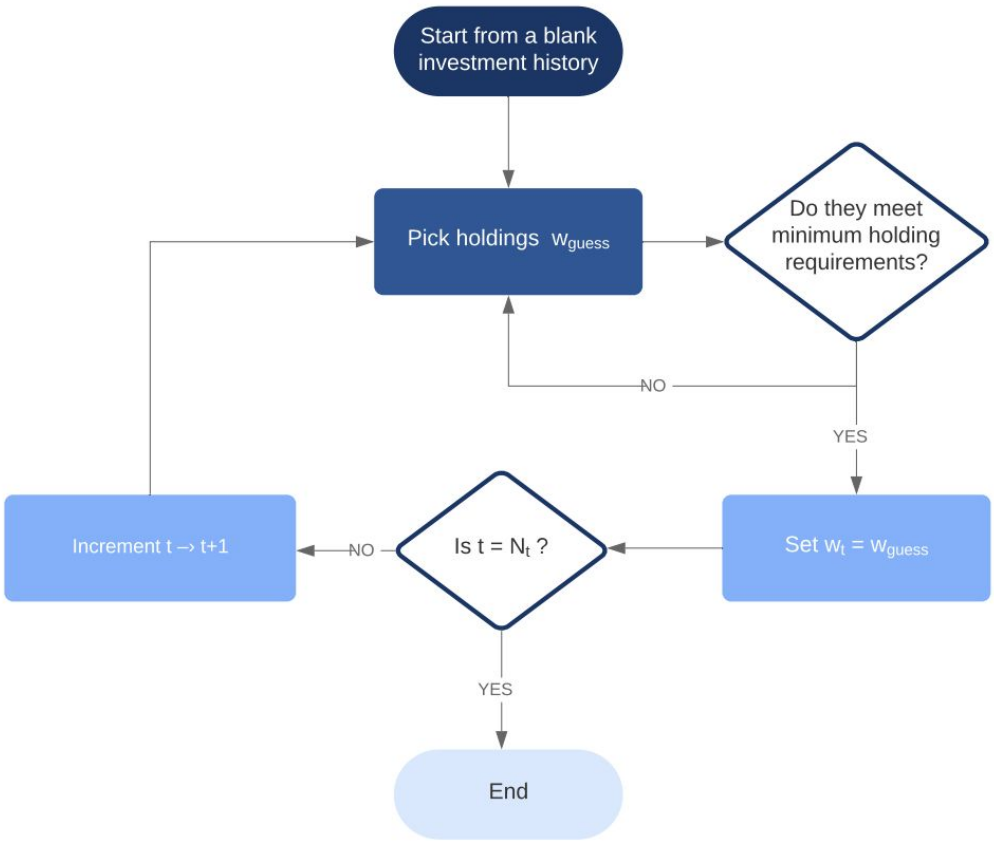

Fig. 1. Post-selection algorithm used to eliminate trajectories which don't meet the criteria (7 day holding period).

Case Study/White Paper

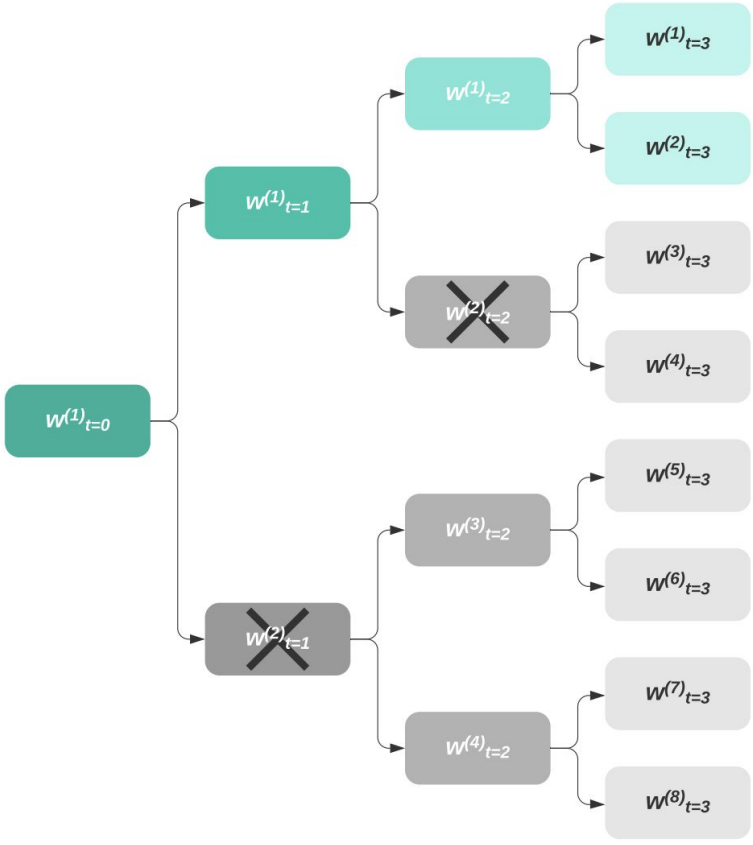

Fig. 2. Post-selection algorithm used to rule out candidate investment trajectories. When the constraint is not met at time t, the node is crossed out and all resulting investment trajectories are eliminated.

Case Study/White Paper

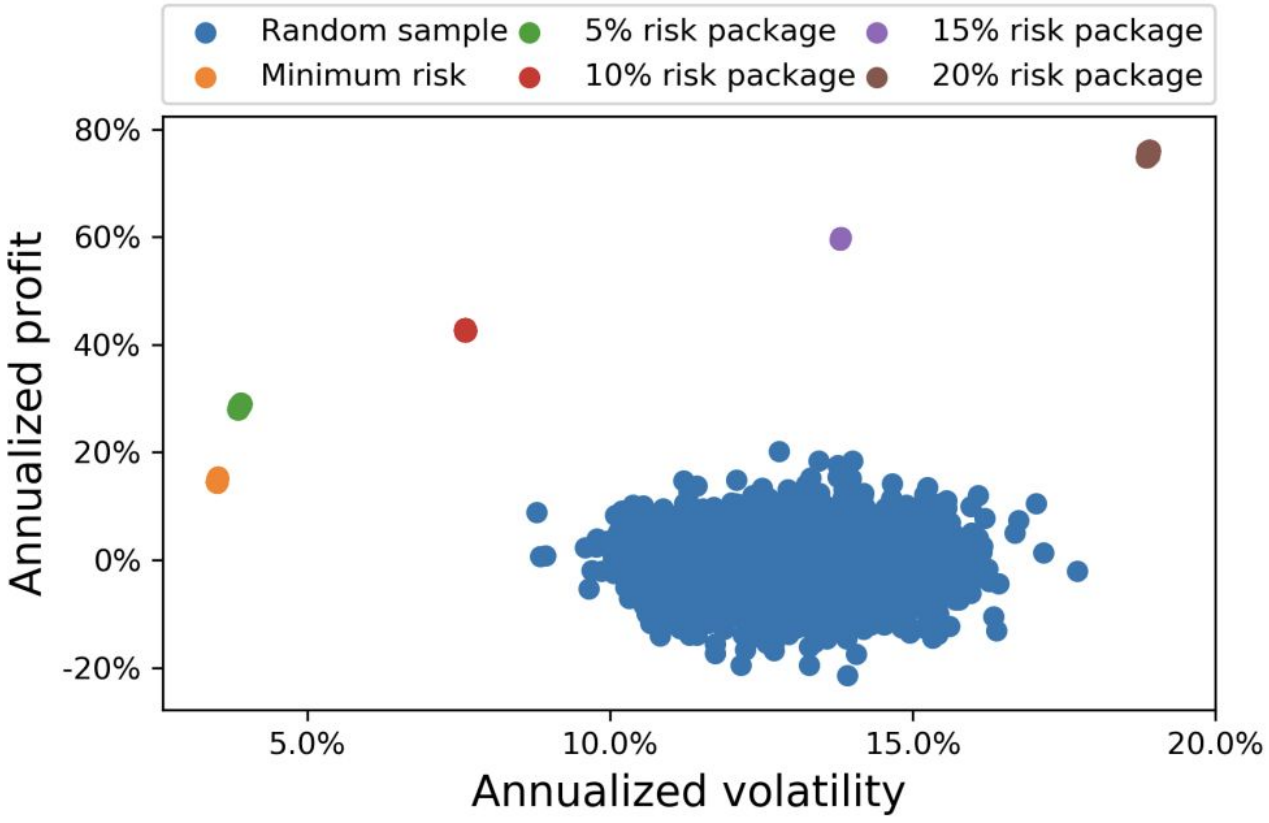

Fig. 3. The results obtained show that the method was efficient and produced results close to the optimal efficient frontier, which was better than typical random portfolios. The method can also fit with trajectories that correspond to different risk profiles.

Intellectual Property

N/A

Investors/Funding Partners

Multiverse computing has received 1$.8M USD (€1.5M) from one round. The round consisted of 8 investors: Creative destruction lab, Mondragon Corp, Penja Strategy, Seed Gipuzkoa, Neotec Capital Riesgo, EASO, Quantonation and BIC Gipuzkoa Berrilan [5].

References

1. https://www.crunchbase.com/organization/multiverse-computing
2. https://www.multiversecomputing.com/
3. https://www.multiversecomputing.com/singularity/
4. https://arxiv.org/pdf/2012.01091.pdf
5. https://www.crunchbase.com/organization/multiverse-computing/company_financials

Quantum Brilliance Gen1: Quantum Brilliance

Quantum Brilliance
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Website: www.quantumbrilliance.com
Contact: mark.luo@quantum-brilliance.com

TRL 5

Overview

Quantum Brilliance is a startup based in Canberra, Australia with offices in Stuttgart, Germany [1]. The company was founded in 2019 as a spinoff of the Australian National University [2]. The company has received $11.5M USD in funding over 2 rounds [1]. The company is a hardware developer for quantum computing with the aim of creating quantum computers that can be used anywhere, with their first commercially available quantum computer being “Gen1” [2, 3].

Product Description

Quantum Brilliance has developed the “Quantum Brilliance Gen1”, a quantum computer that can be used at room temperature and is already on the market [3]. The product was the result of research done at the Australian National University by Dr. Marcus Doherty and Dr Andrew Horsley [2]. The quantum computer works through an accelerator, which uses synthetic diamonds in the microprocessors. In particular, the computers exploit the properties of nitrogen-vacancy (NV) centre in diamonds. The NV centres have a long coherence time of any room temperature quantum state [3].

Quantum Brilliance Gen1: Quantum Brilliance

Product Description

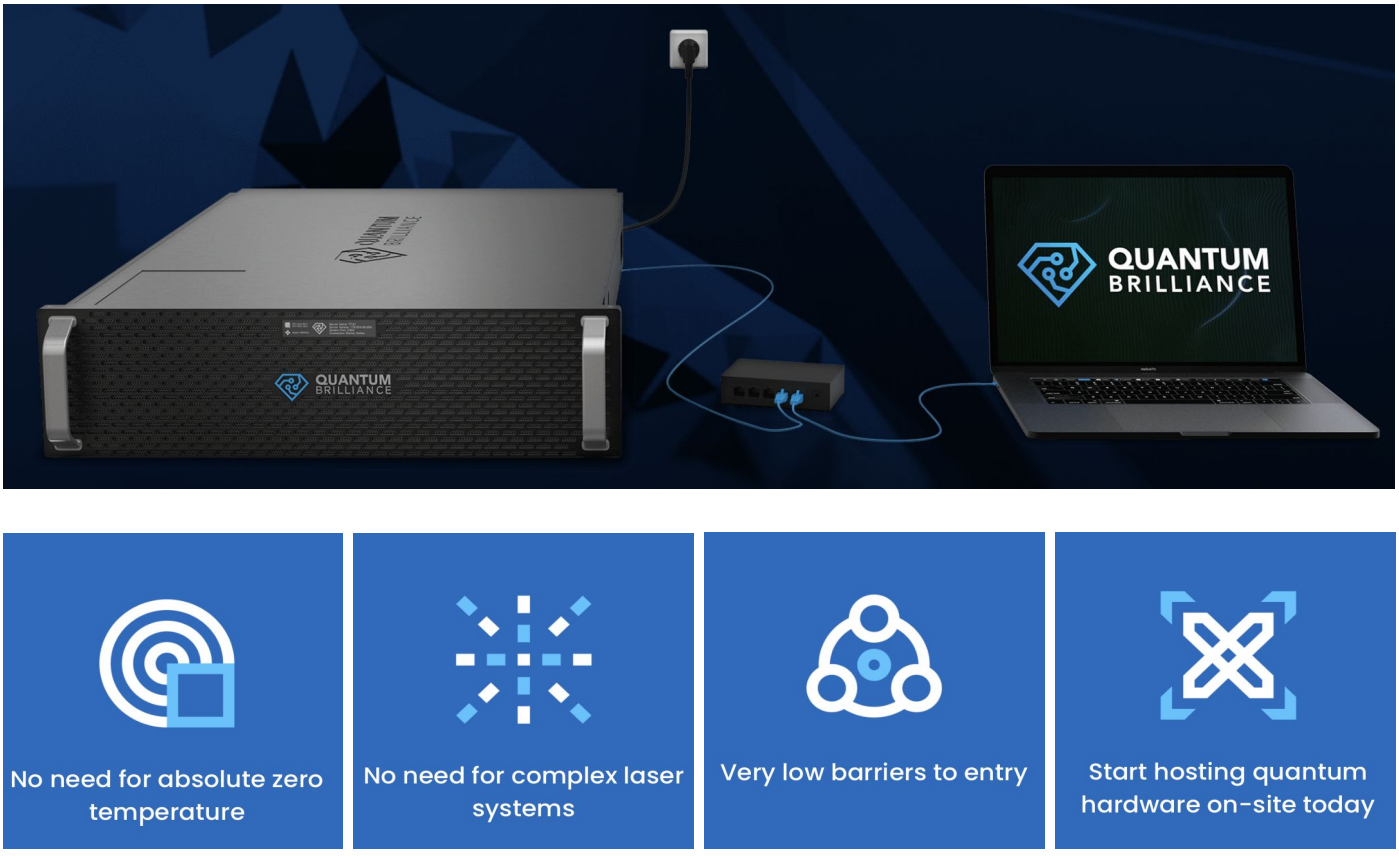

Figure 1. Quantum Brilliance quantum computer “Gen1”.

The diamond quantum computers consists of an array of processor nodes, each comprising of a nitrogen vacancy (NV) center and a cluster of nuclear spins (Fig. 2). The NV center is a defect in the diamond lattice that consists of a substitutional nitrogen atom adjacent to a vacancy. The nuclear spins acr as the qubits while the NV centers act as mediators of the initialization and the readout of qubits and qubit operations. The NV properties are the ones that allow Quantum Brilliance accelerators to perform at room temperature.

Product Description

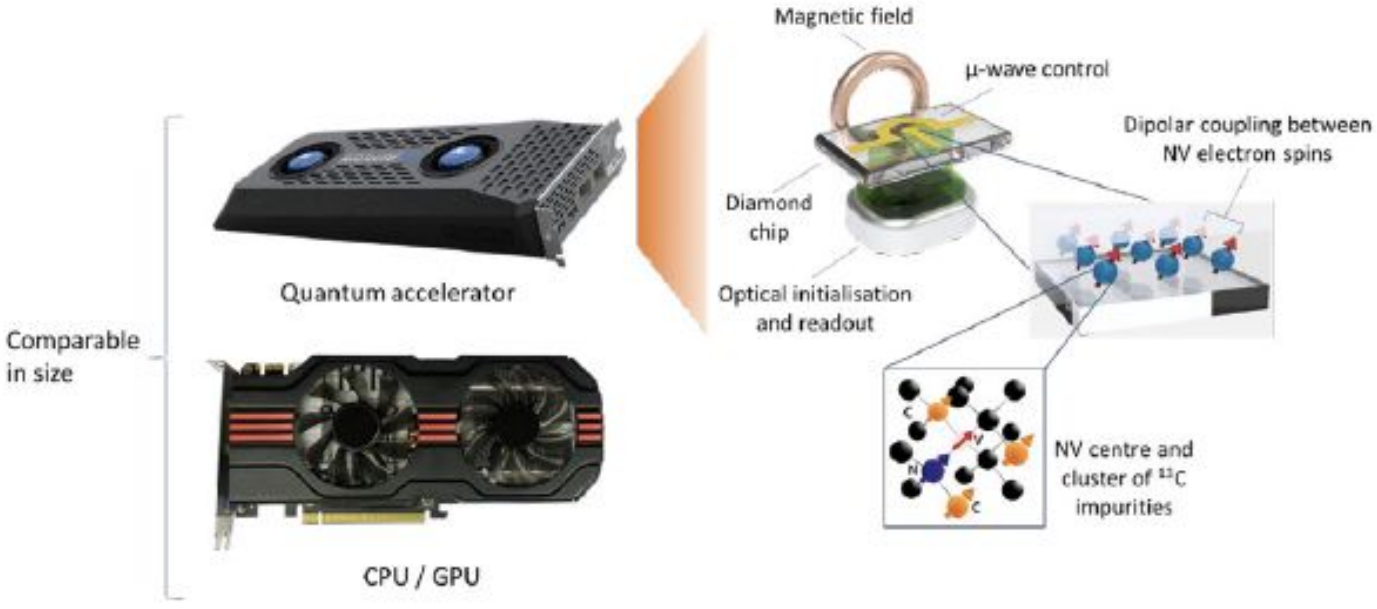

Figure 2. Quantum Brilliance's quantum accelerator.

Intellectual Property

Indicate any patents the company has patented/applied. Please include:

Patent Name/Title: Quantum information processing device, assembly, arrangement, system and sensor

Patent No: WO2021051163A1

Status: Published

Brief description: A quantum information processing device. The device contains host chips, a defect custer and optical structures that direct an excitation light.

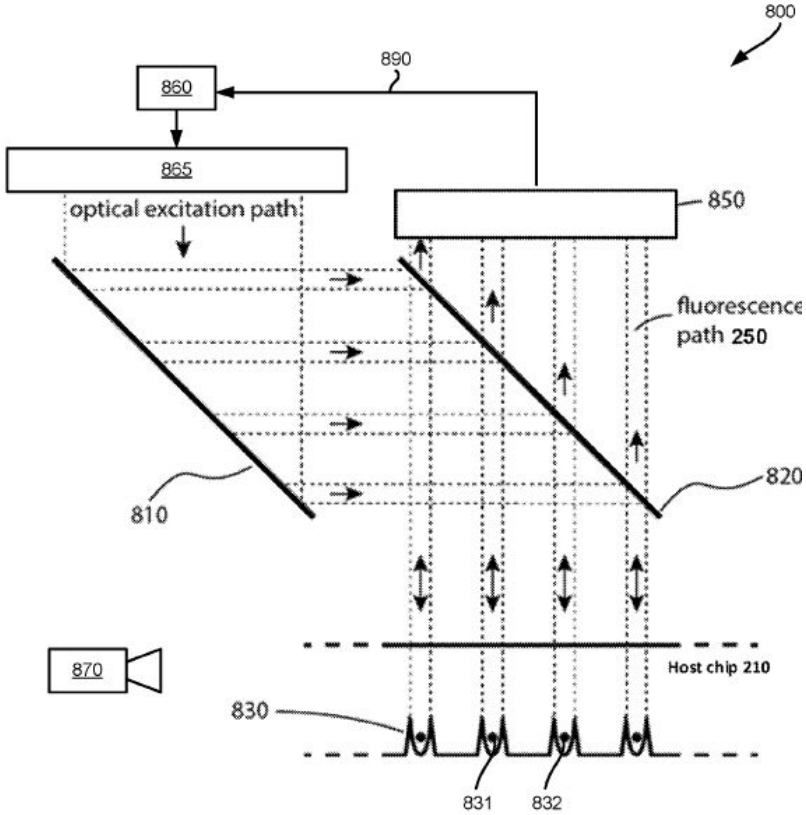

Figure 3. Schematic of an example of an integrated quantum information processing system (800) for optically addressing multiple quantum processors provided by a single host chip having defect clusters (830), a modulator (810), a light source (865), an electromagnetic control signal source (870), one or more photon detectors (850), and a controller (860) operatively coupled to the light source (865).

Investors/Funding Partners

The company has received funding for $11.5M in two rounds. The first round achieved a sum of $1.8M USD (2.5M AUD) funded by CP ventures [1]. In the second round, Quantum Brilliance raised $9.7M in seed funding from several participants: Investible, CP ventures, Main sequence, Jelix Ventures, Moelis Australia Asset management [1, 6].

References

1. https://www.crunchbase.com/organization/quantum-brilliance
2. https://www.anu.edu.au/news/all-news/anu-start-up-to-power-next-generation-of-quantum-computing
3. https://quantumbrilliance.com/quantum-brilliance-hardware
4. https://quantumbrilliance.com/download
5. WO2021051163A1
6. https://www.businesswire.com/news/home/20210825005293/en/Quantum-Brilliance-Raises-9.7-Million-Seed-Funding-to-Advance-Diamond-Quantum-Accelerator-Development-and-Deployment

QAD Cloud: HQS Quantum Simulations

HQS Quantum Simulations
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Contact: qad@quantumsimulations.de

TRL 5

Overview

HQS provides software for materials scientists in the chemical industry, as well as in academia. The company, founded in 2017, has set itself the goal of predicting molecule properties using software based on quantum algorithms. Sophisticated quantum-level models of materials and their molecular properties give researchers the deeper insights they need to identify the ideal solution for their needs. This is intended to be of particular help in the development of materials or drugs.

Product Description

With its simulation software, HQS aims to simplify the testing and manufacturing process for chemicals, materials and pharmaceuticals. The prospect of quantum computers makes this possible. So far, this has often been very complicated, time-consuming and therefore expensive.

To this end, the start-up is developing quantum algorithms that can predict the behavior of molecules using the laws of quantum physics. So far, the software has been run on classic computers, which does not yet allow productive applications. However, insights for the future can be obtained in this way. As soon as quantum computers can be used commercially, the knowledge and software can then easily be transferred.

Product Description

Quantum Assisted Design (QAD) is an integrated development environment designed to enable the simulation of molecules and materials on quantum computers. The features of QAD Cloud is fellows.

- Easy to use online platform
- New API support
- Software package enables the solution of fermionic lattice models in 1D and 2D
- Lattice models will be one of the first use cases that will allow for quantum advantage
- Cloud based: easily scalable computational power

QAD enables the solution of fermionic lattice problems in 1D and 2D, using a self-consistent cluster-bath approach (Figure 1).

A lattice model is solved iteratively, using a combined system which is divided into a fully-interacting cluster coupled to a non-interacting bath. The simulation proceeds until the result is self-consistent. This approach is similar to Dynamical Mean-Field Theory (DMFT) and Density Matrix Embedding Theory (DMET), and a detailed description of the method will be published in the near future.

The QAD Cloud can also serve as an easy-to-use backend to a DMRG solver for performing simulations of Hubbard-like models in 1- and 2-dimensions (Figure 2).

The cloud-based toolbox can be used directly by calling an API in a python script. One additional, major feature that we would like to implement in the future is support for quantum computation as a backend. However, this is ultimately dependent upon the development of quantum computing hardware.

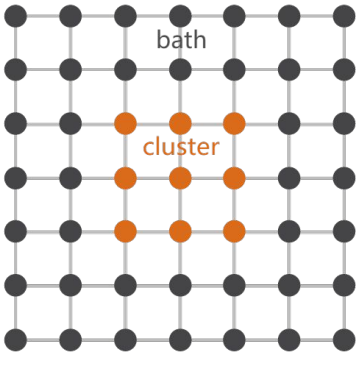


Figure 1. Lattice divided into a combined cluster-bath system

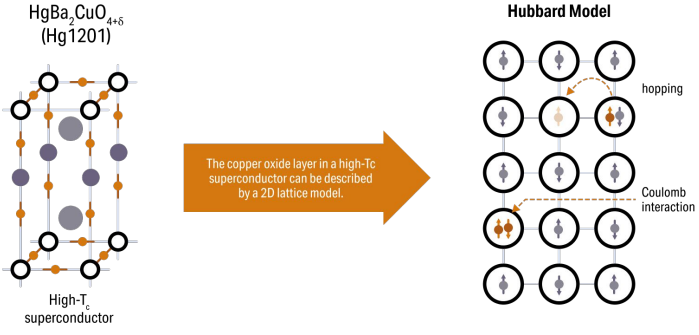


Figure 2. Hubbard-like model

Case Study/White Paper

- **HQS Quantum Simulations participates in AVaQus project to build alternative quantum computer**

The AVaQus project, funded by the European FET Open grant, will receive 3M€ over 3 years to develop a superconducting coherent quantum annealer, an alternative to gate-based quantum computing, aiming to solve real-life optimization problems.

After a successful application, the European Union has awarded a grant to HQS Quantum Simulations, alongside two other quantum startups and five research institutes to build quantum annealer prototype. The kickoff is planned for October 2020 and will run until the end of September 2023, in the context of the Future and Emerging Technologies (FET) Open grant programme.

The approach investigated by the AVaQus project is quantum annealing, which does not depend on gates: the method consists in letting a quantum system evolve towards its least energetic state; the system having been prepared in such a way that it mimics the behavior of a desired problem. Then, the final result of the evolution is measured and by equivalence gives the expected solution. Quantum annealing can be applied to optimization problems and physical systems alike.

AVaQus is coordinated by the Institute for High Energy Physics in Barcelona, and successfully made its bid during the H2020-FETOPEN-2018-2019-2020-01 call for proposals, which put forth a total budget of more than 500M€. HQS Quantum Simulations participated as the quantum software partner during the call, and will develop applications based on solving spin problems. The parent programme, Horizon 2020, aims for industrially mainstream quantum computing in the next 15-20 years. Until September 2021, it remains in ramp-up phase.

Case Study/White Paper

- **Bosch, BASF, HQS Quantum Simulations, institutes team up in MANIQU project to research novel materials on quantum computers**

Materials with unusual physical properties, pave the way for future technologies, as their properties show interesting and promising characteristics that cannot be reproduced on current structures. For example, strongly-correlated electron systems, where electrons experience a much deeper coupling than in ordinary materials, resulting in phenomena such as the ability to switch from metal to insulator, high-temperature superconductivity.

These properties, no matter how desirable, are still difficult to probe, especially to simulate, owing to their fundamentally quantum nature. Quantum correlations mean that simulations of these systems take the form of wavefunctions, which exponentially grow in computational space with each new electron, and cause even the best supercomputers to fail at accurately simulating systems of a sufficient size to provide fruitful results.

Quantum computers, which possess inherently quantum effects, bypass this difficulty through their innate physical properties, and in the specific case of these topics, speed up calculations by an immense amount, allowing research to move past this roadblock, eventually leading to mastery of these characteristics, and their use in advanced technologies.

In order to reach the ability to exploit the strongly-correlated electron effects, quantum computing must first be tamed too, as the noise in the machines still disrupts most calculations, rendering results invalid; as things stand, for now, their effectiveness is too low to prove useful in this domain.

The MANIQU project was created with the goal to render near-term quantum computers, named noisy intermediate-scale quantum (NISQ) computers, useful for such simulations. This requires a thorough study of the noise present in the apparatus, from its nature – whether it is quantum or classical – to deciphering its pattern in order to design algorithms most resilient to it.

The group is composed of Robert Bosch GmbH, BASF SE, HQS Quantum Simulations, the Friedrich-Alexander University in Erlangen, and the Heinrich-Heine University in Düsseldorf. Together, the members will develop software that maps strongly correlated electrons problems to NISQ computers in a way that mitigates the errors due to noise. It will run from March 2021 to February 2023.

Case Study/White Paper

- **HQS Quantum Simulations launches an overhauled quantum circuit representation library.**

HQS Quantum Simulations announced the release of roqoqo, a new engine for the qoqo library, which empowers developers to create, process and serialize quantum circuits in an efficient manner and provides a thin runtime for quantum measurements. Roqoqo becomes the new basis of qoqo, whose previous quantum circuit engine was written in Python. Python is now used to interface with the roqoqo toolkit.

The qoqo toolkit was designed from the ground up with two goals in mind: Efficient serialization of quantum programs including measurement inputs and high performance handling of quantum circuits containing symbolic variables, including parameter replacement. Complete serialization allows using qoqo for quantum program exchange with minimal information overhead, meeting commercial IP compliance rules. Efficient handling of large circuits lets qoqo scale up efficiently to support future quantum hardware with hundreds or thousands of qubits.

Intellectual Property

Patent Name/Title: Method for modeling of a system by means of a quantum computer

Patent No: US20210232739A1

Status: Pending

Brief description: For manufacturing-related reasons, the qubits of known quantum computers are not to be regarded as equivalent, but instead a standard quantum computer has not only high-performance qubits with long decoherence times and good fidelities of operation but also low-performance qubits with short decoherence times and poor fidelities of operation. The invention utilizes these by subdividing a system to be modeled with such a quantum computer into a bath part of low relevance and a cluster part of high relevance, wherein a rough description of the bath part is assigned to the low-performance qubits and an exact description of the cluster part is assigned to the high-performance qubits.

Intellectual Property

Patent Name/Title: METHOD FOR SIMULATION OF A QUANTUM MECHANICAL SYSTEM

Patent No: DE102019135807A1

Status: Pending

Brief description: It is known to simulate structures, for example of chemical systems, on quantum computers, since these are able to accurately simulate systems that exceed the computing power of conventional computers. However, there is the problem that the qubits of a quantum computer are prone to errors and can therefore change to the ground state through decay. In the context of a simulation, this can lead to a system with an incorrect number of electrons being mapped and thus the measured values of the simulation no longer correspond to the physical properties of the simulated system. The invention provides for a departure from the previous exercise, excited states in the system with qubits in excited states. This significantly reduces the effects of the disintegration of individual qubits in the overall system.

Investors/Funding Partners

HQS Quantum Simulations has raised a total of $2.6M in funding over 2 rounds. Their latest funding was raised on Oct 21, 2019 from a Seed round. HQS Quantum Simulations is funded by 6 investors. btov Partners and Unternehmertum Venture Capital Partners are the most recent investors.

References

1. https://quantumsimulations.de/about
2. https://quantumsimulations.de/
3. https://www.crunchbase.com/organization/hqs-quantum-simulations/company_financials
4. https://quantumsimulations.de/news/hqs-quantum-simulations-participates-in-avaqus-project-to-build-alternative-quantum-computer
5. https://quantumsimulations.de/news/bosch-basf-hqs-quantum-simulations-institutes-team-up-in-maniqu-project-to-research-novel-materials-on-quantum-computers
6. https://quantumsimulations.de/news/hqs-quantum-simulations-launches-an-overhauled-quantum-circuit-representation-library
7. https://craft.co/hqs-quantum-simulations
8. https://patentimages.storage.googleapis.com/01/00/1e/f7f41bdfbc710d/DE102019135807A1.pdf
9. https://patentimages.storage.googleapis.com/28/be/42/c3c6c8d9a9377f/US20210232739A1.pdf
10. https://quantumsimulations.de/qad-grafik
11. https://qad.quantumsimulations.de/

Hyrax: Rahko

Rahko
Headquarters: London, United Kingdom
Website: https://rahko.ai/
Contact: https://rahko.ai/#contact

TRL 5

Overview

Rahko is a London-based quantum machine learning company building the capability to better model the behaviour of drugs, chemical reactions and the design of advanced materials with greater speed and accuracy than current state-of-the-art technologies. Rahko brings together a multidisciplinary team of experts in machine learning, quantum chemistry and quantum computing, to solve some of the world's most complex problems. The company has the backing of Balderton Capital, Europe's leading early-stage venture capital investor and a scientific advisory board with many leading figures in computational chemistry and quantum machine learning. Rahko's customers include several multinational pharmaceutical manufacturers and discovery CROs. Partners include AWS, IBM, Nvidia and Microsoft.

Product Description

Rahko brings together three technologies in its proprietary quantum discovery platform Hyrax: computational chemistry, machine learning and quantum computing. Hyrax enables faster and cheaper drug discovery with AI today, and discovery with significantly higher prediction accuracy using quantum computing tomorrow.

Product Description

The path to discovering and developing safe, effective drugs is slow and expensive, with a high rate of drug candidate attrition, and frequent, costly failure in clinical trials. Predicting the behavior of drugs is a complex problem that typically relies on two components: physics-based simulations of chemical and biological processes, and data-driven predictions of interactions in the human body. The speed and accuracy of physics-based simulations is limited due to the classical computer ability to simulate quantum mechanics. Data-driven predictions are limited by the scarcity of large, high-quality datasets.

The quantum machine learning models in Hyrax combine physics and machine learning, enabling speedups of chemical simulations, systematic limitation of prediction errors and reduction of the amount of data required. This allows Hyrax to overcome the critical barriers in drug discovery of speed and prediction accuracy. In addition, Hyrax is designed to seamlessly integrate with current high performance computers, and multiple leading quantum computers including a range of QPUs including devices based on superconducting qubits, trapped ions, Rydberg atoms and photonics.

Hyrax offers AI (quantum-based machine learning) for drug discovery that allows customers to accelerate and slash costs of drug discovery today, and create a clear pathway to the game-changing prediction accuracy of the quantum computers of tomorrow.

Hyrax brings together quantum-based machine learning and quantum machine learning descriptors and models for best-in-class lead identification and optimization of drug candidates. It drastically improves the speed at which customers can screen drug candidates.

Case Study/White Paper

- **Efficient, large-scale Density Functional Theory on the cloud**

As part of project Quantifi, an Innovate UK funded project, Rahko, Johnson Matthey and Amazon Web Services (AWS) have jointly demonstrated the use of high-performance computing ('HPC') to deliver efficient, large-scale Density Functional Theory ('DFT') calculations on the cloud.

Cloud computing provider AWS offers parallel clusters with a low latency Elastic Fabric Adapter ('EFA') suitable for scaling calculations up to thousands of nodes with fast internode communication.

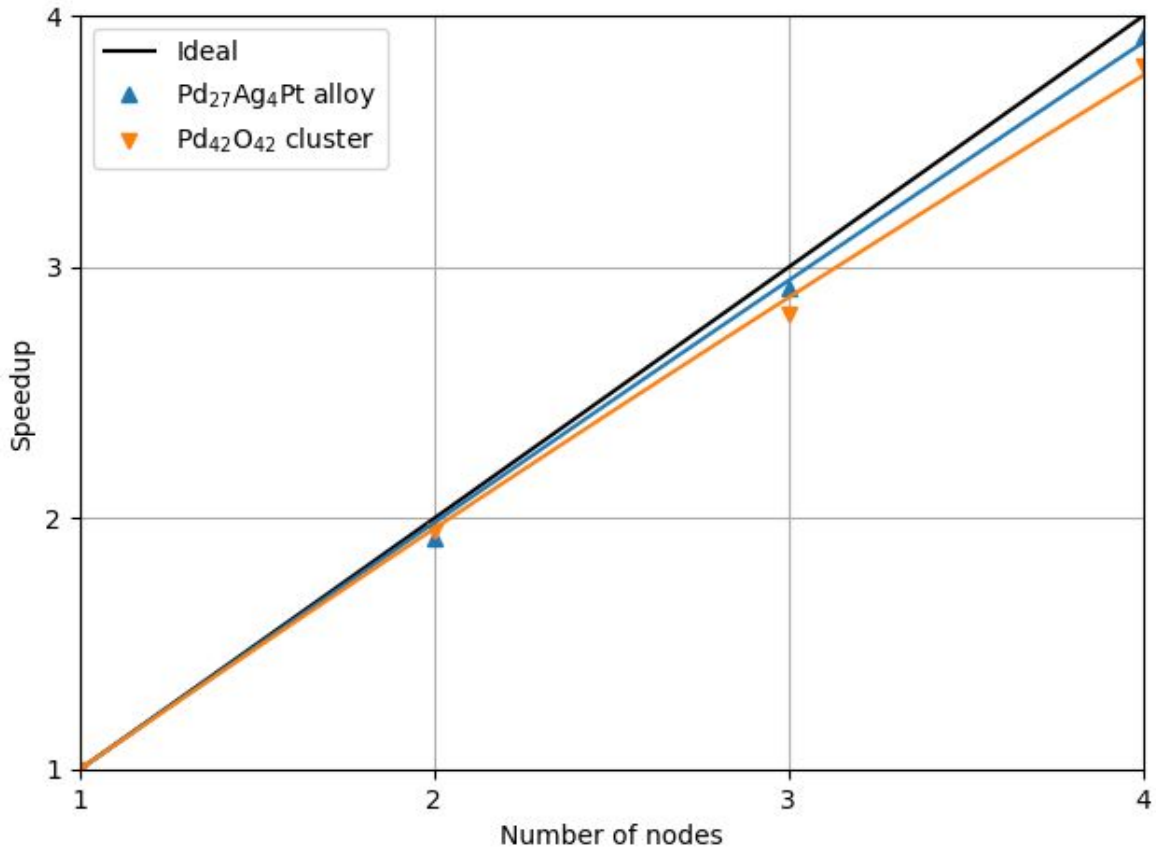


Figure 1. Strong scaling results comparing large cluster and alloy calculations on AWS ParallelCluster

Case Study/White Paper

- **Efficient, large-scale Density Functional Theory on the cloud**

Quantifi researchers' test calculations on a Pd42O42 cluster and a Pd27Ag4Pt alloy demonstrate that 98-99% parallelization can be achieved on multiple c5n.18xlarge nodes for large gas phase cluster and solid state calculations with the Quantum Espresso materials modelling software using the Intel Math Kernel Library, and Intel MPI as can be seen from the Figure 1 on strong scaling results below.

The estimated speedup for the systems investigated is up to 50-100x, with speedups expected to increase in line with larger system sizes.

This implementation has been a valuable addition to Hyrax, Rahko's quantum discovery platform, and is easily integrated into existing discovery workflows.

Case Study/White Paper

- **Rahko Reaches Groundbreaking Accuracy on Honeywell's Latest QPU 'System Model H0'**

Using Rahko's Discriminative Variational Quantum Eigensolver ('DVQE'), researchers have reached groundbreaking accuracy on Honeywell's latest QPU, System Model H0, giving strong early indication of the powerful capability quantum computing will offer for the computation of electronic structure.

The Honeywell System Model H0 offers a 6-qubit quantum register with outstanding gate fidelities, achieving a total quantum volume of 64, which puts it among the forefront of QPUs of its generation.

With the benefit of the device's low error rates and a fully connected set of qubits, Rahko has used its DVQE method (a fully variational method) to reach groundbreaking accuracy in the first excited state of a 4-qubit molecule on Honeywell's System Model H0 (Figure 2).

The DVQE method was combined with light-touch error mitigation techniques that are able to further improve results on near-term QPUs.

	Accuracy on a 2-qubit molecule	Accuracy on a 4-qubit molecule
Ground energy	**99.8%** *(Circuit depth = 6, on 2 qubits)*	**99.6%** *(Circuit depth = 15, on 4 qubits)*
First state energy	**99.6%** *(Circuit depth up to 18, on 3 qubits)*	**93.3%** *(Circuit depth up to 41, on 5 qubits)*

Figure 2. The results from the latest quantum processing unit ('QPU') implementation

- **Rahko announces Merck collaboration**

May 2020, Rahko announced a 3-year collaboration with the science and technology company Merck. The collaboration is focused on exploring and leveraging the potential for quantum inspired machine learning to enable the discovery and development of novel drugs, molecules and materials – faster, and with greater efficiency and precision than what is currently possible.

Case Study/White Paper

- **Pasqal and Rahko partner to advance quantum chemistry aided by Quantum Computing**

Pasqal and Rahko have announced a 2-year collaborative project co-funded by Région Ile de France, as part of the Innov'up Leader PIA programme (Figure 3). Within the project, Pasqal and Rahko will jointly develop algorithms to solve advanced chemistry problems, and fully implement them on Pasqal's upcoming Rydberg atoms Quantum Processor.

Figure 3. The project for advanced quantum chemistry aided by Quantum Computing

Intellectual Property

Patent Name/Title: Method for Identifying a Valid Energy State

Patent No: US20210241150A1

Status: Pending

Brief description: A method for identifying an excited energy state of a system of interacting electrons, comprising providing a first quantum circuit defined by a generator function and providing a second quantum circuit defined by a discriminator function.

Patent Name/Title: Quantum computing system and method

Patent No: GB202100468D0

Status: Pending

Brief description: N/A.

Investors/Funding Partners

Rahko has raised a total of £1.3M in funding over 1 round. This was a Seed round raised on Oct 11, 2019. Rahko is funded by 5 investors, including Balderton Capital, John Spindler, James Field, Charlie Songhurst, and Tom McInerney. John Spindler and James Field are the most recent investors.

