Computer Architecture

Rev.12-30-24

Quantum Computing

by
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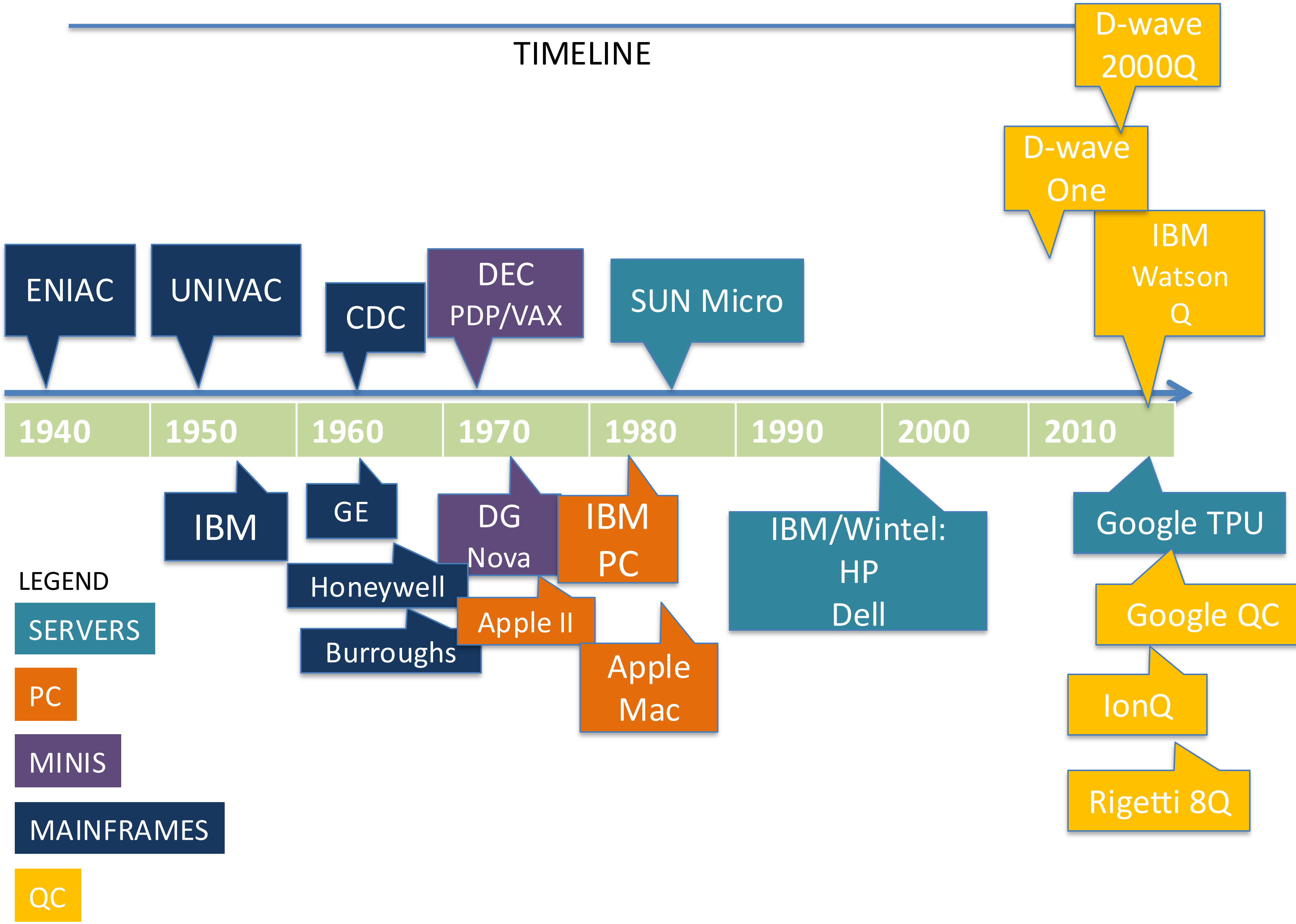
Computers & QC's



Top QC Companies

- IBM
- Google
- Intel
- Microsoft

- IonQ
- D-Wave
- Rigetti

Outlook

Businesses are hoping the advancement of quantum computers—by tech giants such as Google, IBM, and Intel, as well as startups such as Rigetti Computing—will lead to unprecedented scientific and technical breakthroughs in the coming years. They're eyeing applications from new chemical reactions for the development of drugs, fertilizers, and batteries, to the improvement of optimization algorithms and mathematical modeling.

