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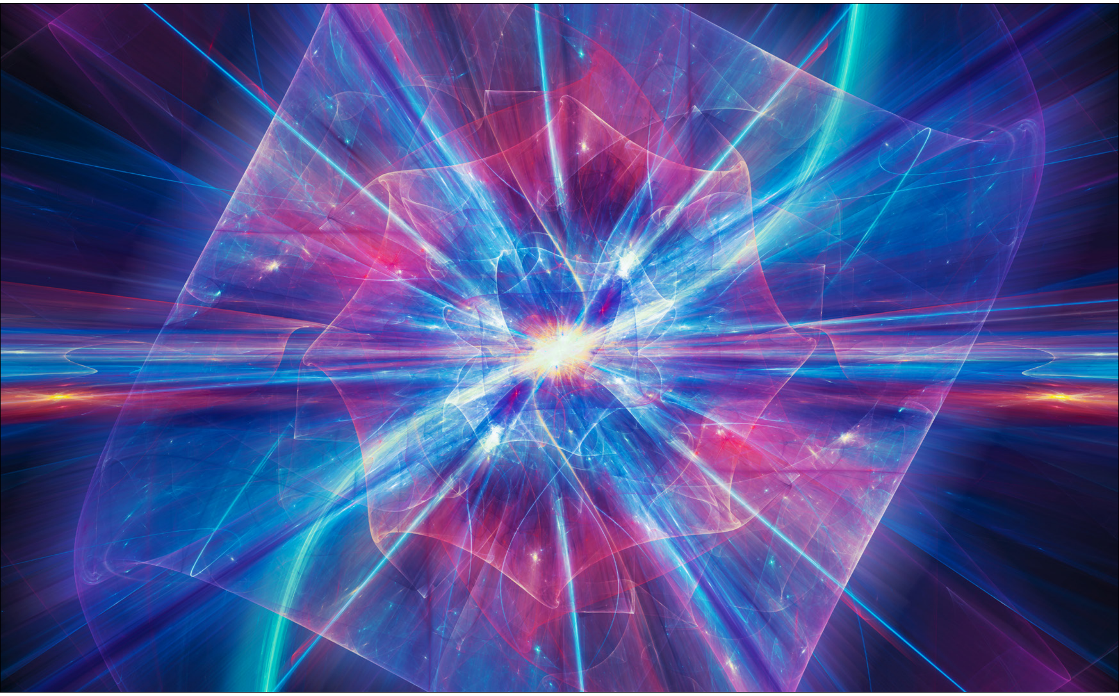
THE COMPLETE GUIDE TO QUANTUM COMPUTING



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Quantum leap

Despite the title of this report, this is anything but a 'complete guide' to quantum computing considering that the technology is notoriously hard to comprehend, even for top academics in the field.

That being said there have been some major breakthroughs in the past couple of years regarding the development of a computer that can start to harness the power of quantum technology, promising vastly superior processing power and potential step changes in the fields of advanced cryptography, complex modelling to running advanced artificial intelligence algorithms.

Here we will provide a quick rundown of the basics of quantum computing – from qubits to Fredkin gates – before diving into how enterprise vendors like IBM are leading the charge to make quantum computing a reality, and some examples of companies looking to get in early regarding uses of the technology. **Scott Carey**

Contents

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What is Quantum tech and could it take off in the UK?

Quantum computing could improve technologies like cryptography and imaging. The UK is hoping to pave the way to our quantum future

While we regularly hear about artificial intelligence, the Internet of Things and blockchain, quantum technology has received less public fanfare lately, despite the tech's potential to revolutionize computing as we know it.

The idea behind modern quantum technology has its roots in the work of renowned physicists Paul

Benioff, Yuri Manin, Richard Feynman and David Deutsch. This was advanced by Australian quantum theoretical quantum physicist Gerard J. Milburn, who suggested that by harnessing the properties of quantum mechanics, technologies such as cryptography, imaging and computing could be radically improved.

However, practical research into this sphere only really started to take off in 2010. Today, many companies and governments are experimenting in the field, with firms including IBM, Google, and smaller competitors such as IonQ, Rigetti Computing and Quantum Circuits all racing to develop their own quantum computing systems.

At present IBM is leading the charge, with the unveiling of the world's first commercial quantum computer, IBM Q System One, in January 2019. It's a 20-qubit system (read on for an explanation) that incorporates both classical and quantum computing systems, all neatly packaged in a nine by nine foot suitably-futuristic-looking airtight box. This isolated environment is essential to keeping the hardware cool.

This quantum computer is the first that is able to operate outside of the research lab, and will be used to solve some problems in areas such as financial services, pharmaceuticals and artificial intelligence, according to the company. However, IBM stressed that this is only the first iteration of a still highly immature form of technology, and as such is not powerful enough to carry out most of the commercial tasks predicted as one day possible.