References

1. https://rahko.ai/
2. https://www.crunchbase.com/organization/rahko
3. https://patentimages.storage.googleapis.com/87/7d/30/9c8705e873018f/US20210241150A1.pdf
4. https://patents.google.com/patent/GB202100468D0/en?assignee=+:Rahko+Limited
5. https://rahko.ai/efficient-large-scale-density-functional-theory-on-the-cloud/
6. https://rahko.ai/rahko-reaches-groundbreaking-accuracy-on-honeywells-latest-qpu-system-model-h0/
7. https://rahko.ai/rahko-announces-merck-collaboration/
8. https://rahko.ai/pasqal-and-rahko-partner-to-advance-quantum-chemistry-aided-by-quantum-computing/

the Advantage™ quantum system and the Leap™ hybrid solver: D-Wave Systems

D-Wave Systems
Headquarters: Burnaby, British Columbia, Canada
Website: https://www.dwavesys.com/
Contact: +1 604-630-1428

TRL 7

Overview

Founded in 1999, D-Wave is the leader in the development and delivery of quantum computing systems, software, and services and is the world's first commercial supplier of quantum computers. Their mission is to unlock the power of quantum computing for the world. Their employees are experts in their fields across processor development, chip fabrication, physics, cloud infrastructure, and more. Approximately 20% of their employees have PhDs in their respective fields. D-Wave's innovation and commitment to advancing the science of quantum computing has resulted in over 200 U.S. patents granted and over 100 peer-reviewed papers published in leading scientific journals.

They do this by delivering customer value with practical quantum applications for problems as diverse as logistics, artificial intelligence, materials sciences, drug discovery, scheduling, cybersecurity, fault detection, and financial modeling. D-Wave's systems are being used by some of the world's most advanced organizations, including NEC, Volkswagen, DENSO, Lockheed Martin, USRA, USC, and Los Alamos National Laboratory. With headquarters near Vancouver, Canada, D-Wave's US operations are based in Palo Alto, CA. D-Wave has a blue-chip investor base including PSP Investments, Goldman Sachs, BDC Capital, NEC Corp., and In-Q-Tel.

Product Description

D-Wave has put the power of the Advantage quantum computer behind the easily accessible Leap quantum cloud service and has developed hybrid solvers that combine the best of classical and quantum resources into easy-to-use tools.

Product Description

- **The Advantage™ quantum system**

The Advantage™ quantum system (Figure 1) is the first and only quantum system designed for business and is the most powerful and connected commercial quantum computer in the world. Advantage gives customers the ability to solve far larger, more complex problems and drive real-world value for their businesses.

Figure 1. The Advantage™ quantum system

Advantage is allowing customers to solve larger, more complex real-world problems.

- Richer topology: The Advantage quantum processing unit (QPU) has 5000+ qubits with 15-way connectivity.
- Better solutions: With 2.5x greater connectivity, larger, more complex problems can be more efficiently mapped to Advantage than to previous-generation systems, giving customers better solutions.
- Much larger problems: With the release of Advantage, the HSS now accepts problems of up to 1 million variables making it suitable for truly enterprise-scale problem solving.
- Quantum annealing controls: The Advantage system gives power users fine-grained control over the quantum annealing process, supporting:
    - Per-qubit anneal offsets.
    - Changes to the global anneal schedule, including annealing time, anneal pause and quench, and reverse anneal.
    - Time-dependent gain on linear coefficients.

Product Description

- **The Leap™ hybrid solver**

Leap (Figure 2 & 3) is the quantum cloud service featuring real-time access to the quantum system and a Quantum Application Environment from D-Wave. Leap brings quantum computing to the real world by providing immediate cloud access to D-Wave resources:

- Quantum computers (QCs) customers can program.
- Quantum-classical hybrid solvers that accept larger than processor problems.
- Open-source software and an online integrated developer environment (IDE) for developing customers' own quantum applications.

Figure 2. The Leap™ hybrid solver

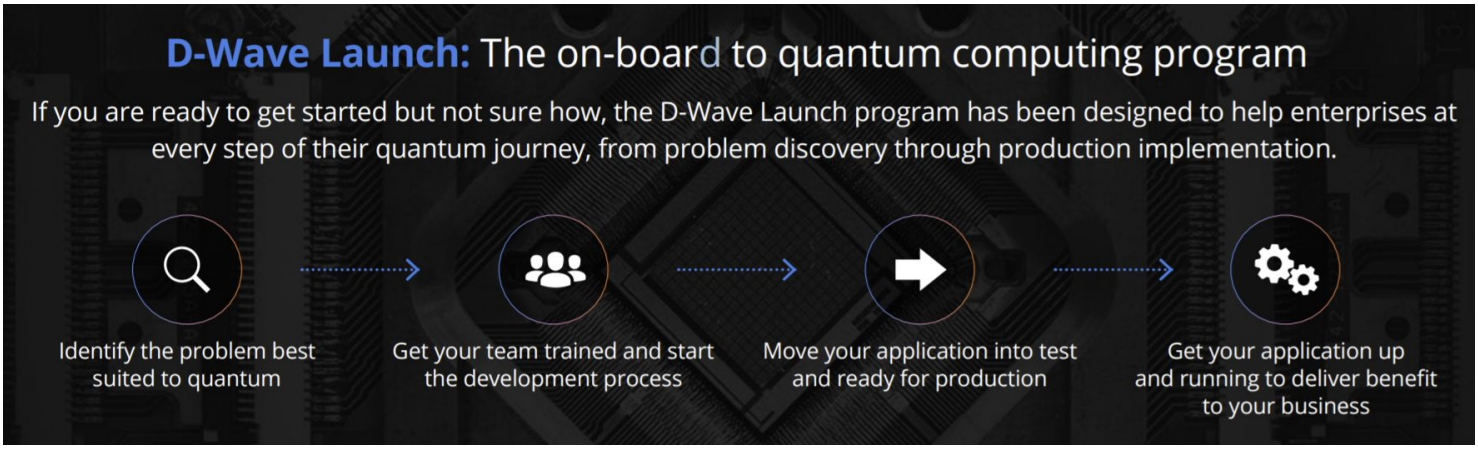


Figure 3. The workflow of Leap™ hybrid solver

Case Study/White Paper

- **Menten AI Battles COVID-19 with Quantum Peptide Therapeutics**

With the rise of COVID-19, Menten set its sights on using quantum computing to explore options for creating antiviral binders to fight the disease.

Menten created a fixed 'backbone' to serve as a starting point for the peptide (Figure 4). Through D-Wave's hybrid solver, they used the D-Wave Advantage™ quantum computer to explore a huge combinatorial space and determine the optimal composition and configuration of the side chains or branches. The challenge was to design the peptide in such a way that it binds as closely, specifically, and seamlessly as possible to its target. Using D-Wave's hybrid solver, Menten produced several different peptide designs. Two key features of these peptides are that they are designed from scratch (in de novo or "from the new") and made with both natural and non-natural amino acids. These new molecules are an expansion of the fundamental building blocks of life beyond those that have been used by nature up until now (Figure 5).

The designs have been computationally validated and chemically synthesized and are currently being used in livevirus testing. Initial results are anticipated to be announced in the near future.

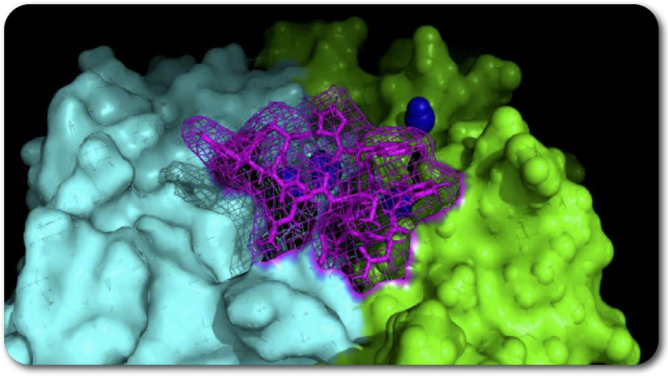


Figure 4. Protein with a peptide 'backbone' or scaffold in place

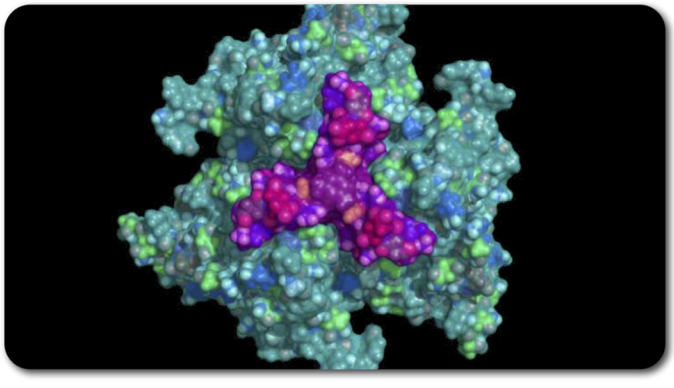


Figure 5. Designed SARS-COV-2 inhibitor peptide

Case Study/White Paper

- **Multiverse and BBVA Optimized a Portfolio for a 60% ROI at Lower Risk**

This portfolio optimization problem has proven intractable to classical computing approaches, but Multiverse Computing has now achieved a remarkable breakthrough on this front. Multiverse is a leader in developing quantum computing-based solutions (Figure 6) for the financial sector. Using the D-Wave hybrid solver service, which combines the strengths of classical and quantum computing, the company was able to develop an algorithmic approach that rapidly generates portfolios that can be optimized against a variety of constraints. They recently demonstrated the power of this approach in a pair of collaborations with two major European banks, BBVA and Bankia.

D-Wave's hybrid solver service and Tensor Network's classical systems could deliver solutions to the XXL dataset. However, the D-Wave approach took 171 seconds to solve the problem, while Tensor Networks' system took more than a day to run.

The results offered a range of portfolio trajectories that delivered robust gains at every level of risk (Figure 7(. For example, the D-Wave analysis identified a portfolio with 15% risk that yielded a 60% return on investment, whereas randomly selected portfolios at the same level of risk were entirely scattered along a continuum ranging from a 20% return to a 20% loss.

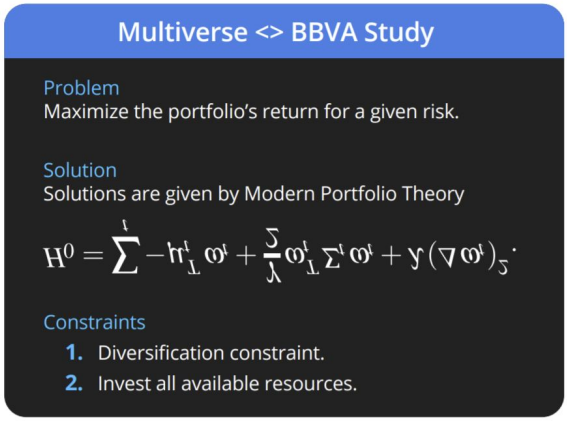


Figure 6. The solutions of Multiverse

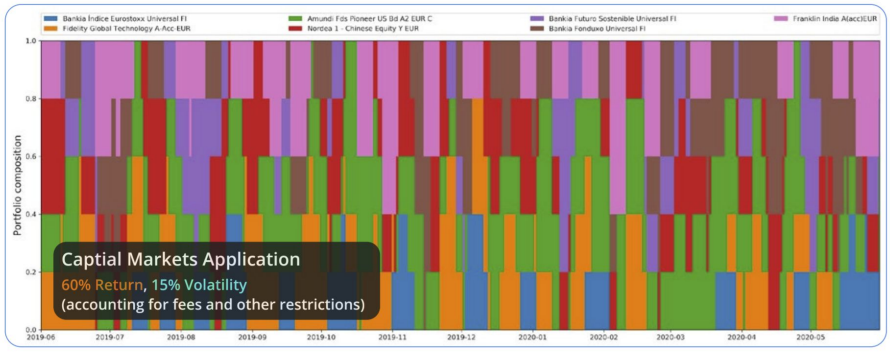


Figure 7. Result of D-Wave

Case Study/White Paper

- **Groovenauts and Mitsubishi Estate Optimized Waste Collection to Reduce CO2 Emissions by 57%**

Groovenauts, Inc. has been one of Japan's preeminent quantum pioneers since 2011. In early 2019, they announced a new commercial service integrating D-Wave's quantum computing capabilities into MAGELLAN BLOCKS. The combination of technologies gave users a quantum hybrid solution for tackling business problems, without requiring specialized physics or programming knowledge. Groovenauts put their new service to the test in partnership with Mitsubishi Estate Co., Ltd., who manages and develops office buildings in major cities across Japan (Figure 8 & 9).

By utilizing the machine learning / deep learning and D-Wave quantum computing technology provided with MAGELLAN BLOCKS, the amount of waste generated was able to be predicted with an extremely high level of accuracy (about 94%), and based on that prediction, the optimal route was able to be determined from amongst a vast set of possibilities. The route enabled a 57% reduction in CO2 emissions, a 59% percent reduction in the number of vehicles needed to perform the work, and a 38% reduction in the total work time (Table 1).

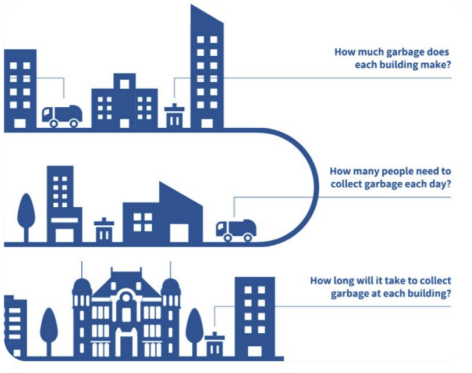


Figure 8. The example of waste collection for multiple buildings

Figure 9. The collection route optimization

Table 1. The results

Item	Current	**Optimized**	Difference
Total Route Distance	2,296.2 km	1004.2 km	▲1,292.0 km
Number of Trucks	75	31	▲44
Total Work Time	8,650.9 mins.	5,372.2 mins.	▲3,278.7 mins.

Intellectual Property

Patent Name/Title: Analog processor comprising quantum devices

Patent No: US11093440B2

Status: Grant

Brief description: Analog processors for solving various computational problems are provided. Such analog processors comprise a plurality of quantum devices, arranged in a lattice, together with a plurality of coupling devices. The analog processors further comprise bias control systems each configured to apply a local effective bias on a corresponding quantum device. A set of coupling devices in the plurality of coupling devices is configured to couple nearest-neighbor quantum devices in the lattice. Another set of coupling devices is configured to couple next-nearest neighbor quantum devices. The analog processors further comprise a plurality of coupling control systems each configured to tune the coupling value of a corresponding coupling device in the plurality of coupling devices to a coupling. Such quantum processors further comprise a set of readout devices each configured to measure the information from a corresponding quantum device in the plurality of quantum devices.

Patent Name/Title: Method of operation in a system including quantum flux parametron based structures

Patent No: US10748079B2

Status: Grant

Brief description: Approaches useful to operation of scalable processors with ever larger numbers of logic devices (e.g., qubits) advantageously take advantage of QFPs, for example to implement shift registers, multiplexers (i.e., MUXs), de-multiplexers (i.e., DEMUXs), and permanent magnetic memories (i.e., PMMs), and the like, and/or employ XY or XYZ addressing schemes, and/or employ control lines that extend in a “braided” pattern across an array of devices.

Intellectual Property

Patent Name/Title: Systems and methods for removing unwanted interactions in quantum devices

Patent No: US10789329B2

Status: Grant

Brief description: Systems, devices, articles, methods, and techniques for advancing quantum computing by removing unwanted interactions in one or more quantum processor. One approach includes creating an updated plurality of programmable parameters based at least in part on a received value for the characteristic magnetic susceptibility of the qubit in the at least one quantum processor, and returning the updated plurality of programmable parameters.

Patent Name/Title: Analog processor comprising quantum devices

Patent No: US10691633B2

Status: Grant

Brief description: Methods and systems for solving various computational problems with quantum processors are provided. Such quantum processors comprise a plurality of quantum devices together with a plurality of coupling devices. The quantum processor is initialized by setting states of the quantum devices and coupling devices and allowed to evolve to a final state which approximates a natural ground state of the computational problem. The final state can include values of nodes arranged in a lattice in the quantum processor and can represent a solution to the computational processor. The computational problem can have complexity P, NP, NP-Hard, or NP-Complete and may be mapped to a quantum processor with nearest-neighbor and next-nearest-neighbor couplings. The solution to the computational problem can be read out from the quantum processor and transmitted as a data signal embodied in a carrier wave.

Intellectual Property

Patent Name/Title: Quantum processor with instance programmable qubit connectivity

Patent No: US10891554B2

Status: Grant

In a quantum processor some couplers couple a given qubit to a nearest neighbor qubit (e.g., vertically and horizontally in an ordered 2D array), other couplers couple to next-nearest neighbor qubits (e.g., diagonally in the ordered 2D array). Couplers may include half-couplers, to selectively provide communicative coupling between a given qubit and other qubits, which may or may not be nearest or even next-nearest-neighbors. Tunable couplers selective mediate communicative coupling. A control system may impose a connectivity on a quantum processor, different than an “as designed” or “as manufactured” physical connectivity. Imposition may be via a digital processor processing a working or updated working graph, to map or embed a problem graph. A set of exclude qubits may be created from a comparison of hardware and working graphs. An annealing schedule may adjust a respective normalized inductance of one or more qubits, for instance to exclude certain qubits.

Investors/Funding Partners

D-Wave Systems has raised a total of $256.2M in funding over 20 rounds. Their latest funding was raised on Mar 11, 2021 from a Grant round. D-Wave Systems is funded by 22 investors, including In-Q-Tel, Government of Canada, Fidelity, PSP Investments, International Investment & Underwriting Limited, etc. Government of Canada and NEC Corporation are the most recent investors.

References

1. https://www.dwavesys.com/
2. https://www.crunchbase.com/search/principal.investors/field/organizations/num_lead_investors/d-wave-systems
3. https://www.dwavesys.com/media/htjclcey/advantage_datasheet_v9.pdf
4. https://www.dwavesys.com/media/ubfgktaf/leap_datasheet_v11.pdf
5. https://www.dwavesys.com/media/kjof1cdh/dwave_menten-ai_case_story-2_v4.pdf
6. https://www.dwavesys.com/media/5qahck2o/multiverse_case_study_v7-1.pdf
7. https://www.dwavesys.com/media/bq5kh520/dwave_groovenauts_case_study_v3.pdf
8. https://patents.google.com/?assignee=D+Wave+Systems&status=GRANT&sort=new
9. https://patentimages.storage.googleapis.com/f6/f2/56/9f46e42246d8f7/US11093440.pdf
10. https://patentimages.storage.googleapis.com/96/c8/df/58b2e98ab66c23/US10748079.pdf
11. https://patentimages.storage.googleapis.com/db/66/28/9b4d861e7c6e1b/US10789329.pdf
12. https://patentimages.storage.googleapis.com/08/60/ba/7d9cbbd71af469/US10691633.pdf
13. https://patentimages.storage.googleapis.com/11/16/33/33a0d05dc0ed75/US10891554.pdf

Xanadu Quantum Cloud, Photonic Hardware, PennyLane and Strawberry Fields: Xanadu Quantum Technologies

Xanadu Quantum Technologies
Headquarters: Toronto, Canada
Website: https://www.xanadu.ai/
Contact: hello@xanadu.ai

TRL 7

Overview

Xanadu Quantum Technologies Inc. is a Canadian quantum technology company, located in the heart of downtown Toronto, and one of the world's leading photonic quantum hardware providers.

Founded in 2016, Xanadu's mission is to build quantum computers that are useful and available to people everywhere. To achieve this mission, the company has taken a full-stack approach and builds hardware, software, and pursues state-of-the-art research with select partners.

Today, enterprises and researchers can begin using Xanadu's photonic quantum computers through the Xanadu Quantum Cloud (XQC) service and Strawberry Fields application library.

The company is also advancing the field of quantum machine learning (QML) through the development of PennyLane, an open-source project that has become a leading software library among quantum researchers and developers.

Product Description

Xanadu design and integrate quantum silicon photonic chips into existing hardware to create truly full-stack quantum computing. Through cloud services, customers also can access Xanadu's quantum computing hardware. Xanadu also develops software, the two main software products are PennyLane and Strawberry Fields. PennyLane lets users run quantum machine learning algorithms on any currently available quantum computing hardware. Strawberry Fields provides the access point for Xanadu's unique photonic quantum computers, as well as a suite of special-purpose quantum simulators.

Xanadu Quantum Cloud, Photonic Hardware, PennyLane and Strawberry Fields: Xanadu Quantum Technologies

Product Description

- **Xanadu Quantum Cloud**

Fully managed quantum cloud service, offering direct access to Xanadu's photonic QPUs. Xanadu launched its quantum cloud platform. Developers can now access Xanadu's gate-based photonic quantum processors with 8-qubit or 12-qubit chips — 24-qubit chips. The startup expects to "roughly double" the number of qubits available in its cloud every six months.

- **Photonic Hardware**

A team of researchers and engineers at Canadian company Xanadu Quantum Technologies Inc., working with the National Institute of Standards and Technology in the U.S., has developed a programmable, scalable photonic quantum chip that can execute multiple algorithms. Overview of apparatus is shown in Figure 1.

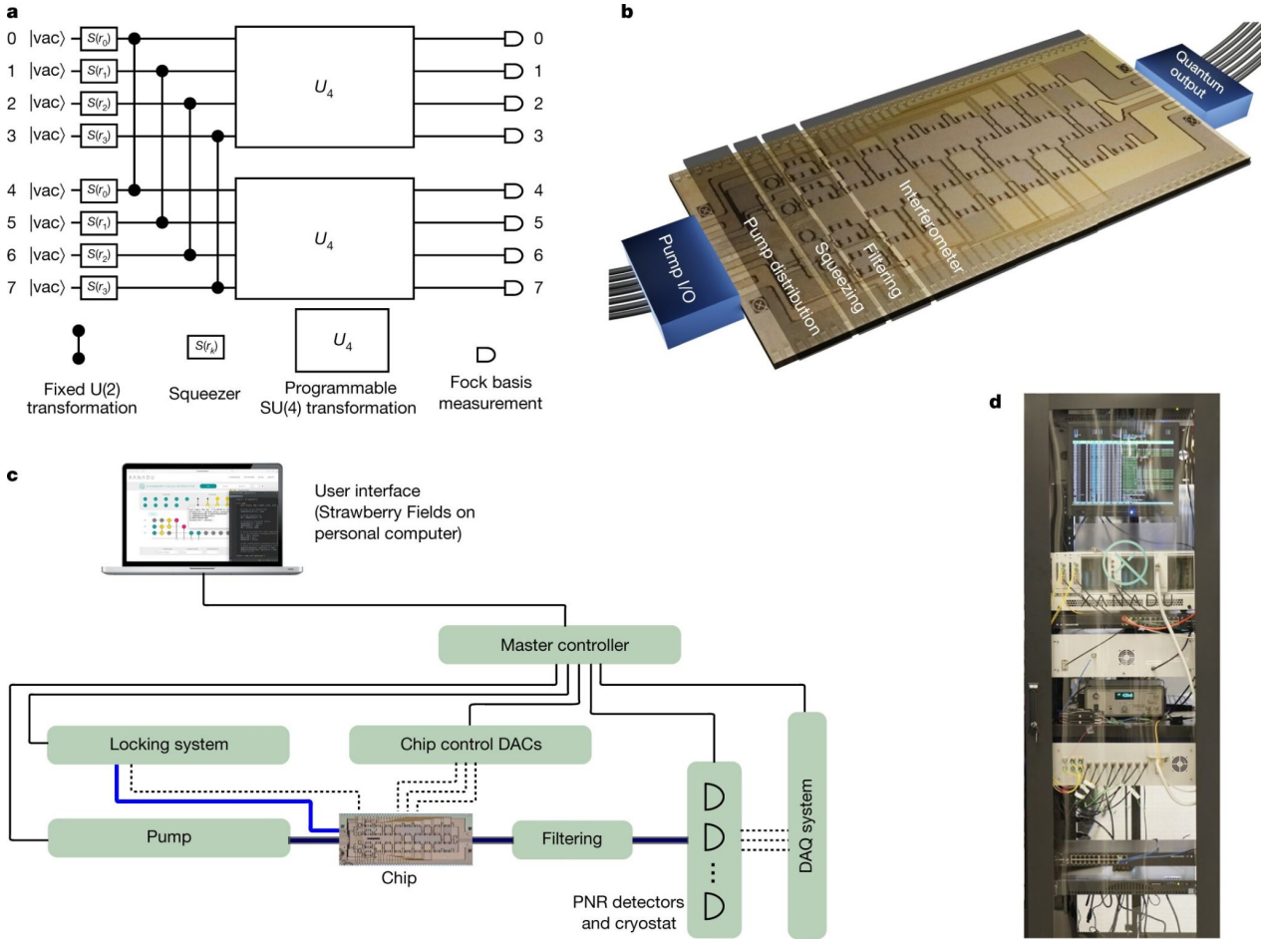


Figure 1. Overview of apparatus.

Product Description

- **Photonic Hardware**

In Figure 1, a, Equivalent quantum circuit diagram illustrating the functionality of the photonic hardware. Up to eight modes initialized as vacuum are squeezed with squeezing parameters rk and entangled (via the fixed two-mode unitary transformation U(2) equivalent to a 50/50 beam splitter with the relative input phase set to produce two-mode squeezing at the output) to form two-mode squeezed vacuum states. Programmable four-mode rotation gates (SU(4) transformation, represented by the large boxes labelled U4) are applied to each four-mode subspace. All eight modes are individually read out by measurements in the Fock basis. b, Rendering of the chip (based on a micrograph of the actual device) showing fibre optical inputs and outputs, and on-chip modules for coherent pump power distribution, squeezing, pump filtering and programmable linear optical transformations. c, Schematic of full apparatus and control system. Solid (dashed) black lines indicate digital (analogue) electronic signals; blue lines indicate optical signals. DAC, digital-to-analogue converter; DAQ, data acquisition; PNR, photon number resolving. d, Photograph of entire system (except for photon-number-resolving detector hardware), which has been fitted into a standard server rack.

The 24 modes chips are shown in Figure 2.

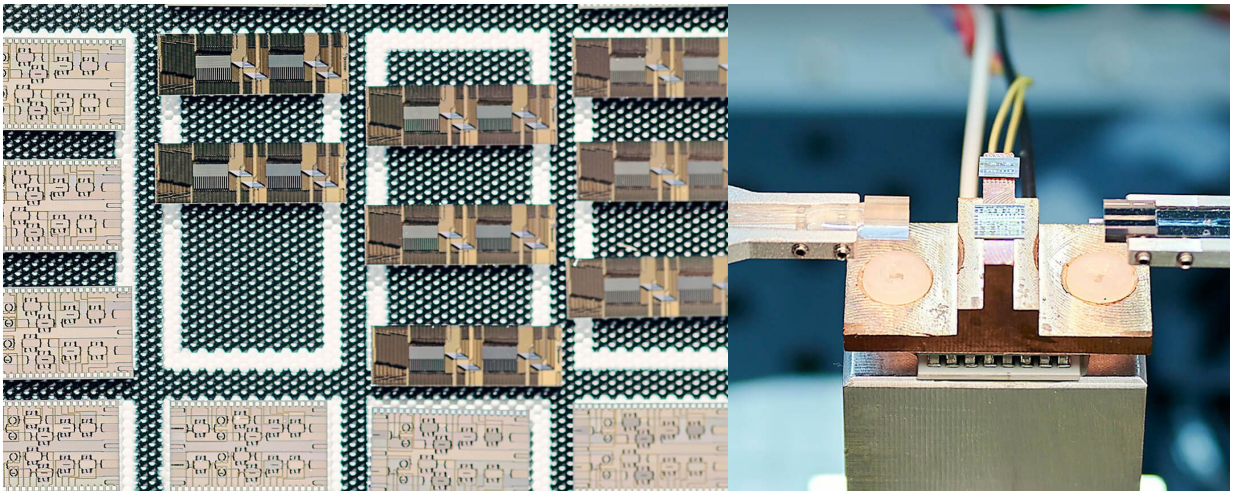


Figure 2. 24 modes photonic chips

Product Description

- **PennyLane**

PennyLane is a Python 3 software framework (Figure 3) for optimization and machine learning of quantum and hybrid quantum-classical computations. PennyLane's core feature is the ability to compute gradients of variational quantum circuits in a way that is compatible with classical techniques such as backpropagation, as fellows.

- Built-in automatic differentiation of quantum circuits.
- Support for hybrid quantum and classical models; connect quantum hardware with PyTorch, TensorFlow, and NumPy.
- Provides optimization and machine learning tools.
- The same quantum circuit model can be run on different backends. Install plugins to access even more devices, including Strawberry Fields, Amazon Braket, IBM Q, Google Cirq, Rigetti Forest, Microsoft QDK, and ProjectQ.

PennyLane can be used for the optimization of variational quantum eigensolvers, quantum approximate optimization, quantum machine learning models, and many other applications. Figure 4 shows a simple example that illustrates the core idea of the framework.

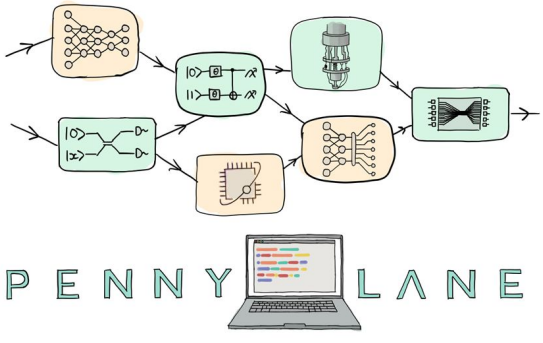


Figure 3. The framework of PennyLane..

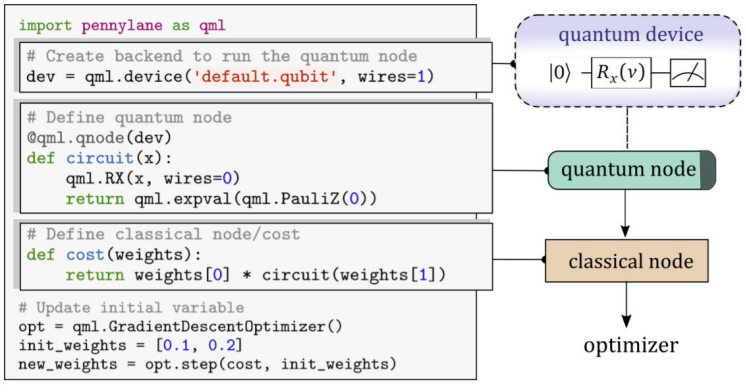


Figure 4. Basic example of a PennyLane program.

Product Description

- **Strawberry Fields**

Strawberry Fields is an open-source quantum programming architecture for light-based quantum computers. Built in Python, Strawberry Fields is a full-stack library for design, simulation, optimization, and quantum machine learning of continuous-variable circuits. The platform consists of three main components: (i) an API for quantum programming based on an easy-to-use language named Blackbird; (ii) a suite of three virtual quantum computer backends, built in NumPy and TensorFlow, each targeting specialized uses; and (iii) an engine which can compile Blackbird programs on various backends, including the three built-in simulators, and - in the near future - photonic quantum information processors.

A pictorial outline of Strawberry Fields' key elements and their interdependencies is presented in Figure 5. Conceptually, the software stack is separated into two main pieces: a user-facing frontend layer and a lower-level backends component. The frontend encompasses the Strawberry Fields Python API and the Blackbird quantum assembly language. These elements provide access points for users to design quantum circuits. These circuits are then linked to a backend via a quantum compiler engine. For a backend, the engine can currently target one of three included quantum computer simulators. When CV quantum processors become available in the near future, the engine will also build and run circuits on those devices.

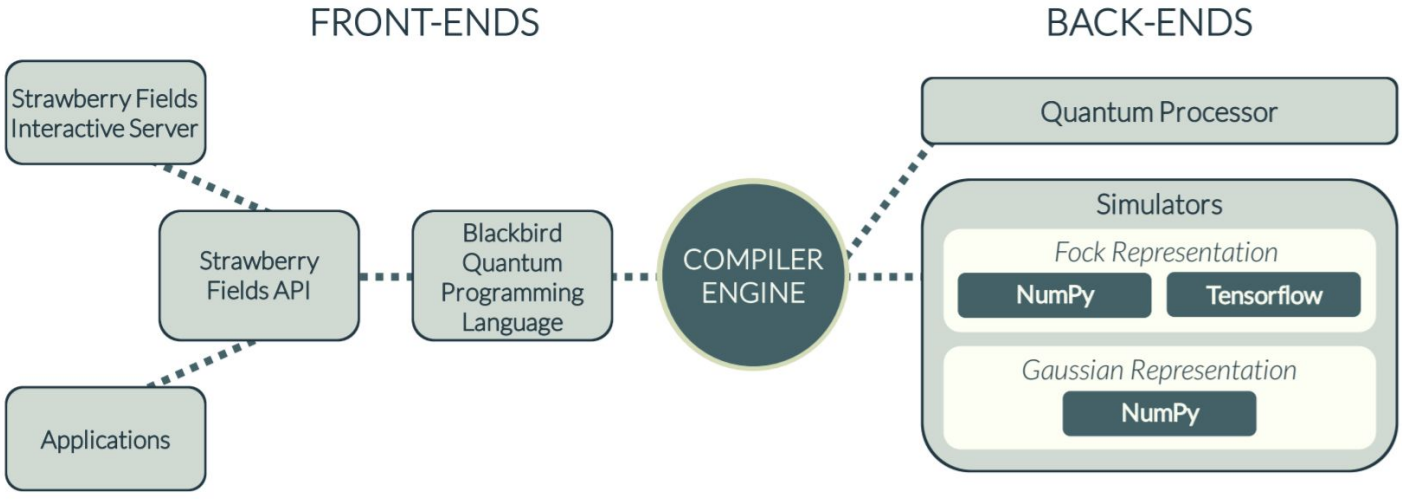


Figure 5. Outline of the Strawberry Fields software stack.

Case Study/White Paper

- **Applications of Near-Term Photonic Quantum Computers: Software and Algorithms**

In this work, researchers introduce the Gaussian Boson Sampling (GBS) applications layer of Strawberry Fields, an opensource Python library for photonic quantum computing. The applications layer is built with the goal of providing users with the capability to implement and test GBS algorithms using only a few lines of code. Specifically, it contains modules dedicated to dense subgraph identification, maximum clique, graph similarity, point processes, and vibronic spectra. Programming of GBS devices, generating samples, and classical post-processing of the outputs are taken care of automatically by built-in functions. The applications layer also provides methods for problem visualization, a collection of pre-generated GBS datasets, and tutorials for first-time users covering each of the algorithms. An overview of GBS algorithms covered in the applications layer is shown in Figure 6.

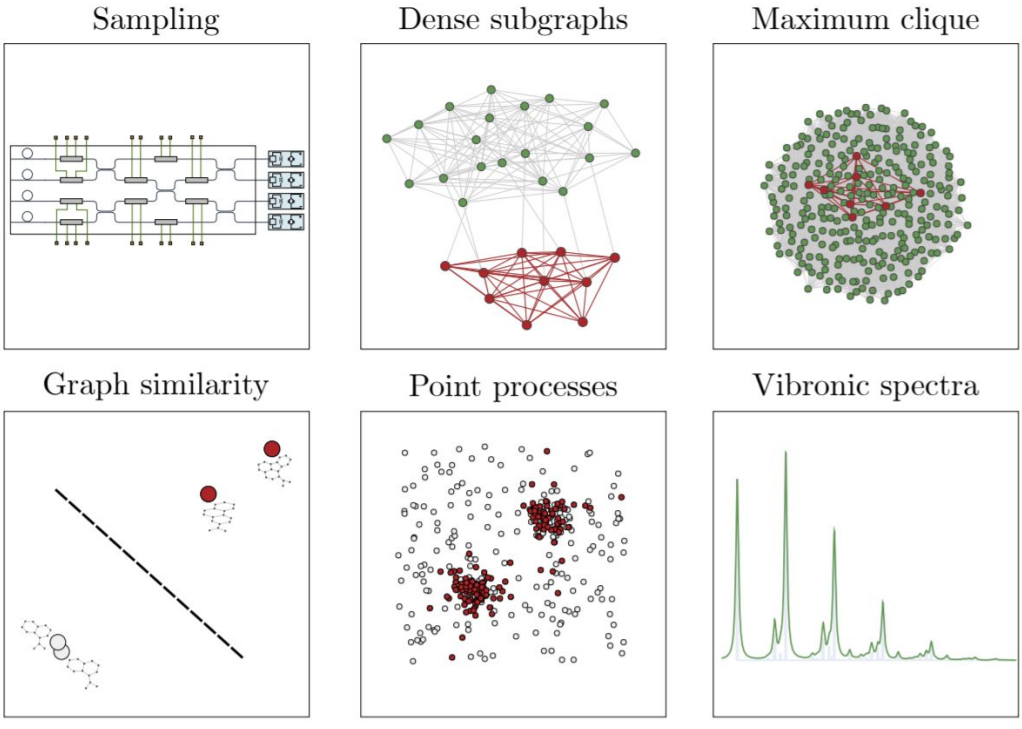


Figure 6. An overview of GBS algorithms contained in the Strawberry Fields applications layer.

Intellectual Property

Patent Name/Title: Systems and methods for nonlinear optical light generation using linearly uncoupled resonators in integrated photonic devices

Patent No: US11003046B2/CA3099435C

Status: Grant

Brief description: A photonic device comprises a plurality of resonators and a plurality of optical channels. Each resonator from the plurality of resonators has a set of resonance frequencies independently selected from a set of resonance frequencies of each remaining resonator from the plurality of resonators. Each resonator from the plurality of resonators lacks substantially any linear coupling between each remaining resonator from the plurality of resonators. The plurality of resonators defines a spatial overlap region between at least two resonators from the plurality of resonators such that nonlinear optical processes are substantially optimized during operation. A plurality of optical channels is operatively coupled to the plurality of resonators. The plurality of optical channels is configured to receive light from the plurality resonators and configured to send light into the plurality of resonators.

Patent Name/Title: Integrated devices for squeezed light generation.

Patent No: US10649307B2

Status: Grant

Brief description: An apparatus includes an optical medium characterized by a third-order nonlinear optical susceptibility. The apparatus also includes a pump light source in optical communication with the optical medium and configured to send a pump light beam to the optical medium. The pump light beam includes a pulsed light beam. The apparatus also includes a drive light source in optical communication with the optical medium and configured to send a drive light beam to the optical medium. The drive light beam includes a continuous wave (CW) light beam. The pump light beam and the drive light beam are configured to generate a signal light beam in a squeezed state of light via spontaneous four-wave mixing in the optical medium.

Intellectual Property

Patent Name/Title: Methods and apparatus for producing highly tunable squeezed light

Patent No: US10809592B2

Status: Grant

Brief description: An apparatus for producing squeezed light includes a substrate and a first beam splitter integrated onto the substrate. The apparatus also includes a Mach-Zehnder interferometer integrated onto the substrate. The Mach-Zehnder interferometer has a first input coupled to a first output of the first beam splitter and a first output coupled to a second output of the first beam splitter.

Investors/Funding Partners

IonQ has raised a total of $82M in funding over 4 rounds. Their latest funding was raised on Jun 16, 2020 from a Series B round. IonQ is funded by 15 investors, including Bessemer Venture Partners, Sustainable Development Technology Canada, OMERS Ventures, DARPA. Cambium Capital Partners and Robert Bosch Venture Capital are the most recent investors.

References

1. https://www.xanadu.ai/
2. https://en.wikipedia.org/wiki/Xanadu_Quantum_Technologies
3. https://www.crunchbase.com/search/principal.investors/field/organizations/num_lead_investors/xanadu-2
4. https://phys.org/news/2021-03-xanadu-programmable-photonic-quantum-chip.html
5. https://www.nature.com/articles/s41586-021-03202-1
6. https://quantum-journal.org/papers/q-2019-03-11-129/
7. https://pennylane.readthedocs.io/en/stable/
8. https://arxiv.org/abs/1912.07634
9. https://patentimages.storage.googleapis.com/4f/d5/e0/8d19c9bea9970d/US11003046.pdf
10. https://patents.google.com/patent/CA3099435C/en?assignee=Xanadu+Quantum+Technologies+Inc.&status=GRANT&sort=new
11. https://patents.google.com/patent/CA3099435C/fr?assignee=Xanadu+Quantum+Technologies+Inc.&status=GRANT&sort=new
12. https://patentimages.storage.googleapis.com/7d/bb/1b/b3f34e1302f384/US10649307.pdf
13. https://patentimages.storage.googleapis.com/fc/e5/93/74b1e1f61c58d2/US10809592.pdf

Trapped ion quantum computation: IonQ

IonQ
Headquarters: College Park, Maryland, United States
Website: https://ionq.com/
Contact: info@ionq.com

TRL 7

Overview

After over 25 years of academic research, IonQ was founded in 2015 by Chris Monroe and Jungsang Kim with $2 million in seed funding from New Enterprise Associates, a license to core technology from the University of Maryland and Duke University, and the goal of taking trapped ion quantum computing out of the lab and into the market. In the following three years, they raised an additional $20 million from GV, Amazon Web Services, and NEA, and built two of the world's most accurate quantum computers. In 2019, they raised another $55 million in a round led by Samsung and Mubadala, and announced partnerships with Microsoft and Amazon Web Services to make their quantum computers available via the cloud.