Existing QC's

Up until now, there have been several quantum computers built with a range mostly under **100 qubits** or so. As of a little while ago, we also had these operational ***superconducting*** QC's:

- Google *Bristlecone* at 72 qubits, *Sycamore* at 53 qubits
- IBM *Q* series up to 53 qubits
- Rigetti at 84 qubits
- D-Wave now claims 4,400+ qubits for *Advantage2*
- UC Berkeley at 10 qubits

And this *trapped ion* version:

- IonQ at 53 qubits

Commercial QC's

List of quantum processors

From Wikipedia, the free encyclopedia

Circuit-based quantum processors [edit]

These QPUs are based on the quantum circuit and quantum logic gate-based model of computing.

Manufacturer	Name/Codename/Designation	Architecture	Layout	Socket	Fidelity	Qubits	Release date
Google	N/A	Superconducting	N/A	N/A	99.5%[1]	20 qb	2017
Google	N/A	Superconducting	7×7 lattice	N/A	99.7%[1]	49 qb[2]	Q4 2017 (planned)
Google	Bristlecone	Superconducting	6×12 lattice	N/A	99% (readout) 99.9% (1 qubit) 99.4% (2 qubits)	72 qb[3][4]	5 March 2018
Google	Sycamore	Nonlinear superconducting resonator	N/A	N/A	N/A	54 transmon qb 53 qb effective	2019

Commercial QC's

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IBM	IBM Q 5 Tenerife	Superconducting	bow tie	N/A	99.897% (average gate) 98.64% (readout)	5 qb	2016[1]
IBM	IBM Q 5 Yorktown	Superconducting	bow tie	N/A	99.545% (average gate) 94.2% (readout)	5 qb	
IBM	IBM Q 14 Melbourne	Superconducting	N/A	N/A	99.735% (average gate) 97.13% (readout)	14 qb	
IBM	IBM Q 16 Rüschlikon	Superconducting	2x8 lattice	N/A	99.779% (average gate) 94.24% (readout)	16 qb[5]	17 May 2017 (Retired: 26 September 2018)[6]
IBM	IBM Q 17	Superconducting	N/A	N/A	N/A	17 qb[5]	17 May 2017
IBM	IBM Q 20 Tokyo	Superconducting	5x4 lattice	N/A	99.812% (average gate) 93.21% (readout)	20 qb[7]	10 November 2017
IBM	IBM Q 20 Austin	Superconducting	5x4 lattice	N/A	N/A	20 qb	(Retired: 4 July 2018)[6]
IBM	IBM Q 50 prototype	Superconducting	N/A	N/A	N/A	50 qb[7]	
IBM	IBM Q 53	Superconducting	N/A	N/A	N/A	53 qb	October 2019

Commercial QC's

Rigetti	8Q Agave	Superconducting	N/A	N/A	N/A	8 qb	4 June 2018[11]
Rigetti	16Q Aspen-1	Superconducting	N/A	N/A	N/A	16 qb	30 November 2018[11]
Rigetti	19Q Acorn	Superconducting	N/A	N/A	N/A	19 qb[12]	17 December 2017

IBM	IBM Ourense[13]	Superconducting	T	N/A	N/A	5 qb	03 July 2019
IBM	IBM Vigo[13]	Superconducting	T	N/A	N/A	5 qb	03 July 2019
IBM	IBM London[13]	Superconducting	T	N/A	N/A	5 qb	13 September 2019
IBM	IBM Burlington[13]	Superconducting	T	N/A	N/A	5 qb	13 September 2019
IBM	IBM Essex[13]	Superconducting	T	N/A	N/A	5 qb	13 September 2019

Annealing quantum processors [edit]

These QPUs are based on quantum annealing.

Manufacturer	Name/Codename/Designation	Architecture	Layout	Socket	Fidelity	Qubits	Release date
D-Wave	D-Wave One (Ranier)	Superconducting	N/A	N/A	N/A	128 qb	11 May 2011
D-Wave	D-Wave Two	Superconducting	N/A	N/A	N/A	512 qb	2013
D-Wave	D-Wave 2X	Superconducting	N/A	N/A	N/A	1152 qb	2015
D-Wave	D-Wave 2000Q	Superconducting	N/A	N/A	N/A	2048 qb	2017
D-Wave	D-Wave Advantage	Superconducting	N/A	N/A	N/A	5000 qb	2020

QC Timeline

Quora Home Answer 157 Spaces Notifications 117

John Bailey, Trying to transfer experience with binary logic design into the domain of qubits

Updated November 3, 2019

Originally Answered: What is the history of quantum computing?