It can maintain the quantum microstate for 100 microseconds, which although an improvement on the 90 microseconds achieved in 2017, means the system is still far off being viable for more advanced uses.

Google and NASA are also currently testing a quantum computer known as ‘D-Wave Two’, developed by Canadian firm D-Wave Systems.

The Fredkin gate

In 2016, scientists from the Griffith University and the University of Queensland managed to build a ‘Fredkin gate’, where two ‘qubits’ (the quantum computing equivalent of bits) are swapped depending on the value of the third. There are government-backed programmes to explore quantum tech in Singapore and the Netherlands. But it is still viewed as a cutting-edge area within tech.

Here in the UK, the government launched a five-year, £270 million initiative to take quantum tech from the realm of academics and labs into commercial, practical use, led by four ‘hubs’ in the universities of Oxford, Birmingham, York and Glasgow. However, the plan’s expiration date is 2019, so the government will need to decide soon whether it will reinvest.

The National Physical Laboratory (NPL) says that quantum technology could become a billion dollar industry for the UK. However, the UK will face stiff competition from China, who aims to be a pioneer in this area. The country has drawn up plans to direct billions of dollars into this blooming area of technology.

For example, a $10 billion national lab for quantum research is set to open in Hefei, in 2020, and the Chinese company, Alibaba is also building its own lab.

But what exactly is quantum technology?

Quantum tech explained

Take a deep breath. Things are about to get complicated. Quantum theory concerns ‘the science of the very small’:

a roughly century-old field of physics which explains how matter behaves at the atomic and sub-atomic level.

There are about four properties within quantum theory that classical physics has traditionally struggled to explain. For the field of quantum tech, two are particularly important: superposition and entanglement.

“Superposition is the idea a particle or object can be in two places or states at the same time,” explains Dr Richard Murray, technologist at the UK government’s science and tech innovation agency Innovate UK.

In the field of quantum computing, this means that rather than a bit being either a 1 or 0, you can have ‘qubits’ which can be a superposition of both a 1 and a 0 simultaneously. Thanks to qubits, quantum computers can hold more information and crunch through data much faster than traditional computers.

The second effect is entanglement, a phenomenon where two objects can be connected by a quantum state, even though they may be physically separated by some distance. The reason it is useful, according to Murray, is that if you try to transmit information using this entangled state, if anyone tried to look at it, the quantum effect would be destroyed, and the person at the other end would see someone had tried to intercept the data. “That makes for a very secure comms network,” he explains.

How quantum tech could be used

Quantum tech can theoretically be deployed in a number of different ways. Some examples include the microprocessor, imaging devices and lasers, which all derive from quantum physics.

As a field of science, quantum mechanics could transform the healthcare sector, including in radiotherapy and imaging. For example, with quantum sensors, MRI machines can be improved to gather ultra-precise measurements. This means that the MRI will have the capabilities to look at single molecules or grouped molecules.

Quantum communication devices could be a way to transmit medical records, defence data or secure government records without worrying they would fall into the wrong hands.

And, of course, the Holy Grail of quantum tech is quantum computing. This could have a major application in cryptography. Quantum computers can more effectively devise secure cryptographic protocol such as generating truly random numbers. Essentially this poses the risk that a quantum supercomputer would be able to hack every 'classical' computer system in the world.

Another possible application for quantum computing is AI, where experts foresee the vast number-crunching capabilities to inevitably power superior AI.

Could the UK be a market leader?

So what's next? Naturally the UK is looking to position itself as a leader in quantum tech. The government predicts that quantum tech will be worth £1 billion in the UK economy in the next ten years. In 2017, the University of Bristol announced plans to build the world's first Quantum Technologies Innovation Centre.

Although the centre is not expected to open in full until 2021, the UK remains the first country so far to have begun planning towards such investment. It is anticipated that the centre will provide 9,000 new jobs, while generating almost £300 million for the economy. **Charlotte Jee and Laurie Clarke**

Credit: iStock

Which firms are working with quantum computers?

Quantum is the next frontier, but who is leading the way?

Quantum computers rely on highly complex technology, but their potential is being hailed by many as world-altering. However, developing a quantum computer that works in practical terms is no mean feat.

In the race to develop viable quantum technologies, the aim is to elongate the length of time that quantum bits (qubits) can hold a stable state (and we're talking in the realm of microseconds) before starting to deteriorate. The longer this highly volatile state can be maintained, the more functions the quantum computer can effectively carry out. However, achieving the conditions for this state poses a raft of issues, as the core components must be kept at very cool temperatures within a highly controlled atmosphere, for one.