Product Description

At IonQ's computer's core is a machine that uses a quantum system, like the spin of an electron, to do a very specific type of math. They use a naturally occurring quantum system: individual atoms. These atoms are the heart of their quantum processing units (Figure 1). They trap them in 3D space, and then use lasers to do everything from initial preparation to final readout. It requires counterintuitive physics, precision optical and mechanical engineering, and fine-grained firmware control over a variety of component. Their engineering prototype contains 11 Q-bits.

Figure 1. The IonQ's trapped ion quantum computer.

Product Description

In the engineering prototype, they present an 11-qubit fully-connected, programmable quantum computer in a trapped ion system composed of 13 Yb+ ions. They demonstrate average single-qubit gate fidelities of 99.5%, average two-qubit-gate fidelities of 97.5%, and SPAM errors of 0.7%. The schematic of the hardware is shown in Figure 2.

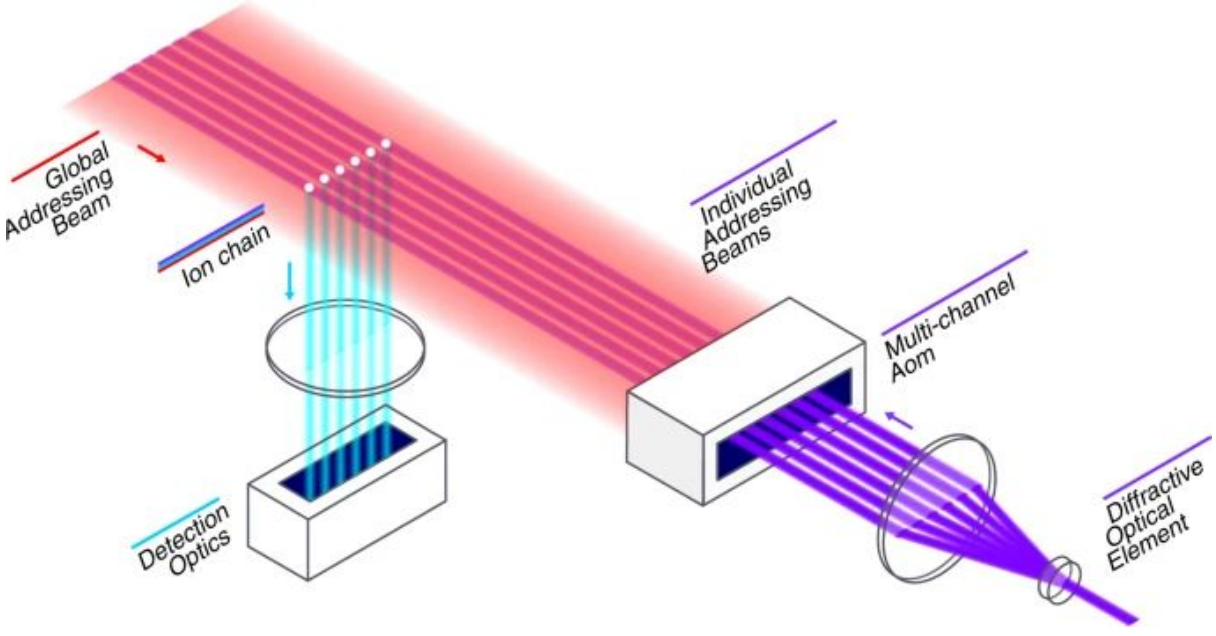


Figure 2. The schematic of the hardware.

The performance benchmarks of IonQ computer are shown in Figure 3.

Figure 3. The performance benchmarks.

Case Study/White Paper

N/A.

Intellectual Property

Patent Name/Title: Quantum logic gate design and optimization

Patent No: US10790807B1

Status: Grant

Brief description: A method of performing a computational process using a quantum computer includes generating a laser pulse sequence comprising a plurality of laser pulse segments used to perform an entangling gate operation on a first trapped ion and a second trapped ion of a plurality of trapped ions.

Patent Name/Title: Methods and apparatuses for two-qubit gate reduction in quantum circuits

Patent No: US11010517B2

Status: Grant

Brief description: The disclosure describes a method, an apparatus, a computer-readable medium, and/or means for reducing two-qubit gates in quantum circuits may include receiving a netlist including information relating to a first plurality of two-qubit quantum gates.

Patent Name/Title: Acousto-optic modulator configurations for quantum processing

Patent No: US11033981B2

Status: Grant

Brief description: Aspects of the invention generally relate to quantum systems, and more specifically, to acousto-optic modulator (AOM) configurations for quantum processing in quantum systems.

Intellectual Property

Patent Name/Title: Quantum compiler

Patent No: US10908885B2

Status: Grant

Brief description: Technologies are described herein to compile a Turing-complete quantum programming language program into a quantum circuit. The techniques described and recited herein include compiling TCQPL source code to generate a quantum circuit by generating a function object ensemble, generating an abstract syntax tree from received source code, and annotating nodes corresponding to the abstract syntax tree with corresponding function objects.

Patent Name/Title: Tunable, mechanically stable radio-frequency amplifier

Patent No: US10756683B2

Status: Grant

Brief description: The invention describes a tunable, mechanically stable radio-frequency (RF) amplifier. It describes an RF amplifier designed to be tunable and mechanically stable to match and maintain stable driving of an ion trap for quantum processing applications. A precision actuator is used to finely tune the RF amplifier input in a repeatable and mechanically stable way to match the ion trap resonance. Low-loss tangent materials and torch annealing techniques are used to make the amplifier section mechanically stable.

Patent Name/Title: Automated optimization of large-scale quantum circuits with continuous parameters

Patent No: US10922457B2

Status: Grant

Brief description: The invention describes the implementation of automated techniques for optimizing quantum circuits of the size and type expected in quantum computations that outperform classical computers. It shows how to handle continuous gate parameters and report a collection of fast algorithms capable of optimizing large-scale-scale quantum circuits.

Intellectual Property

Patent Name/Title: Classical optimizer for quantum chemistry circuit synthesis

Patent No: US10776544B2

Status: Grant

Brief description: It provides a computer-implemented method, system and a computer readable medium storing executable instructions for optimizing a quantum circuit.

Patent Name/Title: Quantum hybrid computation

Patent No: US11087232B2

Status: Grant

Brief description: The invention provides technologies herein to implement quantum hybrid computations. Embodiments include receiving a hybrid program, assigning respective functions corresponding to the hybrid program to either of CPU processing or QPU processing, scheduling processing for the respective functions, initiating execution of the hybrid program, and collating results of the execution of the classical-quantum hybrid program.

Investors/Funding Partners

IonQ has raised a total of $82M in funding over 4 rounds. Their latest funding was raised on Jun 16, 2020 from a Series B round. IonQ is funded by 15 investors, including New Enterprise Associates, GV, Samsung Catalyst Fund, and Cambium Capital Partners, etc. Cambium Capital Partners and Robert Bosch Venture Capital are the most recent investors.

References

1. https://ionq.com/
2. https://www.crunchbase.com/search/principal.investors/field/organizations/num_lead_investors/ionq-inc
3. https://www.nature.com/articles/s41467-019-13534-2
4. https://patentimages.storage.googleapis.com/f5/6b/c1/157ca9dd59b4bf/US10790807.pdf
5. https://patentimages.storage.googleapis.com/8d/1e/9d/92ba5f6f29deb8/US11010517.pdf
6. https://patentimages.storage.googleapis.com/79/2e/66/eaa441b2542394/US11033981.pdf
7. https://patentimages.storage.googleapis.com/1f/88/9b/9355383ee54d9d/US10908885.pdf
8. https://patentimages.storage.googleapis.com/58/d6/ba/b6c18e7a96f685/US10756683.pdf
9. https://patentimages.storage.googleapis.com/81/2a/33/72135649782feb/US10776544.pdf
10. https://patentimages.storage.googleapis.com/f1/3c/bf/f4abfe293684db/US10922457.pdf
11. https://patentimages.storage.googleapis.com/bb/0a/6f/aad92f59653214/US11087232.pdf

Phoenix quantum computing system: Atom Computing, Inc.

Atom Computing, Inc.
Headquarters: Berkeley, California, United States
Website: https://www.atom-computing.com/
Contact: N/A

TRL 5

Overview

Atom Computing builds truly scalable quantum computers out of individual atoms.Atom Computing was founded in 2018 and based in Berkeley, California. The company's quantum computers use quantum mechanical properties of atoms to process information and solve problems beyond the reach of traditional computers, including drug design, computational chemistry, and more. Atom Computing has raised a total of $20M in funding over 2 rounds. The significant investment Atom Computing received from its successful Series A funding came from a number of investors led by Venrock, Innovation Endeavors, and Prelude Ventures. Additionally, the quantum computing start-up is the recipient of three National Science Foundation grants. Together, these have allowed Atom Computing to invest in boosting its strength, forming a team of engineers and quantum physicists that led to the development of the Phoenix quantum computing system.

Product Description

Atom Computing provides cloud access Phoenix quantum computing system to large numbers of very coherent qubits by optically trapping and addressing individual atoms. In addition, the company also builds and creates complicated hardware control systems for use in the academic community.

Phoenix quantum computing system: Atom Computing, Inc.

Product Description

Phoenix is the current solution sounds a bit more like a technology demonstration, but the solution is a 100 atom in a vacuum chamber with what the company calls “optical tweezers.” Then the company’s demonstration manipulates quantum states with lasers. The benefit is that it can achieve greater coherence times versus other solutions. The Phoenix’s quantum processor is shown in Figure 1.

Figure 1. Atom Computing Cover.

Case Study/White Paper

N/A.

Intellectual Property

Indicate any patents the company has patented/applied. Please include:

Patent Name/Title: Scalable neutral atom based quantum computing

Patent No: US10504033B1

Status: Grant

Brief description: The invention provides methods and systems for performing non-classical computations. The methods and systems generally use a plurality of spatially distinct optical trapping sites to trap a plurality of atoms, one or more electromagnetic delivery units to apply electromagnetic energy to one or more atoms of the plurality to induce the atoms to adopt one or more superposition states of a first atomic state and a second atomic state, one or more entanglement units to quantum mechanically entangle at least a subset of the one or more atoms in the one or more superposition states with at least another atom of the plurality, and one or more readout optical units to perform measurements of the superposition states to obtain the non-classical computation.

Investors/Funding Partners

Atom Computing has raised a total of $20M in funding over 2 rounds. Their latest funding was raised on Jul 21, 2021 from a Series A round. Atom Computing is funded by 8 investors, including Innovation Endeavors, Prelude Ventures, etc. Prelude Ventures and Fifty Years are the most recent investors.

References

1. https://www.atom-computing.com/
2. https://www.crunchbase.com/organization/atom-computing
3. https://www.servethehome.com/atom-computing-unveils-phoenix-quantum-computing/
4. https://patentimages.storage.googleapis.com/23/9e/1d/2fd055774c0432/US10504033.pdf
5. https://venturebeat.com/2021/07/21/atom-computing-raising-15m-to-create-phoenix-quantum-computing-system/

Quantum Annealing Technology: NEC

NEC Corporation
Headquarters: Shiba, Minato, Tokyo, Japan
Website: https://www.nec.com/
Contact:

TRL 6

Overview

Founded in 1899, NEC Corporation is a Japanese multinational information technology and electronics corporation, headquartered in Minato, Tokyo. The company was known as the Nippon Electric Company, Limited, before rebranding in 1983 as NEC. It provides IT and network solutions, including cloud computing, AI, IoT platform, and telecommunications equipment and software to business enterprises, communications services providers and to government agencies, and has also been the biggest PC vendor in Japan since the 1980s. NEC was the world's fourth largest PC manufacturer by 1990. NEC was #463 on the 2017 Fortune 500 list. [1]

Product Description

NEC is aiming to establish practical applications for quantum annealing machines, which are a type of quantum computer. Quantum annealing machines can solve combinatorial optimization problems that were previously difficult to solve due to the need for massive amounts of computation. In addition, while awaiting the realization of high-performance quantum annealing machines, NEC is developing annealing simulators based on vector computers that can handle large-scale combinatorial optimization problems. Through such advanced efforts, NEC will continue contributing to value creation for customers. [2]

hrough quantum computing research and development that has continued since the 1990s, NEC has successfully developed advanced technologies such as the world's first solid-state quantum bits. By pressing forward with research, NEC aims to establish practical applications for all-to-all connected quantum annealing machines by 2023.

Product Description

While pending the realization of high-performance quantum annealing machines, NEC is also pursuing research and development aimed at increasing the speed and scale of simulated annealing machines that can handle large-scale combinatorial optimization problems, and simultaneously moving ahead with applicability verification. For these efforts, NEC is making use of its supercomputer technology represented by SX-Aurora TSUBASA to enhance the ability to handle larger-scale combinatorial optimization problems.

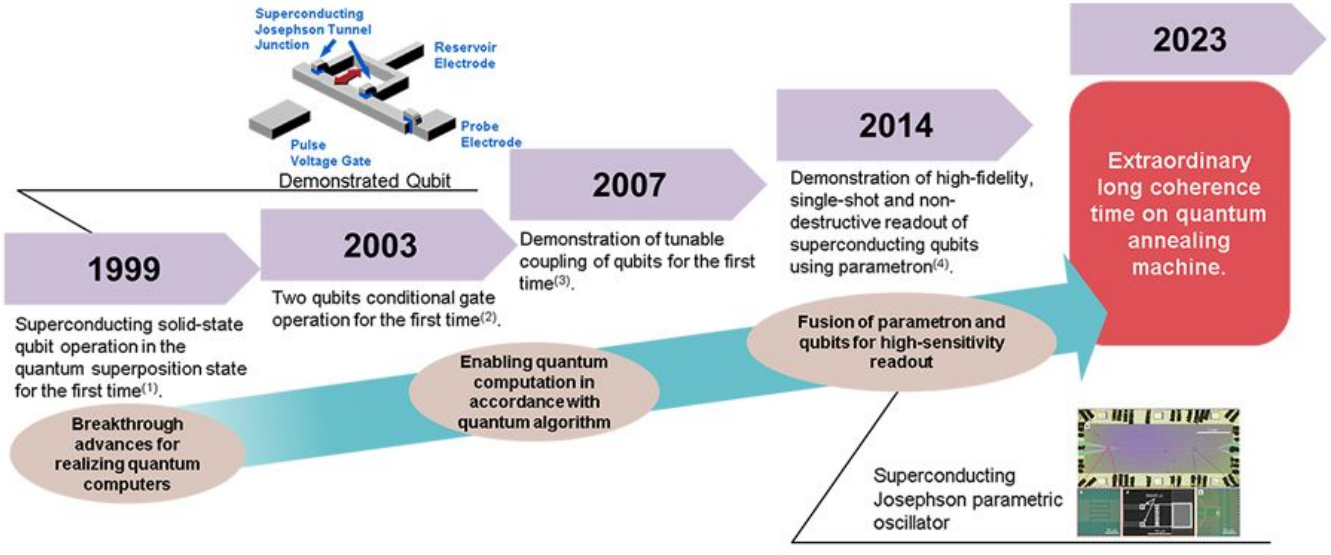


Figure 1. quantum computing research by NEC from 1999 to 2023

Until now, the major technical issues in realizing quantum annealing machines have been to sustain the quantum state for a long time, which is expected to realize high-speed and high-precision quantum annealing calculation.

It is speculated that if the superconducting parametric oscillators that NEC successfully developed and verified in 2014 could be converted for use in quantum annealing, it would enable the quantum state to be sustained for a longer time. By arranging these superconducting parametric oscillators on a plane according to a certain rule, the scale can be expanded while logically maintaining the all-to-all connected architecture.

By employing such methods, it may be possible to solve combinatorial optimization problems at ultra-high speed even when the scale of the target problem is large.

Product Description

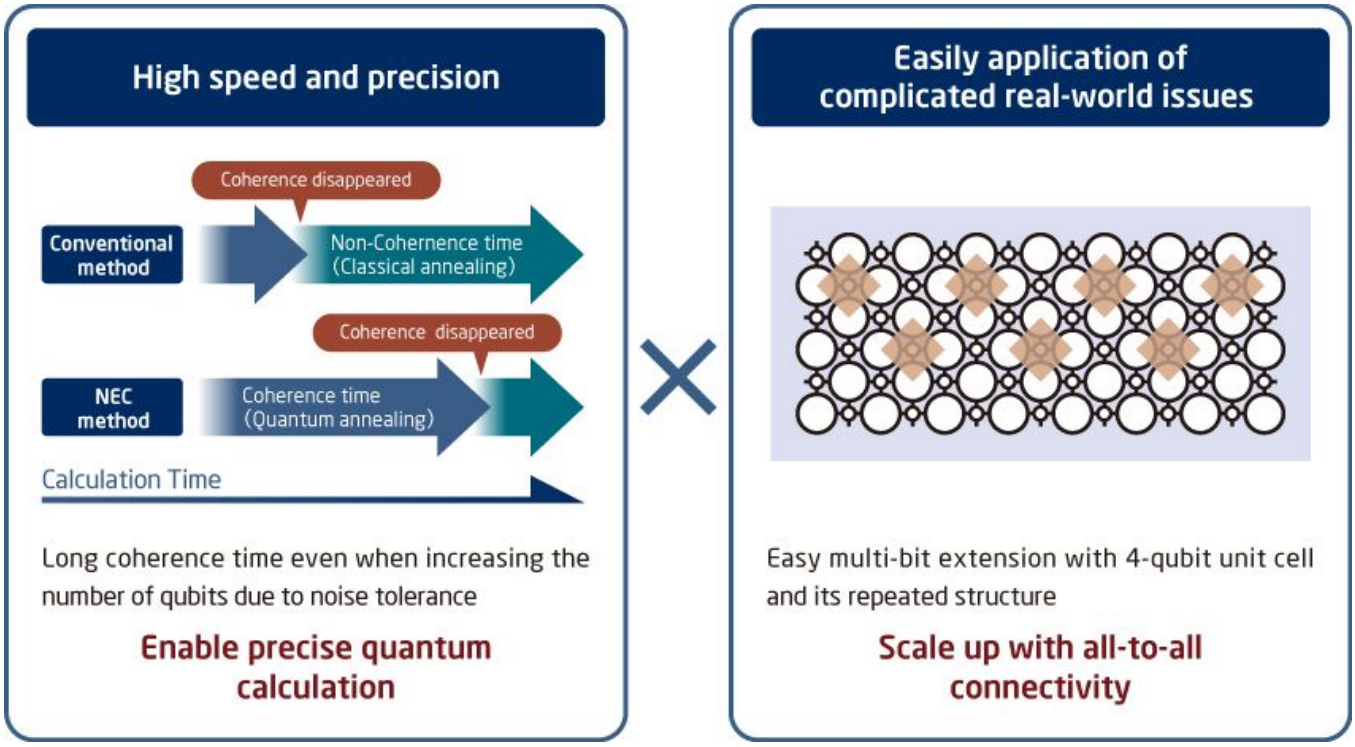


Figure 2. Long quantum coherence time and all-to-all connected architecture enable high-accuracy solutions to diverse combinatorial problems

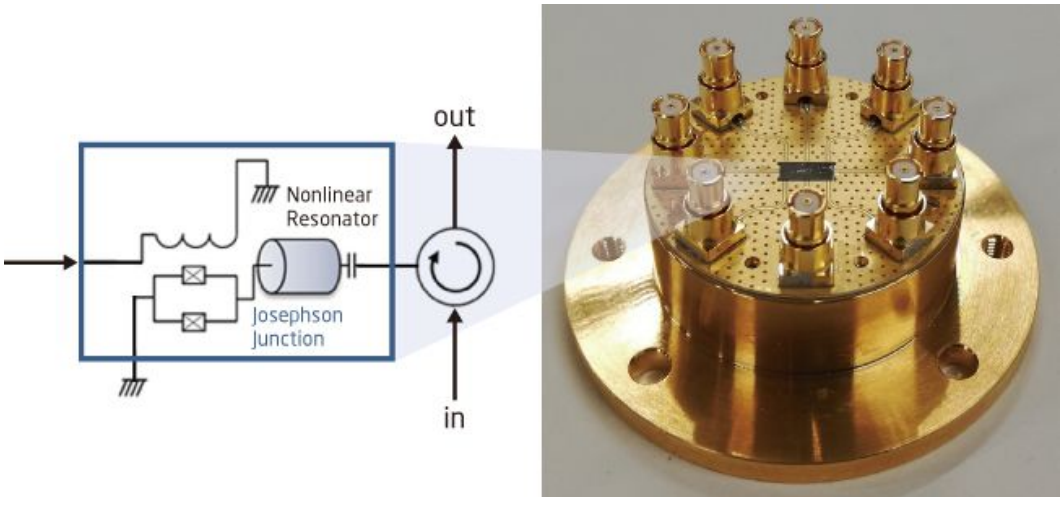


Figure 3. Quantum annealing device and its holder

Product Description

NEDO project

The New Energy and Industrial Technology Development Organization (NEDO) selected NEC Corporation to participate in the "Project for Innovative AI Chips and Next-Generation Computing Technology Development," along with Tokyo Institute of Technology, Waseda University, and Yokohama National University. In addition, the National Institute of Advanced Industrial Science and Technology (AIST) was selected to participate as NEC's joint implementation partner, and Osaka University was selected to participate as NEC's subcontractor. *5

This project is aimed at contributing to the promotion of high-efficiency, high-precision social systems for Society 5.0 by realizing a high-speed, high-accuracy optimization solution platform that can be used to address real problems facing all industrial domains through the integration of quantum annealing machines and common software infrastructure.

Through the research and development of quantum annealing technologies that use superconducting parametron elements, NEC aims to tackle the issues of coherence time and integration, which are two issues pertaining to quantum annealing machines that have the potential to deliver a breakthrough in providing high-speed solutions to combinatorial optimization problems, while also developing elemental technologies that lead to the realization of a quantum annealing machine in Japan.

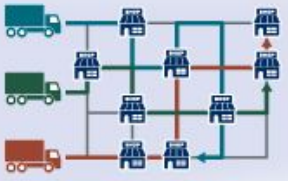
The addition of a completely new calculation principle to cloud computing made possible with quantum annealing machine technology is expected to enable high-speed, high-accuracy solutions to optimization problems that have conventionally relied on approximate solution methods with low accuracy due to time constraints.

Quantum Annealing Technology: NEC

Product Description

Fast resolution of a wide range of social issues

Logistics route optimization, manufacturing process optimization, power network optimization, operational resource optimization, radio resource optimization, investment optimization, drug discovery, material synthesis, etc.



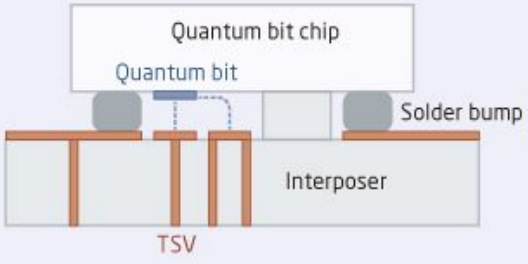
Large scale
- 3D integration
- Low-temperature control electronics

Quantum annealing machine

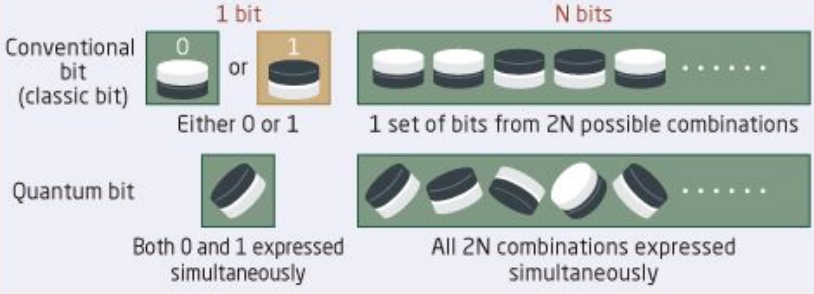
System architecture & performance evaluation
- Machine design optimization
- System performance simulation

Acceleration
- High-coherence quantum bits
- Quantum bit coupling method & theory

Scaling up with 3D integration technology



Accelerating computational performance with quantum bits that take full advantage of quantum effects



Case Study/White Paper

NEC to create hybrid quantum systems alongside D-Wave [3]

In 2020, NEC has announced that it has teamed up with D-Wave to work on systems that combine the former's supercomputers with the latter's quantum annealers. NEC will be using D-Wave's Leap quantum cloud service as the basis for the hybrid services, which are said to have applications in transportation, materials science, and machine learning.

The two companies will apply D-Wave's collection of over 200 early customer applications to six markets identified by NEC, such as finance, manufacturing and distribution. The two companies will also explore the possibility of enabling the use of NEC's supercomputers on D-Wave's Leap quantum cloud service.

NEC and ParityQC Collaborate to Develop Highly-scalable, Practical Quantum Computers [4]

NEC Corporation and ParityQC today announced that they have started collaborating in the field of quantum annealing, a method of quantum computing. ParityQC is a quantum architecture company from Austria which develops blueprints for quantum computers to solve optimization problems based on the ParityQC architecture. NEC will be the first company worldwide implementing the ParityQC architecture for quantum annealing devices.

NEC implementing the ParityQC Architecture, ParityQC's new paradigm on how to solve optimization problems on a quantum computer, into its own superconducting parametron quantum devices. This will pave the way for highly-scalable, practical quantum annealers capable of solving large-scale combinatorial optimization problems such as financial portfolio optimization and manufacturing planning. NEC aims to develop such quantum annealers for practical use by 2023.

The combination of ParityQC's software, which ensures a compact encoding of industry-relevant problems, and the architecture's capabilities allow organizations to benefit by performing larger computations. Realizing quantum devices using the ParityQC architecture provides a path to resolving challenges on the route to practical large scale quantum annealers.

NEC, partially supported by Japan's New Energy and Industrial Technology Development Organization (NEDO), is now developing quantum annealers using superconducting parametron qubits and working on increasing the number of all-to-all connected qubits, with an aim to realize practical machines by 2023. NEC will apply the results of the collaboration with ParityQC to the ongoing project with NEDO.

Intellectual Property

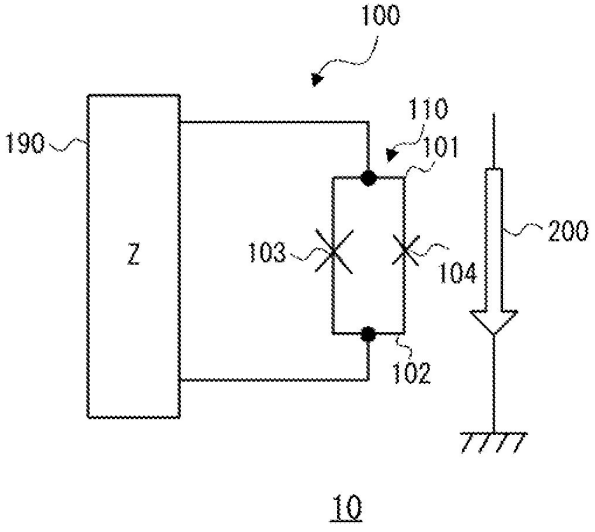
Indicate any patents the company has patented/applied. Please include:

Patent Name/Title: Resonator, oscillator, and quantum computer

Patent No: US20210201188A1

Status: Pending

Brief description: This patent provides a method using a resonator, an oscillator, and a quantum computer that is capable of preventing oscillation conditions for generating a parametric oscillation from becoming complicated. A resonator includes at least one loop circuit in which a first superconducting line, a first Josephson junction, a second superconducting line, and a second Josephson junction are connected in a ring shape, in which critical current values of the first and second Josephson junctions are different from each other.



A resonator comprising at least one loop circuit in which a first superconducting line, a first Josephson junction, a second superconducting line, and a second Josephson junction are connected in a ring shape, wherein critical current values of the first and second Josephson junctions are different from each other.

Intellectual Property

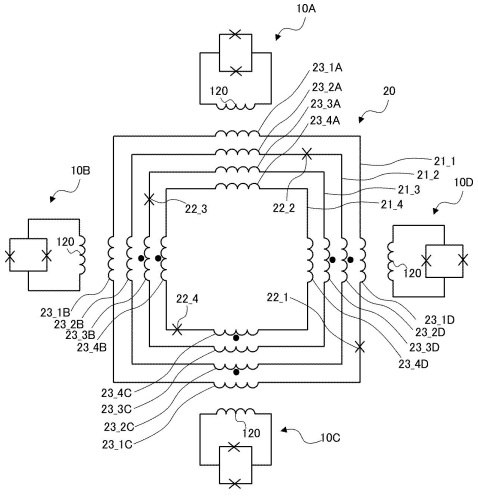
Indicate any patents the company has patented/applied. Please include:

Patent Name/Title: Superconducting circuit and quantum computer

Patent No: WO2021014888A1

Status: Pending

Brief description: This patent provides a superconducting circuit and a quantum computer which are capable of achieving a four body interaction, while suppressing the amount of hardware. A superconducting circuit comprises four superconducting quantum bit circuits, and a coupling circuit inductively coupled with the four superconducting quantum bit circuits. The superconducting quantum bit circuits each represent a quantum bit by assuming a first phase state or a second phase state. If, among the four the superconducting quantum bit circuits, the number of superconducting quantum bit circuits that assume the first phase state is an even number, an interaction term of the Hamiltonian of the superconducting circuit takes a first value. If, among the four the superconducting quantum bit circuits, the number of superconducting quantum bit circuits that assume the first phase state is an odd number, the interaction term takes a second value.



1

1 Superconducting circuit 2 Superconducting circuit 3 Quantum computer 4 Quantum computer 10 Superconducting quantum bit circuit 11 First control unit 12 Second control unit 13 Reading unit 20 Coupling circuit 21 Loop circuit 22 Josephson junction 23 inductor 30 Coupling circuit 31 Loop circuit 32 Josephson junction 33 Incubator 40 Coupled circuit 101 First superconducting line 102 Second superconducting line 103 First Josephson junction 104 Second Josephson junction 105 First part 106 Second part 110 Loop circuit 120 Inverter 130 Loop circuit 151 Loop circuit 152 Loop circuit 153 Loop circuit

Investors/Funding Partners [5]

NEC Corporation has raised a total of $560M in funding over 1 round. This was a Post-IPO Equity round raised on Jun 25, 2020.

NEC Corporation is registered under the ticker TYO:6701

NEC Corporation is funded by Nippon Telegraph and Telephone.

NEC Corporation has made 20 investments. Their most recent investment was on Dec 2, 2020, when NanoBridge Semiconductor raised ¥130M.

NEC Corporation has had 5 exits. NEC Corporation's most notable exits include SpaceTime Insight, Link_A_ Media, and Beceem Communications.

NEC Corporation has acquired 8 organizations. Their most recent acquisition was Avaloq on Oct 5, 2020. They acquired Avaloq for $2.2B.

References

[1] https://en.wikipedia.org/wiki/NEC
[2] https://www.nec.com/en/global/quantum-computing/index.html
[3] https://www.zdnet.com/article/nec-to-create-hybrid-quantum-systems-alongside-d-wave/
[4] https://www.hpcwire.com/off-the-wire/nec-and-parityqc-collaborate-to-develop-highly-scalable-practical-quantum-computers/
[5] https://www.crunchbase.com/organization/nec/company_financials

Digital Annealer: Fujitsu Limited

Fujitsu Limited
Headquarters: Shiodome City Center, Minato, Tokyo, Japan
Website: https://www.fujitsu.com/global/
Contact:

TRL 6

Overview

Established in 1935, Fujitsu Limited is a Japanese multinational information and communications technology equipment and services corporation. Fujitsu was the world's fourth-largest IT services provider by annual revenue, after IBM, Accenture and AWS, in 2018. The hardware offerings from Fujitsu are mainly of personal and enterprise computing products, although the corporation and its subsidiaries also offer a diversity of products and services in the areas of data storage, telecommunications, advanced microelectronics, and air conditioning. It has approximately 132,138 employees and its products and services are available in approximately 180 countries. [1]

Product Description

Digital Annealer is a new technology that is used to solve large-scale combinatorial optimization problems instantly. Digital Annealer uses a digital circuit design inspired by quantum phenomena and can solve problems which are difficult and time consuming for classical computers. [2, 3]

Product Description

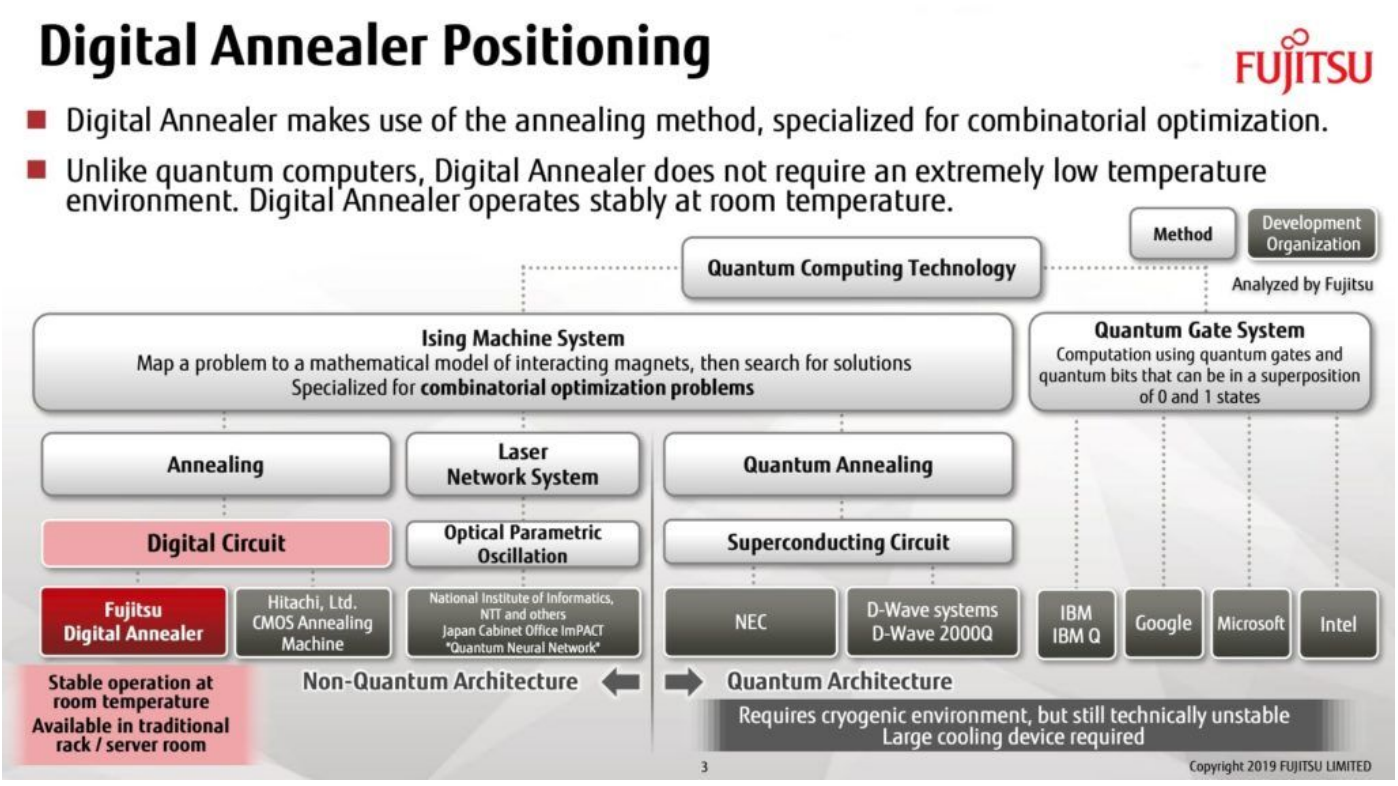


Figure 1. Digital Annealer Position.

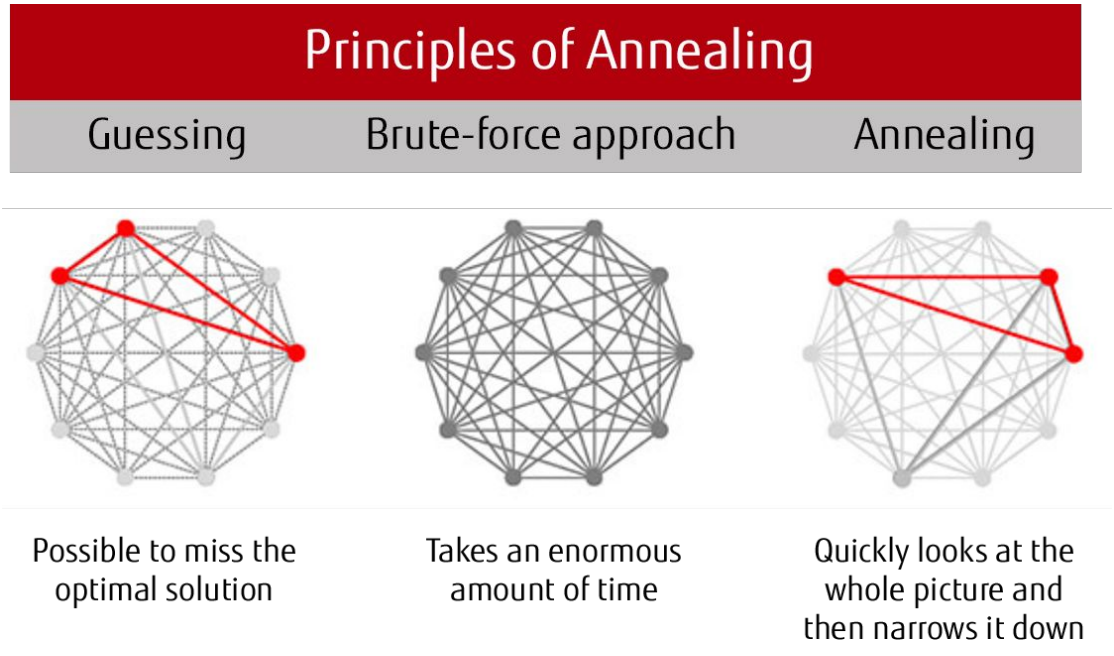
Product Description

Digital Annealer is the a quantum-inspired digital technology architecture, capable of performing parallel, real-time optimization calculations at speed, with precision and on a scale classical computing cannot. [4]

It is a ground-breaking solution inspired by the key characteristics of quantum computing - superposition, quantum tunneling, and entanglement to enable the simultaneous evaluation of a staggering number of potential options and the delivery of lightning-fast insights.

Complex large-scale combinatorial problems can be solved in seconds, which means problems that were previously impossible to solve with classical computers or needed to be processed by brute force, can now be solved in near real-time.

The fully connected architecture enables the free exchange of signals across all bits to rapidly solve large-scale problems. Optimum solutions are found in a process to drive out inefficiencies and improve productivity.

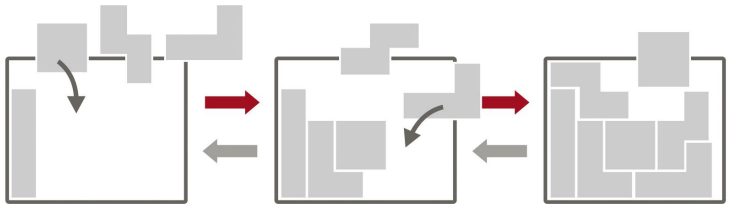


Digital Annealer: Fujitsu Limited

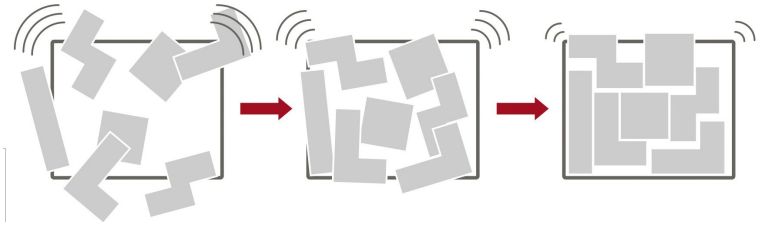
Product Description

In quantum mechanics, which inspired Digital Annealer, the phenomenon known as 'superposition' refers to the simultaneous existence of two different states, 0 and 1. This phenomenon is the basis of 'quantum bits' or qubits, which can dramatically improve calculation speeds. Digital Annealer emulates qubits in a digital circuit.

Among the various quantum computing methods that exist in the market today, Digital Annealer is categorized as an example of an enhanced annealing method, which focuses on solving combinatorial optimization problems and the achievement of successful results with rapid operational capabilities. Unlike classical computers, Digital Annealer does not require programming; instead, simply setting parameters allows calculations to be performed.



Conventional Method:Put the pieces in order; step back if a failure occurs.