After pruning the wiki article: Timeline of quantum computing for my own edification, three characteristics emerge:

1, There has been no shortage of programming efforts for a computer that does not yet exist.

2. There has been much work on components reported

3. There had been little progress in integration of the components

4. Progress as measured by qubits processed is still at the "few" level

5. A company called D-Wave Home claims remarkable progress

The Revolutionary Quantum Computer That May Not Be Quantum at All | Enterprise | WIRED

Here is my edited version of the wiki history of quantum computing

* 1980 Yuri Manin proposed an idea of quantum computing[2]
* 1981 Richard Feynman proposed a basic model for a quantum computer that could simulate quantum processes.
* 1981 Paul Benioff proposes the first recognizable theoretical framework for a quantum computer[4]
* 1985 – David Deutsch, at the University of Oxford, described the first universal quantum computer.
* 1990 Peter Shor discovers an algorithm allows a quantum computer to factor large integers quickly.
* 1996 Lov Grover, at Bell Labs, invented the quantum database search algorithm.
* 1998 A working 2-qubit NMR quantum computer used to solve Deutsch's problem
* 2000 First working 7-qubit NMR computer demonstrated at the Los Alamos National

QC Timeline

2001-2014

Quora   Home   Answer 157   Spaces   Notifications

Laboratory.
* 2001 First execution of Shor's algorithm at IBM's Almaden Research Center and Stanford University. Factored 15 into 3 and 5.
* 2006 First 12 qubit quantum computer benchmarked. [21]
* 2006 First use of Deutsch's Algorithm in a cluster state quantum computer.[35]
* 2006 D-Wave Systems claims to have working 28-qubit quantum computer, (unverified) [61]
* 2008 D-Wave Systems claims to have produced a 128 qubit computer chip, (unverified) [91]
* 2011 D-Wave develops quantum annealing and introduces their product called D-Wave One. [133]
* 2011Quantum computer employing Von Neumann architecture[141] Page on arxiv.org reported.
* 2012 D-Wave claims a quantum computation using 84 qubits.[147]
* 2014 Documents leaked by Edward Snowden confirm the Penetrating Hard Targets project,[152] by which NSA seeks to develop a quantum computing capability for cryptography purposes.[153][154][155]

Bracketed numbers above refer to these references. Timeline of quantum computing

Assessing the claims of D-Wave, it appears their "quantum annealing" approach to computation allows faster than conventional solution to a certain set of optimization problems. It does not appear they have developed the ability to execute algorithms others have devised for mainstream quantum computing such as Shor's Algorithm for factoring primes or Grover's algoritm for search. They have simply progressed along a branch away from the mainstream of Quantum Computer development. They perhaps have not helped their reputation for "science by press release" as they have reported progress, although this may have helped them secure juicy contracts from corporations and agencies with spare cash for far out ventures (think 10^100)

QC Timeline

2009

Quora Home Answer 157 Spaces Notifications 117

Mena Refaat Zaki, AI and Automation Engineer (2016-present)
Answered January 28

Originally Answered: When was the first quantum computer made?

In August 2009, a National Institute of Standards and Technology (NIST) team led by Jonathan Home unveiled the first small-scale device that could be described as a quantum computer. The work represented a huge step forward – so much so that we choose this development as the very first *Physics World* 2009 Breakthrough of the Year 10 years ago in 2009.

Building up to the breakthrough, Home's team had used ultra cold ions to demonstrate separately all of the steps needed for quantum computation – initializing the qubits; storing them in ions; performing a logic operation on one or two qubits; transferring the information between different locations in the processor; and reading out the qubit results individually. But in 2009, the group made the crucial breakthrough of combining all these stages onto a single device. Home's set-up had an overall accuracy of 94% – impressive for a quantum device – but not good enough to be used in a large-scale quantum computer.[1]

QC Timeline

2019-2020

2019 [edit]

See also: 2019 in science

- IBM unveils its first commercial quantum computer, the IBM Q System One,[235] designed by UK-based Map Project Office and Universal Design Studio and manufactured by Goppion.[236]
- Nike Dattani and co-workers de-code D-Wave's Pegasus architecture and make its description open to the public.[237][238]
- Austrian physicists demonstrate self-verifying, hybrid, variational quantum simulation of lattice models in condensed matter and high-energy physics using a feedback loop between a classical computer and a quantum co-processor. [239]
- A paper by Google's quantum computer research team was briefly available in late September 2019, claiming the project has reached quantum supremacy.[240][241][242]
- IBM reveals its biggest yet quantum computer, consisting of 53 qubits. The system goes online in October 2019.[243]

2020 [edit]