Working on these issues are a number of tech giants and a bunch of nimble start-ups looking to the lead the way into the world of quantum. Here are some of the most notable ones.

IBM

IBM is one of the companies leading the way in the quantum space. The company is racing to be the first to develop a fully functional and commercially viable quantum computer. In January 2019, the company announced that it had developed its first 'commercial' quantum computer – Q System One (pictured on **page 12**), but the prototype was widely judged as not quite ready for the full gamut of commercial applications one day envisioned for quantum computers.

Rigetti

Rigetti is a name that often crops up in relation to quantum computing. The start-up has been praised for keeping pace with much larger tech giants in the world of quantum. Its products are billed as 'quantum cloud services'. Founded in 2013, the Berkeley-based company is raking in funding from notable sources such as Amazon's venture arm and Bloomberg. The firm has developed a hybrid quantum computing platform that is currently in private beta. It claims to combine the power of a quantum processor and a classical processor. Rigetti was founded by Chad Rigetti, a quantum computing physicist who formerly worked in the quantum computing group at IBM.

D-Wave

D-Wave is a smaller company that is making, ahem, waves in the realm of quantum. In late 2018 it launched Leap, the first real-time quantum application environment, providing remote access to a live quantum computer. The firm has partnered with DENSO Corporation, a leading supplier of advanced automotive technology to major carmakers, and says that it can improve factory automation routing by 15 percent. D-Wave has also directly partnered with Volkswagen on developing a traffic management system for taxis.

IonQ

IonQ advertises itself as having created the most powerful quantum computer to date. It's slightly different from other quantum computers as it uses trapped ions for qubits. IonQ describes it as 'storing information on individual atoms'. "The qubits in the new IonQ systems are individual atoms of the rare earth element Ytterbium, suspended in a vacuum," reads its website.

This 'ion-trapping' technique is at odds with the approach of other tech companies in this space such as Google and IBM, who instead create qubits on silicon chips which are chilled to zero. However, the company asserts that it's due to this that quantum states have been difficult to maintain.

IonQ was founded in 2016 by Christopher Monroe and Jungsang Kim with $2 million in seed funding from New Enterprise Associates, and a license to core technology from the University of Maryland and Duke University. The following year, the firm raised another $20 million from GV, Amazon Web Services, and NEA.

Google

Of course, the search giant would be looking to get a head start on the world on quantum computing. In fact, Google has partnered with NASA on the testing of a quantum computer known as 'D-Wave Two', developed in partnership with D-Wave.

The Google AI faction of the tech conglomerate is working in the area of quantum. Right now, the main priorities are building quantum processors and developing new quantum algorithms with the aim of speeding up computational tasks for machine learning. Some of the areas the unit is currently looking at include superconducting qubit processors, qubit metrology, quantum simulation, quantum assisted optimization and quantum neural networks. **Laurie Clarke**

Credit: IBM

Inside IBM Q System One

An archetype for the quantum computing frontier?

At the Consumer Electronics Show (CES) in Las Vegas earlier in the year, IBM Quantum displayed a replica of its first 'commercial' quantum computer – Q System One. Following years of painstaking attention from a team of engineers and designers, the technology giant has created what it hopes will be an archetype for the next mode of computing.

We talked with the CTO of IBM Quantum Bob Wisnieff, along with industrial designers Will Howe of Map Project Office and Jason Holley of Universal

Design Studio (UDS), to find out more about the boundary-pushing project.

Q System One is touted by IBM as a “universal” quantum computing system for scientific and commercial use. Unlike the company’s previous efforts in quantum, System One is designed to be operated outside of a laboratory setting.

The two-year project to create an integrated system that brings the individual components of a quantum computer together in one ‘box’ can, IBM says, deliver a more stable environment than anything previously created – bolstered by intricate cryogenic engineering that maintains a continuous cold and isolated environment to allow quantum bits (qubits) to perpetuate their all-important quantum state.

“About two years ago we had a project to begin looking at how we will get a commercial quality system,” says IBM Q CTO Bob Wisnieff. “As we began to look at that problem, we realized that there’s an awful lot of systems engineering potential within quantum computing – to begin to optimize not only each of the subsystems, at a subsystem level, but to look at the synergistic optimization between all of the subsystems, to try to get to the overall best performance for the system.

“The core driver of this – quantum computing – is that as the number of qubits increases, the fidelity or error rate of the system has to be decreased at about 1/n^2. So we want to grow over time and we know that we need to continue to do better and better on every aspect of the system in order to achieve that.”

IBM has major electronics projects underway to exert better control over the qubits to minimize error rates. “We have developed specialized gate control pulses in order to control the qubits more accurately," Wisnieff explains, "we have developed better methods of reducing the vibration within the machine, in order to eliminate one method of decoherance [when quantum behaviour in a system is lost] for the qubits.