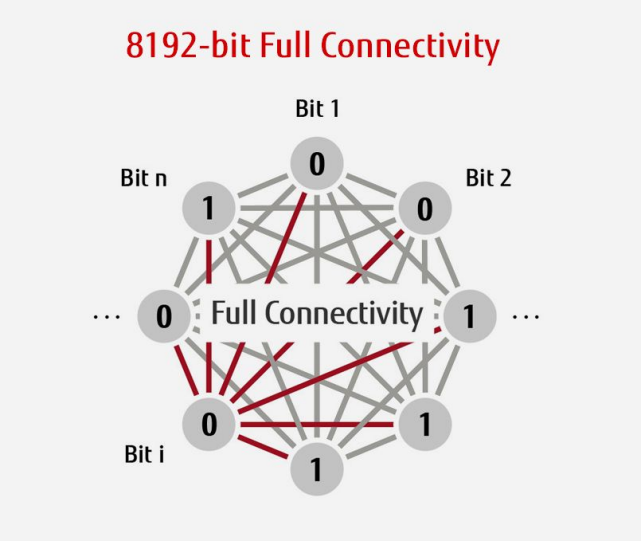
Annealing: Shake, and the pieces fall into place.

Product Description

Digital Annealer features and benefits

- Enormous energy savings with small factor systems running at room temperature in comparison to power consumption intensive quantum computers
- fully coupled 8,192-bit connectivity that allows for large-scale problem solving
- 64-bit (264) gradations allow high accuracy in expressing combinatorial optimization problems

A key challenge in quantum computing is the requirement to contain the system and keep it free from interference, which can require operation at very low temperatures, close to 0 degrees Kelvin. Digital Annealer does not require such a complex environment. With digital circuits, Digital Annealer operates at room temperature – without specific requirements or complex infrastructure.



Real world use cases [2]

- Automotive: Factory Optimization
- Faster Molecular Similarity Search: Drug Discovery
- Banking and Financial Services: Low-Risk Portfolio Optimization
- Distribution: Warehouse Inventory Management
- Retail: Personalized Digital Marketing

Case Study/White Paper [5]

Powered by pioneering quantum -inspired technology, the Fujitsu Digital Annealer delivers unprecedented disruptive new solutions including prioritizing rollout locations for next-generation mobile networks to maximize customer uptake, drug discovery, and molecular simulations. The second generation Fujitsu Digital Annealer is now enabling organizations to make a rapid and affordable leap to solve complex combinatorial optimization problems – enabling breakthroughs in areas such as optimizing manufacturing processes, minimizing traffic congestion and enabling financial services providers to align investment portfolios against ever-changing risk landscapes.

The Digital Annealer's unparalleled compute power can be deployed as a cloud-hosted or on-premises service solution, depending on customer preference. It integrates seamlessly into standard data center operating environments, without the need for complex infrastructure required by regular quantum computers, which are energy-intensive and need expensive cooling systems running at near absolute-zero temperature.

Digital Annealer rapidly solves complex combinatorial problems

Unique simultaneous data processing capabilities allow the Fujitsu Digital Annealer to instantly find the optimal combination of massively complex, previously unmanageable data variables. For example, choosing the most valuable combination of 40 from 100 items to be put in a backpack for a trek could result in a number of possibilities exceeding one million times the number of stars in the universe. With the Digital Annealer, the problem can be solved in less than one second.

However, even this representation of a complex combinatorial problem does not meet the complexity of the types of business challenges the Digital Annealer is designed to handle, which go way beyond what conventional computing can do. One example of a business application is for a bank to optimize a delivery round of money to ATM cashpoint machines, prioritized by amount. The Fujitsu Digital Annealer can instantly work out which ATMs a particular driver should visit, calculate the optimal route to take, while simultaneously suggesting how much to deposit in each machine.

Case Study/White Paper

Digital Annealer finds near-instant answers to business challenges

The Fujitsu Digital Annealer is already delivering huge benefits to customers in multiple industries. In financial services, NatWest bank is leveraging the technology to optimize its mix of liquid assets. The Digital Annealer has enabled the bank to complete highly-complex calculations significantly faster than traditional systems with an even higher degree of accuracy. As a result, NatWest has been able to identify new, profitable investment opportunities while achieving full regulatory risk compliance and at the same time helps to reduce the risk of human error.

In the automotive industry, Fujitsu is working with several leading global manufacturers to trial the Digital Annealer in use cases that include streamlining of shop floor job scheduling, enhancing smart mobility services and refining car design to reduce noise while driving. Furthermore, for a recent reorganization of Fujitsu's own warehousing, the Digital Annealer recommended optimized routing and stock placement. This reduced the distance travelled to collect items by 45 percent, resulting in significant time and cost savings.

Intellectual Property

Indicate any patents the company has patented/applied. Please include:

Patent Name/Title: Automated resolution of NP problems in annealing systems

Patent No: CN112116093A

Status: Pending

Brief description: The present invention relates to automatically solving non-deterministic polynomial time (NP) problems in annealing systems. Methods can be displaying an electronic user interface including a plurality of user-selectable options corresponding to classification information for a plurality of optimization questions;

Investors/Funding Partners [6]

Fujitsu is registered under the ticker TYO:6702

Fujitsu has raised a total of ¥15B across 2 funds:

- ¥10B from Fujitsu Ventures Fund announced on Mar 31, 2021
- ¥5B from Fujitsu Corporate Venture Fund announced on Apr 1, 2015

Fujitsu has made 15 investments. Their most recent investment was on Jun 19, 2020, when Palantir Technologies raised $550M.

Fujitsu has had 1 exit, which was Palantir Technologies.

Fujitsu has acquired 19 organizations. Their most recent acquisition was Symfoni ESM on Aug 1, 2016.

References

[1] https://en.wikipedia.org/wiki/Fujitsu
[2] https://www.nextbigfuture.com/2019/08/fujitsu-has-a-1-million-qubit-quantum-annealer-in-the-lab-and-8192-qubits-commercially-available.html
[3] https://www.fujitsu.com/jp/documents/digitalannealer/services/da-shoukaiEN.pdf
[4] https://www.fujitsu.com/ca/en/services/business-services/digital-annealer/what-is-digital-annealer/
[5] https://www.fujitsu.com/dk/about/resources/news/press-releases/2019/fujitsu-digital-annealer-revolutionizes-problem-solving.html
[6] https://www.crunchbase.com/fund/fujitsu-raised-fujitsu-corporate-venture-fund--663781e7

Quantum Computing: Intel

Intel Corporation
Santa Clara, California, U.S.
Website:
Contact:

TRL 4

Overview

Founded in 1968, Intel Corporation is an American multinational corporation and technology company. Intel supplies microprocessors for computer system manufacturers such as Lenovo, HP, and Dell. Intel also manufactures motherboard chipsets, network interface controllers and integrated circuits, flash memory, graphics chips, embedded processors and other devices related to communications and computing. [1]

Product Description

Quantum computing is a new computing paradigm that harnesses the power of quantum mechanics to deliver the ultimate in parallel computing. It has the potential to tackle problems that conventional computing – even the world's most powerful supercomputers – can't quite handle. While this technology will be transformational for areas such as drug development, logistics optimization, and natural disaster prediction, we need to overcome many challenges – and pass many mile markers – on this incredible journey of discovery before it can be ready for mainstream business adoption and deliver broad societal impact. Intel is advancing its vision of quantum practicality in collaboration with leading industry and academic partners to bring quantum from the lab to commercial reality. Intel's quantum computing research spans the complete stack – from qubits and algorithms research to control electronics and interconnects—required to make practical quantum computers for real-world applications a reality. [2]

Product Description

Intel Labs is producing quantum processors in Oregon and doing system-level engineering that targets production-level quantum computing within ten years. [3]

Work by Intel Labs on quantum computing draws on ongoing internal research, paired with collaborative relationships and investment across global academia and industry, as well as Intel's leadership in silicon fabrication techniques. Research has been ongoing for decades, growing from a theoretical level with thought experiments throughout much of the 20th century, with the first functional hardware components for quantum computing developed only in the past several years.

Followings are the highlights for the quantum computing: [3]

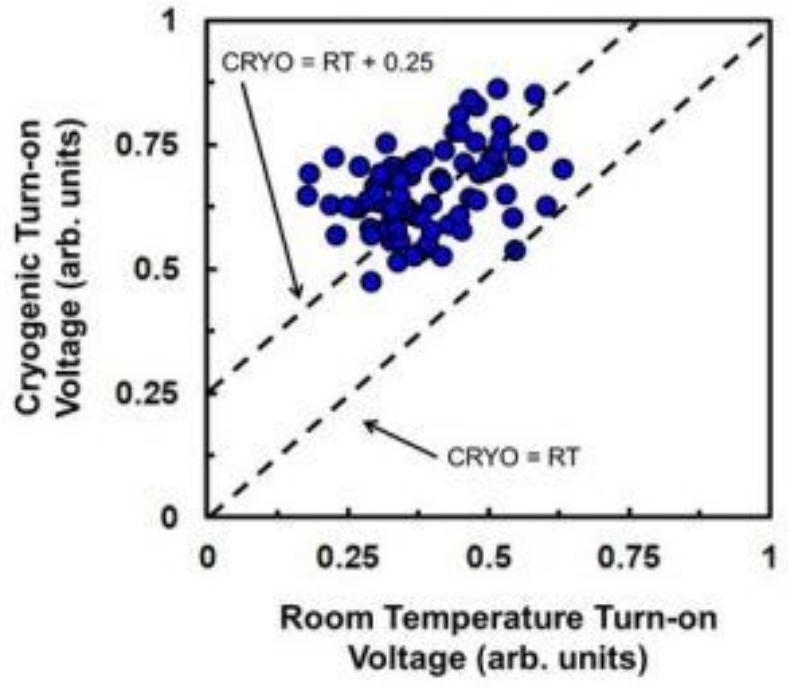
- Quantum computing is expected to power breakthroughs across research disciplines
- The Intel Labs quantum computing ecosystem stretches across industry and academia
- Third-generation Tangle Lake quantum processors contain 49 superconducting qubits
- Ongoing research with QuTech in the Netherlands is solving system-level design challenges
- Spin qubits have potential for reduced thermal constraints, greater stability, and smaller physical size

Case Study/White Paper

Intel Drives Development of Quantum Cryoprober with Bluefors and Afore to Accelerate Quantum Computing [4]

Intel, Bluefors* and Afore* have introduced the first cryoprober, a quantum testing device named the Cryogenic Wafer Prober, developed specifically to speed the development of quantum computing solutions. Intel identified the need for a quantum testing tool to collect more data about quantum chips called "qubits."

In 2019, Intel approached Bluefors, a leader in building cryogen-free dilution refrigerator systems with a strong focus on quantum computing, who partnered with Afore, a leading micro-electro-mechanical systems (MEMS) test solutions provider based in Finland, to design and manufacture the device. The Cryogenic Wafer Prober allows researchers to test qubits on 300mm wafers down to temperatures of a few kelvins, making it a first-of-its-kind testing tool for quantum computing. The first Cryogenic Wafer Prober will be located at Intel's Oregon campus next to several quantum computing dilution refrigerators.



Initial data characterizing multiple Intel qubit devices from the Cryogenic Wafer Prober illustrate the increased voltage required for qubit gate "turn-on" at cryogenic temperatures when compared with room temperatures across a 300mm wafer. (Credit: Intel Corporation)

Case Study/White Paper

Intel's Horse Ridge II Streamlines the Complexity of Quantum Control Systems [5]

At the International Solid-State Circuits Conference (ISSCC) in 2021, Intel reveals technical details for the company's second generation cryogenic quantum control chip: Horse Ridge II.

The new chip draws from thecompany's deep interdisciplinary expertise across Intel's Integrated Circuit Design, Intel Labs and Technology Development teams. A quantum computer operates in the millikelvin range – just a fraction of a degree above absolute zero. But silicon spin qubits – the underpinning of Intel's quantum efforts — have properties that could allow them to operate at 1 kelvin or higher, which would significantly reduce the challenges of refrigerating the quantum system. Intel's cryogenic control research focuses on achieving the same operational temperature level for both the controls and silicon spin qubits.

Horse Ridge II Features

Building on the ability of Horse Ridge I to manipulate the state of the qubit by generating radio frequency pulses — known as qubit drive — Horse Ridge II is a highly integrated system-on-chip (SoC) that introduces additional features, including ability to read the qubit state and simultaneously control multiple qubit gates.

- Horse Ridge II is a highly integrated cryogenic SoC composed of more than 100 million transistors and is implemented using Intel® 22 nanometer (nm) low-power FinFET technology. Its functionality and performance have been verified at 4 kelvins (K).
- Like its predecessor, Horse Ridge II leverages frequency multiplexing to reduce the number of radio frequency (RF)cables for both qubit drive and readout. A digitally intensive architecture with an integrated instruction set enables the cryogenic chip to elegantly integrate into existing quantum control stacks.

Intellectual Property

Indicate any patents the company has patented/applied. Please include:

Patent Name/Title: Quantum computing assemblies

Patent No: US10380496B2

Status: Active

Brief description: This patent includes methods on assembling Quantum computing devices.

Investors/Funding Partners [8]

Intel has raised a total of $12.5M in funding over 2 rounds: $10M from a Post-IPO Equity - Intel round in 2021 and $2.5M from an Intel seed round in 1968.

Intel is registered under the ticker NASDAQ:INTC

Intel is funded by 3 investors. Arthur Rock & Co and Max Palevsky are the most recent investors.

Intel has made 68 investments. Their most recent investment was on Jun 1, 2021, when ZVISION Technologies raised

Intel has made 6 diversity investments. Their most recent diversity investment was on Feb 24, 2016, when CODE2040 raised $1.3M.

Intel has had 32 exits. Intel's most notable exits include North, VMware, and HyTrust.

Intel has acquired 101 organizations. Their most recent acquisition was cnvrg.io on Nov 4, 2020.

References

[1] https://en.wikipedia.org/wiki/Intel
[2] https://www.intel.com/content/www/us/en/newsroom/resources/press-kits-quantum-computing.html#gs.bd4zwb
[3] https://www.intel.ca/content/www/ca/en/research/quantum-computing.html
[4] https://newsroom.intel.com/news/intel-drives-development-quantum-cryoprober-bluefors-afore-accelerate-quantum-computing/#gs.bd4v1k
[5] https://newsroom.intel.com/wp-content/uploads/sites/11/2021/02/Intel-Horse-Ridge-II_Fact-Sheet-650989.pdf
[6] https://www.forbes.com/sites/gilpress/2020/08/17/intel-advances-on-the-road-to-quantum-practicality/?sh=319842b7407c
[7] https://www.businesswire.com/news/home/20200826005282/en/Intel-Collaborates-with-Argonne-National-Laboratory-DOE-in-Q-NEXT-Quantum-Computing-Research
[8] https://www.crunchbase.com/organization/intel/company_financials

Quantum Computing: GE

GE
Headquarters: Boston, Massachusetts, United States
Website: http://www.ge.com/
Contact: https://www.ge.com/in/contact/contact_us.html

TRL 5

Overview

Founded in 1892, General Electric company (10,001+ employees) [7] offers infrastructure and financial services worldwide. It operates in various segments, including power and water, oil and gas, energy management, aviation, healthcare, transportation, appliances and lighting, GE capital, and more. Their research division (GE Research) undertakes new innovative initiatives and they have actively started looking into quantum computing domain. The company is publicly listed [3] and had a revenue of $79.619B in 2020 [4].

Product Description

In October 2018, GE was awarded $12.6 million from DOE for quantum-level cybersecurity of critical power assets.

With a commitment to safeguarding the nation's most critical power assets in the coming age of **quantum computing and networks**, interdisciplinary teams of scientists and engineers from GE Global Research in Niskayuna, New York will lead three projects with the U.S. Department of Energy (DOE) to develop advanced cyber-protection technologies that detect, locate, and neutralize attacks on critical power systems and assets.

GE scientists are aiming to build the world's first industrial immune system that can detect, locate, and neutralize cyber threats just like the human immune system detects and acts to neutralize viruses that infect the body.

GE has been actively filing patents in the quantum computing domain, as of date, the company has **2798 patents** assigned to its name in the field of quantum computing.

Case Study/White Paper

IonQ and GE Research partner to explore how quantum computing could impact risk management [5]

On 23rd September 2021, IonQ, Inc., a leader in quantum computing, announced an initiative in partnership with GE Research to explore the impact of quantum computing and IonQ's quantum computers in the pivotal field of risk analysis. The initiative is expected to lay the groundwork for risk management across key sectors including finance, government and others.

"Quantum computing has the potential to accelerate disruptive innovation for many industries," ***said Dave Vernooy, a Senior Executive and Digital Technologies Leader at GE Research.*** *"A big focus for us is finding ways to make quantum real across our industries. We can do this by collaborating with leading quantum computing vendors such as IonQ to show how quantum-based approaches can help organizations better model risk and its impacts, and we're excited to see how this work can be extended into classification, machine learning and network partitioning."*

Intellectual Property

Patent Name/Title: System and method for detection of rare failure events [6]

Patent No: US9928131B2

Status: Granted in March 2018.

Brief description:

A method includes generating a system model representative of a socio-technical system having a plurality of system parameters. The method further includes selecting one or more essential system parameters from the plurality of system parameters. The method also includes determining a probability of the rare event using a variance reduction technique based on a plurality of particles obtained from the at least one hyperbox. The probability of the rare event is representative of a performance of the socio-technical system. It may be noted that the variance reduction may also be performed using other techniques such as a quantum computing based optimization technique. In another embodiment, the variance reduction is performed by a combination of the Interacting Particle System (IPS) technique and the quantum computing based technique.

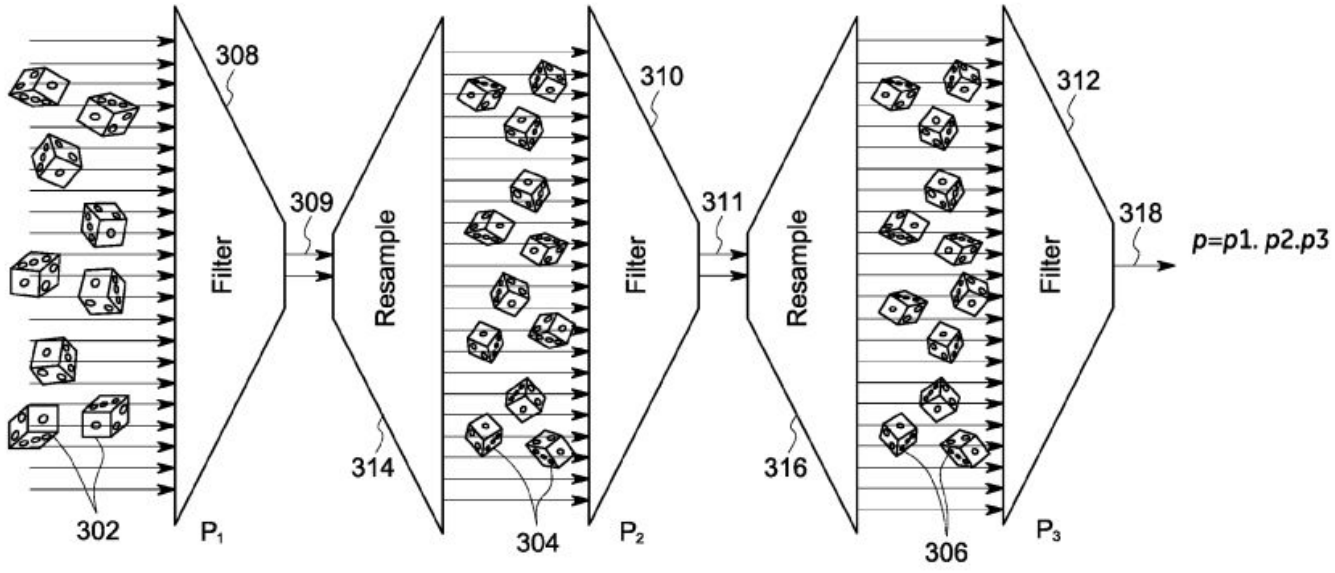


FIG. 3 from the patent illustrates a schematic of an Interacting Particle System (IPS) used for statistical simulation of a rare event

Investors/Funding Partners

- General Electric (GE) has raised a total of $2.2M in funding over 2 rounds. Their latest funding was raised on Dec 7, 2017 from a Grant round.
- General Electric (GE) is registered under the ticker NYSE:GE.
- General Electric (GE) is funded by Massachusetts Clean Energy Center.
- General Electric (GE) has made 42 investments. Their most recent investment was on Sep 14, 2018, when Crowntech Photonics raised
- General Electric (GE) has made 3 diversity investments. Their most recent diversity investment was on Jun 16, 2015, when SunEdison raised $402.5M.
- General Electric (GE) has had 13 exits. General Electric (GE)'s most notable exits include SunEdison, Quirky, and A123 Systems.
- General Electric (GE) has acquired 30 organizations. Their most recent acquisition was IQP Corporation on Jul 30, 2017.

References

1. https://www.ge.com/research/newsroom/ge-research-awarded-126-million-us-department-energy-develop-quantum-level-cybersecurity
2. https://www.windpowerengineering.com/ge-awarded-12-6-million-from-doe-for-quantum-level-cybersecurity-of-critical-power-assets/
3. https://www.crunchbase.com/organization/general-electric
4. https://www.ge.com/sites/default/files/GE_Company_Overview_September_2021.pdf
5. https://www.hpcwire.com/off-the-wire/ionq-and-ge-research-partner/
6. http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&p=1&u=/netahtml/PTO/srchnum.html&r=1&f=G&l=50&d=PALL&s1=9928131.PN.
7. https://www.linkedin.com/company/ge/about/

IBM Quantum Network: IBM

IBM
Headquarters: Armonk, New York, USA
Website: https://www.ibm.com/
Contact: ews@us.ibm.com

TRL 6

Overview

IBM is an IT technology and consulting employer, offering technology innovation, consulting services predictive analytics, software development, and systems management [1]. The company was founded in 1906 and currently has more than 10000 employees, with ana anual revenue of $77.87B [2].

Product Description

IBM is working with Fortune 500 companies to advance in quantum computing technology. These companies access, through IBM cloud, to IBM quantum technology, and have access to proprietary Qiskit extensions (a quantum programming framework) [3].

The IBM Quantum Network has three main areas of focus:

- Accelerate research: organizations and university participating in the program have the ability, knowledge and tools to collaborate and also advance individually advance.in the quantum computing field.
- Develop applications: by using IBM's quantum systems through the IBM cloud, the companies participating in the program can access to proprietary Qiskit extensions. According to IBM, "Qiskit is an open source, modular, and extensible quantum programming framework".
- Educate and prepare: companies and academia receive training and support from IBM experts in the quantum computing field, so professionals can build new skills and capitalize quantum computing.

Product Description

The IBM quantum computing capabilities are the following:

- 750B+ quantum circuits, which run on IBM quantum software.
- 64,128 total quantum volume across the cloud of IBM
- 50 available qubits in the IBM quantum machines

Additionally, IBM offers IBM Quantum System One, an on-site quantum computer with 27 qubit Falcon processor, and a quantum volume of 32. In addition, IBM plans to release a 1,000-plus qubit device, called IBM Quantum Condor, at end of 2023.The company claims their IBM Quantum System One is “upgradeable to their 65 qubit Hummingbird processor” (which has 8:1 readout multiplexing, that is, the readout signals are combined from eight qubits into one), “and 127 qubit Eagle processor when they become available in late 2023”. This last processor will surpass the 100-qubit milestone [10, 11].

They also offer IBM Quantum Services, which provide IBM Cloud access to several systems. They claim there currently are over 20 systems available adjusted to their client needs, and several of them are open source [10].

In 2022, IBM plans to release the 433-qubit IBM Quantum Osprey system. They claim it will be more efficient, and the cryogenic control will enable to scale up the processors without sacrificing performance. In 2023, they plan to release the 1,121-qubit IBM Quantum Condor processor, which they claim it will be more efficient, it will lower critical two-qubit errors, and run longer quantum circuits [11].

To make all those advances, IBM team have introduced a 10-foot-tall and 6-foot-wide “super-fridge,” which is a dilution refrigerator designed by the team, keeping in mind they would like to achieve a million qubit system, thus, linking dilution refrigerators, each holding one million qubits.

Product Description

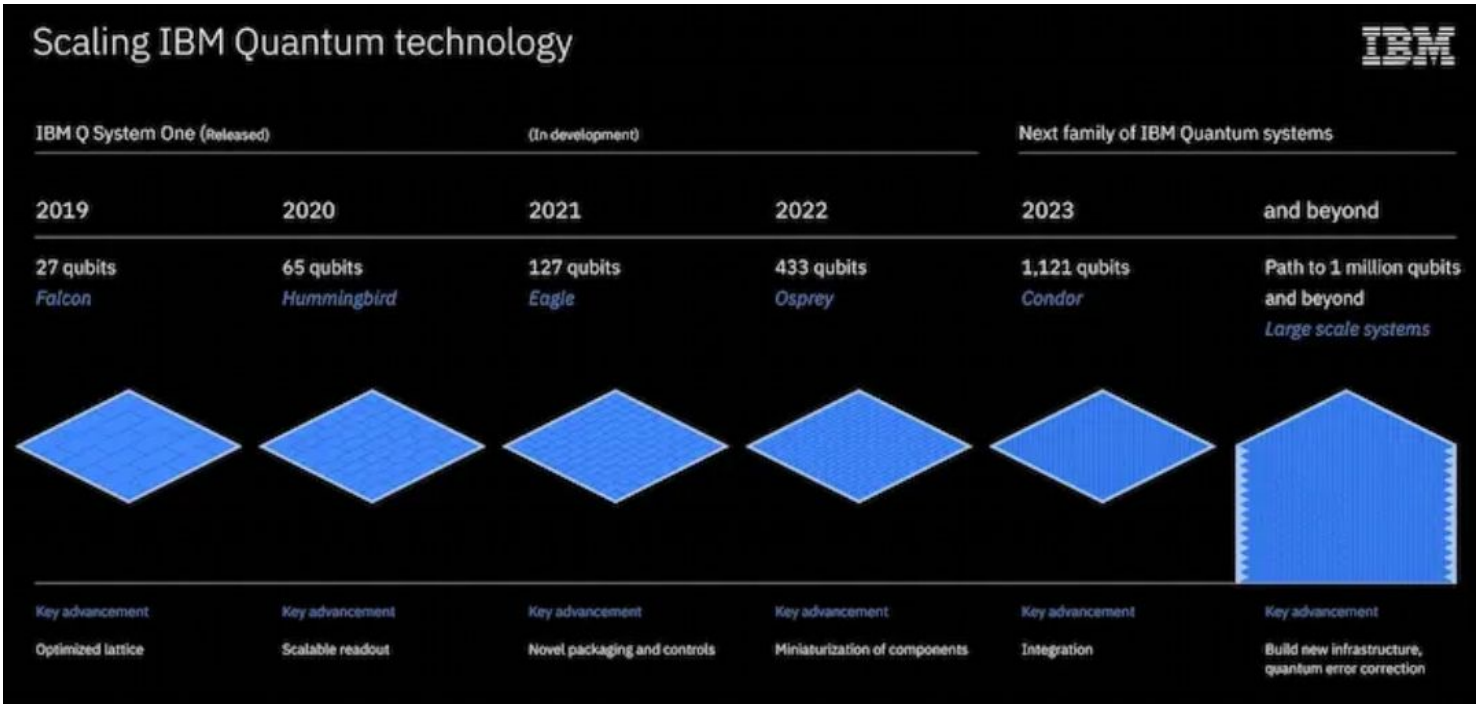


Figure 1: IBM's roadmap for scaling quantum technology

Case Study/White Paper

Mercedes-Benz bets on quantum to craft the future of electric vehicles [4]

Mercedes-Benz is trying to advance electrical cars batteries, by partnering with IBM and using quantum computing.

For that, they think energy dense batteries, made of lithium and sulfur, would work best. To develop the hypothetical batteries, they will simulate molecular properties and behaviors on a computer, so they can explore and analyze different options before testing the physical prototypes.

Qubits enable to represent more information than a classical bit. This allows to double the performance and boost the ability to run algorithms. This way, IBM claims a new electrical car battery would be ready within 3 years, instead of a decade.

ExxonMobil & IBM Explore Quantum Algorithms to Solve Routing Formulations [12]

IBM and ExxonMobil have partnered to explore more efficient maritime inventory routes by using quantum devices, saving energy and time in transportations. They have done so with Mixed Integer Programming (MIP) and Quadratic Unconstrained Binary Optimization (QUBO). The mathematical formulations represent the routing decisions such as routes traveled, possible movements between customer/port locations, order in which each customer/port location is visited in a vehicle route.

ExxonMobil claims that now they have better perspective of modelling possibilities, quantum solvers available, and feasible alternatives for routing problems.

IBM Quantum's Partnership with CERN [13]

CERN is currently searching for the origins of the universe, and has partnered with IBM to use quantum computing and try to detect spot connections and hidden features of the universe. CERN is using the 23 available IBM computing devices and their open sources, to analyze the Higgs boson.

The algorithm used is known as a quantum support vector machine (QSVM) and has been shown to perform as good as CERN's algorithms.

Case Study/White Paper

IBM partners with JSR, Mitsubishi Chemical, and Keio University to explore new forms of light with quantum computing [14].

This collaboration seeks to discover new molecular structures to develop new Organic LED materials, which are flexible, scalable and enable to produce more light with less energy.

Researchers are performing calculations on atom's orbitals (how they're spaced and how many electrons are in each in a given state), to find new molecules, and for that they are using different algorithms in order to come up with accurate analyses of the molecules in searched, their reactions and interactions.

Mitsubishi Chemical conducts battery R&D at the speed of change [15].

Similar to Mercedes-Benz collaboration, researchers at Mitsubishi are studying how to improve lithium batteries. For that, they are analyzing the mechanism for lithium superoxide rearrangement, which is a key chemical step in lithium-oxygen batteries.

They are using IBM quantum computing to model and simulate the chemical reaction to create an accurate representation of what is happening inside the battery. The algorithms will enable them to understand lithium-oxygen's potential as an energy source.

Intellectual Property

Patent Name/Title: **Quantum Circuit Optimization Using Machine Learning** (2020) [5].

Patent No: 0342344 A1

Status: Filing

Brief description: The patent describes a quantum computing system configuration. The methods includes a data processing environment and different quantum circuits.

Patent Name/Title: **Quantum Computing Device Design** (2019) [6].

Patent No: 149503 A1

Status: Filing

Brief description: The patent describes a methodology to develop a quantum device that includes a simulation component and a modeling component.

Patent Name/Title: **Array of quantum systems in a cavity for quantum computing** (2014) [7].

Patent No.: 2506077 A

Status: Inactive

Brief description: The patent describes a device that includes several quantum systems, enclosed by electromagnetically conducting walls.

Patent Name/Title: **Quantum Pulse Optimization Using Machine Learning** (2019) [8].

Patent No: 0004707 A1

Status: Filing

Brief description: The patent describes machine learning techniques to optimize quantum pulsing, by suing a classical processor.

Investors/Funding Partners

IBM has multiple partners and Fortune 500 companies collaborating with quantum computing. In addition. IBM also invests in other companies [9].

References

1. https://www.crunchbase.com/organization/ibm
2. Revenue
3. https://www.ibm.com/quantum-computing/ibm-q-network/
4. https://www.ibm.com/case-studies/daimler/
5. https://worldwide.espacenet.com/searchResults?query=US+20200342344+A1
6. https://worldwide.espacenet.com/searchResults?query=WO+2019149503+A1
7. https://worldwide.espacenet.com/searchResults?query=GB+2506077+A
8. https://worldwide.espacenet.com/searchResults?query=US+20210004707+A1
9. https://www.ibm.com/investor
10. https://www.ibm.com/quantum-computing/systems/
11. https://research.ibm.com/blog/ibm-quantum-roadmap
12. https://www.ibm.com/case-studies/exxonmobil/
13. https://www.ibm.com/case-studies/cern/
14. https://www.ibm.com/case-studies/jsr-mitsubishi-keio/
15. https://www.ibm.com/case-studies/mitsubishi-chemical/

Google Quantum AI: Quantum Processors

Google
Headquarters: Mountain View, California, USA
Website: https://quantumai.google/
Contact: google@google.com

TRL 6

Overview

Google is a California based multinational, founded in 1998 which currently has more than 10000 employees, $36.1M in total funding amount and $146.9B in annual revenue [1, 2]. Google offers internet-related services, and currently, the company offers quantum computing tools for researchers.

Product Description

Google offers remote access to its quantum computer, processors and simulators, to scientists developing algorithms. They offer Cirq, an open source framework to program quantum computers; and a hardware to build scalable quantum computers [3]. Both their software and hardware are designed to develop new algorithms, that enable to solve near-terms practical applications.

- Cirq: this is a Python software library to write, manipulate and optimize quantum circuits, and the run the on quantum computers. This technology provides abstractions to deal with intermediate-scale quantum computers.
- Hardware: they enable to build scalable quantum computers to solve problems

Google has opened a Quantum AI campus in Santa Barbara. where the quantum data center is located, and they fabricate prototypes and perform quantum research [4].

Product Description

The processors offered by Google are the following:

- The Bristlecone processor preserves the qubit linear array technology, and uses the same infrastructure for coupling, control, and readout. The new feature is that it is scaled to a square array of 72 qubits, which they claim facilitates quantum algorithm development [11].
- Sycamore processor is a 54 qubit-device that is claimed to be fast, and provide high-fidelity quantum logic gates. The processor is able to performed target computation in 200 seconds and it can develop an algorithm from a small dictionary of elementary gate operations. It is comprised of two-dimensional grid, where each qubit is connected to four other qubits. This provides the chip with enough connectivity, so the qubit states interact throughout the entire processor quicker. The processor is fully programmable and is able to run general-purpose quantum algorithms [12]

Figure 1: Quantum computing processors offered

Case Study/White Paper

Quantum supremacy using a programmable superconducting processor [5].

This research article describes the Sycamore processor, which is claimed to take " 200 seconds to sample one instance of a quantum circuit a million times". The company claims this is an enormous increase in speed, compared to known classical algorithms. This processor has programmable superconducting qubits, to create quantum states on 54 qubits. This would correspond to a computational state-space of dimension 253 (about 1016).

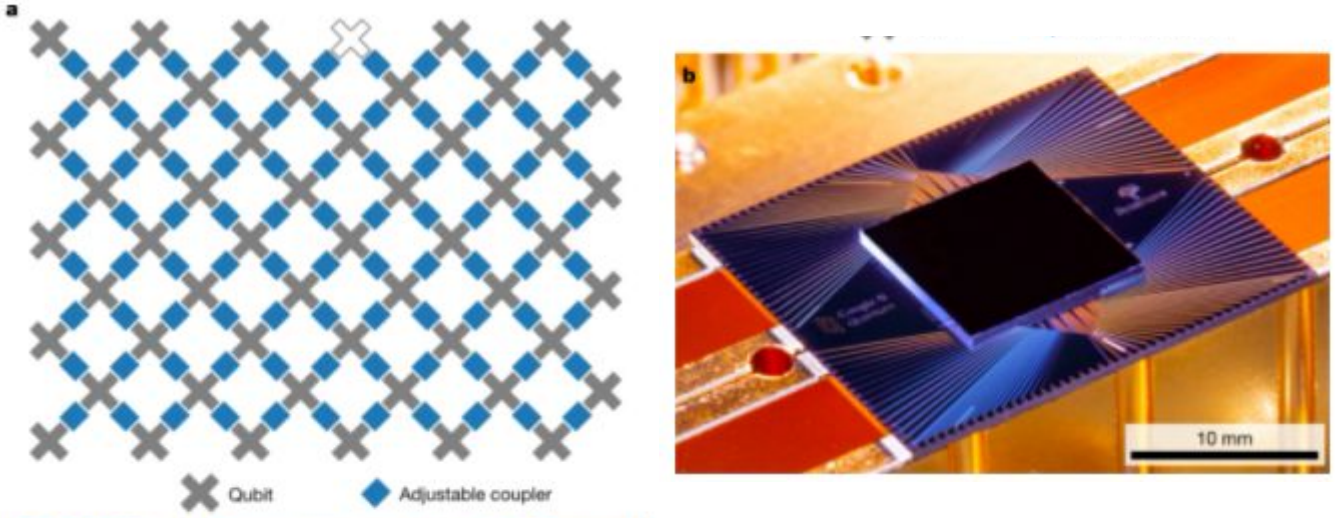


Figure 2: Layout of processor, showing a rectangular array of 54 qubits (grey), each connected to its four nearest neighbours with couplers (blue). The inoperable qubit is outlined.

For the quantum circuit generation (Figure 3), researchers applied single-qubit gates on all qubits, randomly chosen from (square root X, square root Y and square root Z), and then two-qubits gates in pairs of qubits. A single entangled state was created, to minimize the circuit depth during the supremacy circuits creation.

They estimated the supremacy regimen by using three variations to decrease complexity of the circuits. They also removed a slice of two-qubit gates in patch circuits, so they splitted the circuit in two patches, spatially isolated and non-interacting. Then, they computed the total fidelity as the product of the patch fidelities. They also removed a fraction of the two-qubit gates in the elided circuits, so the patches could be entangled. Lastly, they run full verification circuits with the same gate counts as their supremacy circuit, although they used a different pattern for the sequence of two-qubit gates.

Case Study/White Paper

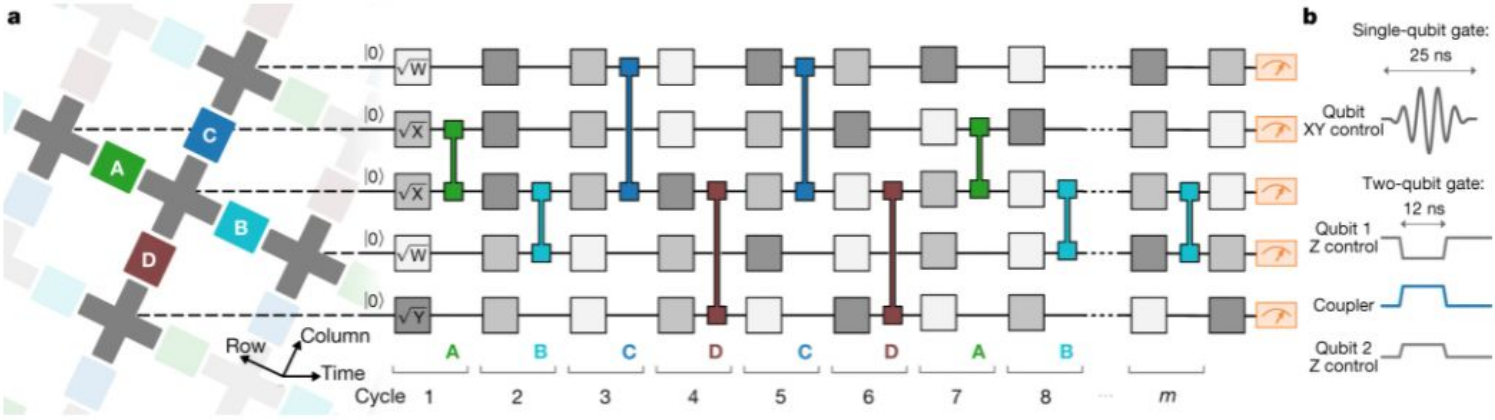


Figure 3: :Example quantum circuit instance used in their experiment. Every cycle includes a layer each of single- and two-qubit gates.

They checked that the patch and elided versions of the verification circuits indeed had the same fidelity as the full verification circuits up to 53 qubits. Predicted patch and elided fidelities also showed agreement with the fidelities of full circuits, regardless of the differences in computational complexity, thus demonstrating that elided circuits can be used to estimated fidelity of more complex circuits. Fidelity can be verified up to circuits that have 53 qubits and a simplified gate arrangement. Random circuit performance at 0.8% fidelity, takes one million cores 130 seconds, which corresponds to a million-fold speedup of the quantum processor relative to a single core.