- UNSW Sydney develops a way of producing 'hot qubits' – quantum devices that operate at 1.5 Kelvin.
- Griffith university, UNSW and UTS in partnership with 7 USA universities develop Noise cancelling for quantum bits via machine learning, taking quantum noise in a quantum chip down to 0%.
- UNSW performs electric nuclear resonance to control single atoms in electronic devices.
- Bob Coecke (Oxford university) explains why NLP is quantum-native. A graphical representation of how the meanings of the words are combined to build the meaning of a sentence as a whole, was created.
- Tokyo university and Australian scientists create and successfully test a solution to the quantum wiring problem, creating a 2d structure for qubits. Such structure can be built using existing integrated circuit technology and has a considerably lower cross-talk.

QC 2024 Update

1^{st}-2^{nd}-3^{rd} Gen Machines

- **IBM**
- **Google**
- **IonQ**
- **D-Wave**
- **Rigetti**

QC Company

IBM

QC

Even the most powerful traditional computers use binary digits, or bits, which can either be 0s or 1s. Quantum computers use quantum bits, or qubits, which represent and store information in both 0s and 1s simultaneously, known as super-position. Such machines have the potential to sort through a vast number of possible solutions to a problem within a fraction of a second to come up with a likely answer.

IBM Q

Quantum advantage

IBM is on track to deliver a fault-tolerant, error-corrected system by 2029, according to IBM Director of Research Dario Gil, and expects to achieve "quantum advantage" with its systems even before that point. That means solving some problems faster or more accurately than traditional computers by providing precise solutions to problems whose answers can only be estimated today.

QC

The big question, Gil said, is when this research will lead to so-called fault-tolerant quantum computers, which will have the capacity to correct the errors that occur when quantum machines interact with interferences from the outside world, including sound, microwaves, or temperature fluctuations. Those interactions disrupt the fragile quantum state in which these machines are effective, narrowing the window in which they can function and the work they can do.

QC

Rebooting encryption

Some companies are already moving ahead. IBM has created a quantum-safe technology stack for its latest z16 mainframes, which store much of the world's transaction data, using two of the NIST quantum-safe algorithms. Those two algorithms, which IBM said it developed, are embedded in application programming interfaces that can be used to modernize existing enterprise applications or build new ones.

IBM System 2

The center opened in October and holds the three 'chandeliers' you see here, which contain the inner workings of IBM's latest attempt at building a quantum computer: System Two.

High-tech chandeliers

EHNINGEN, GERMANY

IBM System 2

Quantum computing may sound complicated, but its purpose is simple. It's intended to solve complex problems faster and more efficiently than traditional computers. It could make it possible for us to simulate molecular structures at the atomic level, model plant growth to optimise crop yields and much more.