"As we began to put all of these projects together, we realized that a little over a year ago now, there was a tremendous potential to begin to think of it as a totality – and at that point we began working very closely with Map and UDS to do the design of the overall systems."

A synergistic dance

Wisnieff and the IBM Q team believed that by bringing together the various quantum computing elements into close proximity, they could create a "distinct break" from the exploratory-oriented systems that the company had previously built – to involve a system design that had the potential to serve as a patient-zero archetype for quantum computing in a more public domain.

Although quantum computing is unlikely to supplant conventional computing, the ability to solve totally different kinds of algorithms could lead to advances in solving problems that have evaded even the world's top supercomputers – such as unlocking the mysteries of the human genome, shedding further light on the structure of the universe, or even human consciousness.

One concrete example of a problem quantum computing might be able to solve in the near future relates to chemistry and the creation of new, more effective materials. A quantum system might be able to unfurl complex chemical systems such as nitrogen fixation in nitrogenase, according to the American National Academy of Sciences. If this problem was solved, more efficient, low-energy materials could be used for better fertiliser – a product that currently accounts for 3 percent of the world's total energy output.

Quantum computing is very much at a "primordial" stage right now, to borrow a phrase from Wisnieff. But he is clear that for IBM, the resources it is investing into quantum computing is wholly strategic. Whether this system is, as it stands, as commercially viable a product as the company claims is up for debate – but it makes clear the firm's goals for establishing itself as a business leader in this largely uncharted realm.

"If you think about the path of commercializing quantum computing, there are several things that we have to be able to do successfully," he says. "The first is to get to a sufficient number of high-quality qubits that we can solve problems that are relevant.

"The intermediate scale quantum machines we're working on now, what we aspire to is to have qubits in the range of 50 to 100 qubits – where we'll cross in to a domain where quantum computers will be able to do problems that are not doable, not feasible by conventional means.

"We know several things about that domain. We don't know precisely what the right algorithm is going to be at this point, but we do know that this quantum computer is going to work very closely with a conventional supercomputer – and that the two as a synergistic dance will solve algorithms in the future."

IBM Quantum, then, is aiming for the 'close coupling' between a supercomputer and a quantum computer in one machine.

"We also knew that over the course of the next several years that we will continue to rapidly evolve the capabilities of the machines themselves, going through one generation after another, so we knew that we wanted to build a machine we could do a rapid upgrade on," Wisnieff explains.

"[Design leads] Will and Jason – what they came up with was an extraordinarily clever way, a beautiful way, to replace all sub-elements of the machine very rapidly. We can now do in a few days what would typically take us two months – more than a 10x reduction in the time it takes to do a major upgrade on the machine."

By bundling all the relevant components at close proximity into an integrated system, the designers have also drastically lowered the physical footprint of the system. Not only does this mean more quantum compute per square metre, but it also leads to benefits in machine performance.

"When done properly, bringing these things close allows us to also improve the fidelity, the accuracy of the overall machine," Wisnieff adds. "That is core to us in continuing to be able to make progress."

The anatomy of a quantum system

Will Howe, director of the London-based Map Project Office, is one of the industrial designers involved in making System One a concrete reality. He works as part of a wider design group that includes Universal Design Studio, whose director, Jason Holley, we also spoke to.

"It's very, very rare a project comes along where you get to define a completely new archetype for a product," Howe says. "We're hoping that when people think of quantum computing, they'll actually think of System One."

Before System One, Howe points out, all of the different elements that make up a quantum computing system – the highly sensitive equipment and instruments – were disparate and in isolation from one another.

System One is enclosed by a nine-by-nine foot glass panel designed by Milanese specialists Goppion, making it simpler for engineers and researchers to upgrade the computer or to perform maintenance. Inside, the cryostat – the instrument which contains the chip and maintains the extremely low temperature and isolated environment necessary for the stability of qubits – is sealed away from external sound, vibrations, electromagnetic waves and other such interferences.

The system comprises a series of complex interwoven structures that are consolidated into a single volume, say the designers, with each structure supporting a custom set of components, including the "intricately engineered" cryostat where the chip is suspended.

The 'conventional' four-poster frame design that supported the cryostat was iteratively revised into a cantilevered concept. This was bolted to the concrete slab below the raised floor of the system, which "enabled the cryostat to be foregrounded towards the front of the machine, allowing 360-degree access for the engineers as well as becoming the focal point of the design".

The glass vitrine is fitted with a two-axis hinge that enables it to open up and wrap around the sides of the system, while the back of it is where the electronics and the gas handling system that serves the cryostat sit, which are all attached to an independent frame. All of this had to be designed so that the instruments wouldn't touch each other, nor obstruct the heat exchanges, based underneath, which blow controlled air throughout.