Lastly, they measured the FXEB for 53-qubit patch and elided versions of the full supremacy circuits, with more depth. They collected $N_s = 30 \times 106$ samples in 10 circuit instances for the largest circuit with 53 qubits, and they obtained $FXEB=(2.24\pm0.21)\times10-3$ for the elided circuits. They concluded they average fidelity is greater than 0.1%

Case Study/White Paper

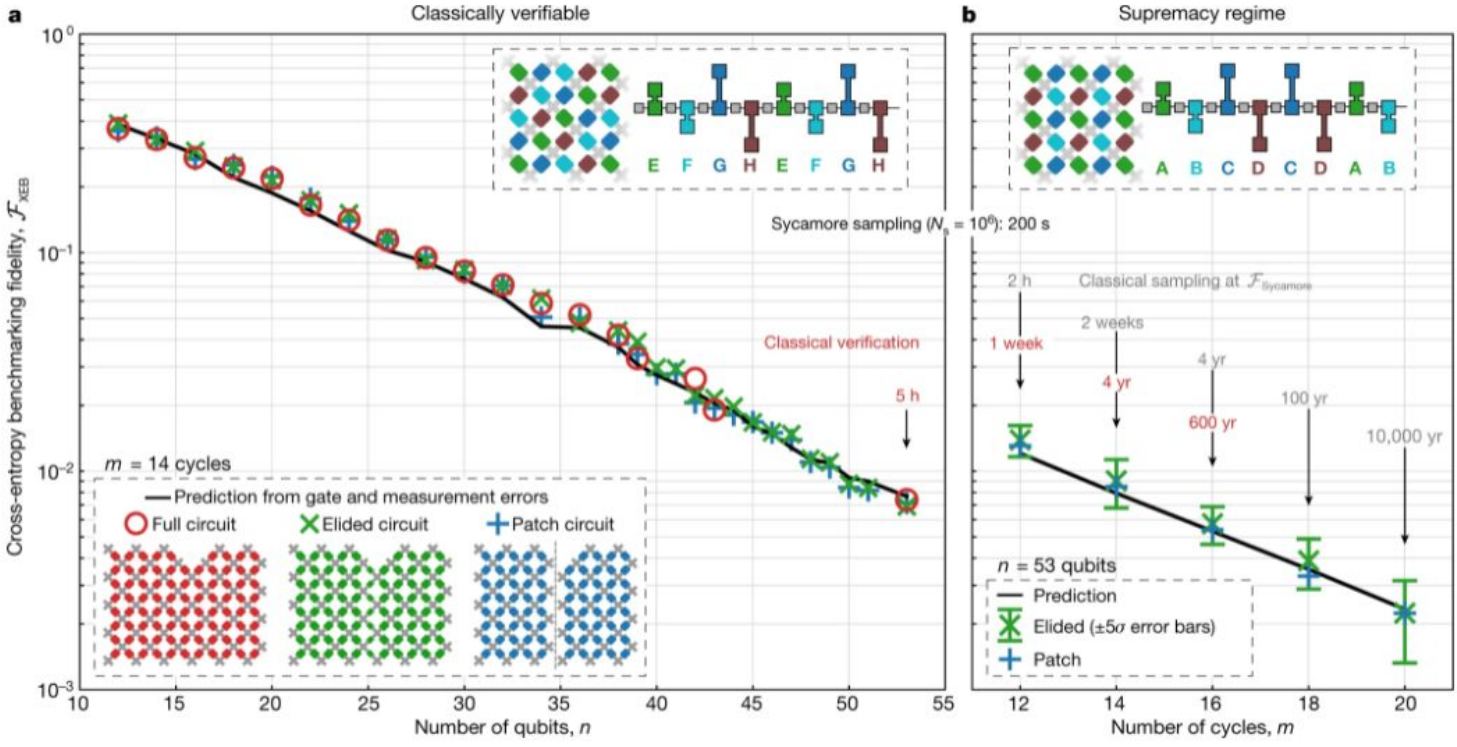


Figure 4: :Demonstrating quantum supremacy

Intellectual Property

Patent Name/Title: **Chips including classical and quantum computing processors** (2015) [6]

Patent No: 230964 B2

Status: Filing

Brief description: The patent describes a device that includes a substrate, a classical computing processor, a quantum computing processor and one coupling components between the classical computing processor and the quantum computing processor.

Patent Name/Title: **Bayesian Quantum Circuit Fidelity Estimation** (2020) [7]

Patent No: 263302 A1

Status: Filing

Brief description: The patent describes a method to estimate the fidelity of a quantum system. The method includes random quantum circuits definition, set of experimental data generation, polarization parameter estimation and fidelity determination.

Patent Name/Title: **Nonlinear Calibration of a Quantum Computing Apparatus** (2017) [8]

Patent No: 3062793 A1

Status: Examination

Brief description: The patent describes a method for non linear calibration of a quantum device. The patent claims the model is adjusted to determine a revised physical model.

Patent Name/Title: **Signal Distribution for a Quantum Computing System** (2020) [9]

Patent No: 027779 A1

Status: Filing

Brief description: The patent describes a method to manufacture a chip to distribute signals in circuit elements within a quantum device.

Investors/Funding Partners

Google provides venture capital funding to bold new companies. There is no information about companies investing on Google [10].

References

1. https://www.crunchbase.com/organization/google
2. https://www.statista.com/statistics/266206/googles-annual-global-revenue/
3. https://quantumai.google/
4. https://quantumai.google/learn/lab
5. https://www.nature.com/articles/s41586-019-1666-5
6. https://worldwide.espacenet.com/searchResults?query=AU+2015230964+B2
7. https://worldwide.espacenet.com/searchResults?query=WO+2020263302+A1
8. https://worldwide.espacenet.com/searchResults?query=CA+3062793+A1
9. https://worldwide.espacenet.com/searchResults?query=WO+2020027779+A1
10. https://www.gv.com/
11. https://ai.googleblog.com/2018/03/a-preview-of-bristlecone-googles-new.html
12. https://ai.googleblog.com/2019/10/quantum-supremacy-using-programmable.html

Google Quantum AI: “Time Crystal”

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TRL 4

Overview

The Quantum Artificial Intelligence Lab (also called the Quantum AI Lab or QuAIL) was announced by Google Research in a blog post on May 16, 2013. It is a joint initiative of NASA, Universities Space Research Association, and Google (specifically, Google Research) whose goal is to pioneer research on how quantum computing might help with machine learning and other difficult computer science problems. The lab is hosted at NASA's Ames Research Center. At the time of launch, the Lab was using the most advanced commercially available quantum computer, D-Wave Two from D-Wave Systems.[1, 2, 3] Currently, they use the Sycamore quantum computer with 53 qubits.

Product Description

Today’s quantum computers are far from ideal—they have only a few dozen quantum bits, and these “qubits” are noisy, prone to random errors that can’t be corrected. However, the google quantum AI team of researchers has now shown that such “noisy intermediate-scale quantum” (NISQ) devices can nevertheless be used to simulate a complex type of quantum behavior. They show theoretically that an NISQ device like Google’s Sycamore quantum computer can be used to simulate an object called a discrete time crystal, whose components undergo spontaneous collective oscillations.[4, 5] They implement a continuous family of tunable CPHASE gates on an array of superconducting qubits to experimentally observe an eigenstate-ordered DTC. They demonstrate the characteristic spatiotemporal response of a DTC for generic initial states. Their work employs a time-reversal protocol that discriminates external decoherence from intrinsic thermalization, and leverages quantum typicality to circumvent the exponential cost of densely sampling the eigenspectrum. In addition, we locate the phase transition out of the DTC with an experimental finitesize analysis.

Product Description

In an equilibrium setting, quantum phases of matter are classified by long-range order or broken symmetries in low-temperature states (Fig. 1a). The unique combination of spatial long-range order and time translation symmetry breaking in an isolated dissipation-free quantum many-body system is the hallmark of the MBL-DTC (many-body localization-discrete time crystal, Figure 1 b & c).

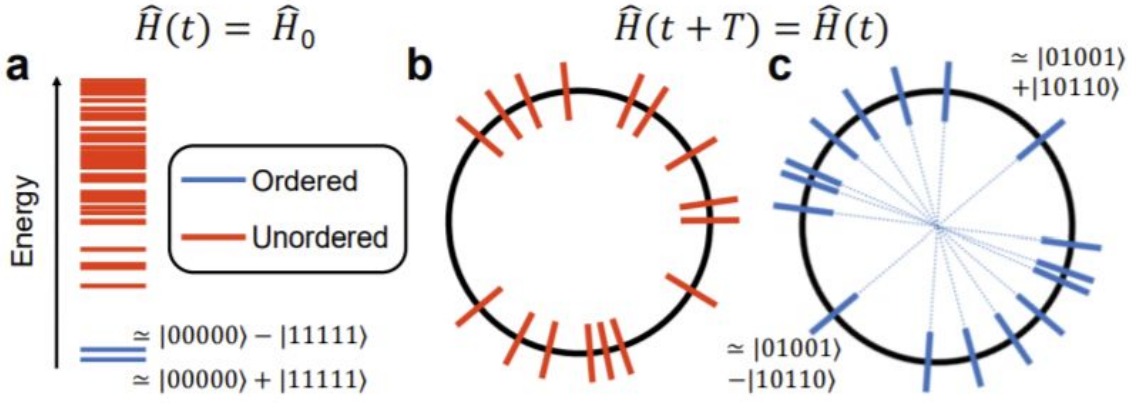

Figure 1. ***Order in eigenstates.*** *a. Equilibrium phases are characterized by long-range order in low-energy eigenstates of time-independent Hamiltonians; b. Floquet systems typically have no ordered states in the spectrum; c. In MBL Floquet systems, every eigenstate can show order.*

Product Description

The characteristics of a many-body localized discrete time-crystal simulated by a quantum computer are observed by the method shown in Figure 2.

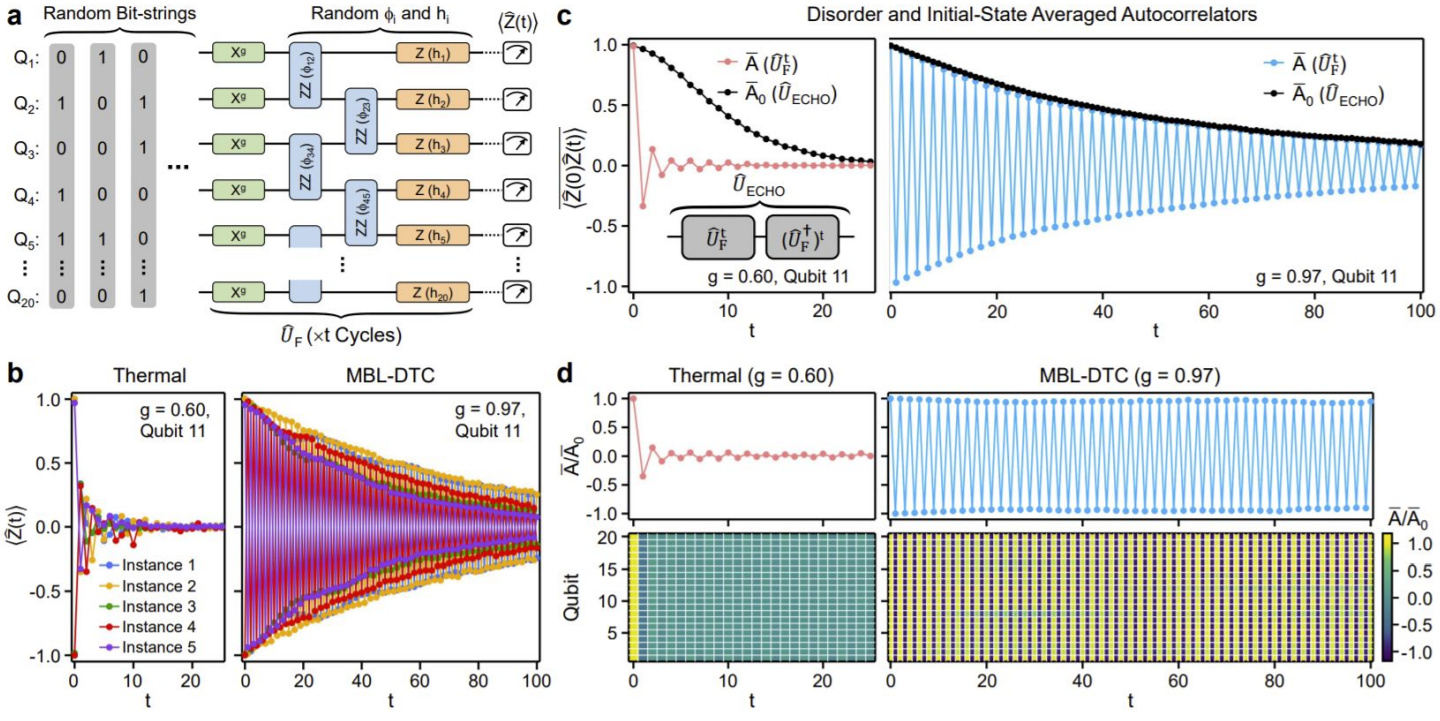

Figure 2. ***Observing a many-body localized discrete time-crystal.*** *a, Schematic of the experimental circuit composed of t identical cycles of the unitary UˆF; b. Experimental values of hZˆ(t)i measured at qubit 11. Data are shown for five representative circuit instances deep in the thermal (g = 0.60) and MBL-DTC (g = 0.97) phases; c. Autocorrelator A = hZˆ(0)Zˆ(t)i at qubit 11, obtained from averaging the results of 36 circuit instances; d. Top panels: The ratio A/A0 obtained from panel c. Bottom panels: A/A0 as a function of t and qubit location.*

These results establish a scalable approach to study non-equilibrium phases of matter on current quantum processors.In a separate paper the researchers collaborate with the Google team to put their approach into practice on Sycamore [6].

Product Description

Google Quantum AI team and their co-authors demonstrate the characteristic long-lived spatiotemporal order and confirm that it is robust for generic initial states. Their results are consistent with the realization of an out-of-equilibrium Floquet phase of matter and establish a programmable quantum simulator based on solid-state spins for exploring many-body physics. The schematic of the programmable spin-based quantum simulator is shown in Figure 3.

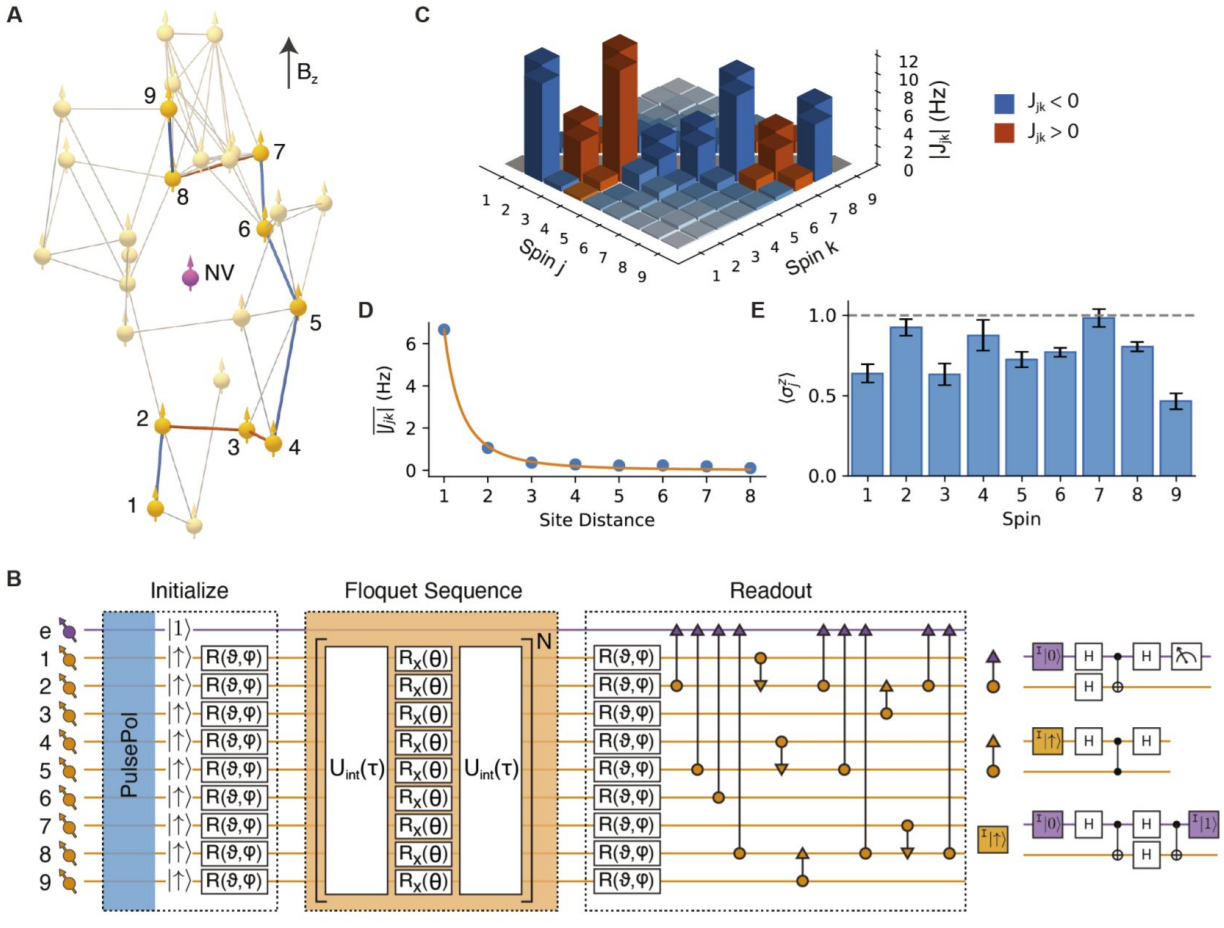

Figure 3. ***Programmable spin-based quantum simulator.*** *a. they program an effective 1D chain of 9 spins in an interacting cluster of 27 13C nuclear spins (orange) close to a single NV center. Connections indicate nuclear-nuclear couplings |Jjk| >1.5 Hz, and blue (red) lines represent negative (positive) nearest-neighbor couplings within the chain. Magnetic field: Bz ~ 403 G; b. Experimental sequence; c. Coupling matrix for the 9-spin chain; d. Average coupling magnitude as a function of site distance across the chain; e. Measured expectation values hσzj i after initializing the state |↑↑↑↑↑↑↑↑↑>.*

Product Description

The results are shown in Figure 4 are consistent with a DTC.

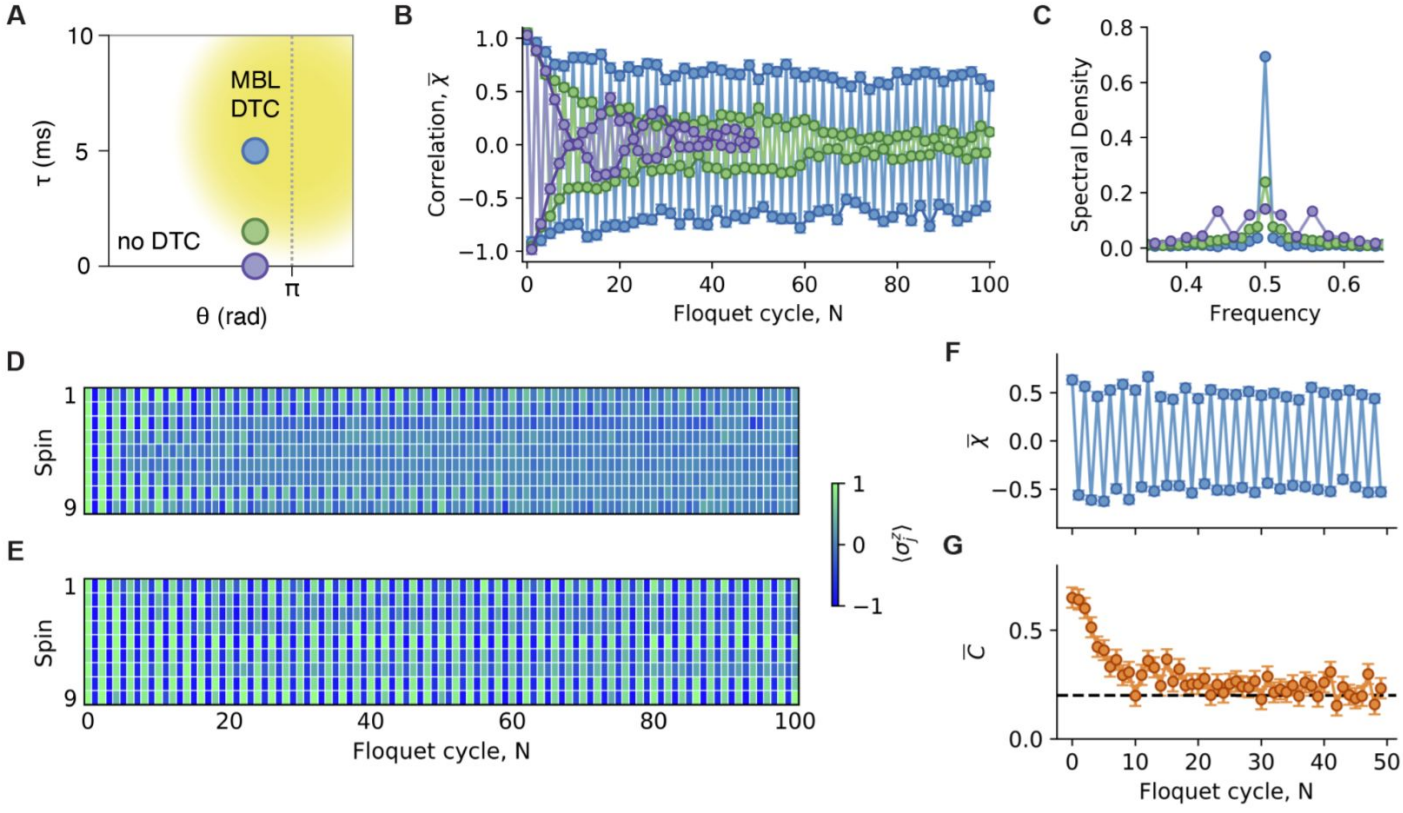

Figure 4. . Discrete time crystal in the 9-spin chain.

Product Description

They present an observation of the hallmark signatures of the many-body-localized DTC phase (Figure 5). Unlike previous experiments, our quantum simulator operates in a regime consistent with MBL and the DTC response is observed to be stable for generic initial states. This result highlights the importance of both many-body interactions and disorder for stabilizing time-crystalline order.

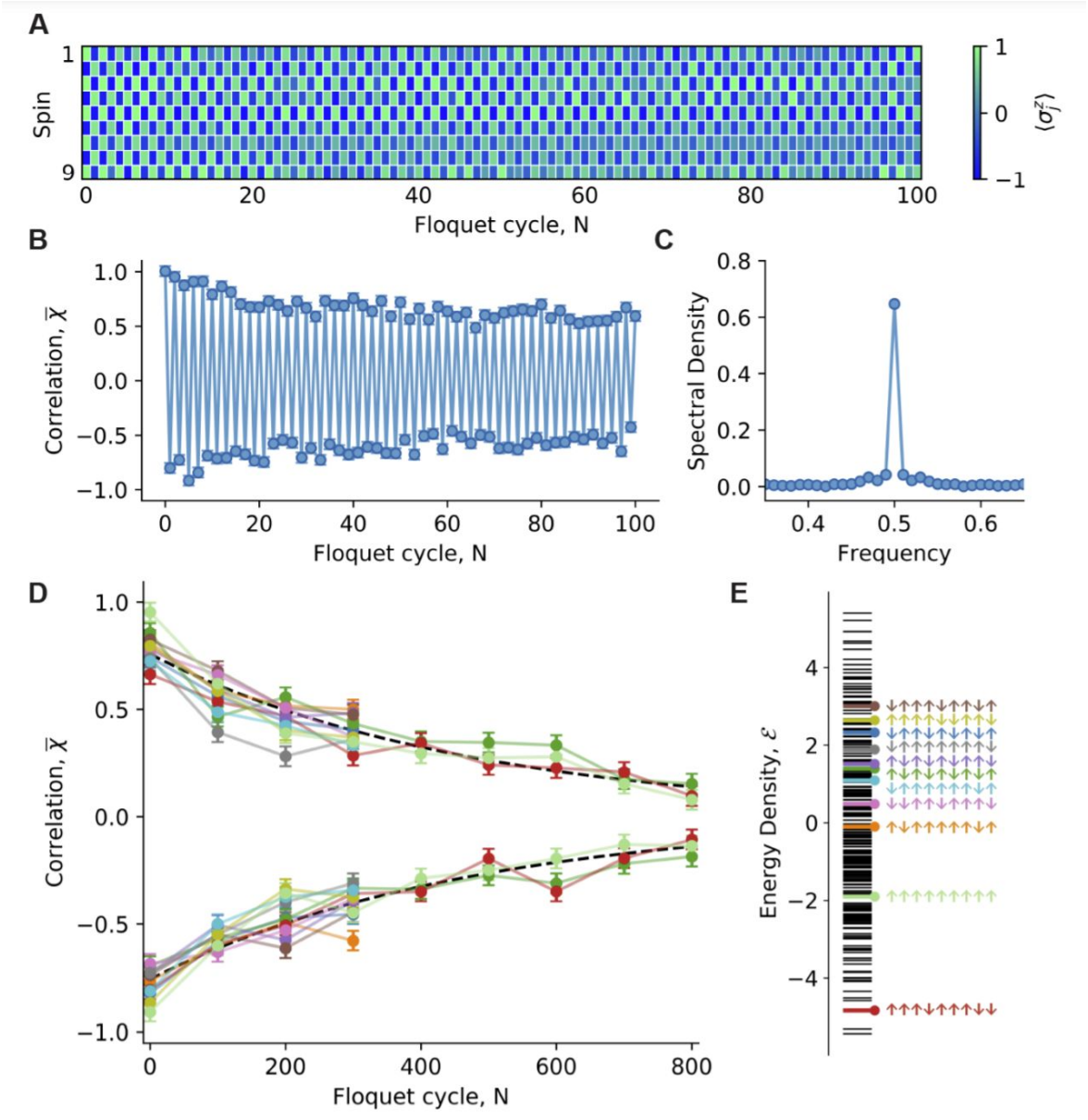

Figure 5. Observation of the DTC response for generic initial states.

Time Crystal: Google Quantum AI

Case Study/White Paper

This technology is still in its infancy.

Intellectual Property

No patents on time crystals.

Investors/Funding Partners

Google.

References

1. https://ai.googleblog.com/2013/05/launching-quantum-artificial.html
2. https://web.archive.org/web/20150310044853/http://www.nas.nasa.gov/quantum/
3. https://en.wikipedia.org/wiki/Quantum_Artificial_Intelligence_Lab
4. https://physics.aps.org/articles/v14/131#c1
5. https://arxiv.org/pdf/2107.00736.pdf
6. https://arxiv.org/pdf/2107.13571.pdf
7. https://www.quantamagazine.org/first-time-crystal-built-using-googles-quantum-computer-20210730/

Azure Quantum: Microsoft

Microsoft
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TRL 6

Overview

MIcrosoft is a multinational founded in 1975, which currently has more than 10000 employees, $1M in total funding amount and $41.7B in annual revenue [1, 2]. The company offers softtware solutions, and lately, they have developed a platform named Azure, offering cloud based technology and services.

Product Description

Azure offers remote access to its technology. For developers, the technology enables to accelerate the developing process; for businesses, it helps with decision making and long term cost-saving solutions [3].

The platform is claimed to be an open ecosystem, enabling to access it from Microsoft and its partners. It is also scalable and secure, and it adapts as the quantum technology evolves.

Microsoft Azure also offers a Quantum development kit, that includes a hardware and software unified. Also, Microsoft partners for this project (Honeywell, IONQ, Quantum Circuits, Inc. 1Qbit and Toshiba), ensure that the hardware and software innovations don't bring big changes to the code base.

The Quantum Development Kit is an open source tool to develop quantum applications for quantum hardware, and for scalable hardware. It also offers tools to design optimization problems to run on large-scale hardware resources [4].

Product Description

The Quantum Development Kit (QDK) is an open-source tool to develop quantum applications and formulate optimization problems. This kit comes with Q# language, a high level programming language that enables to focus on the algorithm and application, to create quantum programs. It is a quantum-focused programming language and Azure Quantum is the quantum cloud platform [11]. The QDK includes the following:

- Programming language
- Simulator and resource estimator, to provide low cost solutions
- Ready-to-use libraries with samples for machine learning, arithmetic and chemistry: they enable to keep a high-level code, and include standard libraries, that implement patterns that are common for several quantum algorithms, and domain-specific libraries, like chemistry and machine learning.
- Optimization solvers. These can be run in accelerated compute resources in the cloud
- Quantum computing simulators, that enable to run small simulations of the program and see what can be obtained with the current hardware access.
- A resource estimator that allows to estimate real world costs needed to perform the solutions wanted.

The CDK enables to work with Visual Studio and Visual Studio Code and Jupyter Notebooks, as it includes extensions for those. Q# can be used alone in notebooks, or use a host language that QDK supports, with Python and .NET languages. Azure Quantum has partnered with Honeywell, IONQ and Quantum Circuits Inc. to run Q# quantum programs on real hardware and test codes and simulations.

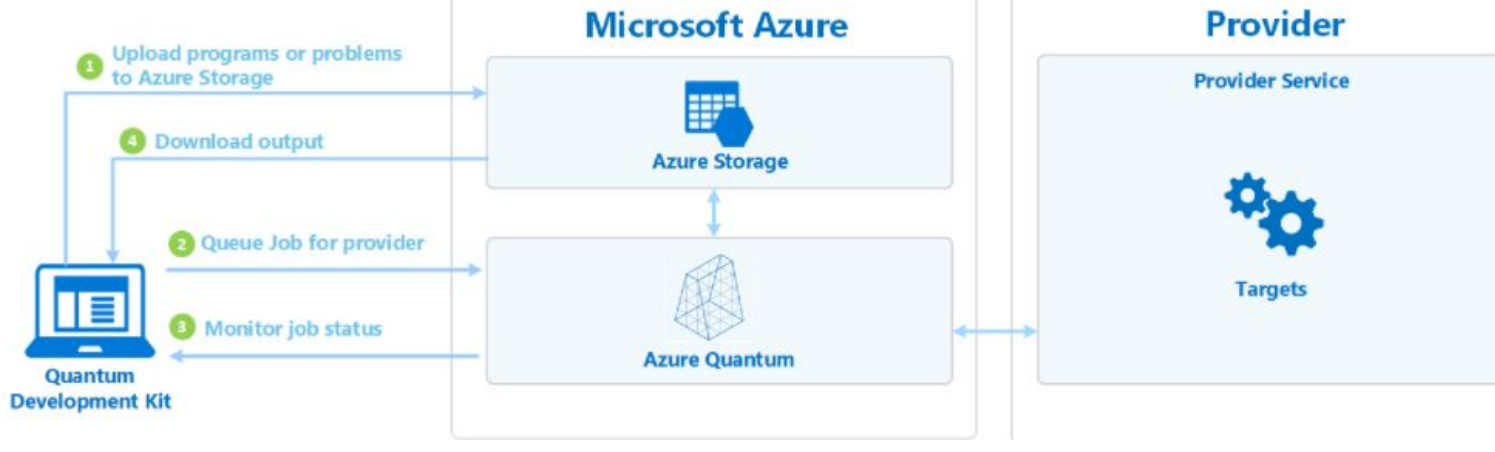

Figure 1: Quantum Development Kit (QDK)

Product Description

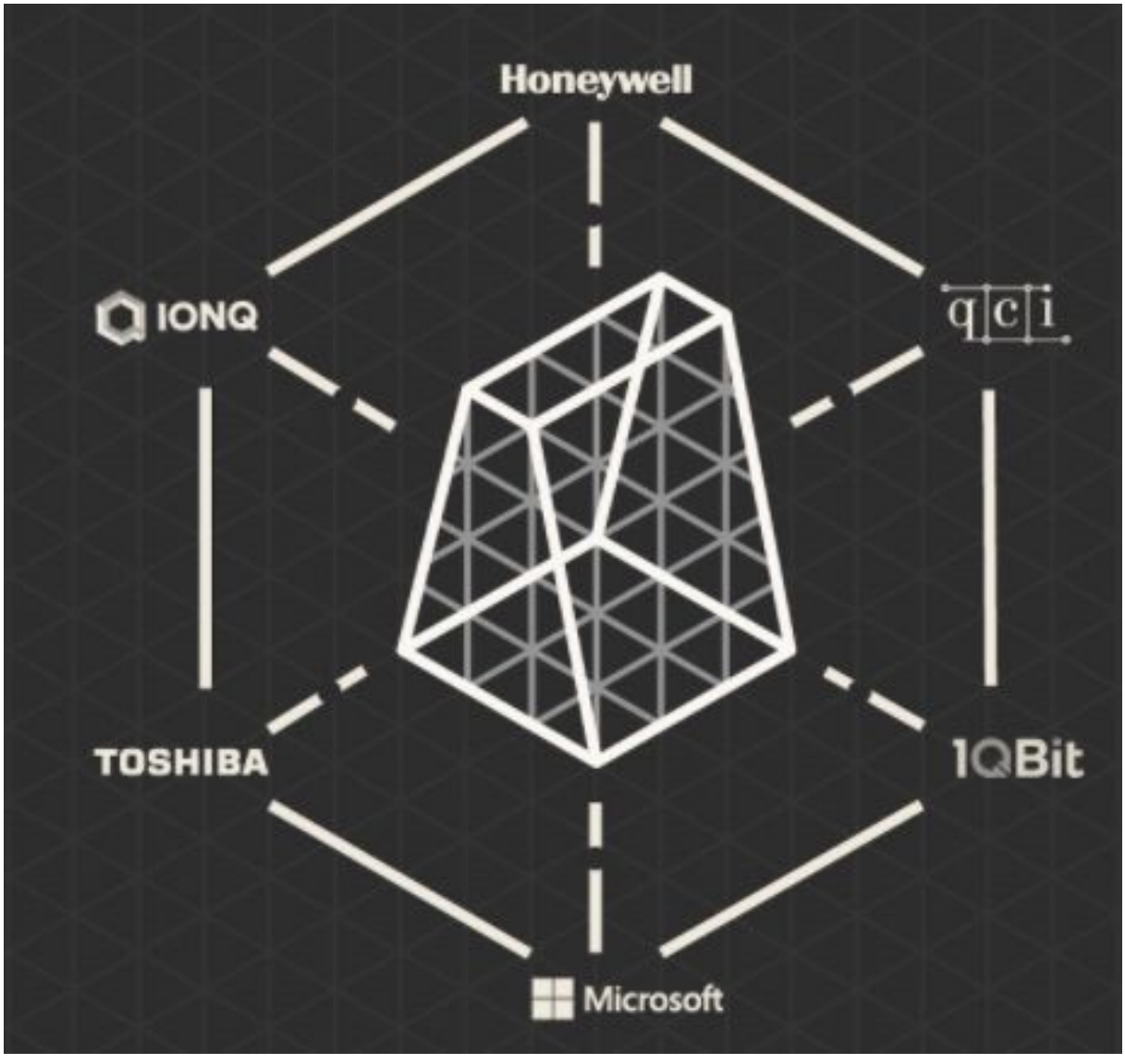

Figure 2: Microsoft Azure Quantum computing providers

Case Study/White Paper

Quantum computing enhanced computational catalysis [12]

This study presents a new quantum algorithms to simulate catalytic processes. This can be applied to the context of climate change, to find efficient catalysts for carbon fixation. Researchers claim they found a new algorithm 10 times lower than recent state-of-the-art algorithms that would decrease the time needed to run chemical simulations. The research also describes the size of quantum computers and their runtime, as well as how to ybrid quantum-classical computing system to handle this type of problem.

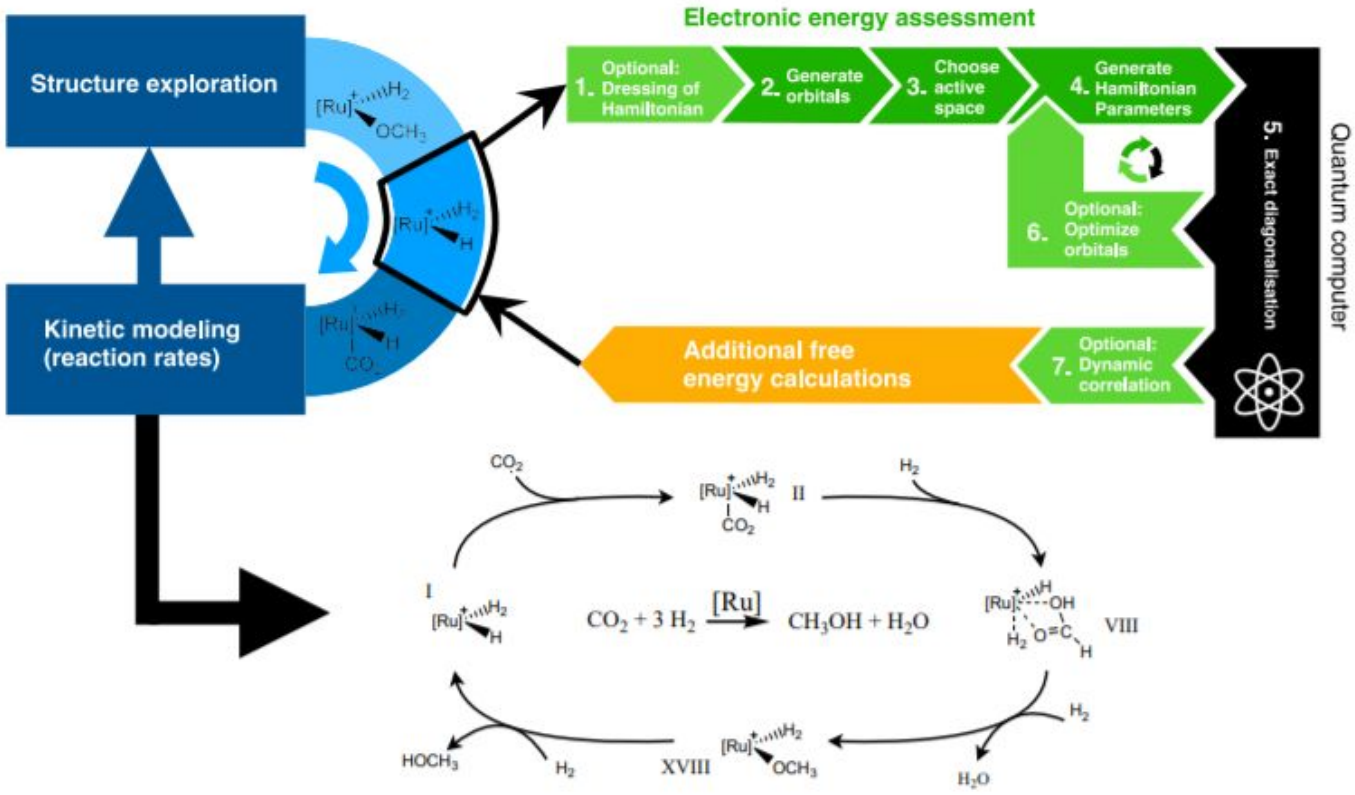

Figure 3: Protocol of computational catalysis with the key step of quantum computing embedded in black, which is usually accomplished with traditional methods such as CASSCF, DMRG, or FCIQM.

Case Study/White Paper

OTI Lumionics: Accelerating materials design with Azure Quantum[5]

OTI Lumionics has partnered with Azure Quantum to develop new methods which enables them to compute algorithms for computational chemistry simulations that can be represented binary optimization problems. For that, they run their quantum methods with Azure Quantum, and they claim they are getting results more accurate than with other algorithms tested.

By using Azure Quantum, they have performed a complete active space configuration interaction simulation of an archetype green light emitting OLED material – Alq3 [Tris (8-hydroxyquinolinato) aluminum]. This same simulation of Alq3 would require 42 error-corrected qubits on gate-based quantum hardware. Also, using OTI Lumionics reparametrization would require a quantum annealer (or QUBO solver) that could handle 58,265 variables, which in turn would require a supercomputer. By using Azure Quantum, they claim that the higher-order binary problem requires 132 variables only, in classical hardware.

The company claims that with Azure Quantum they can “open their computational pipeline to run more accurate simulations at significantly higher speeds, which could ultimately lead to timelier and lower cost materials design, and thus better OLED displays”.

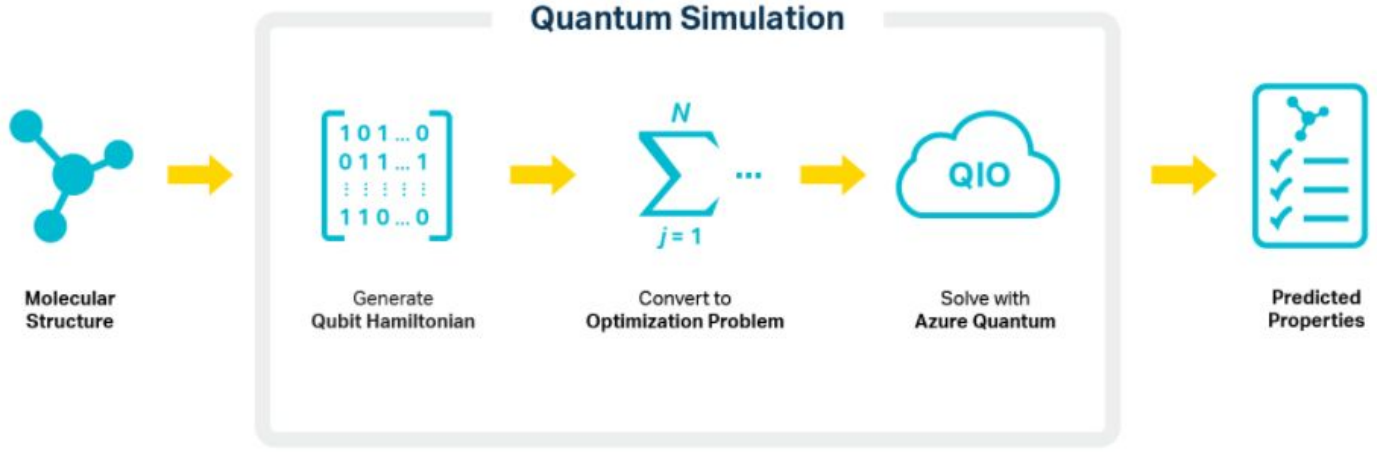

Figure 4: Quantum simulation

Intellectual Property

Patent Name/Title: **Using Compiler Optimization to Enable Automatic Generation of Combinational Circuits From High-Level Programs** (2021) [6]

Patent No: 146007 A1

Status: Filing

Brief description: The patent describes a quantum computing device which includes a quantum programm to be implemented in the device.