IBM System 2

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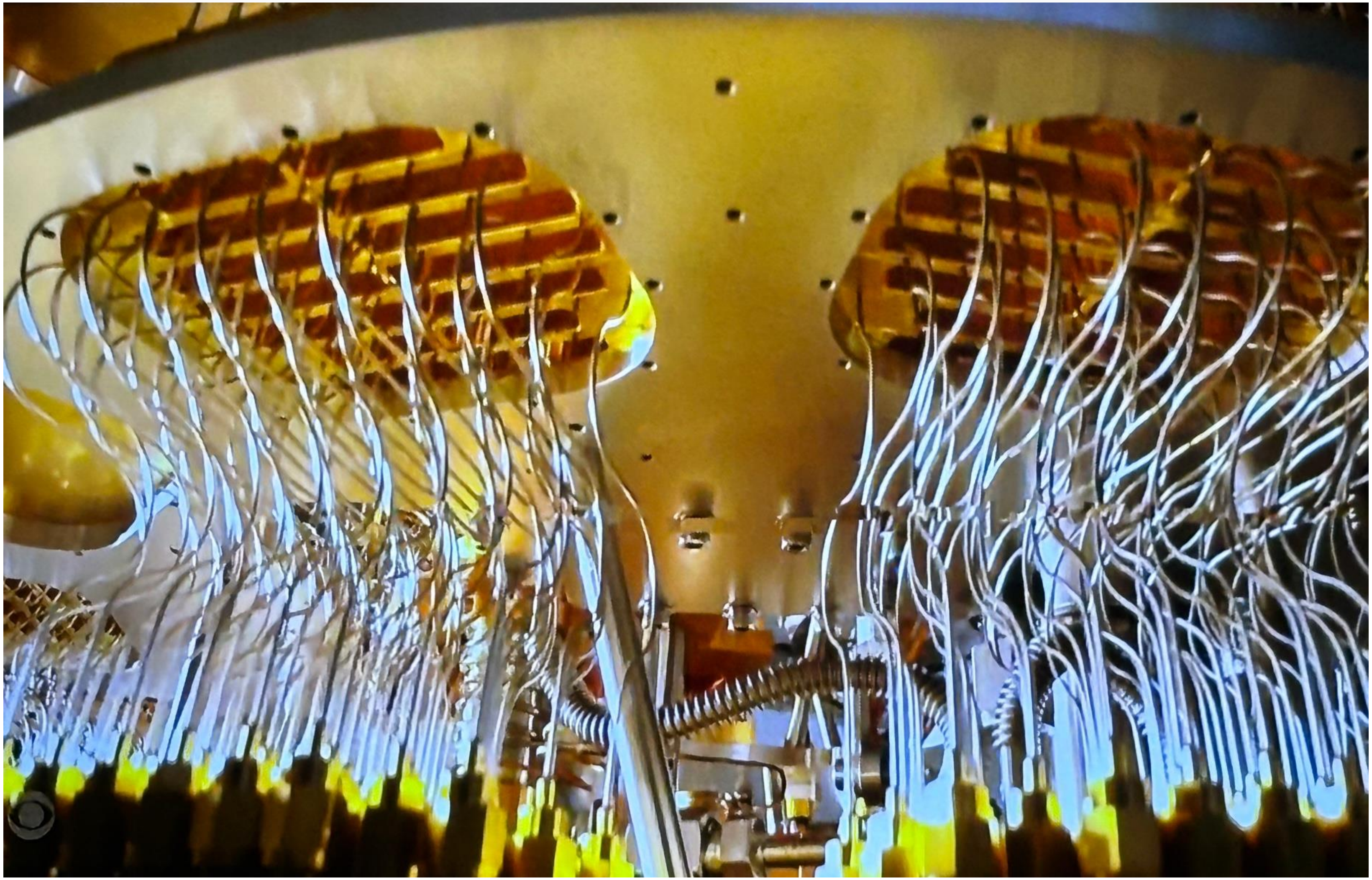
"System Two is IBM's next-generation, modular quantum computing architecture – the cornerstone of IBM's vision of quantum-centric supercomputing," says Dr Rajeev Malik, programme director of systems engineering at IBM Quantum.

Malik claims this model is capable of a 25-fold increase in speed over IBM's last quantum processor, putting it leagues ahead of the computers most of us know and use.