The designers say that there were initially reservations about how the cantilevered frame would maintain absolute stability as well as shielding qubits from interference. Ultimately this approach delivered better results than the original – allowing the cryostat to be cooled down to 0.01 kelvin – just above the lowest possible temperature.

Speaking about the instruments within the IBM Q lab, Holley adds that although they were dispersed, there were elements of them that were “very specific” to quantum computing, such as the suspended cryostat, which he thought conveyed a kind of ‘character’ from a design perspective.

“There was no precedent for a way to design a quantum computer, and this was one of the challenges we faced, which obviously for us as designers is incredible – you can’t really rely on anything, so it’s a very exciting moment for us and it opens up lots of questions,” he says.

“There was something very particular, very specific about [the cryostat] that already begins to make you think: yeah, that is what you would expect a quantum computer to look like. There was something really reassuring to that sort of thing, there was actually already something here – it already has some really interesting design to it – so I think part of what we felt we wanted to do was try and channel that to bring them together into one volume, but in doing that, to really simplify, to really focus the character of what this thing was.

“It’s heralding a new era of computing, so its role as a symbol and as an incredible development in technology – they go hand in hand.”

Howe adds that the iterative design wasn’t “just about creating something iconic” but that they also worked extremely closely with the engineers who use, tune, and program the machines every day. So at the top of their considerations were how it could be made serviceable, commercial, and the footprint. Howe says: “How can the doors open so it can fit into a relatively small footprint within a dedicated data centre – which is something that’s going to happen this year? Incremental steps to bringing it more into a sort of commercial reality.”

Quantum-ready to quantum-advantage

According to Wisnieff, hundreds and hundreds of people have contributed to the project, many of whom continued their day jobs at IBM in parallel – for example, taking “the best people in the corporation” for running modelling of the computational fluid dynamics of the airflow within the machine, or for heat-flow calculations.

“This is something for the IBM corporation that is really deemed completely strategic,” Wisnieff repeats. “This is the future we want to create, and we want to help lead the world to do this.”

However, he concedes that quantum “will not succeed on the efforts of any one group alone”.

In 2017, the company launched the open source quantum framework Qiskit, which since has seen community engagement soar to 90,000 downloads when we interviewed research staff member Ali Javadi last year, following the IBM Q Experience which allows anyone to experiment with quantum computation via the cloud.

Qiskit, reveals Wisnieff, is a “fundamental part” of System One. “What we have done inside IBM is to reach out broadly to the community with the Quantum Experience, where we have 100,000 users doing over six million runs on the computer. But also through the

IBM Q Network of commercial relationships as well – and they're working with 43 partners. We get to see how where, inside different organizations and industries, quantum computing might fit – and what it would take to actually cross the threshold to get to quantum advantage for these individual groups.

"That insight is invaluable – I am firmly convinced that is the kind of insight that will lead to success in quantum computing – being open source, being able to have organizations easily pick it up, allows us to have something that is easily learned – that people can build upon the work of others, and that rapidly becomes a very stable and growing set of software."

Qiskit, then, is "core to everything we are doing".

"That's how we are going to get the insights that will allow us to really be successful," adds Wisnieff. "And tying Qiskit down into the higher and higher performance systems over time is what we're about in terms of the IBM Q System one."

What IBM wants to have is not just the archetype for quantum computing but also to be on the ground floor of the evolving Qiskit framework, to improve performance and run "more and more complex algorithms, and become more and more precise in our answers".

Misconceptions

Although businesses and researchers tend to be approaching IBM for collaboration, there are certain misconceptions about quantum computing, Wisnieff says, that need to be addressed.

One of the biggest is that quantum is a sped-up version of conventional computing. "The reality is that quantum computing is computing in a completely different way," he explains. "We are going to use the laws of quantum mechanics to perform algorithms. It requires reimagining how you're going to redo your algorithms in fundamental ways. It is not a solution for everything, it will never replace computing as we know it.

"What it will do is extend the range of what can be computed in certain domains that are really important. As we work with partners, they internalize that, and they look at the problems that if they could solve would allow them to do more or do better. Then we can also begin to look at how we can develop those algorithms that work on quantum computers."

In this "early, sort-of primordial state" considerable efforts are underway to understand which of these algorithms will be viable on the machines that will be realized in the coming years.

"What we are really looking for are those first few applications that will push us into quantum advantage," Wisnieff explains.

So IBM is 'quantum-ready' to perform quantum algorithms, but is not yet at a point where the calculations can exceed the performance of conventional computing.