Patent Name/Title: **Quantum Computing Device Model Discretization** (2021) [7]

Patent No: 066960 A1

Status: Filing

Brief description: The patent describes a quantum computing device that includes memory storing, a processor to generate a discretized model.

Patent Name/Title: **Quantum annealing simulator** (2013) [8]

Patent No: 9152746 B2

Status: Filing

Brief description: The patent describes a quantum annealer simulator that uses algorithms to approximate approximate unitary time evolution of a quantum system.

Patent Name/Title: **Nonuniform Discretization of Quantum Computing Device Model** (2021) 9]

Patent No: 080789 A1

Status: Filing

Brief description: The patent describes a quantum computing device with memory storage and a processor, configured to receive, via an application-program interface (API), a nonuniform grid having a nonuniform spacing along a first spatial dimension.

Investors/Funding Partners

It has been reported that the top investors of Microsoft are Satya Nadella, Bradford L. Smith, Jean-Philippe Courtois, Vanguard Group Inc., BlackRock Inc. (BLK), and State Street Corp. [10].

References

1. https://www.crunchbase.com/organization/microsoft
2. Revenue
3. https://azure.microsoft.com/en-us/services/quantum/#product-overview
4. https://azure.microsoft.com/en-us/resources/development-kit/quantum-computing/#overview
5. https://arxiv.org/abs/2007.14460
6. https://worldwide.espacenet.com/searchResults?query=WO+2021146007+A1
7. https://worldwide.espacenet.com/searchResults?query=WO+2021066960+A1
8. https://worldwide.espacenet.com/searchResults?query=US+9152746+B2
9. https://worldwide.espacenet.com/searchResults?query=WO+2021080789+A1
10. https://www.investopedia.com/articles/investing/122215/top-4-microsoft-shareholders.asp
11. https://docs.microsoft.com/en-us/azure/quantum/overview-azure-quantum
12. https://cloudblogs.microsoft.com/quantum/2020/01/21/oti-lumionics-accelerating-materials-design-microsoft-azure-quantum/

Amazon Braket: Amazon

Amazon
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Website: https://aws.amazon.com/
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TRL 6

Overview

Amazon is an international e-commerce website and company, that offers products from third party vendors and sellers. It also offers music and streaming services. The company was founded in 1994 and currently has more than 10000 employees, with $108M in total funding amount and $113.1B in annual revenue [1, 2].

Product Description

Amazon Braket is a quantum computing service that enables researchers to start on quantum computing technology and accelerate their research. This technology provides all the tools necessary to build, test and run quantum algorithms on AWS. The company claims that it includes a "unified development environment, a choice of classical circuit simulators, and access to different types of quantum computers" [3]. The technology includes the following:

- Hardware-agnostic developer framework, named Amazon Braket SDK. it removes the need to code against quantum programming environments and allows researchers to build algorithms and run them on any hardware provided through the Amazon Braket service.
- Hybrid quantum computing with PennyLane, an open source software framework, that enables to train quantum circuits to find solutions.
- Fully managed Jupyter notebooks that enable to build quantum algorithms and manage experiments.
- Pre-built algorithms and tutorials that are already installed in the notebooks and SDK hardware.
- Simulators: there are four available simulators, one is a local simulator that is included in the Amazon Braket SDK and three fully managed simulators

Product Description

- Quantum computers: Amazon Braket enables to access to both annealing and gate-based quantum computers.
- Expert help
- Management and security.

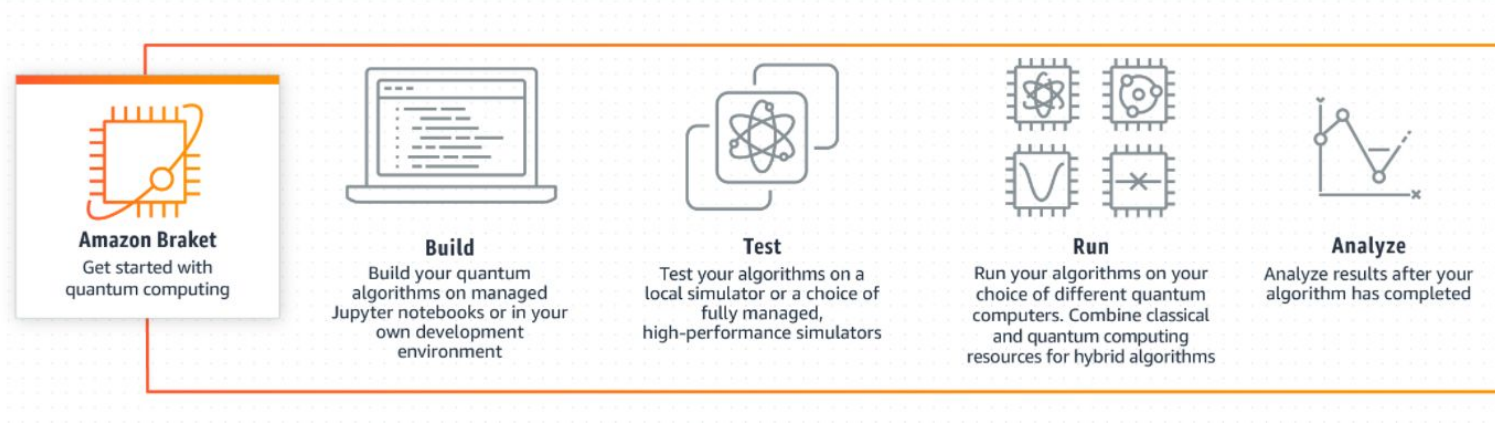

Figure 1: How Amazon Braket works

Figure 2: Amazon Braket partners

Case Study/White Paper

Exploring industrial use cases in the BMW Group Quantum Computing Challenge [8]

The BMW Group has partnered with the Amazon Quantum Solutions Lab to launch an innovation competition, to find new computational challenges that exist within the automotive engineering, manufacturing, and logistics domains industries.

Participants would have to define a method to optimize the configuration of features for a number of cars, such as:

- Material Deformation in Production: components have to be evaluated to check the feasibility of being implemented by existing tooling and materials. The challenge would be to develop a quantum algorithm or perform an analysis of an existing algorithm to model mechanical behavior.
- Vehicle Sensor Placement: sensors gather information from the surroundings, and the more sensors and information they gather, the greater the cost. Currently, genetic algorithms are used to implement sensors. In this case, the challenge would be to find an optimal configuration of vehicle sensors, so it can detect obstacles in different driving scenarios, by using quantum computing.
- Machine Learning for Automated Quality Assessment: convolutional neural networks are currently used as a machine learning tool to assess the quality of new vehicles. For this case, the challenge would be to find quantum, nature-inspired, or hybrid classical-quantum machine learning (QML) approaches, with the potential to provide quicker, more efficient training and more accuracy, to improve automatic quality assessment.

AWS supporting the Quantum Software Research Hub led by Osaka University in Japan [9]

Amazon is contributing with the Quantum Software Research Hub at the Osaka University, by providing support to the university to develop its libraries and cloud-based system, to access different hardwares and simulators, including Amazon Braket. Also, Amazon is developing quantum software applications and libraries in different fields of knowledge, such as quantum machine learning, quantum chemistry, and mathematical finance. University members can run their experiments in quantum hardwares devices such as onQ, Rigetti, and D-Wave.

Case Study/White Paper

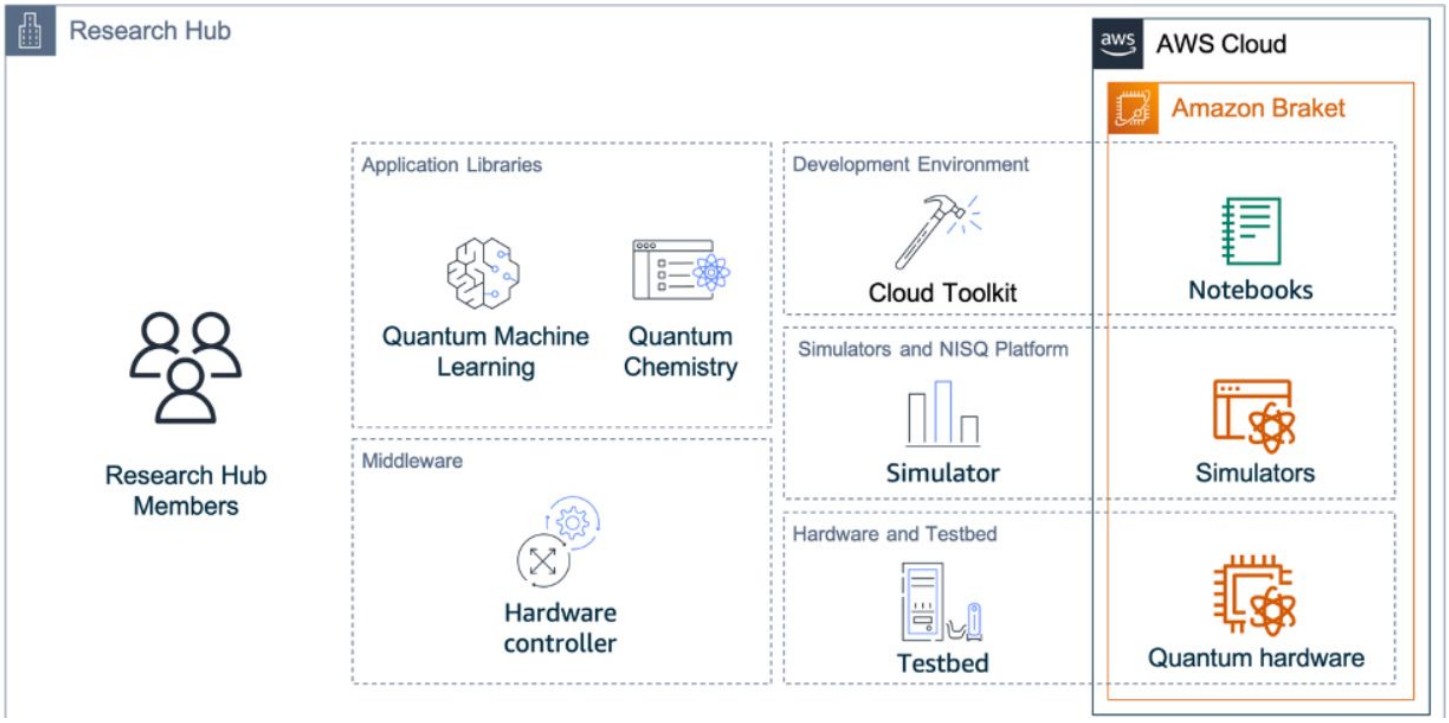

Figure 3: Research Hub and AWS team collaboration

Intellectual Property

Patent Name/Title: **Quantum Computing Service With Local Edge Devices Supporting Multiple Quantum Computing Technologies** (2021) [4]

Patent No: 0157662 A1

Status: Filing

Brief description: The patent describes a quantum computing service that includes connections with quantum computers and hardware, as well as computing devices.

Patent Name/Title: **Quantum Computing Service Supporting Local Execution of Hybrid Algorithms** (2021) [5]

Patent No: 0158199 A1

Status: Filing

Brief description: The patent describes a quantum computing service that includes connections with hardware providers and an edge computing device, which is configured to run computing portions of a hybrid algorithm.

Patent Name/Title: **Cloud-based access to quantum computing resources** (2017) [6]

Patent No: 10817337 B1

Status: Filing

Brief description: The patent describes a methodology for quantum cloud based access, and include computing devices configured to execute a control plane of a provider network and multiple quantum bits.

Patent Name/Title: **Development environment for programming quantum computing resources** (2017) [7]

Patent No: 10592216 B1

Status: Filing

Brief description: The patent describes a methodology for programming quantum computing resources. These resources include multiple quantum bits.

Investors/Funding Partners

The top 3 companies that are investors of Amazon, have been reported to be Advisor Group Inc., Vanguard Group Inc., and BlackRock Inc. [8].

References

1. https://www.crunchbase.com/organization/amazon
2. Revenue
3. https://aws.amazon.com/braket/features/
4. https://worldwide.espacenet.com/searchResults?query=US+20210157662+A1
5. https://worldwide.espacenet.com/searchResults?query=US+20210158199+A1
6. https://worldwide.espacenet.com/searchResults?query=US+10817337+B1
7. https://worldwide.espacenet.com/searchResults?query=US+10592216+B1
8. https://www.investopedia.com/articles/insights/052816/top-4-amazon-shareholders-amzn.asp
   https://aws.amazon.com/blogs/quantum-computing/exploring-industrial-use-cases-in-the-bmw-quantum-computing-challenge/
9. https://aws.amazon.com/blogs/quantum-computing/aws-supporting-the-quantum-software-research-hub-led-by-osaka-university-in-japan/

Quantum technology: Honeywell

Honeywell
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TRL 6

Overview

Honeywell is an international company that offers energy, safety, and security solutions and technologies in the aerospace and engineering field. It also offers electronic materials and chemicals, as well as energy saving solutions in transportation, commercial buildings, industrial, and residential. The company was founded in 1906 and currently has more than 10000 employees with $11.4M in total funding amount and $32.64B in annual revenue [1, 2].

Product Description

This company offers quantum computing services to multiple type of industries, by using their trapped-ion qubits. These are manufactured uniformly, and they use the term “Nature’s Qubit”. The company claims these can be controlled more easily and quickly, compared to other technologies that don't use atoms [3].

The company claims their quantum technology can be applied to multiple industries:

- Pharmaceutical: for drug discovery and drug design
- Chemical: to accelerate development of new compounds
- Finance: to reduce risk
- Aerospace and defense: to develop new materials and military technologies
- Oil and gas: to optimize production
- Data center: to accelerate machine learning and data analysis
- Manufacturing: to visualize limitations and designs
- Telecommunications: to optimize bandwidth and antenna efficiency.

Product Description

The 10-qubit System Model H1 is Honeywell quantum processor, with a quantum volume of 1024 achieved in March 2021. Its operations have been increasing since its release in September 2020. To achieve this, they set some milestones: for the single-qubit gate fidelity was 99.99(1)% and the two-qubit gate fidelity was 99.72(6)%. The state preparation and measurement (SPAM) fidelity was 99.70(5)%. Then they run 800 circuits with 20 shots each, and for that they used QV optimization techniques, achieving 108.59 two-qubit gates per circuit [7].

The Honeywell's quantum systems through different platforms, such as Microsoft's Azure Quantum, Cambridge Quantum Computing's tket™ Zapata Computing's Orquestra®, and the Strangeworks QC™ platform. Also, their system has a combination of mid-circuit measurement with qubit reuse and conditional logic, that allows users to explore new algorithms and reduce qubits needed.

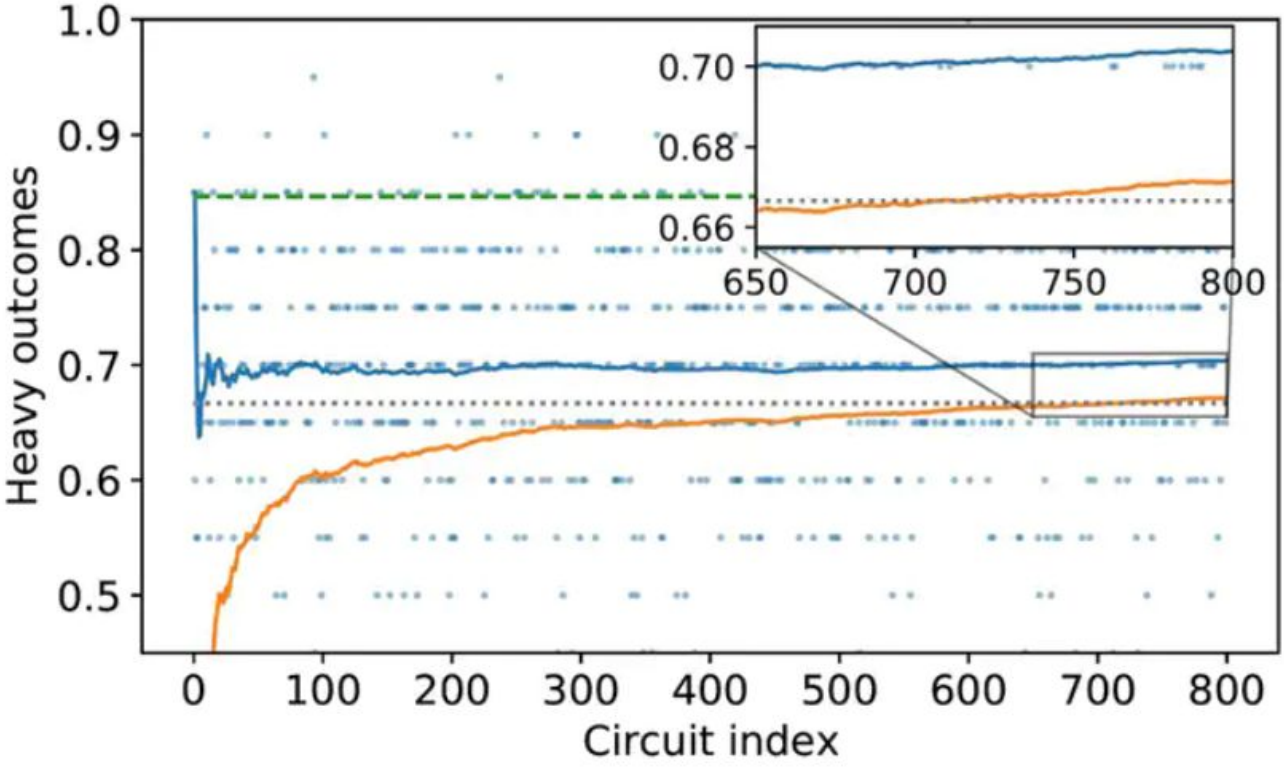


Figure 1: Individual heavy outputs for each Quantum Volume 1024 run. The blue line is an average of heavy outputs and the orange line is the lower 2-sigma error bar which crosses the 2/3 threshold after 707 circuits.

Case Study/White Paper

In March 2020, Honeywell published that they were close to present what the claimed to be the “most powerful quantum computer on the market in the next three months”. For that, they used a metric called "quantum volume". This metric enables to measure the performance of the qubits in the quantum system, by combining different metrics [4].

BMW Can Maximize Its Supply Chain Efficiency with Quantum [8]

Entropica Labs, a quantum software startup from Singapore, and BMW are collaborating with Honeywell Quantum Solutions to explore new technologies and improve their operations. For that, they are using Honeywell’s H1 processor, and the Recursive Quantum Approximate Optimization Algorithm (R-QAOA) to face number partitioning, which is an entry point to logistics and supply chain. H1 processor was leveraged by its features (full qubit connectivity, high fidelity and angular resolution of quantum gates). It has been observed that the R-QAOA algorithm has a performance that is comparable to the classical Karmarkar-Karp (KK) heuristic

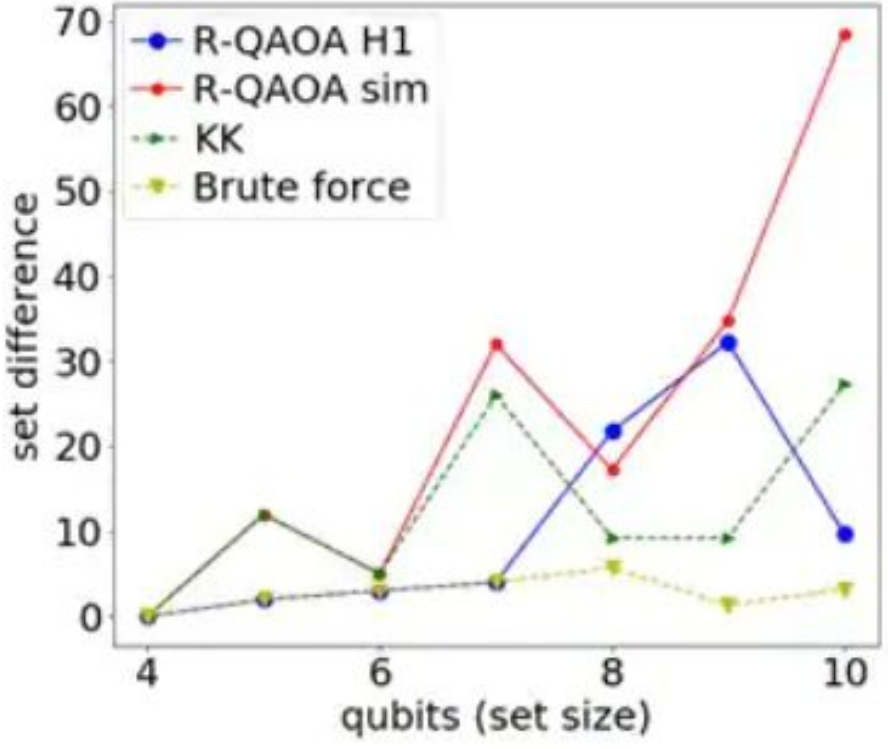


Figure 2: Experimental data taken on the Honeywell System Model H1 demonstrating the performance of the R-QAOA vs. the classical KK heuristic, and the brute force answer (smaller set difference is better). For both H1 (blue) and the simulator (red), 200 shots were taken.

Case study/white paper

Can Quantum Improve Phone Batteries? Samsung Explores the Possibility [9]

Honeywell has partnered with Samsung and researchers at the Imperial College London to develop better batteries by using quantum computing. They have explored new quantum algorithms and simulated dynamics of an interacting spin model, a mathematical models used to examine magnetism. For that, they used the Honeywell's System Model H1, in which they run deep circuits and use as many as 100, two-qubit gates to support the calculation. They claimed the System Model H1 "can handle complex algorithms with a high degree of accuracy giving researchers confidence that their results are correct".

How Quantum Computing Can Help Nippon Steel Improve Scheduling at Plants [10]

Nippon Steel, a manufacturer of steel, has partnered with Cambridge Quantum Computing (CQC) to develop and improved and optimal schedule to deliver and receive intermediate products that they use in the manufacturing process. For that, they used Honeywell's System Model H1 to develop an algorithm and run it. They claim the H1 system was able to find solution in just a few steps and they are planning on scaling up the problem to bigger instances.

Intellectual Property

Patent Name/Title: **Photoacoustic cell incorporating a quantum dot substrate** (2008) [5].

Patent No: US7895880B2

Status: Expired

Brief description: This patent describes a photoacoustic cell that includes a quantum dot, excitation source and a chamber.

Investors/Funding Partners

Honeywell provides venture capital funding to bold new companies. There is no information about companies investing on Honeywell [6].

References

1. https://www.crunchbase.com/organization/honeywell
2. https://en.wikipedia.org/wiki/Honeywell
3. https://www.honeywell.com/us/en/company/quantum
4. https://www.protocol.com/honeywell-quantum-computing-breakthrough
5. https://worldwide.espacenet.com/patent/search/family/040875146/publication/US7895880B2?q=pn%3DUS7895880B2
6. https://www.honeywell.com/us/en/company/ventures
7. https://www.honeywell.com/us/en/news/2021/07/honeywell-sets-another-record-for-quantum-computing-performance
8. https://www.honeywell.com/us/en/news/2021/01/exploring-supply-chain-solutions-with-quantum-computing
9. https://www.honeywell.com/us/en/news/2021/02/samsung-explores-quantum-computing-possibilities
10. https://www.honeywell.com/us/en/news/2021/06/how-quantum-computing-can-help-nippon-steel-improve-scheduling-at-plants

The full-stack technology of commercial quantum computing: Rigetti Computing

Rigetti Computing
Headquarters: Berkeley, California, United States
Website: https://www.rigetti.com/
Contact: https://www.rigetti.com/get-quantum

TRL 6

Overview

Rigetti Computing is a full-stack quantum computing company, a term that indicates that the company designs and fabricates quantum chips, integrates them with a controlling architecture, and develops software for programmers to use to build algorithms for the chips. The headquarters of Rigetti Computing locates in the State of California. Currently (Sept 2021), Rigetti Computing has 132 employees.[1][2][3]

Product Description

Building quantum computers combines advances in engineering, physics, computer science, and manufacturing. Rigetti Computing focuses on integrating all these specialties under one roof and in one technology stack.[4] Their services are primarily based on their k-quantum hardware, software and cloud technology. Rigitti's state-of-the-art product (Aspen-9) performance is shown in the chart below

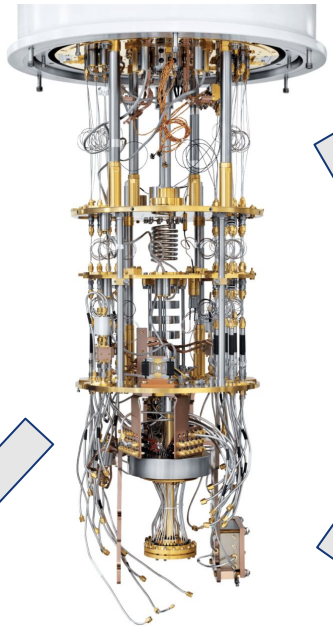
Aspen-9		Median Time Duration (μs)		Median Fidelity (per op.)	
Deployed	07.02.21	T1 Lifetime	27	Single-qubit gates	99.8%
Qubits	31	T2 Lifetime	19	Two-qubit gates (CZ)	95.8%
				Two-qubit gates (XY)	95.4%

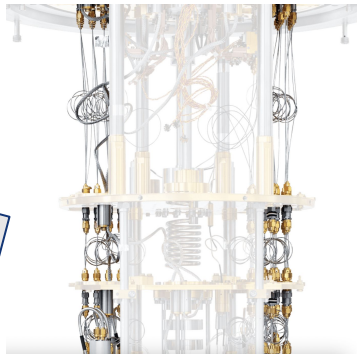
The full-stack technology of commercial quantum computing: Rigetti Computing

Product Description

- **Quantum hardware**[1]

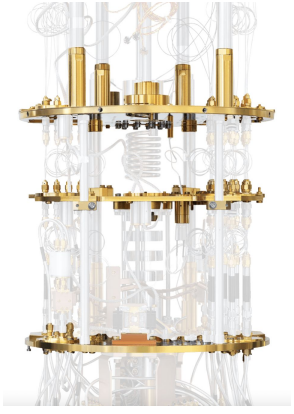
The Quantum Machine.



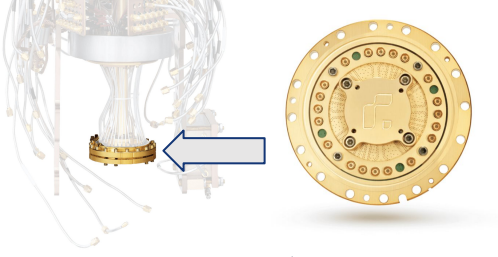


1. **Shell.** These cans nest inside each other and act as thermal shields, keeping everything super cold and vacuum-sealed inside.

2. **Nerves.** These photon-carrying cables deliver signals to and from the chip to drive qubit operations and return the measured results.



3. **Skeleton.** These gold plates separate cooling zones. At the bottom, they plunge to one-hundredth of a Kelvin—hundreds of times as cold as outer space.



5. **Brain.** The QPU (quantum processing unit) features a gold-plated copper disk with a silicon chip inside that contains the machine's brain.

4. **Heart.** Inside, different forms of liquid helium separate and evaporate, diffusing the heat.

Product Description

- **Design & Fabrication**

Quantum processor chips are the foundation of their technology stack. Manufacturing these chips begins with the ability to design high quality quantum-coherent superconducting microwave devices. We leverage advanced modeling and simulation tools to design linear and nonlinear chip components, accurately predict performance behavior of large scale integrated quantum circuits (QuICs), and produce masksets to be fabbed in our manufacturing facility, Fab-1.

- **Superconducting Quantum Processors**

Superconducting Qubits

Rigetti systems are powered by superconducting qubit-based quantum processors. At the chip level, each superconducting qubit consists of a non-linear Josephson inductance in parallel with an ultra-low-loss capacitor to create a resonant structure in the 3-6GHz range. Qubits are coupled to a linear superconducting resonator for readout. The combination of the qubit, the linear readout resonator, and the associated wiring provides a general purpose quantum circuit element capable of reliably encoding, manipulating, and reading out quantum information. Rigetti processors use arrays of qubits coupled to one another with on-chip capacitances. Single and multi-qubit logic operations are implemented through the application of microwave or DC pulses.

Scalable Quantum Processors

Rigetti processors leverage their Fab-1 capabilities to achieve both performance and scalability, including superconducting through-silicon vias and superconducting flip-chip cap bonding. Each of these plays a dual role in the qubit and processor design, providing an electromagnetic housing for each qubit while also enabling targeted connections to other qubits and to signal delivery wiring. Further scalability enhancements, such as multiplexed readout, are created through on-chip design features that allow single input/output lines to address a plurality of qubits.

Product Description

- **Control Systems**

Turning a quantum processor into a fully functional computer requires the ability to control the qubits in a reliable and programmable way. In a superconducting quantum computer, QuICs are packaged and housed in cryogenic dilution refrigerators. Room temperature microwave control electronics generate qubit control and readout signals that are then delivered to and received from the quantum processor through a cryogenically compatible interconnect system. These hardware technologies enable state-of-the-art qubit energy relaxation and dephasing times, as well as <0.1% amplitude crosstalk and high one- and two-qubit gate fidelities.

- **QCS Platform**

Rigetti Quantum Cloud Services platform (QCS) could support ultra-low latency connectivity—less than one millisecond—between a customer's high-performance classical hardware and Rigetti QPUs.

- **Software Tools**

Rigetti offers a suite of open source tools through its Forest SDK, ranging from higher level language interfaces for Quil and device simulation, to circuit optimization and compilation software for efficiently designing experiments and performing algorithm research.

Product Description

- **Clients**[4]

Rigetti Quantum Compute Center in Berkeley, CA.

Public cloud providers who redistribute on-demand computational resources to end users.

HPC and scientific computing organizations that offer shared resources to select user communities.

Private cloud operators and enterprises who want to capture the benefits of quantum computing without maintaining on-prem quantum hardware.

Professional services and application providers who leverage existing cloud infrastructure to power their solutions and services.

Case Study/White Paper

- **Entanglement Across Separate Silicon Dies in a Modular Superconducting Qubit Device[5]**

They demonstrate a modular solid state architecture with deterministic inter-module coupling between four physically separate, interchangeable superconducting qubit integrated circuits, achieving two-qubit gate fidelities as high as 99.1±0.5\% and 98.3±0.3\% for iSWAP and CZ entangling gates, respectively. The quality of the inter-module entanglement is further confirmed by a demonstration of Bell-inequality violation for disjoint pairs of entangled qubits across the four separate silicon dies. Having proven out the fundamental building blocks, this work provides the technological foundations for a modular quantum processor: technology which will accelerate near-term experimental efforts and open up new paths to the fault-tolerant era for solid state qubit architectures.

- **Quantum simulation of ϕ^4 theories in qudit systems[6]**

They discuss the implementation of quantum algorithms for lattice Φ^4 theory on circuit quantum electrodynamics (cQED) system. The field is represented on qudits in a discretized field amplitude basis. The main advantage of qudit systems is that its multi-level characteristic allows the field interaction to be implemented only with diagonal single-qudit gates. Considering the set of universal gates formed by the single-qudit phase gate and the displacement gate, they address initial state preparation and single-qudit gate synthesis with variational methods.

The paper is organized as follows: First they define the theory and Hamiltonian. they discuss the discretization of a field and expand the field in harmonic oscillator basis. In the single qudit section, they discuss state preparation, gate preparation with variational algorithms and finding a ground state of a field when nonlinearity is present. In multiple the qudit section, they argue how a field can be modeled in entangled cavities. Lastly, in simulations section, they show the simulation algorithm for the full Hamiltonian.

Intellectual Property

N/A.

Investors/Funding Partners

Rigetti Computing has raised a total of $198.5M in funding over 10 rounds. Their latest funding was raised on Aug 4, 2020 from a Series C round. Rigetti Computing is funded by 36 investors, including Y Combinator, The Alchemist Accelerator, Andreessen Horowitz, etc. [7]

Franklin Templeton Investments and DCVC are the most recent investors.Rigetti Computing has a post-money valuation in the range of $500M to $1B as of Aug 4, 2020, according to PrivCo. Sign up for a free trial to view exact valuation and search companies with similar valuations.Rigetti Computing has acquired QxBranch on Jul 11, 2019.

References

1. https://www.rigetti.com/
2. https://www.crunchbase.com/organization/rigetti-computing/technology
3. https://craft.co/rigetti-computing
4. https://www.rigetti.com/what
5. https://arxiv.org/abs/2102.13293
6. https://arxiv.org/abs/2108.13357
7. https://www.crunchbase.com/organization/rigetti-computing/company_financials

Quantum Oracle: JP Morgan Chase

JP Morgan Chase
Headquarters: New York City, New York, U.S.
Website: https://www.jpmorgan.com/global
Contact: +1 212 270 6000

TRL 4

Overview

J.P. Morgan is a global leader in financial services, offering solutions to the world's most important corporations, governments and institutions in more than 100 countries. JPMorgan Chase ran Honeywell's quantum computer through its paces, publishing data last week about one of its quantum-computing experiments that could help the financial industry protect accounts and make better investment choices. In this paper, they present a novel, canonical way to produce a quantum oracle from an algebraic expression. [1]

Product Description

The goal of the FLARE program at JPMorgan Chase & Co. is to design and conduct research across multiple frontier technologies, in order to enable novel discoveries and inventions, and to inform and develop next-generation solutions for the firm's clients and businesses. The immediate areas of focus include the field of Quantum Computing, Cloud Computing, Augmented Reality and Virtual Reality, and Internet of Things. [2]

Product Description

- **Quantum Computing**

JPMorgan Chase is one of the first financial institutions worldwide to invest in quantum computing and to build an internal team of scientists to work on new quantum algorithms and applications to address business use cases in finance, AI, optimization and cryptography. There is a need for standardization across the quantum industry in areas including consistent metrics to quantify hardware fidelity, post-quantum cryptographic algorithms, and quantum secure channel communication protocols. We also believe that there will be a shift from optimizing an entire algorithm to breaking it apart into a hybrid classical/quantum algorithm where quantum will be used only for portions of the computation that are exponential in nature, thereby creating the need for smart compilers that automatically perform this hybrid mapping.

- **Quantum Key Distribution for Quantum-Secured Communications**

The advent of quantum computers has created a potential threat to the current data encryption methodologies. Based on the principles of Quantum Mechanics, Quantum Key Distribution (QKD) can establish unconditional secure communication channels. QKD will play a crucial role in securing JPMorgan Chase's critical network infrastructure against any eavesdropping attempts, hence largely nullifying the threat of Quantum Computers. For this reason, FLARE is actively conducting research on QKD technology.

Case Study/White Paper

- **Canonical Construction of Quantum Oracles. [3]**

Selecting a set of basis states is a common task in quantum computing, in order to increase and/or evaluate their probabilities. This is similar to designing WHERE clauses in classical database queries. Even though one can find heuristic methods to achieve this, it is desirable to automate the process. A common, but inefficient automation approach is to use oracles with classical evaluation of all the states at circuit design time. In this paper, they present a novel, canonical way to produce a quantum oracle from an algebraic expression (in particular, an Ising model), that maps a set of selected states to the same value, coupled with a simple oracle that matches that particular value. They also introduce a general form of the Grover iterate that standardizes this type of oracle. We then apply this new methodology to particular cases of Ising Hamiltonians that model the zero-sum subset problem and the computation of Fibonacci numbers. In addition, this paper presents experimental results obtained on real quantum hardware, the new Honeywell computer based on trapped-ion technology with quantum volume 64. The corresponding probability distribution of results is shown in Figure 1.

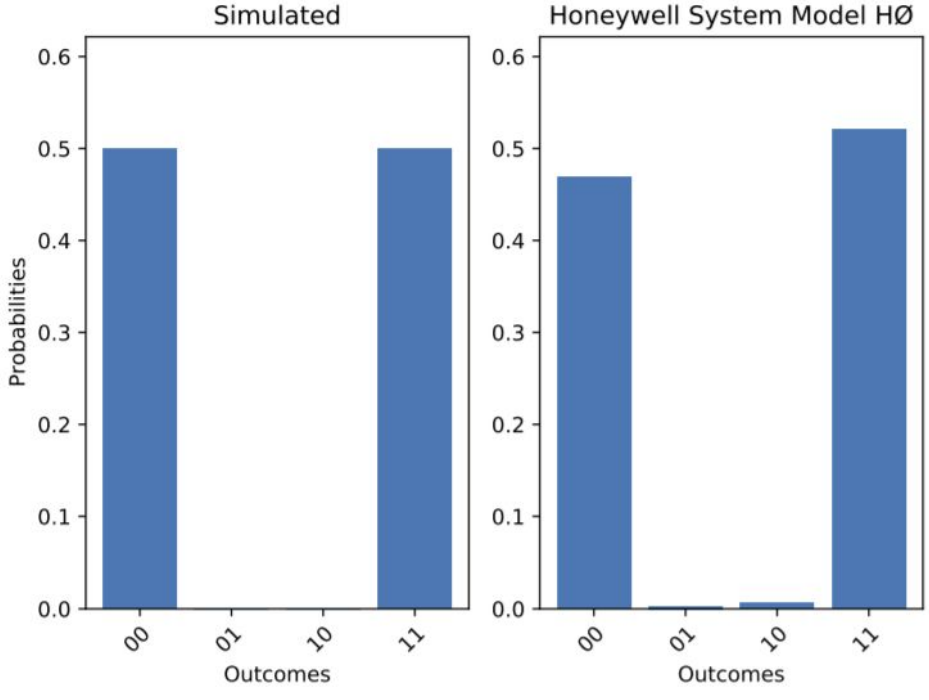


Figure 1. The result of running the circuit on a simulator (left) and the Honeywell System Model HØ (right).

Case Study/White Paper

- **Foundational Patterns for Efficient Quantum Computing. [4]**

They present a number of quantum computing patterns that build on top of fundamental algorithms, that can be applied to solving concrete, NP-hard problems. In particular, they introduce the concept of a quantum dictionary as a summation of multiple patterns and algorithms, and show how it can be applied in the context of Quadratic Unconstrained Binary Optimization (QUBO) problems. They start by presenting a visual approach to quantum computing, which avoids a heavy-reliance on quantum mechanics, linear algebra, or complex mathematical notation, and favors geometrical intuition and computing paradigms. They also provide insights on the fundamental quantum computing algorithms (Fourier Transforms, Phase Estimation, Grover, Quantum Counting, and Amplitude Estimation, as shown in Figure 2).

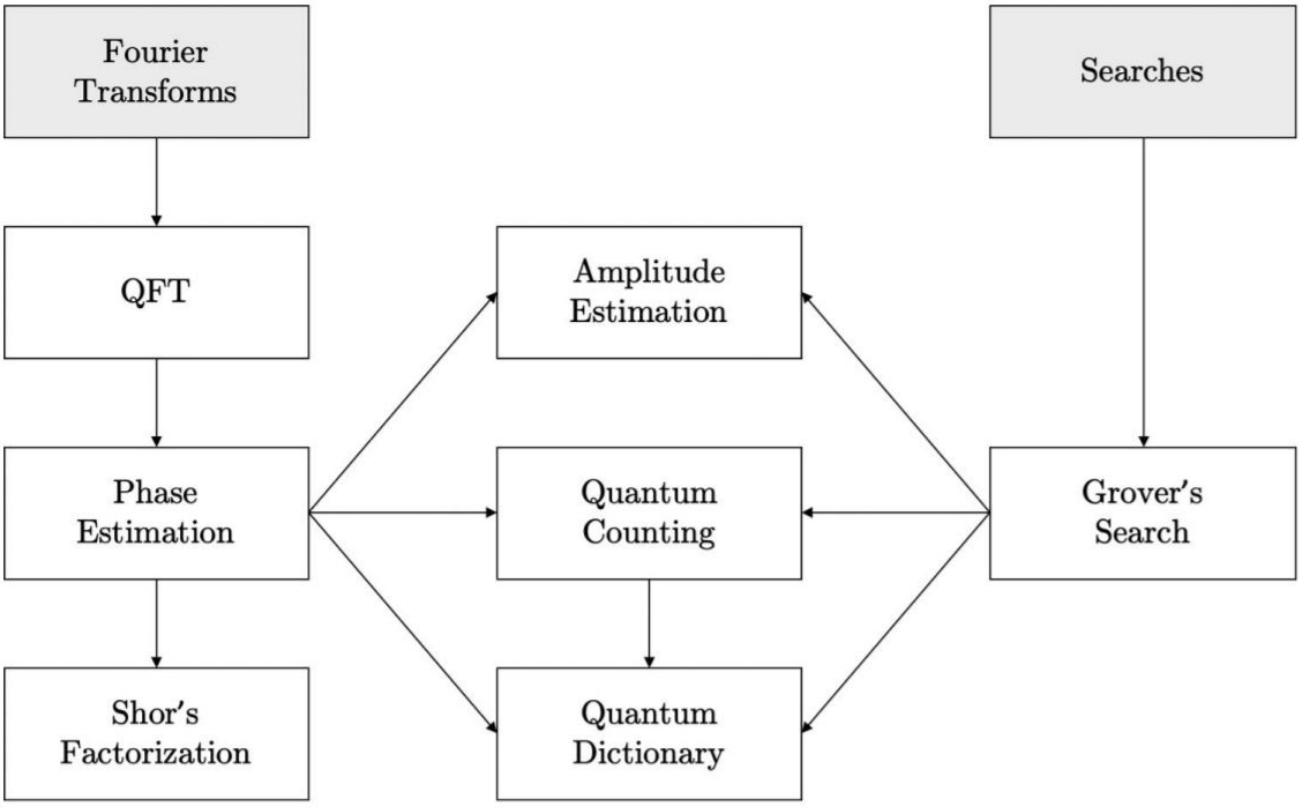


Figure 2. The two main classes of quantum algorithms.

Case Study/White Paper

- **Foundational Patterns for Efficient Quantum Computing. [4]**

The results of the application example are shown in Figure 3, including Equality-Based Value Matching, Inequality-Based Value Matching, QUBO(Quadratic Unconstrained Binary Optimization) and Fibonacci Numbers.

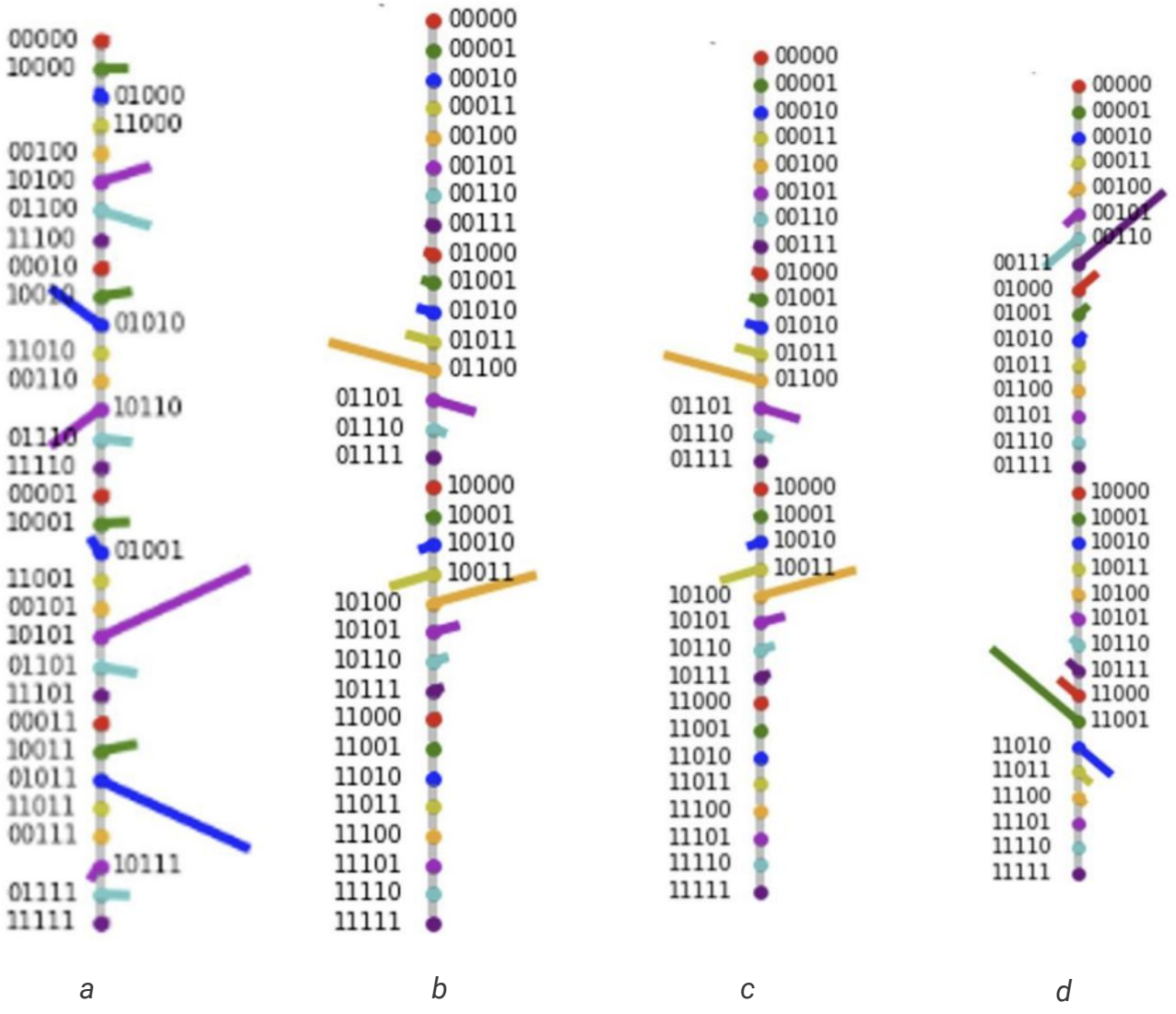


Figure 3. The results of exploring Counting Values and NP-Hard Problems, a. Equality-Based Value Matching; b. Inequality-Based Value Matching; c. QUBO; d. Fibonacci Numbers.

Case Study/White Paper

- **Option Pricing using Quantum Computers. [5]**

They present a methodology to price options and portfolios of options on a gate-based quantum computer using amplitude estimation, an algorithm which provides a quadratic speedup compared to classical Monte Carlo methods. The options that they cover include vanilla options, multi-asset options and path-dependent options such as barrier options. They put an emphasis on the implementation of the quantum circuits required to build the input states and operators needed by amplitude estimation to price the different option types. Additionally, they show simulation results to highlight how the circuits that they implement price the different option contracts. Finally, they examine the performance of option pricing circuits on quantum hardware using the IBM Q Tokyo quantum device. They employ a simple, yet effective, error mitigation scheme that allows they to significantly reduce the errors arising from noisy two-qubit gates.

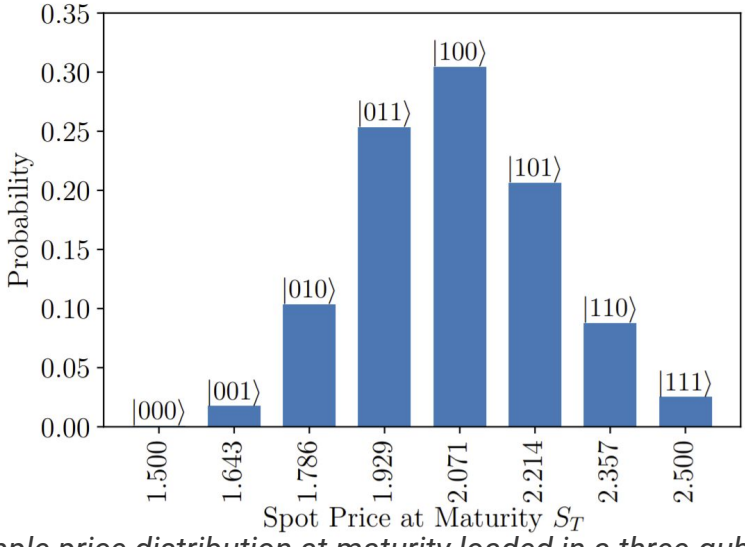


Figure 4. Example price distribution at maturity loaded in a three-qubit register.

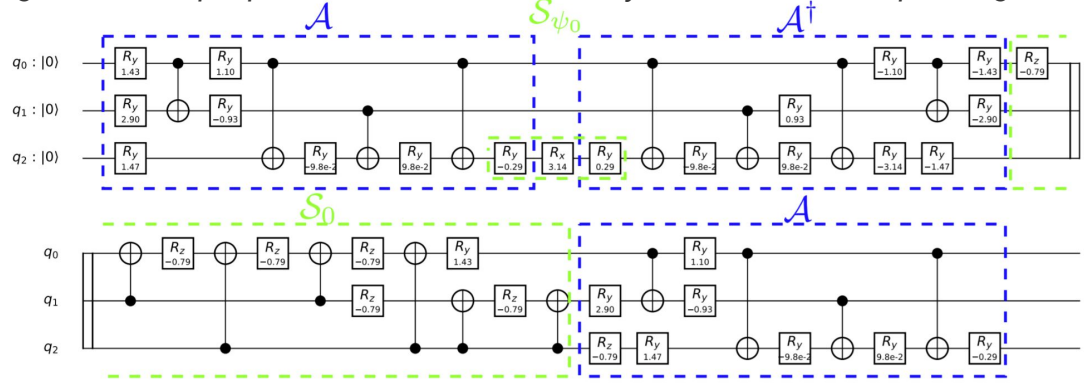


Figure 5. The optimized circuit used for the experiments on real quantum hardware.

Case Study/White Paper

- **Option Pricing using Quantum Computers. [5]**

The results of example are shown in Figure 6.

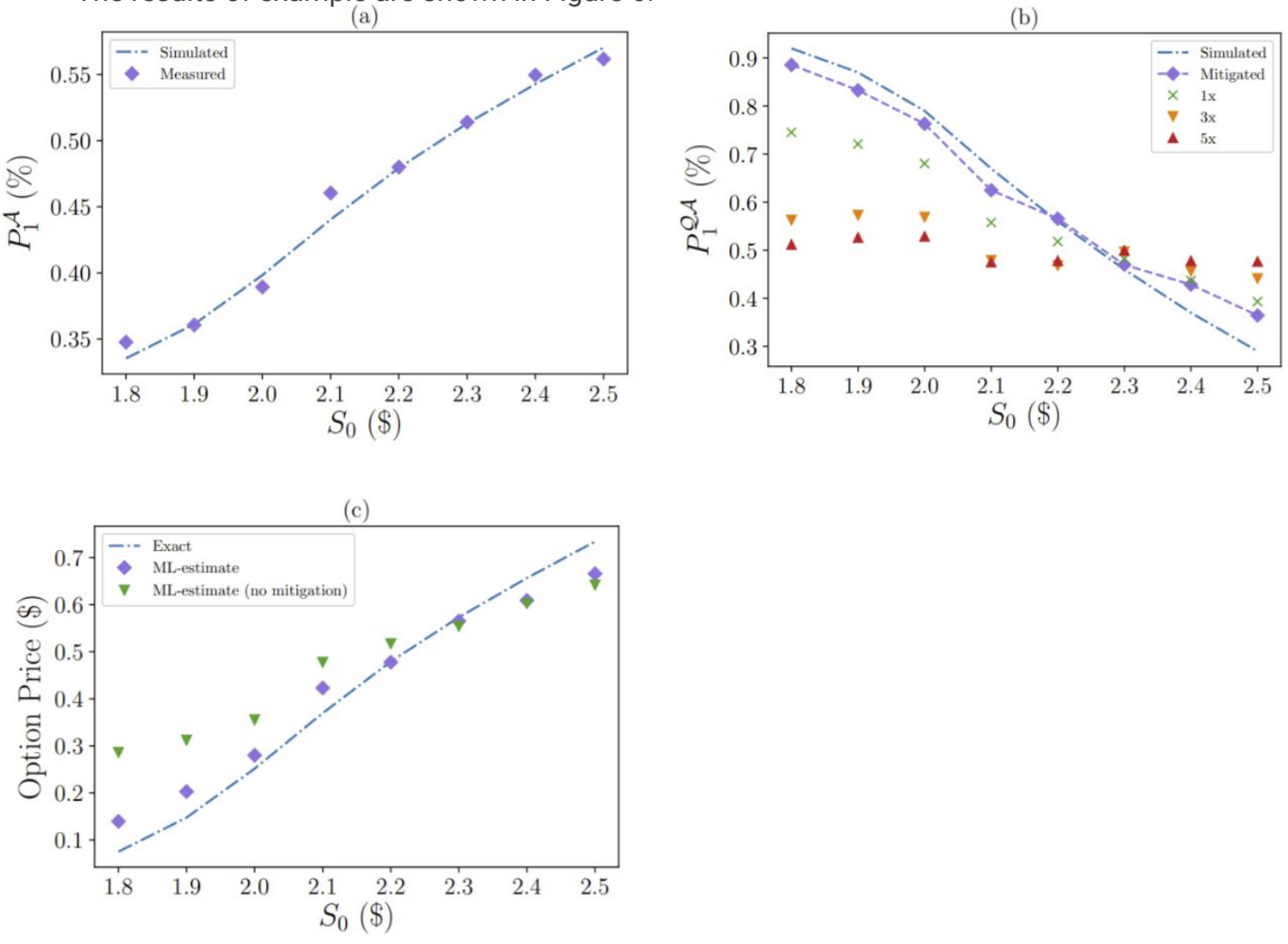


Figure 6. .Error-mitigated hardware results for A |0i3, QA |0i3 and the estimated option price after applying maximum likelihood estimation as a function of the initial spot price S0. a. Probability of measuring |1i for the QA |0i3 circuit; b. Probability of measuring |1i for the QA |0i3 circuit. It shows the measured probabilities when replacing each CNOT by one, three and five CNOT gates (green, orange, red, espectively), the zero-noise limit calculated using a second-order Richardson extrapolation method (purple), and the probability measured using the simulator (blue). c. Option price estimated with maximum likelihood estimation from measurements of QA |0i3 and A |0i3 with error mitigation (purple) and without (green). The exact option price for each initial spot price S0 is shown in blue.

Intellectual Property

N/A.

Investors/Funding Partners

N/A.

References

1. https://www.jpmorgan.com/global
2. https://www.jpmorgan.com/technology/flare
3. https://arxiv.org/abs/2006.10656
4. https://arxiv.org/abs/1907.11513
5. https://arxiv.org/pdf/1905.02666.pdf

Alzheimer's drug: Roche

Roche
Headquarters: Basel, Switzerland
Website: https://www.roche.com/
Contact: +41616881111

TRL 5

Overview

Roche is a pharmaceutical and cosmetic company, focused on drug development and treatment of oncology, virology, inflammation, metabolism, CNS, clinical chemistry, immunology,urinalysis, blood screening, genetics, infectious diseases, and microbiology. The company was founded in 1896 and currently has more than 10000 employees, with $7.8B in total funding amount [1] and $57B in annual revenue [2].

Product Description

Roche has partnered with Cambridge Quantum Computing (CQC) to develop a new drug for Alzheimer's disease, by using quantum computing. The aim is to develop a new algorithm by using the CQC's quantum chemistry platform, EUMEN, so they can research and implement noisy-intermediate-scale-quantum (NISQ) algorithms [3].

By using quantum algorithms, Roche expects to overcome the solubility and pharmaceutical issues that arises when researching for Alzheimer's drug, as well as challenges such as enabling stable and consisting cooling.

Roche has prepared an initiative (pRED – Pharma Research and Early Development), to implement quantum computing in its research and development department [4].

Alzheimer's drug: Roche

Case Study/White Paper

The technology is still developing

Intellectual Property

There are no patents published yet.

Investors/Funding Partners

Not available

References

1. https://www.crunchbase.com/organization/roche
2. https://en.wikipedia.org/wiki/Roche
3. https://www.datacenterdynamics.com/en/news/roche-strikes-quantum-computing-deal-to-develop-early-stage-alzheimers-drugs-with-cqc/
4. https://www.cambridgeindependent.co.uk/business/alzheimer-s-is-first-target-as-cambridge-quantum-computing-collaborates-with-roche-9155359/

Enterprise Software and Services for Quantum Computing: QC Ware

QC Ware
Headquarters: Palo Alto, California, USA
Website: https://qcware.com/
Contact: info@qcware.com

TRL 5

Overview

Founded in 2014, QC Ware (11-50 employees) [3] develops hardware-agnostic enterprise software solutions for quantum computers. The company's quantum computing software solves problems in combinatorial optimization and machine learning. The company has raised $36.6M in funding [4] and has less than $5M in revenue [5].

Product Description

QC Ware is developing a quantum cloud-computing platform for enterprise applications. QC Ware's software is designed to be hardware-agnostic – **compatible with any quantum-computing hardware.** The QC Ware platform is intended to solve problems in combinatorial optimization and machine learning that traditional high-performance-computing systems can't tackle. The company claims that using the QC Ware platform, scientists, researchers and developers can integrate quantum computing into their existing computational workflows or they can start developing new applications on top of current-generation quantum-computing hardware [1].

In Sept 2019, QC Ware launched the public beta of its Forge cloud service. QC Ware developed Forge to enable large enterprises and public-sector organizations to start building quantum skills and prepare for the potential disruption that quantum computing will bring to the market [9].

Enterprise Software and Services for Quantum Computing: QC Ware

Product Description

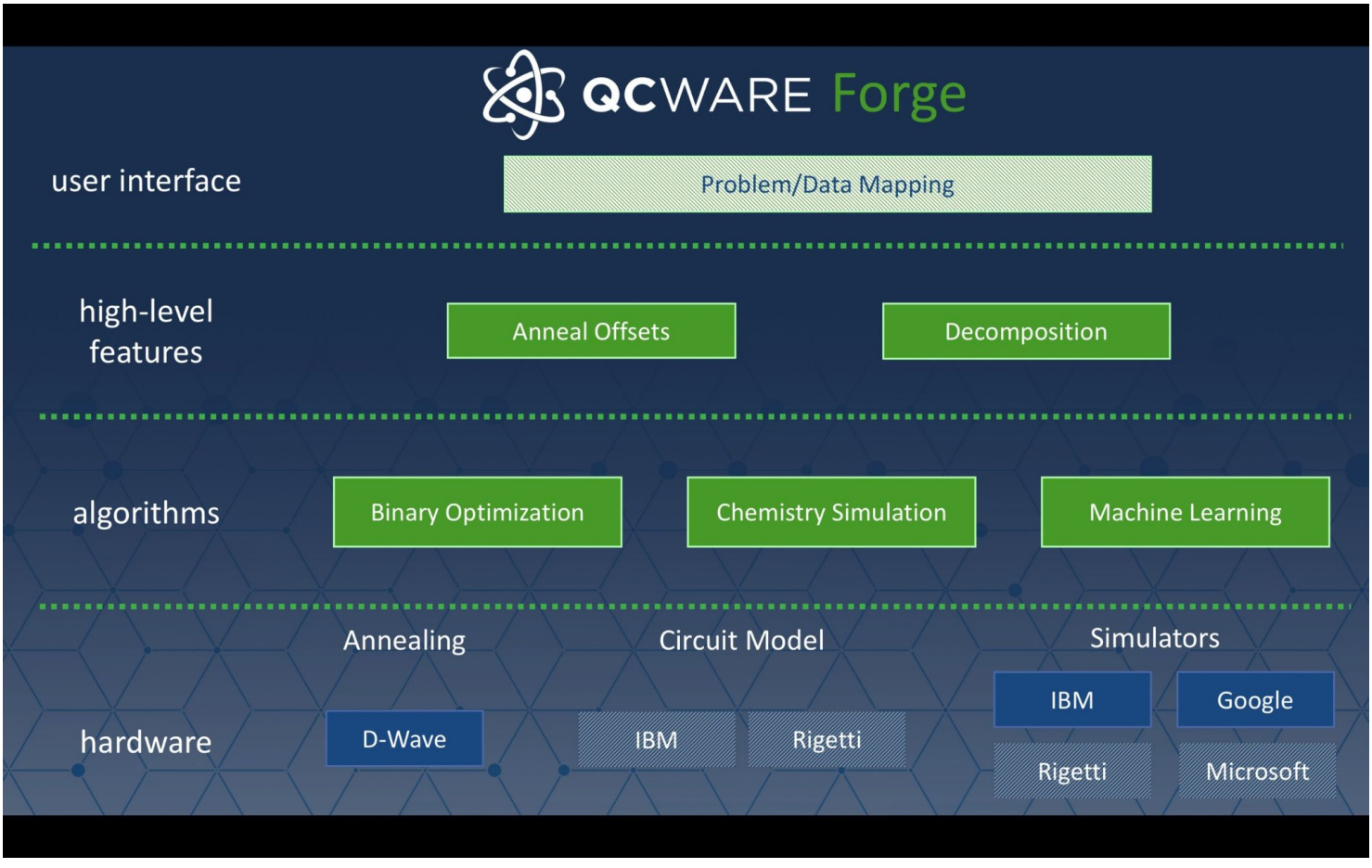


Figure: QC Ware Forge Architecture [9]

Case Study/White Paper

Case study 1: Aerospace Optimization - Airbus [6]

- **Challenge:** How to compute fault-tree diagnostics without multi-hour bottlenecks?
- **Solution:** Reduce the computing resources used during system design, prototyping and production.

Case study 2: Quantum Computing in the Automotive Industry - BMW [7]

- **Challenge:** Massive amounts of data (e.g., millions of miles driven) required to train highly accurate models.
- **Solution:** Use quantum computing to minimize actual miles driven.

Intellectual Property

Patent Name/Title: Quantum computing as a service [8]

Patent No: US10614370B2

Status: Granted in April 2020.

Brief description:

A cloud computing architecture and system for interaction with and use of quantum processing devices is mentioned in this patent. The invention comprises:

- a unified platform as a service for interacting with various quantum processing devices.
- An architecture and methodology for accessing and using a variety of quantum processing devices.
- Other aspects of the invention incorporate various software modules that provide additional functionality for users of quantum processing devices.

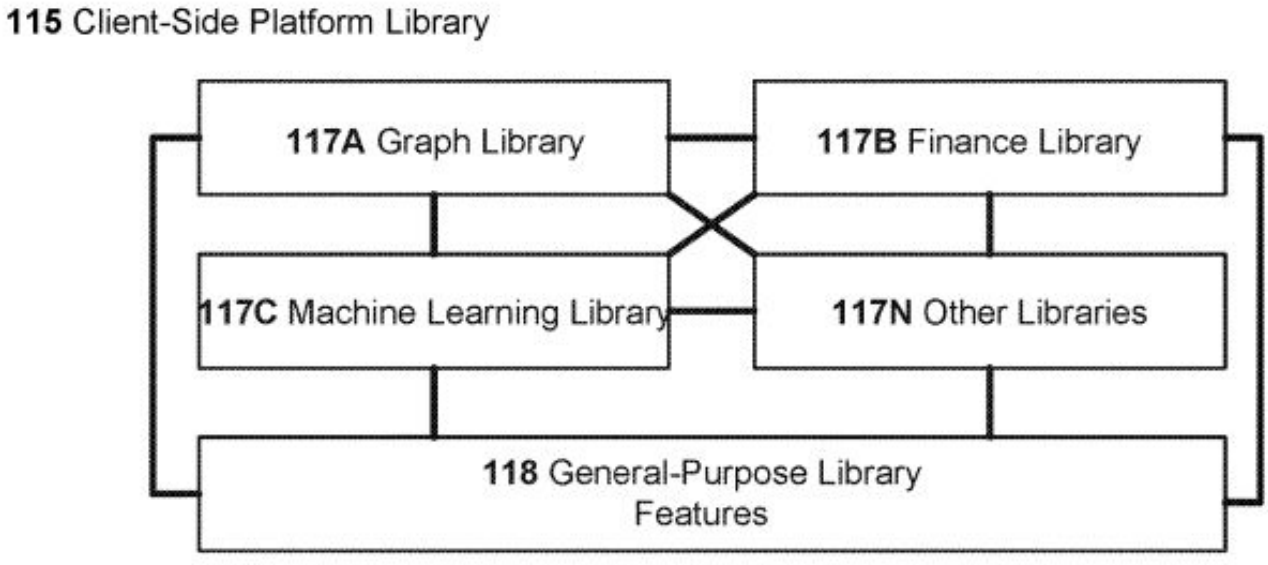


FIG. 3

FIG. 3 from the patent is a logical diagram of some of the various software modules and components of the Client-Side Platform Library

Investors/Funding Partners

QC Ware has raised a total of $36.6M in funding over 4 rounds. Their latest funding was raised on Jul 27, 2021 from a Venture - Series Unknown round. QC Ware is funded by 6 investors. Citi and Goldman Sachs are the most recent investors [4].

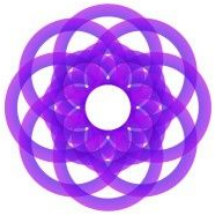
Investor Name	Lead Investor	Funding Round	Partners
Citi	Yes	Series A - QC Ware	–
Goldman Sachs	Yes	Series A - QC Ware	–
D. E. Shaw & Co.	No	Series A - QC Ware	–
Pegasus Tech Ventures	–	Series A - QC Ware	–
Airbus Ventures	–	Series A - QC Ware	–
Airbus Ventures	–	Seed Round - QC Ware	–
D. E. Shaw & Co.	–	Seed Round - QC Ware	–
Alchemist Accelerator	–	Seed Round - QC Ware	–

Table: Investors list

References

1. https://qcware.com/
2. https://www.networkworld.com/article/3489098/10-hot-quantum-computing-startups-to-watch.html
3. https://www.linkedin.com/company/qcware/about/
4. https://www.crunchbase.com/organization/qc-ware
5. https://www.zoominfo.com/c/qc-ware/369200272
6. https://qcware.com/customer/airbus
7. https://qcware.com/customer/bmw
8. http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&p=1&u=/netahtml/PTO/srchnum.html&r=1&f=G&l=50&d=PALL&s1=10614370.PN.
9. https://www.prnewswire.com/news-releases/qc-ware-launches-public-beta-of-forge-300924867.html

Boulder Opal: Q-CTRL



Q-CTRL
Headquarters: Pyrmont, New South Wales, Australia
Website: https://q-ctrl.com/
Contact: https://q-ctrl.com/company/#contact

TRL 5

Overview

Founded in 2017, Q-CTRL (11-50 employees) [5] develops tools that help quantum-computing developers stabilize their quantum hardware against decoherence (the loss of “quantum-ness”) [1]. Q-CTRL has raised a total of $15M in funding [6] and has a revenue of $8M [7].

Product Description [4]

Boulder Opal by Q-CTRL consists of lab-validated, professionally engineered tools that gives the user flexibility to improve and automate quantum hardware. The core capabilities of Boulder Opal fall under the framework of quantum control—the discipline that addresses the question, "How can systems that obey the laws of quantum mechanics be efficiently manipulated to create desired behaviors?" The quantum control functionality underlying Boulder Opal comprises three core activities: System Identification, Control Design, and Performance Verification.

- **System identification:** It involves characterizing key system parameters such as energy levels and interactions (AKA Hamiltonian parameters and sources of performance degradation essential for improving hardware). This is generally accomplished by probing the quantum system and performing analysis on the resulting data. For instance, the user may choose to characterize the transmission lines in a hardware system using a qubit as a probe, or perform noise spectroscopy on an arbitrary Hamiltonian term. This information together results in a model of the system which can be used to inform how to design suitable controls for the system in the next activity.

Product Description

- **Control design:** Otherwise known as optimization, is the creation of control solutions to manipulate D-dimensional quantum systems (Hilbert spaces) so they are resilient to noise, to cancel particular Hamiltonian terms, or to minimize control duration. This can be performed using either a Hamiltonian model of the system or via closed-loop experimental interrogation, and will generally involve a critical calibration step on the hardware. Boulder Opal favors robust control which delivers high performance even in the presence of imperfections in the system.
- **Performance verification:** This involves analyzing control solutions to gain insights into their functionality or effectiveness. This includes techniques to both probe the expected response and action of the control via simulation under realistic conditions and experimental probing of performance through specific validation routines known to highlight or amplify certain errors for easy tuneup.

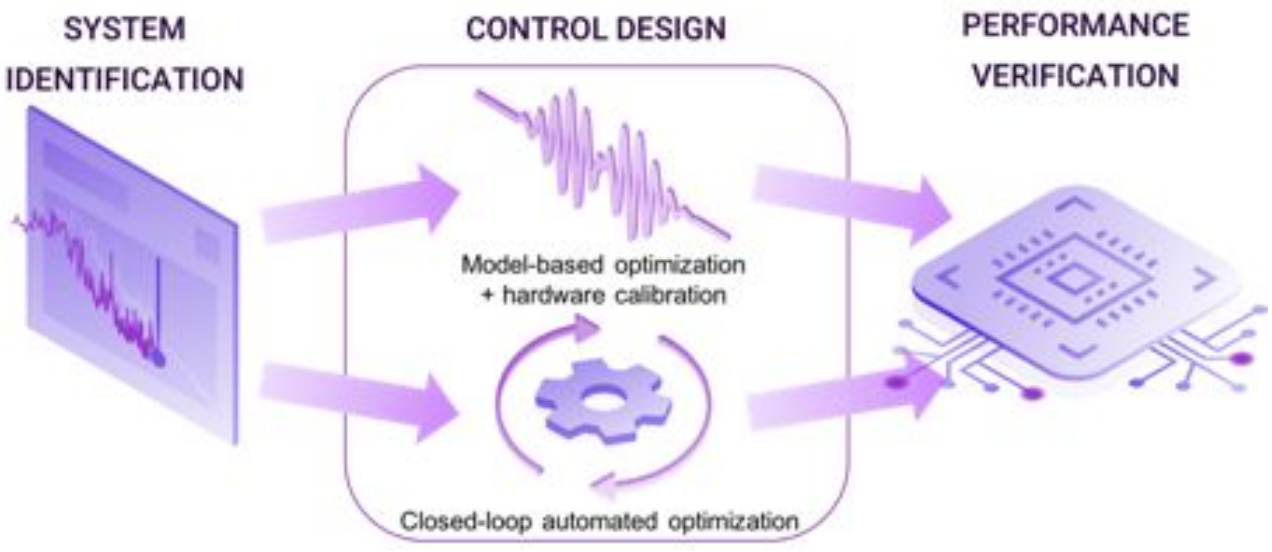


Figure: The quantum control functionality underlying Boulder Opal comprises three core activities: System Identification, Control Design, and Performance Verification.

Product Description

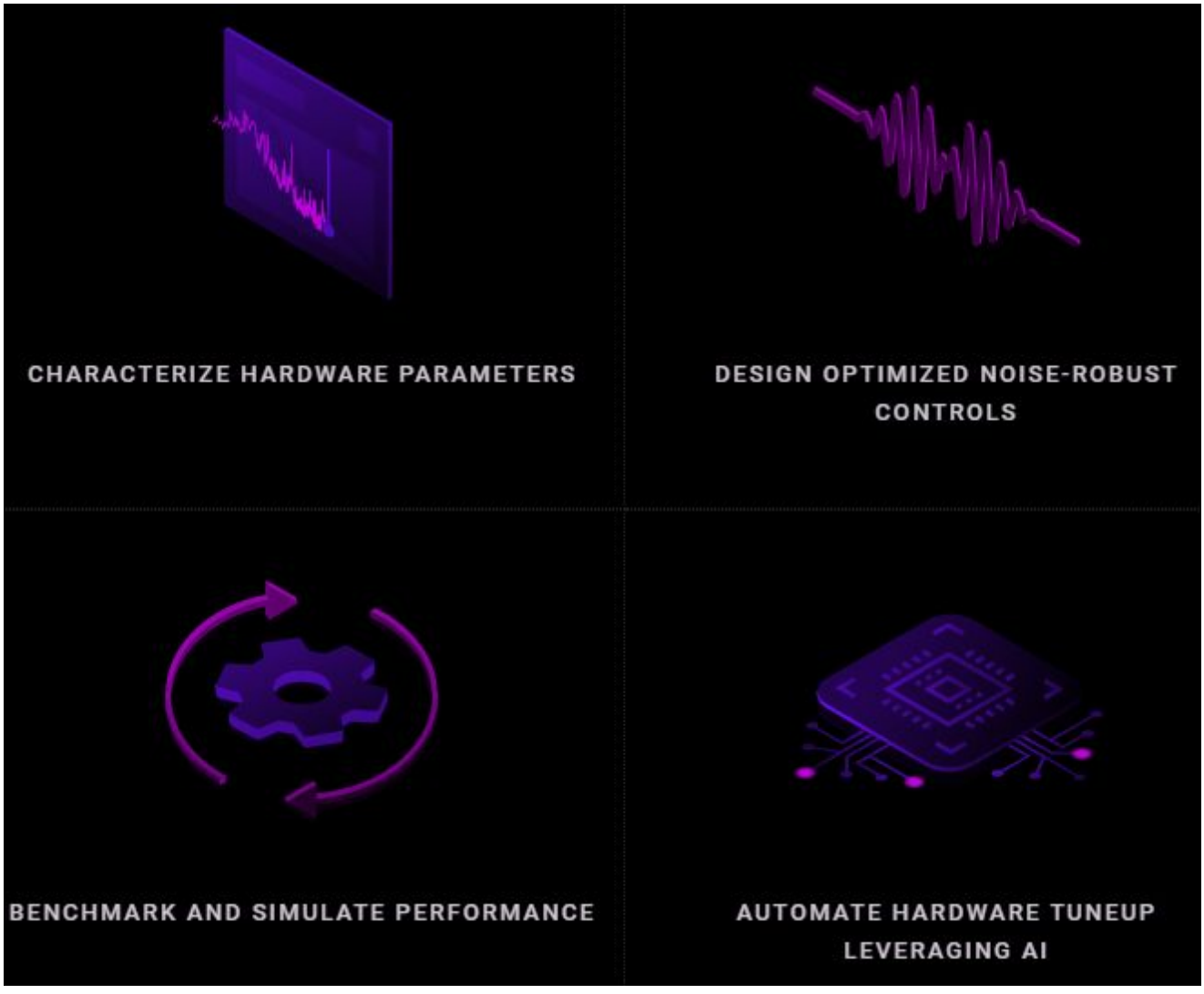


Figure: Black Opal features

Product Description

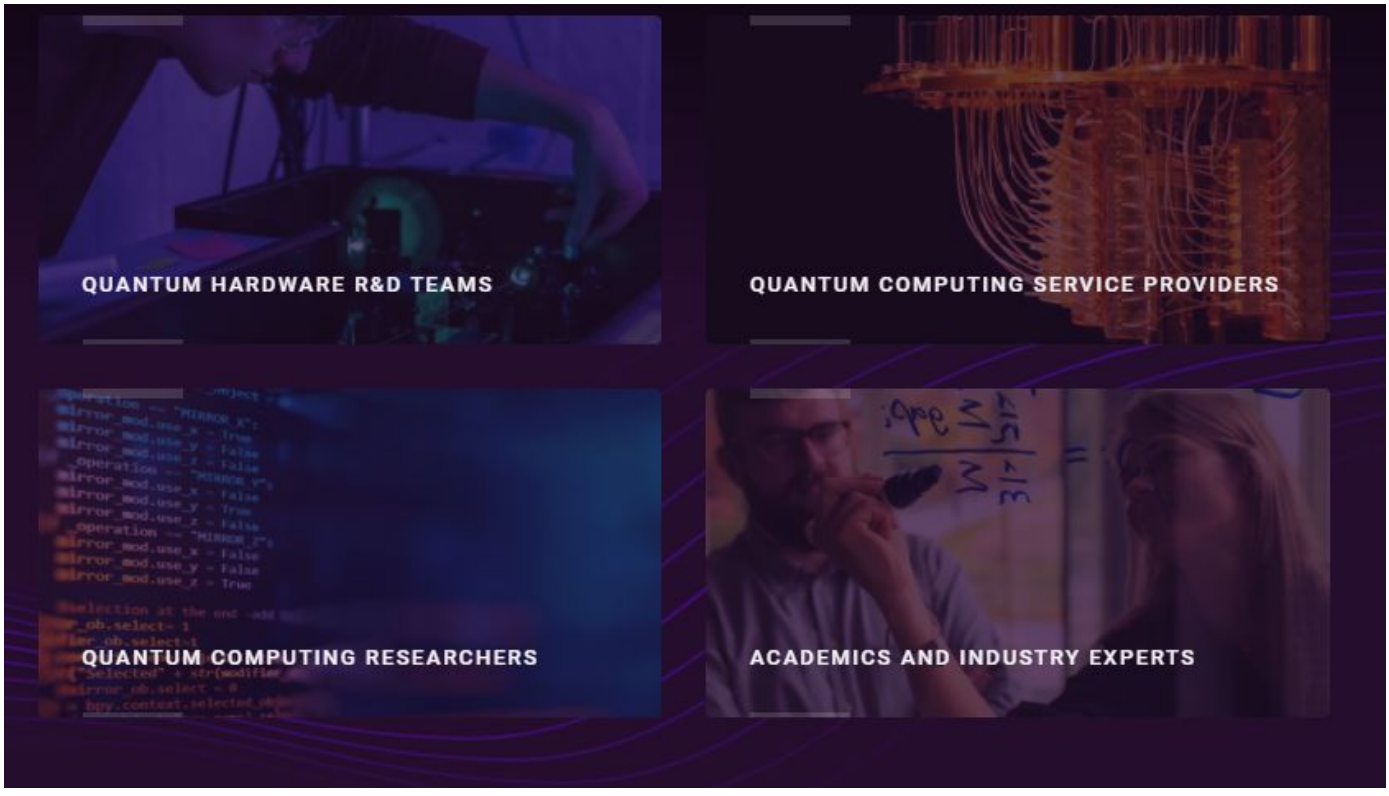


Figure: Who should be using Boulder Opal

Product Description

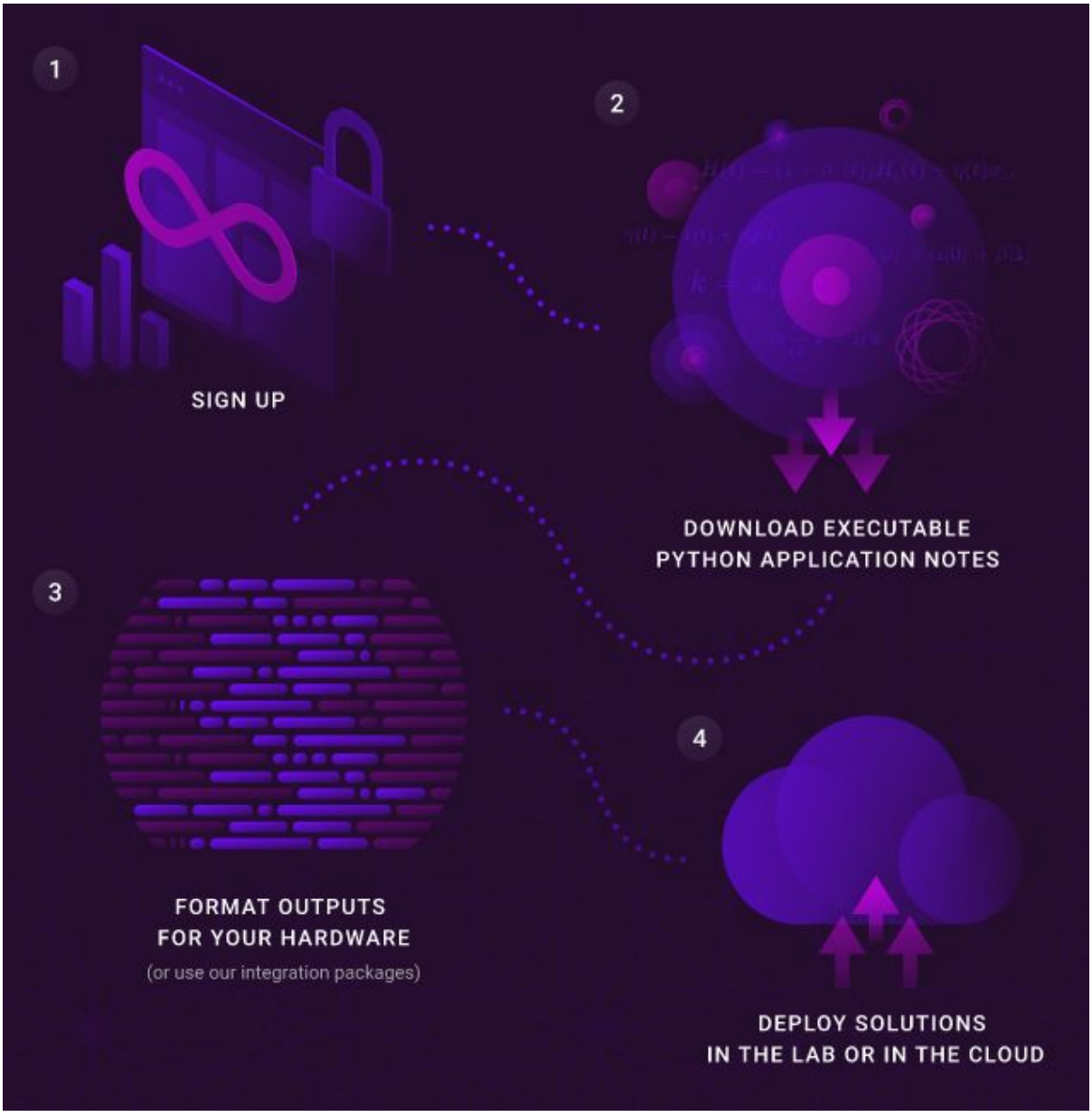


Figure: Boulder Opal workflow

Case Study/White Paper

Quantum gravimetry and magnetometry [8]

Boulder Opal allows to create and deploy optimized noise-robust controls to improve hardware performance in the field - for atomic and solid-state devices. It also provides access to advanced machine-learning routines for environmental spectrum reconstruction enabling efficient data analysis of sensor measurements. Combine with Quantum Professional Services in order to derive novel solutions permitting simultaneous mitigation of control-system noise, advanced time-domain state-tracking, and multisensor data-fusion.