"But we've made dramatic improvements in the last several years," he adds, "and you can now see that getting to the quantum advantage range is not so many years away as people might have thought years ago.

"What this machine is about is setting up the architecture that will allow us to grow rapidly, and help us fix the problems that we know we will need to fix to get from where we are to where we need to be.

"It is all about building machines that can help us lower the overall error of the machine, building machines that allow us to rapidly evolve the capability of the machine, add new features, upgrade the electronics, things like that. And also to make machines that fit into the machine-room spaces, and are maintainable and reliable in those spaces, so we can move to the point where the machine can be depended on to work on a daily basis."

What could that look like?

"The highest one people think about is quantum chemistry," says Wisnieff. "It goes back to [famed physicist] Richard Feynman in the 80s. The quantum computer would be ideal for looking at inherently quantum problems, and quantum chemistry is one of that class. There's certainly others as well.

"That's something where there's just this wonderful fit at the fundamental level. But that's a no-brainer if you will. Above that I think optimization and machine learning both have aspects where quantum computers can provide algorithmic advantage that you can't achieve by regular means."

He adds that in these cases quantum will "never supplant completely" what can be achieved by conventional computing, but instead augment it. Quantum augmentation will allow researchers to gain answers more quickly and accurately.

"Those are areas that I think would have a broad application and drive a rapid evolution in the marketplace as well," Wisnieff argues.

Form, freedom, future

The design of System One was, of course, informed by complex practicalities, with all these instruments interwoven together – but not touching one another.

How much freedom did Map and UDS have to create something that looked aesthetically pleasing – and what informed those decisions?

"We tried to develop a set of principles that would help guide us," explains Howe. "What does a quantum computer look like from the outside? We really wanted to reduce it down to very clean, basic geometry, in the way that you'd think about atoms – and the way that they move around each other – electrons and photons… we wanted to use cubes, and cylinders, and very pure geometry.

"It had to be scalable," he adds. "We wanted to reduce the time it took to upgrade the system, so just creating these very defined sub-volumes inside the main volume, which could be allocated to certain different systems."

The main thing, Howe reveals, was to "explore materiality". The cryostat is this "super-polished stainless steel," and the designers wanted to "evoke the idea that inside the cryostat – at nought-degrees kelvin or roundabout there – it's as cold as you can get".

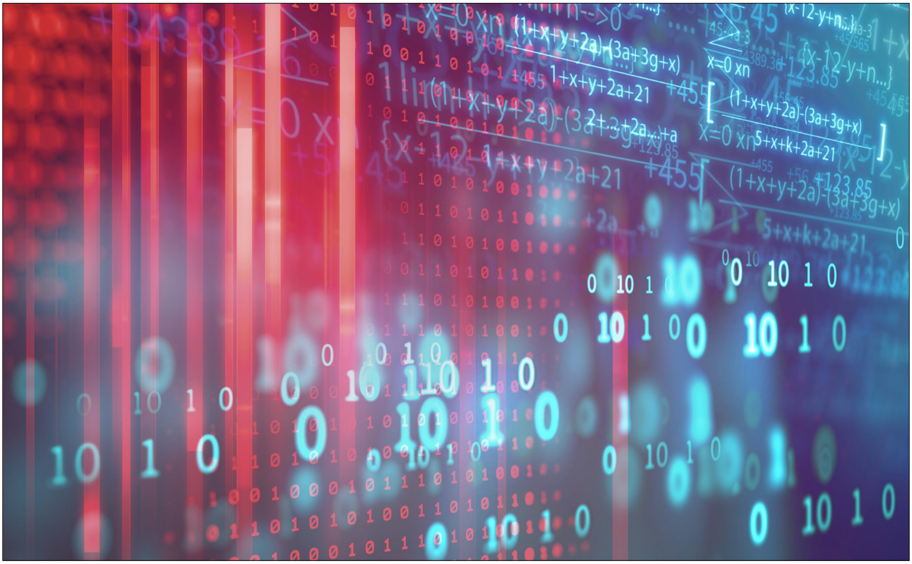
"But how do you invoke the idea that it's super-cold inside? We wanted to do that through material, through stainless steel, people have a tacit understanding that stainless steel is hard and cold to touch."

Holley adds that because of the extreme state that the quantum chip must be held in – 0.01 kelvin, which is colder than outer space at 2.7 kelvin – also informed the final design. "We felt that it was important to support that sort of understanding here," says Holley. "Trying to make sure there was a stripping down of the essence – certainly form and materially – and help with that kind of storytelling."

Instead of the literal and metaphorical ‘black box’ hiding the inner workings of a classical computer, Howe says, the language of quantum is conveyed through the unique visual dialogue between the cryostat and vitrine.