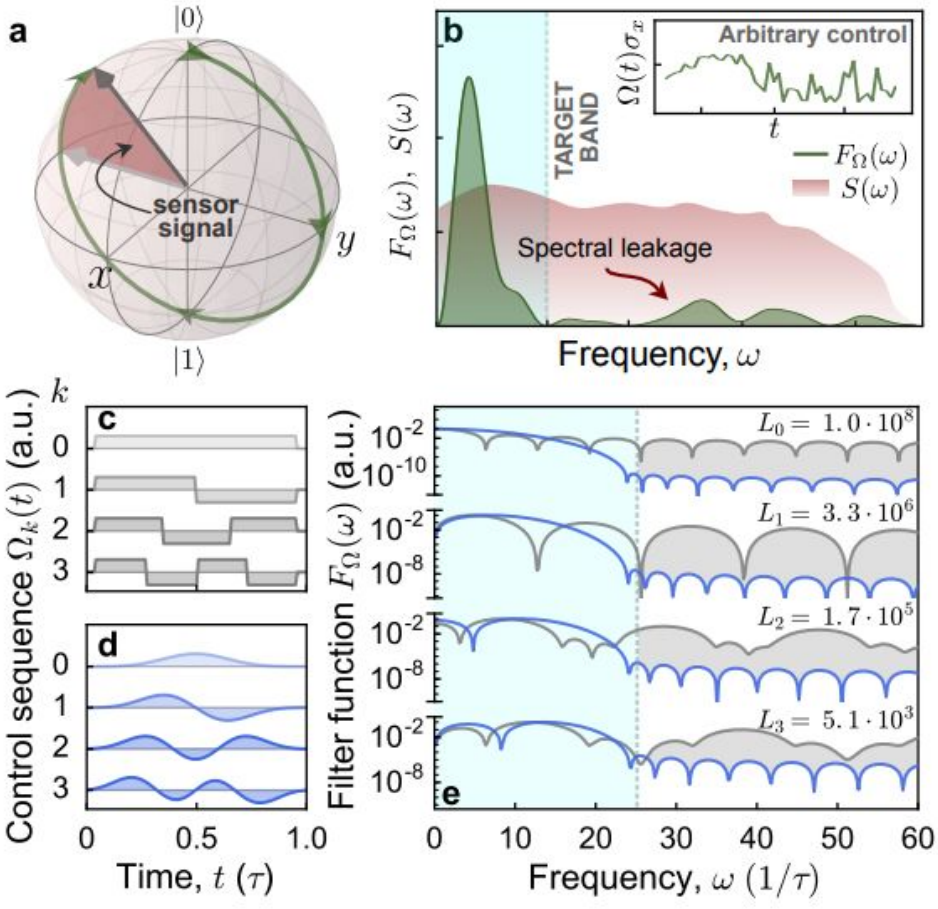


Figure: Schematic illustration of frequency responses of time domain control protocols. [9]

Intellectual Property

Patent Name/Title: Controlling oscillators [3]

Patent No: US9362929B2

Status: Granted in June 2016.

Brief description:

A computer implemented method for controlling an oscillator, the method comprising:

- Determining a first statistical correlation between multiple error values, each error value being indicative of a measurement of a frequency difference between the oscillator and a frequency reference over a period of time, and
- Determining a control value to control the oscillator by maximising a second statistical correlation between a frequency difference at a time of application of the control value to the oscillator and a correction caused by the application of the control value, the frequency difference being a statistical variable estimated based on the first statistical correlation and an application time value indicative of the time of application of the control value to the oscillator.

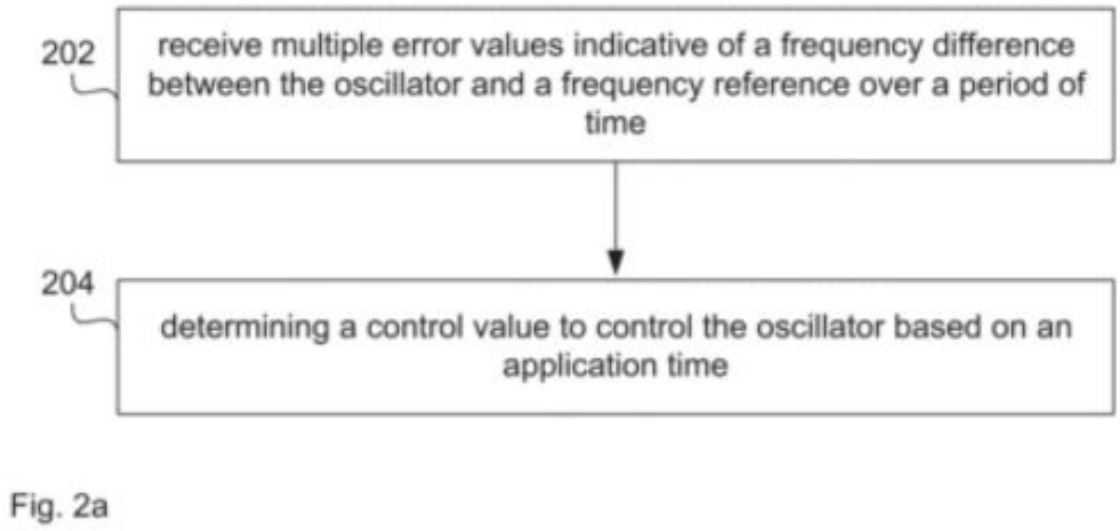


Fig. 2a

FIG. 2a from the patent illustrates a method for controlling an oscillator.

Investors/Funding Partners

Q-CTRL has raised a total of $15M in funding over 4 rounds. Their latest funding was raised on Apr 14, 2020 from a Venture - Series Unknown round. Q-CTRL is funded by 8 investors. In-Q-Tel and Sierra Ventures are the most recent investors [6].

Investor Name	Lead Investor	Funding Round	Partners
In-Q-Tel	Yes	Venture Round - Q-CTRL	Mike Ferrari
Sierra Ventures	–	Series A - Q-CTRL	Ben Yu
Square Peg Capital	Yes	Series A - Q-CTRL	–
Sequoia Capital	–	Series A - Q-CTRL	–
Main Sequence	–	Series A - Q-CTRL	–
Horizons Ventures	–	Series A - Q-CTRL	–
Sequoia Capital China	Yes	Seed Round - Q-CTRL	Steven Ji
DCVC	Yes	Seed Round - Q-CTRL	James Hardiman
Main Sequence	Yes	Seed Round - Q-CTRL	Phil Morle
Horizons Ventures	Yes	Seed Round - Q-CTRL	Jonathan Tam

Table: Investors list

References

1. https://q-ctrl.com/products/boulder-opal/
2. https://www.networkworld.com/article/3489098/10-hot-quantum-computing-startups-to-watch.html
3. http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&p=1&u=/netahtml/PTO/srchnum.html&r=1&f=G&l=50&d=PALL&s1=9362929.PN.
4. https://docs.q-ctrl.com/boulder-opal/topics/boulder-opal-overview
5. https://www.linkedin.com/company/q-ctrl/about/
6. https://www.crunchbase.com/organization/q-ctrl
7. https://www.zoominfo.com/c/q--ctrl-pty-ltd/447014116
8. https://q-ctrl.com/solutions/quantum-sensing/
9. https://arxiv.org/pdf/1704.02050.pdf

Strangeworks QC™ platform: Strangeworks Inc.

Strangeworks Inc.
Headquarters: Austin, Texas, United States
Website: https://strangeworks.com/
Contact: https://strangeworks.com/#contact

TRL 5

Overview

Founded in 2018, Strangeworks (11-50 employees) is a computing software company based in Austin, TX. Founded by whurley, Strangeworks is currently making quantum computing accessible by building and delivering tools for software developers and researchers, and systems management for IT Administrators and CIOs (Chief Information Officer) [3]. The company has raised total funding of $4M [4] and has a revenue of less than $5M [5].

Product Description

Strangeworks QC™ (Quantum Computing) is a quantum computing ecosystem that enables researchers, developers, and enthusiasts to quickly learn, develop and manipulate real quantum code. With Strangeworks QC, users can easily create, organize, and collaborate on quantum computing projects and access libraries of code, frameworks, and languages, including the following: Amazon Braket SDK, Blueqat, Cirq, D-Wave Ocean, Forest, Jupyter Notebooks, Microsoft QDK (Q#), MyQLM, OpenQASM, ProjectQ, Python, Qiskit, Xanadu PennyLane, and Xanadu Strawberry Fields [1].

Platform features:

- Nothing to install or configure
- Supports all major quantum frameworks
- Start with their code, or or the user can write his/her own code
- Run experiments and get results
- Share, collaborate, and publish the work

Strangeworks QC™ platform: Strangeworks Inc.

Product Description

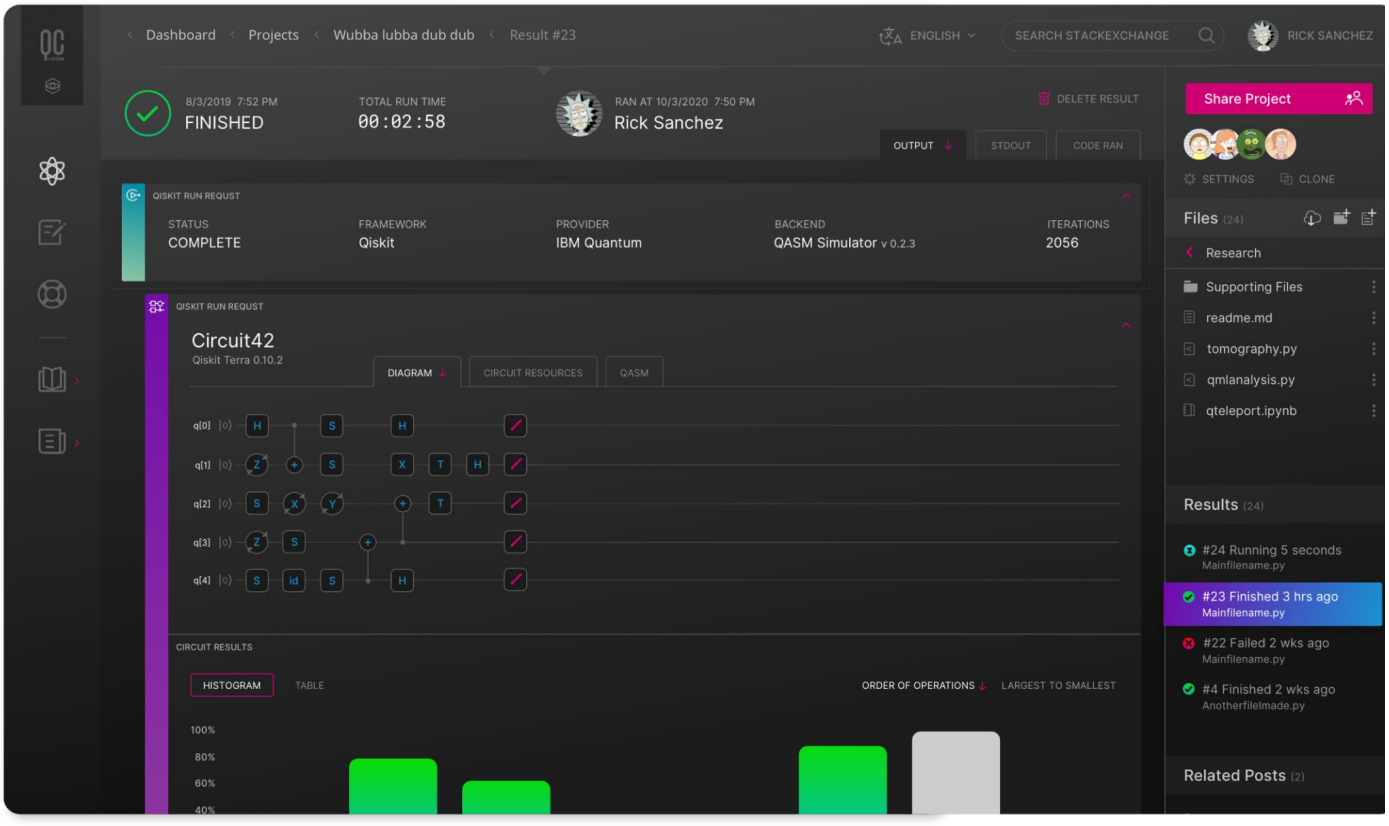


Figure: Strangeworks QC™ platform snapshot

Case Study/White Paper

Strangeworks and IBM announce integration of IBM quantum cloud services into the strangeworks ecosystem [6]

On 3rd June 2021, IBM announced that Strangeworks integrated all of IBM's open quantum computing systems and simulators into the Strangeworks Quantum Computing ecosystem where users can access them directly and completely free via Strangeworks QC™ at quantumcomputing.com. This announcement marks the beginning of the integration of IBM Quantum as a service into the Strangeworks ecosystem. Users will be able to sign up to use IBM Quantum via the Stangeworks ecosystem directly and be able to access IBM Quantum backends and programs using Qiskit and OpenQASM through the Strangeworks cloud platform.

Intellectual Property

N/A

Investors/Funding Partners

Strangeworks has raised a total of $4M in funding over 1 round. This was a Seed round raised on Jun 12, 2018. Strangeworks is funded by 8 investors. Charles Stonehill and Robert Beauchamp are the most recent investors [4].

Investor Name	Lead Investor	Funding Round	Partners
Charles Stonehill	–	Seed Round - Strangeworks	–
Robert Beauchamp	–	Seed Round - Strangeworks	–
BoxGroup	–	Seed Round - Strangeworks	Adam Rothenberg, David Tisch
Lightspeed Venture Partners	Yes	Seed Round - Strangeworks	Adam Goldberg, Barry Eggers, Ravi Mhatre
Jon Soberg	–	Seed Round - Strangeworks	–
Lux Capital	–	Seed Round - Strangeworks	Bilal Zuberi
Amplify Partners	–	Seed Round - Strangeworks	David Beyer, Lenny Pruss, Lisha Li
GreatPoint Ventures	–	Seed Round - Strangeworks	Ray Lane

Table: Investors list

References

1. https://strangeworks.com/platform
2. https://www.networkworld.com/article/3489098/10-hot-quantum-computing-startups-to-watch.html?page=2
3. https://www.linkedin.com/company/strangeworks/about/
4. https://www.crunchbase.com/organization/strangeworks
5. https://www.zoominfo.com/c/strangeworks-inc/449565088
6. https://strangeworks.com/newsroom/strangeworks-and-ibm-announce-integration-of-ibm-quantum-cloud-services-into-the-strangeworks-ecosystem

PQ Chat: PQ Solutions

PQ Solutions
Headquarters: London, UK
Website: https://post-quantum.com/
Contact: info@post-quantum.com

TRL 6

Overview

Founded in 2009, PQ Solutions (11-50 employees) [2] was founded to counter the emergent threat of **quantum cryptanalysis**. The company has since branched out into Identity and Access Management (IAM) and blockchain-enabled enterprise SaaS (software as a service). The company has raised a total of $11.2M [3]. The company has less than $5M in revenue [5].

Product Description

The world's first (claimed) **quantum-safe,** secure, end-to-end encrypted messaging app. Available as a user-friendly app for mobile and desktop, PQChat claims to offer a world-class private messaging experience. This messaging app is used by enterprises and can be combined with Nomidio, company's multi-factor biometric authentication service to ensure only the right individual can access the app. The addition of Quorum, their approval-as-a-service technology, further claims to secure access to storage [1].

Example use cases:

- Secure messaging between company executives
- Trading floor message exchange
- Defence and national security communications

Case Study/White Paper

N/A

Intellectual Property

Patent Name/Title: Method and apparatus for time limited messages in packet communications [4]

Patent No: US10536413B2

Status: Granted in Jan 2020.

Brief description:

This patent relates to data communication, and systems and methods for computer-based instant messaging communications. Systems and methods for direct packet communications and store and forward packet communications are provided that include packets which have attributes which determine the lifetime of the packet contents and these lifetimes are optionally a function of the recipient.

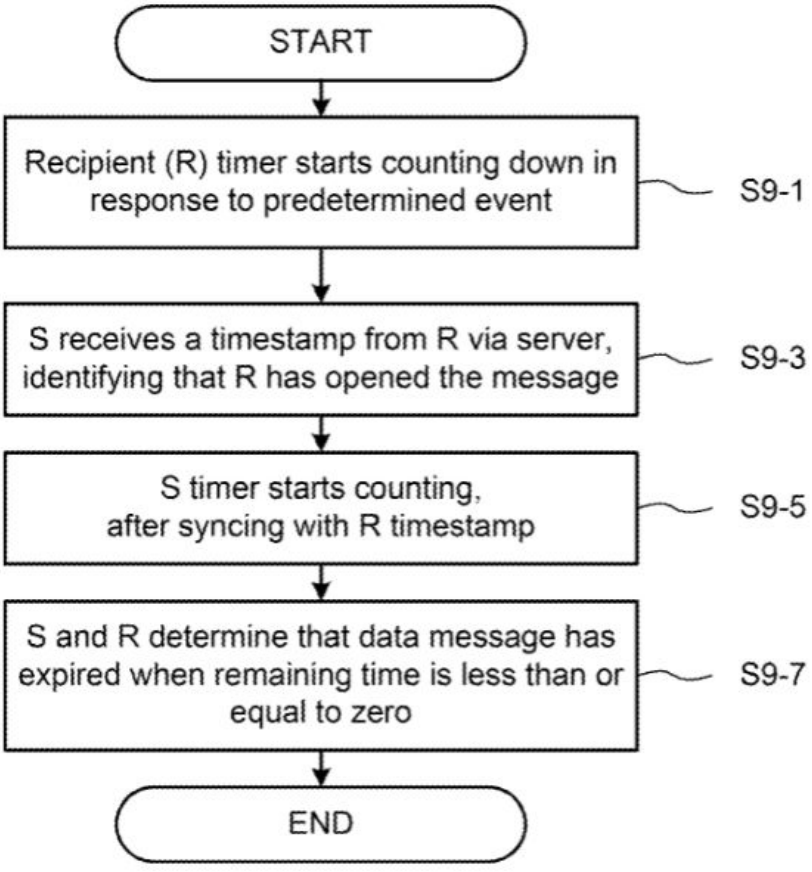


FIG. 9 from the patent is a flow diagram of a synchronization computation process according to an embodiment of the invention.

Investors/Funding Partners

Post-Quantum has raised a total of $11.2M in funding over 3 rounds. Their latest funding was raised on Jul 7, 2016 from a Series A round. Post-Quantum is funded by 3 investors. Techstars and Barclays Accelerator, powered by Techstars - London are the most recent investors [3].

Investor Name	Lead Investor	Funding Round	Partners
Techstars	–	Seed Round - Post-Quantum	Chris Adelsbach
Barclays Accelerator, powered by Techstars - London	–	Seed Round - Post-Quantum	–
Chris Adelsbach	–	Seed Round - Post-Quantum	–

Table: Investors list

References

1. https://post-quantum.com/messaging/
2. https://www.linkedin.com/company/post-quantum/about/
3. https://www.crunchbase.com/organization/pq-solutions-2
4. http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&p=1&u=/netahtml/PTO/srchnum.html&r=1&f=G&l=50&d=PALL&s1=10536413.PN.
5. https://www.zoominfo.com/c/post--quantum/426005111

Scalable Quantum Computer: Quantum Motion

Quantum Motion
Headquarters: Leeds, United Kingdom
Website: https://quantummotion.tech/
Contact: webquery@quantummotion.tech

TRL 5

Overview

Founded in 2017, Quantum Motion (11-50 employees) [2] is led by founders Prof. Simon Benjamin (Oxford University) and Prof. John Morton (UCL) and commercial director Dr. James Palles- Dimmock. The team is working on a patented technology (silicon spin-based qubit architectures) which, for the quantum computing experts out there, are compatible with standard complementary metal-oxide semiconductor (CMOS) fabrication and so provide easier scaling to thousands and millions of qubits. This technology is claimed to be used to make a fully functional, fault tolerant, quantum computer, and also gives the near-term opportunity of easy integration in a hybrid quantum/classical computer [7]. The company has a revenue of less than $5M [4] and has raised a total funding of $9.8M [3].

Product Description

Quantum Motion is developing a quantum computing technology platform; not just a qubit, but a scalable array of qubits based on the silicon technology already used in smartphones and computers. Their team of quantum engineers are developing quantum computing architectures that are compatible with standard silicon processing. The company claims that by creating a scalable quantum computing technology they will be able to tackle currently intractable problems in fields as diverse as chemistry, medicine and artificial intelligence.

Silicon-based integrated circuit technology is the bedrock of the digital revolution. It allows billions of transistors to fit in the size of a stamp. The company is claiming to utilize the power of quantum computing with the silicon. Even a single logical qubit might require a thousand physical qubits to allow the robust error checking required for dependable calculation. THe company claims that only by using a scalable qubit technology the chip size can be controlled.

The same scaling arguments are important for quantum devices: there is a need of an ultra-scalable architecture for quantum computers to reach their full potential [1].

Product Description

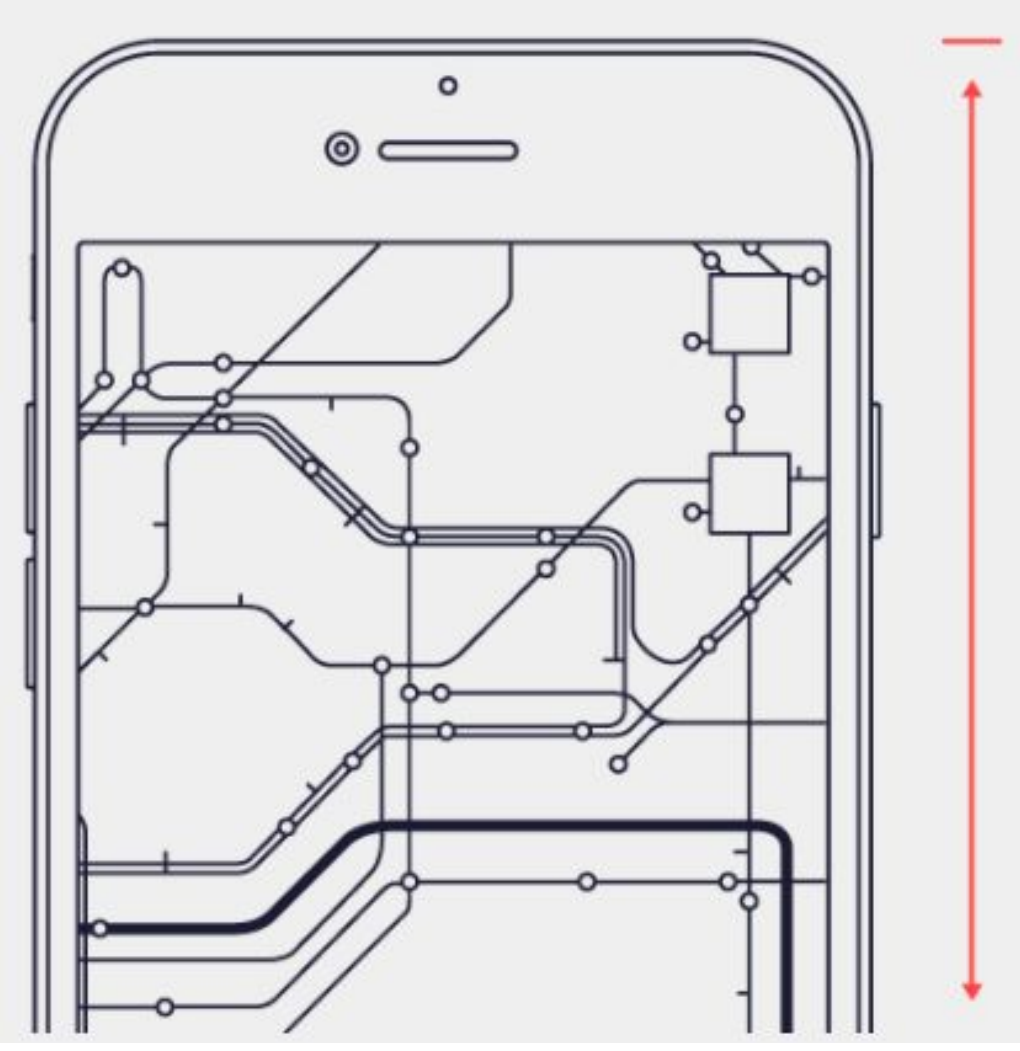


Figure: A smartphone based on vacuum tubes rather than silicon integrated circuits would be 10cm thick and cover an area the size of inner London: ***An argument mentioned on the company website highlighting the usefulness of Silicon technology***

Case Study/White Paper

Neural network powered qubit noise spectroscopy (28 January 2021) [6]

Understanding the spectrum of noise acting on a qubit can yield valuable information about its environment, and crucially underpins the optimization of dynamical decoupling protocols that can mitigate such noise. However, extracting accurate noise spectra from typical time-dynamics measurements on qubits is intractable using standard methods. The demonstrated a neural-network-based methodology that allows for extraction of the noise spectrum associated with any qubit surrounded by an arbitrary bath, with significantly greater accuracy than the current methods of choice. The company claims that their results can be applied to a wide range of qubit platforms, and provide a framework for improving qubit performance.

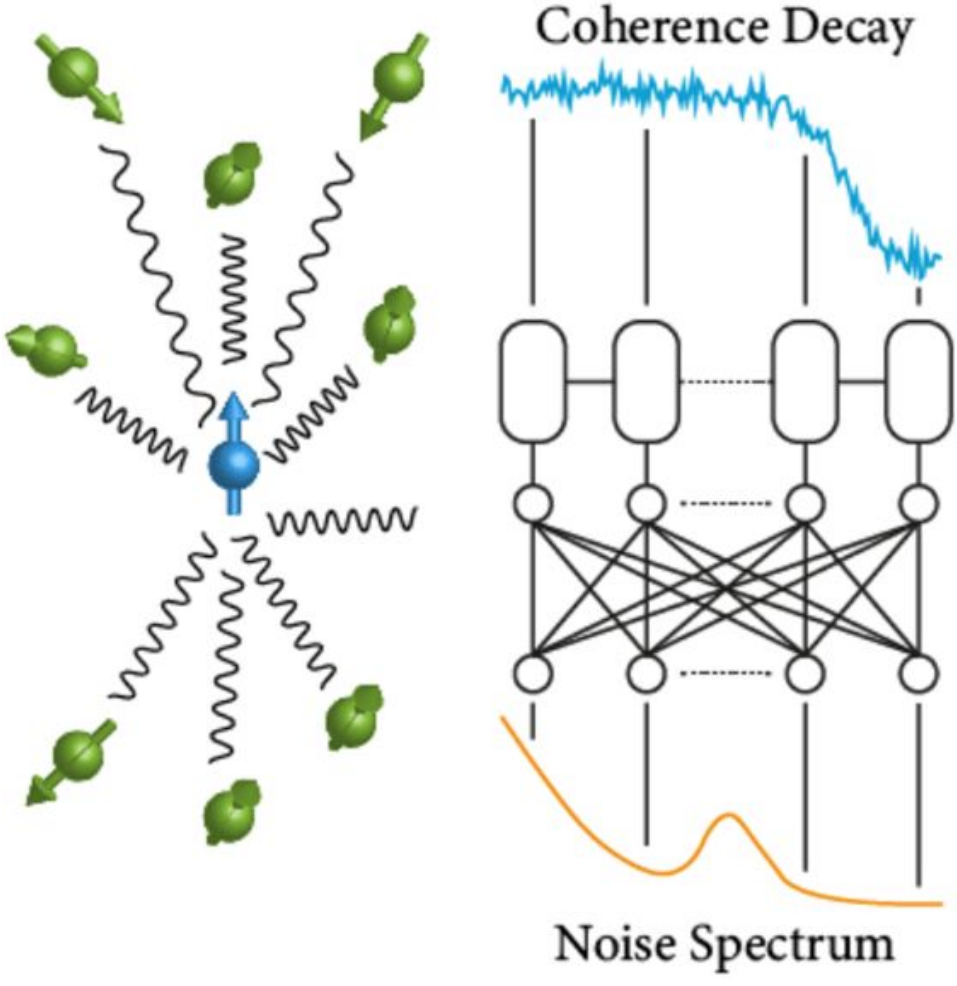


Figure: Neural network powered qubit noise spectroscopy

Intellectual Property

Patent Name/Title: Architectures for quantum information processing [5]

Patent No: WO2020188240A1

Status: Pending

Brief description:

The patent mentions device, architecture and system for use in quantum information processing and storage. The device comprises:

- a first plurality of confinement regions for confining spinful charge carriers for use as data qudits;
- a second plurality of confinement regions for confining spinful charge carriers for use as ancillary qudits, each confinement region of the second plurality of confinement regions couplable to measurement apparatus for measuring an ancillary qudit;
- a third plurality of confinement regions for confining spinful charge carriers, each confi nement region of the third plurality of confinement regions situated between a first confinement region of the first plurality of confinement regions and a second confinement region of the second plurality of confinement regions and for use in mediating interactions between a data qudit of the first confinement region and an ancillary qudit of the second confinement region; and
- one or more charge reservoirs, wherein each confinement region of the third plurality of confinement regions is couplabie to a charge reservoir of the one or more charge reservoirs.

Investors/Funding Partners

Quantum Motion Technologies has raised a total of $9.8M in funding over 2 rounds. Their latest funding was raised on May 14, 2020 from a Series A round. Quantum Motion Technologies is funded by 6 investors. British Business Bank and IP Group Plc are the most recent investors [3].

Investor Name	Lead Investor	Funding Round	Partners
British Business Bank	No	Series A - Quantum Motion Technologies	–
IP Group Plc	No	Series A - Quantum Motion Technologies	–
Parkwalk Advisors	No	Series A - Quantum Motion Technologies	–
Octopus Ventures	No	Series A - Quantum Motion Technologies	–
INKEF Capital	Yes	Series A - Quantum Motion Technologies	–
Oxford Sciences Innovation	No	Series A - Quantum Motion Technologies	–
Parkwalk Advisors	Yes	Seed Round - Quantum Motion Technologies	–
Oxford Sciences Innovation	Yes	Seed Round - Quantum Motion Technologies	–
IP Group Plc	–	Seed Round - Quantum Motion Technologies	–

Table: Investors list

References

1. https://quantummotion.tech/
2. https://www.linkedin.com/company/quantum-motion-tech/about/
3. https://www.crunchbase.com/organization/quantum-motion-technologies
4. https://www.zoominfo.com/c/quantum-motion/480561426
5. http://worldwide.espacenet.com/publicationDetails/biblio?CC=WO&NR=2020188240A1&KC=A1&FT=D
6. https://quantummotion.tech/neural-network-powered-qubit-noise-spectroscopy/
7. https://www.eu-startups.com/2020/05/quantum-motion-raises-e9-million-to-build-fault-tolerant-quantum-computers/

QHealth: Quantum Pharmacogenomics Applied to Aging: aQuantum

aQuantum
Headquarters: Madrid, Spain
Website: https://www.aquantum.es/
Contact: +34 91 787 23 00

TRL 5

Overview

aQuantum is a spanish company specialized in software engineering in the field of quantum computing. It offers consulting services. The company currently has 250-500 employees [1].

The company belongs to a consortium constituted by alhambraIT, Prologue Group. it has partnered with the companies Gloin and Madrija, specialists in software development, as well as the University Institute of Biosanitary Research of Extremadura (INUBE), the University of Extremadura (UEx) and the University of Castilla La Mancha (UCLM) [2].

Product Description

The project "QHealth: Quantum Pharmacogenomics applied to aging" started in August 2020, with a budget of $5.5M. QHealth will explore and develop scientific, methodological and technological models to implement a classical/quantum hybrid system, so it can perform simulations that are not possible in classical hardware. This hybrid system, which will be combined with classical health applications, will be useful to health professionals who will receive the outputs, and would help them to prescribe drugs to older adults. They claim this project will have a human and financial impact, as it will allow to optimize health systems' investments in drug financing. It will also address the adverse effects that drugs usually generate in older people [3].

By using quantum pharmacogenetics algorithms they plan to:

- Correlate genetic and physiological variables, with history of drugs and side effects, to predict possible scenarios in older adults and increase their longevity. Quantum algorithms will be use to run simulations that allow prediction of adverse events.

Product Description

- Avoid side effects of prescribed medications in elderly population, especially when patients are prescribed a new drug.
- Develop software solutions for healthcare, based on quantum computing, so drug prescription can be optimized. The evolution of the patient can also be predicted and mapped, in relation with the drug, as well as the genetic and environmental limitations. Thus, quantum computing would enable to provide proactive aging treatments.

In order to achieve these tasks, aQuantum has developed QPath, a quantum software platform that enables engineers and programmers to develop quantum software that does not need universal skills for development of high-quality quantum software. For that, QPath has the following features [4, 5]:

- Enables the quantum software life cycle and engineering.
- Integrates quantum and classical information systems within its tool services and processes environment. This enables to run quantum processes in a transparent way.
- It contains a hybrid model to develop services without the need to worry about manufacturer's platforms and requirements.
- It can be used by interdisciplinary teams and makes it easy for classid development teams to manage hybrid softwares. It can be used in Chemistry, Economy, Financial Services, Energy, Agriculture, Medicine and Health, Privacy and Cryptography, Logistics, Defense and National Security, …
- Contains applications so that quantum software development can be done by applying quantum engineering principles.
- It contains a set of metalanguages, APIs and QPath´s integration point. This enables to facilitate the integration of classical applications with quantum ones.
- It supports the integration of third-party solutions through pipelines
- It supports the addition of quantum technologies, in an easy manner, as new layers, so solutions can be improved.
- It can be used in different contexts: cloud, on-premise or hybrid.

QHealth: Quantum Pharmacogenomics Applied to Aging: aQuantum

Case Study/White Paper

The technology is still developing

Intellectual Property

There are no patents published yet.

Investors/Funding Partners

Center for the Development of Industrial Technology (CDTI) of the Ministry of Science and Innovation of Spain awarded the project with $4M [2].

References

1. https://www.linkedin.com/company/aquantumsoftwareengineering/about/
2. https://www.quantiki.org/news/project-%E2%80%9Cqhealth-quantum-pharmacogenomics-applied-aging%E2%80%9D-led-aquantum-receives-367-million-euro
   https://www.aquantum.es/rdi/qhealth/
3. https://www.aquantum.es/rdi/qhealth/
4. https://www.quantumpath.es/2020/11/26/qpath_accelerator/

Quantum computing: University of Virginia School of Medicine

University of Virginia School of Medicine
Headquarters: City, State, Country
Website: https://med.virginia.edu/
Contact: sb3de@virginia.edu

TRL 3

Overview

The University of Virginia is an educational institution, founded in 1819 with more than 10000 employees, $217M in total funding amount and $2.5B in annual revenue [1, 2].

The Stefan Bekiranov group focuses on investigating computational statistics methods to be applied to functional genomic data. Particularly, they focus on epigenetic data [3].

Product Description

Researchers at the University of Virginia, have developed a quantum algorithm that enable them to study genetic diseases by using quantum computers [4]. They claim this algorithm would enable to advance in genetic research and, in the long term, in longevity.

Their aim is to develop a quantum classifier that can be implemented on an IBM computer. The new algorithm developed, classifies genetic data and is able to differentiate if a particular sample comes from a disease or a control sample, much more faster than a conventional computer. They claim that “classical computers require 3 billion operations to categorize four building blocks of human DNA (i.e., A, G, C, T) whereas the quantum algorithm only needs 32”.

What they did was to classified control individuals and individuals with diseases, by encoding the input as a string of 1s (presence) or 0s (absence) of a particular genomic attribute within the genome. They divided the genome in blocks of physical regions, and developed two hamming-distance-like classifiers. Hamming distance is a natural distance between two binary strings, and this distance shares properties with an inner product between qubits [5].

Quantum computing: University of Virginia School of Medicine

Product Description

The two Hamming-distance-like classifiers apply two different products, “active” and “symmetric”, to classify an input into two training classes. To take into consideration different disease and control samples, each training class, can be composed of an an arbitrary number of bit strings, which can then be compressed into one input string per class.

In spite of the number of training classes, the group claims their circuits require the same number of qubits. The algorithms were executed and implemented on 5-qubit BMQX4 and 14-qubit IBMQX16 architectures, and implement a training bisection decision plane. IBMQX16, enable to encode 64 training features throughout the genome for two training classes (disease and control).

Case Study/White Paper

The technology is still developing

Intellectual Property

There are no patents published yet.

Investors/Funding Partners

Investors at the University of Virginia are mainly alumni [1].

References

1. https://www.crunchbase.com/organization/university-of-virginia
2. https://evp-coo.virginia.edu/annual-financial-reports#:~:text=UVA%20is%20now%20in%20a,increasingly%20efficient%20and%20effective%20operations.
3. https://med.virginia.edu/faculty/faculty-listing/sb3de/
4. https://news.virginia.edu/content/uva-pioneers-study-genetic-diseases-mind-bending-quantum-computing
5. https://arxiv.org/pdf/1907.08267.pdf

Next Steps

TRL Rating Scale

The Technology Readiness Level (TRL) Scale is an industry standardized metric by which PreScouter evaluates technologies for each client. Based on the constraints on the innovation challenge, PreScouter assigns a TRL number to each identified academic, company or patent.

This process allows each solution to be easily identified for commercialization potential.

Higher number TRL's do not always equate to the best technology – for example, most late stage academic technology is best suited for optimization and integration, but would have a TRL between 2-4.

TRL 9 **Systems operation -** Actual system operated over full range of expected conditions

TRL 8 **System commissioning -** Actual system completed and qualified through demonstrate tests

TRL 7 **System commissioning -** Full-scale, similar prototype demonstration in relevant environment

TRL 6 **Technology demonstration -** Engineering / pilot scale Prototype testing in relevant environment

TRL 5 **Technology development -** Lab-scale validation in relevant environment

TRL 4 **Technology development -** Component or system validation in lab environment

TRL 3 **Research to prove feasibility -** Analytical and experimental test of critical function - proof of concept

TRL 2 **Basic technology research -** Technology concept and/or application formulated

TRL 1 **Basic technology research -** Basic principles observed and reported

Next Steps

SOME POSSIBILITIES THAT PRESCOUTER CAN OFFER FOR CONTINUATION OF OUR RELATIONSHIP

- ☑ COMPETITIVE INTELLIGENCE
- ☑ TECHNOLOGY & PATENT LANDSCAPING
- ☑ TECHNOLOGY ROADMAPPING
- ☑ MARKET RESEARCH & ANALYSIS
- ☑ TRENDS MAPPING
- ☑ REVIEW BEST PRACTICES
- ☑ PATENT COMMERCIALIZATION STRATEGY
- ☑ DATA ANALYSIS & RECOMMENDATIONS
- ☑ ACQUIRE NON-PUBLIC INFORMATION
- ☑ SUPPLIER OUTREACH & ANALYSIS
- ☑ CONSULT WITH INDUSTRY SUBJECT MATTER EXPERTS
- ☑ INTERVIEWING COMPANIES & EXPERTS

WE CAN ALSO DO THE FOLLOWING

- ✔ **CONFERENCE SUPPORT:** Attend conferences of interest on your behalf.
- ✔ **WRITING ARTICLES:** Write technical or more public facing articles on your behalf.
- ✔ **WORKING WITH A CONTRACT RESEARCH ORGANIZATION:** Engage with a CRO to build a prototype, test equipment or any other related research service.

For any requests, we welcome your additional questions and custom building a solution for you.

About PreScouter

PRESCOUTER PROVIDES CUSTOMIZED RESEARCH AND ANALYSIS

PreScouter helps clients gain competitive advantage by providing customized global research. We act as an extension to your in-house research and business data teams in order to provide you with a holistic view of trends, technologies, and markets.

Our model leverages a network of 3,000+ advanced degree researchers at tier 1 institutions across the globe to tap into information from small businesses, national labs, markets, universities, patents, start-ups, and entrepreneurs.

CLIENTS RELY ON US FOR:

Innovation Discovery: PreScouter provides clients with a constant flow of high-value opportunities and ideas by keeping you up to date on new and emerging technologies and businesses.

Privileged Information: PreScouter interviews innovators to uncover emerging trends and non-public information.

Customized Insights: PreScouter finds and makes sense of technology and market information in order to help you make informed decisions.

500+
CLIENTS WORLDWIDE

4000+
RESEARCH REPORTS CREATED

150,000+
HOURS OF RESEARCH COMPLETED FOR CLIENTS