This expresses the notion, he explains, of “an unwritten future and of territories yet to be explored”.

Tamlin Magee



Credit: iStock

Experts from IBM, Oxford and MIT make quantum breakthrough

IBM, University of Oxford and MIT breakthrough could enable machine learning on quantum machines in the "near future"

Although in its preliminary stages, IBM's quantum computing team – in partnership with University of Oxford and MIT – have developed and tested a quantum algorithm that they say could enable machine learning on quantum machines in the "near future".

The research paves the way for quantum machines to 'feature map' complex sets of data – that is, breaking down data into core identifiers, for example, separating all of the pixels from a single image, and then placing them in a new grid based on characteristics such as by colour.

Where a quantum machine would differ from a 'regular' machine learning algorithm is that it would be able to take enormous data sets full of complex information and spot patterns that might be invisible to a classical computer.

The paper, titled: 'Supervised learning with quantum enhanced feature spaces', has been published in peer-reviewed journal *Nature*, and sets out how the researchers put together a "blueprint with new quantum data classification algorithms and feature maps".

IBM says of the research: "That's important for AI because the larger and more diverse a data set is, the more difficult it is to separate that data out into meaningful classes for training a machine learning algorithm. Bad classification results from the machine learning process could introduce undesirable results; for example, impairing a medical device's ability to identify cancer cells based on mammography data."

Antonio D. Córcoles, who co-authored the paper and works in the experimental team at IBM, tells us that the main idea wasn't to simply copy the techniques well-established in classical machine learning and shift them over to quantum, but to find a distinction in the algorithm that provides the quantum method with an advantage.

Today, says Córcoles, quantum machines aren't large enough or noiseless enough to tackle the problems in a bigger way, but the paper, and the team's work, demonstrates that a quantum approach is possible, laying the foundations for future work. "At this stage we are not going to use this algorithm to try to tackle real world data," explains Córcoles, adding that quantum enthusiasts or researchers could try it if they liked, because their findings will be rolled in to open source quantum framework, Qiskit.

"But that was not our goal," he reveals. "Our goal was to say: we are going to prove that there are feature maps you can use that give you an advantage. Now that we have proven that, the next stage of research will be, can we understand these quantum feature maps better, to gain insight into how we can apply them to real-world problems?"

Quantum advantage is, loosely defined, when using a quantum methodology brings about better results than those with traditional computers.

IBM physicist Kristan Temme told The Next Web that this experiment was designed to work with the noisy, imperfect quantum systems of today.

There are clear implications for the experiment in encouraging further research in the field, says Córcoles, as well as providing educational use for other researchers and enthusiasts.

"I think it's very important to test these ideas in a real setting rather than just having them expressed theoretically," says Córcoles, adding that sometimes the theory reveals into a lab setting brings up new, unexpected problems, complicating matters.

"So having systems that you can actually use with these ideas is very important for us," he says. "Now, for the rest of the world – we think this is interesting to the artificial intelligence community in general because this gives a path that is very preliminary, that is very exploratory still, but is also very hopeful because as far as we know in complexity theory, this is an important result. For all we know this algorithm will scale well for quantum, but it will scale extremely poorly for classical [computing]. So now people will have something that they can try to map the problems into, and to see if they can get some advantage from using this."

"They can try to see or gain some insight for the level of noise that this algorithm will tolerate, by trying to run it in more than two qubits – which is what we did in the paper – and will see what kind of success they will get," says Córcoles.

Potential next steps are also in the early stages but Córcoles adds that the feature map could become more generalized, and they are working on a way to find feature maps that are similar to the one demonstrated but can be tuned to specific data sets.

The team's work will be available in Qiskit Aqua, a library of cross-domain quantum algorithms, allowing researchers to run it in their simulators or in the actual quantum devices. Córcoles adds that he used parts of Qiskit to actually run the experiments.

"Qiskit is very powerful at compiling your circuits into something that is more efficient than you initially wrote," he says. "That was useful for me as a user in the lab." **Tamlin Magee**

Credit: Red Hat

Inside the quantum challenge at Airbus

An ongoing challenge from Airbus shows a potential path to take academic research into applied science to solve enterprise problems

Airbus is seeking to pool together the best minds in quantum computing to push forward aviation design, optimization and modelling, with a competition that will run throughout the year.

One of the goals of the competition is to find areas where quantum computing can provide an advantage over more traditional high performance computing (HPC). The challenges are split into five problem statements, and these concern: aircraft climb optimization, computational fluid dynamics, quantum neural networks for solving partial differential equations, wingbox design optimization, and aircraft loading optimization.

Quantum computers are still in their infancy, but the aim is to elongate the length of time that quantum bits (qubits) can hold a stable state before starting to deteriorate. The longer this highly volatile state can be maintained, the more functions the quantum computer can effectively carry out, potentially offering vastly superior computation to that in even the most modern computers.

Speaking to us earlier this year, Dr Thierry Botter, head of Airbus's Blue Sky research lab, told us that the company had already been examining quantum in the context of aviation for a number of years – not least with an investment in QC Ware through its venture capital wing last year. "We're being pragmatic about this, we're not asking the question: can it be done today? But rather can we see an indication that in some future there will be an advantage from quantum computers?" he asked. "How can we prepare ourselves today to be ready at that point in the future?"

This competition, then, extends that into an effort to engage with the quantum computing community "as widely as possible", he added.

"We laid down a number of problem statements all having to do with one of our core businesses, like flight physics, and essentially laid down the challenge to the community," said Botter, "to say: please help us out, please help us understand the promise, the potential of quantum computing, and how that new technology could be used to answer some of these problems."

At the time of our interview in March, Botter revealed that there were already 350 registered participants in the competition from 45 different countries, signalling a strong global interest.

"It makes us all the more excited for the end of the submission period," said Botter. "Right now, we're still in the early stages – individual teams are crafting their submissions, their ideas."

Potential participants can register their interests at the Airbus quantum challenge website here.

Take-off

Although the cruising segment of a flight lasts the longest, and is considered by airlines to be the most important related to fuel and time optimization, the increasing prominence of short-haul flights, driven by greater competition from budget airlines, means that fuel optimization during climb and descent are also incredibly critical to an airline's bottom line.

"Problem statement one has to do with the very first part of an aircraft to fly, it's going not from the runway to cruising altitude but from a starting point in-flight and still relatively near the take-off point of an aircraft," said Botter.

"We want to map that leg of the climb, from the early stage of the flight all the way until the aircraft reaches cruising altitude – we'd like to optimize that segment of the flight."

Optimization can be measured and calculated in various ways, but at its core reducing time or fuel consumption, or a combination of the two, is key.

"Can we optimize that early segment? That is the question," explained Botter. "There are classical ways to tackle the problem, and we know them. That's not the point of this particular problem statement – it's to put ourselves in the future and ask the question: can quantum computers help us find an even further optimal solution to these problems? If so, how are we going to carry that calculation? What would we need to do in order to obtain an even better, even more optimal, solution to this challenge?"

Participants submitting proposals are asked to put forward details of their processes and their methodology, as well as some metrics and indications of potential performance by running simulations at a smaller scale. The idea is that even with limited access to resources to actually run the problems, Airbus and the other judges will be able to gauge some level of the expected performance boosts.

Following the challenge, Airbus hopes to work with the winners directly, providing them with access to expensive quantum computing hardware so that they can test the problem statements out with real quantum technology.

Botter added that although the quantum computers of the near future are not going to be as powerful as the error-corrected quantum machines of the future, they can "nonetheless potentially start to provide some added benefit".

"The question is how, and for what application? I think this is the big quest that we at Airbus and many others are engaged in, to find those key applications that will be able to draw already on the near-term potential use of these quantum computers, and further place us in a position of strength for when the future, error-corrected quantum computers come in."

Applying quantum

A major part of that will be taking a technology that has matured in a laboratory environment and been driven by academics, and translate it into the real world.

“Going beyond the bounds of aerospace there are other sectors also looking at how quantum computing can help them, from the finance sector to the energy sector, and many other transportation sectors,” he said. “For all of them to get engaged and tap into the development that has already been done, that is emanating out of academic research labs, this is the big challenge we see globally outside of just Airbus.”

Fundamentally Botter sees quantum computing as a potentially game changing technology, but only if academics and industry collaborate.

“The engagement of as many actors, and as many end users as possible, is only going to improve and accelerate the development of quantum computers for all applications,” he explained. “It’s one of those rare scenarios where there are only winners. Everybody has calculations that are rather challenging, and difficult, and traditionally very computationally hungry, and can benefit from having improved, better technologies – namely quantum computing – come in and help them with their calculations.”

One area where quantum might be able to help (but that is outside the scope of this particular challenge) is in satellite vision optimization. “Today we have a constellation of Earth-observing satellites, they each have their own characteristics in terms of imaging capability,” he said. “They’re on their own orbital track. Together they form an ensemble of potential imaging devices, whose type of imaging we want to optimize, and we want to map that as best as possible to a series of requests that are coming in from customers.

"To do this mapping in the most optimal way is again an optimization problem. There are techniques today that can be applied, but we're already preparing the future and asking the question of how quantum computing can help – this work of trying to identify the different segments of potential applications of quantum computers to harness and improve existing HPC is a big, big push that we are after." **Tamlin Magee**

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