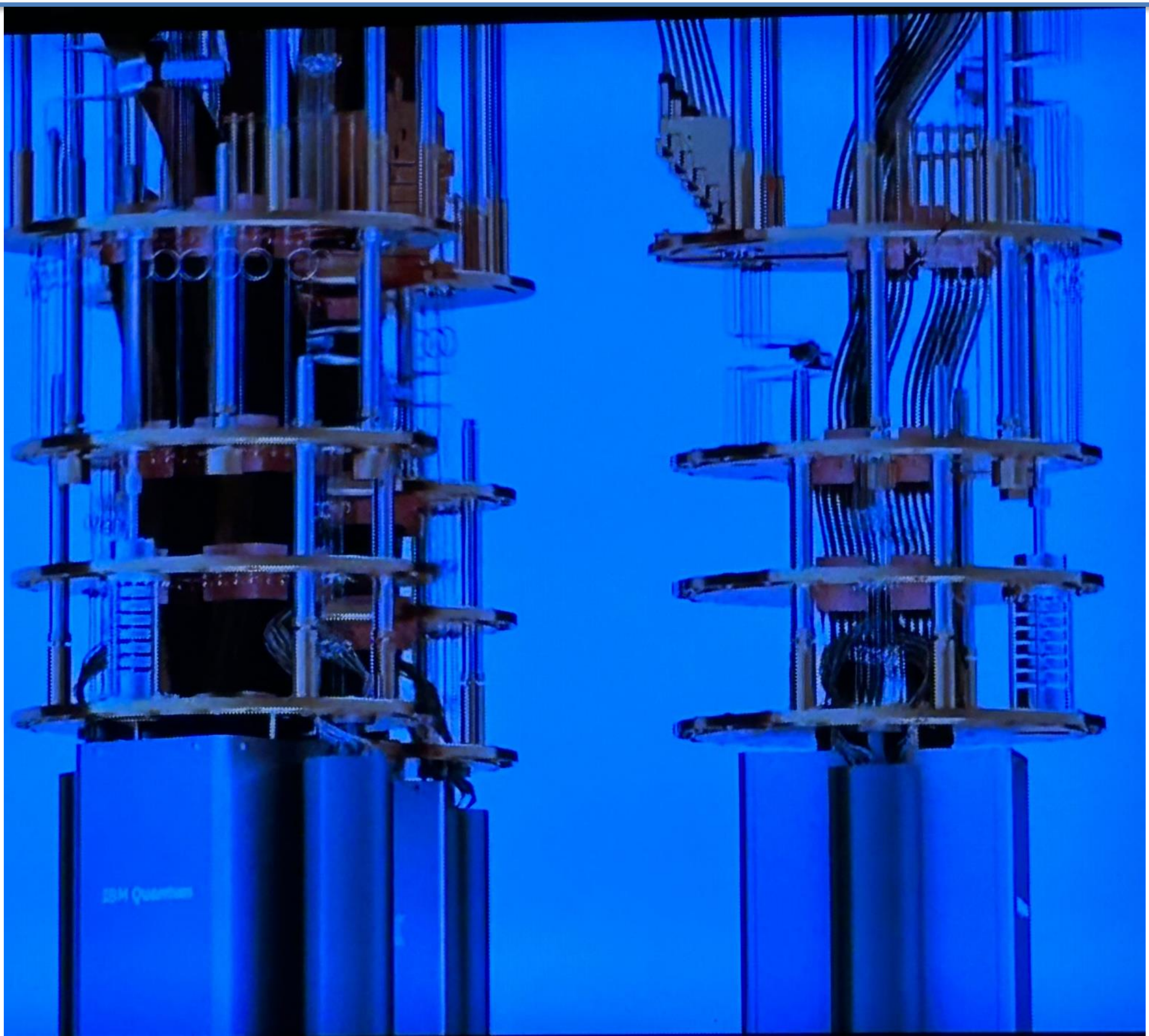
2nd Gen: IBM Q2

2^{nd} Gen: IBM Q2

2nd Gen: IBM Q2



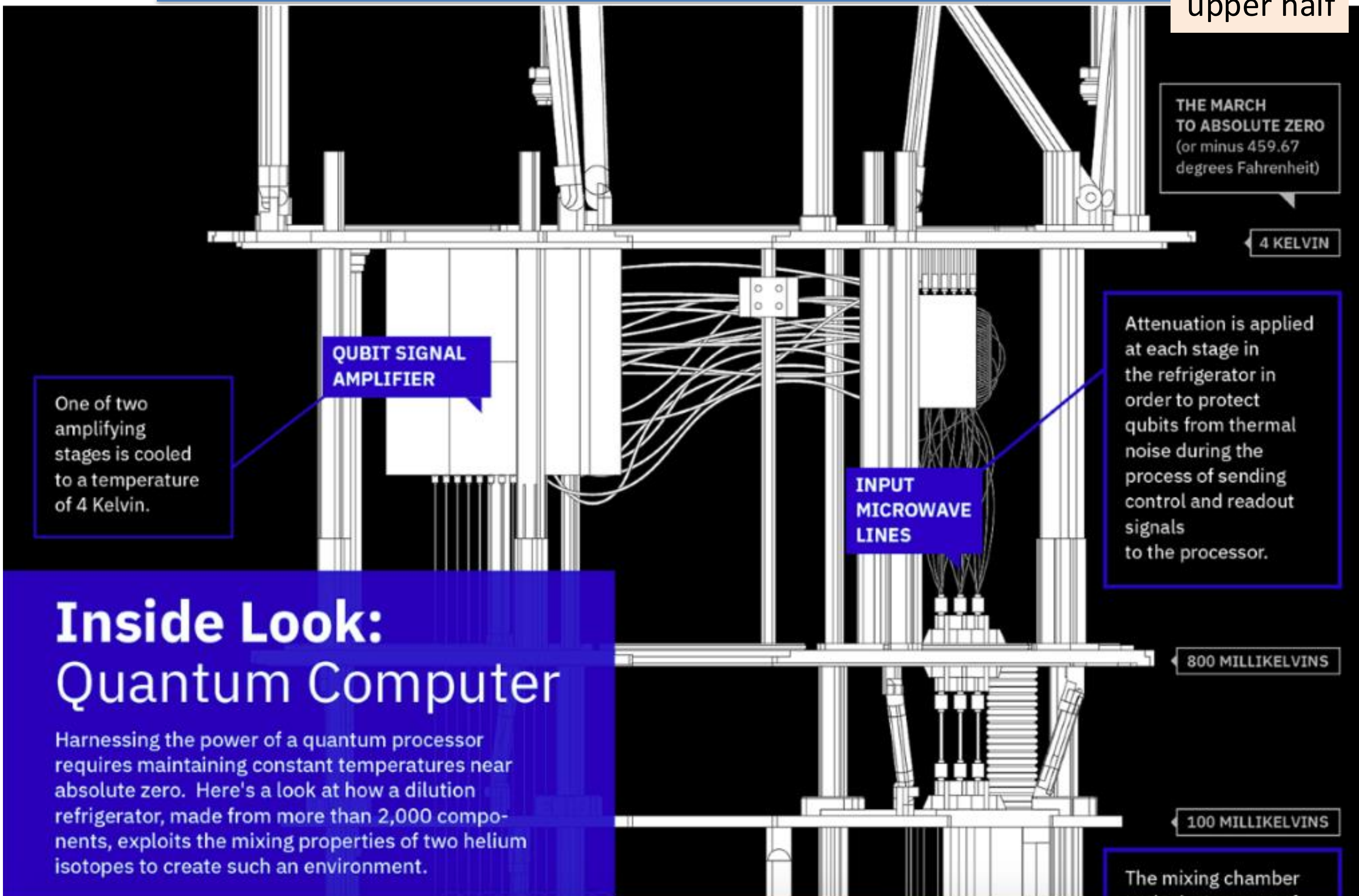
2nd Gen: IBM Q2



2nd Gen: IBM Q2

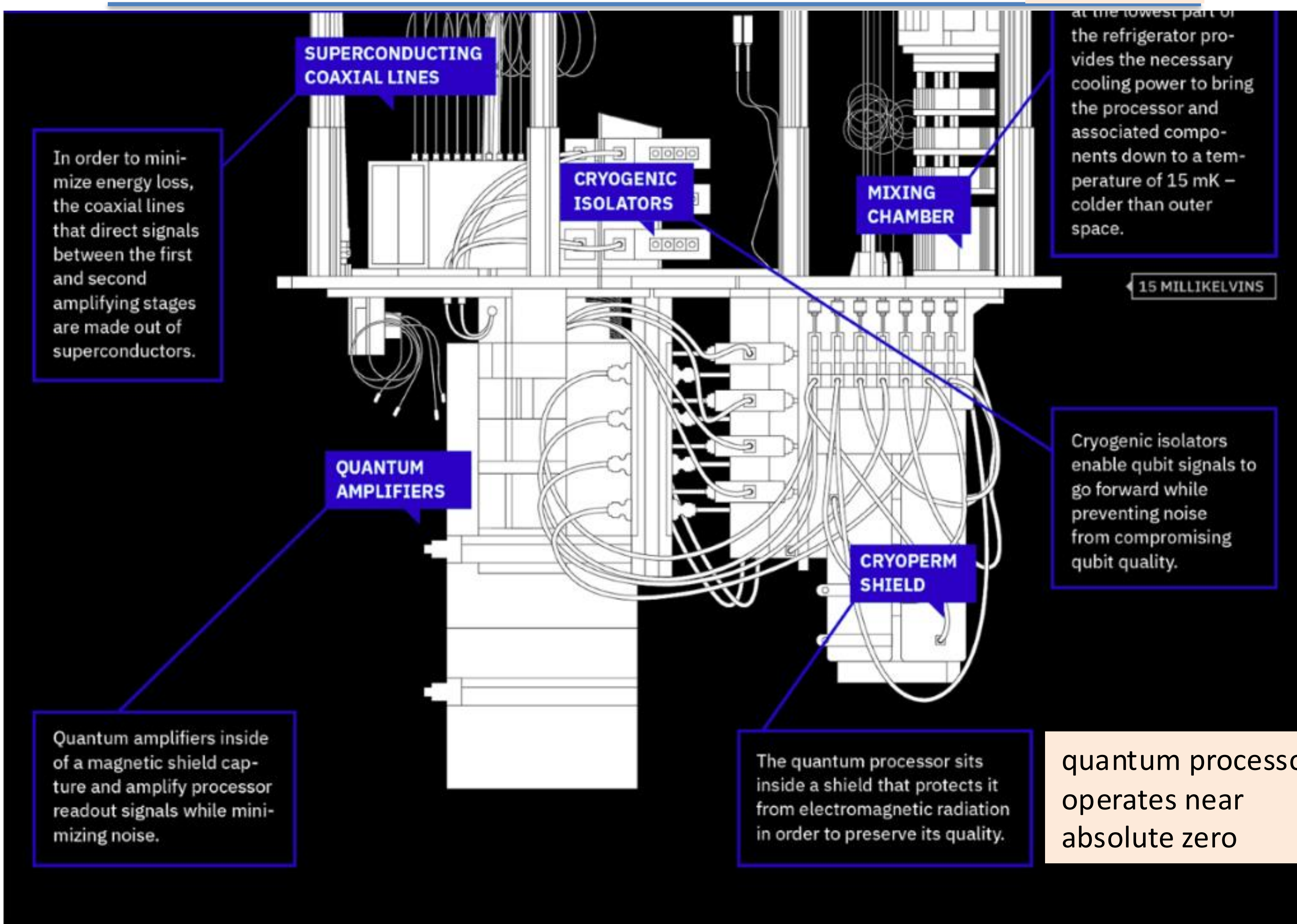
IBM's Q1

upper half



IBM’s Q1

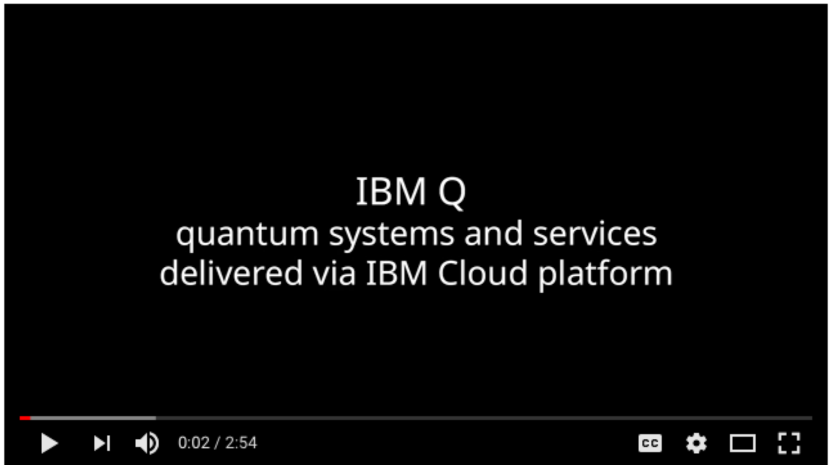
lower half



quantum processor operates near absolute zero

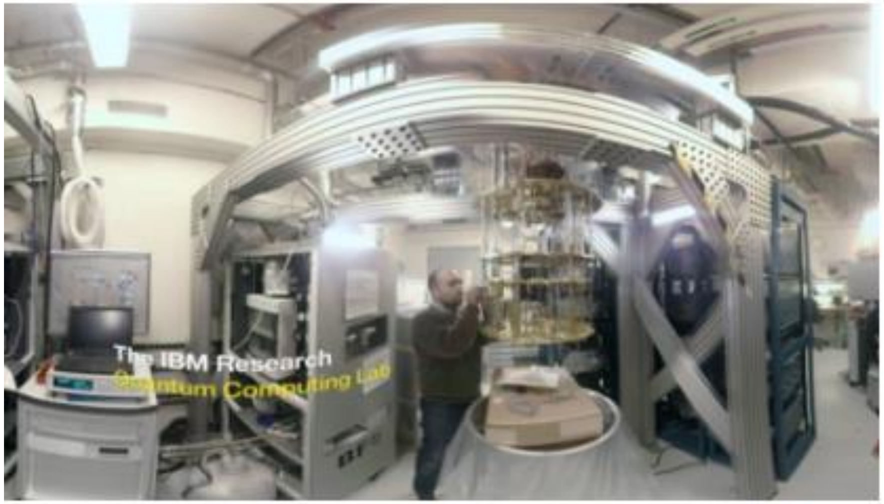
IBM’s Q1

https://www.youtube.com/watch?time_continue=174&v=2B680d-qvhI



https://www.youtube.com/watch?v=yy6TV9Dntlw

IBM's Q1



IBM's quantum computer in the cloud free to use for all comers.
Source: IBM

LAKE WALES, Fla. — IBM's quantum computer — free online as IBM's Q — is going commercial at the Supercomputing Conference 2017 this week in Denver.

Q's now time-proven capabilities, attained from the *free* trial period, will still be cloud hosted with a ready-to-go 20-qubit version and a 50-qubit prototype that demonstrates how to solve NP Hard (non-deterministic *polynomial-time* hard) problems impossible for the fastest supercomputer today.

IBM will also provide an open-source quantum information software kit (QIS-Kit). The key to its QIS-Kit is you don't need a quantum computer to compose and debug your quantum application software, but can prove its correctness first on a conventional computer. Once debugged, the software can be assured to achieve its desired goals with NP-Hard problems. In fact, IBM claims over 60,000 users have beta-tested and debugged their QIS-Kit on over 1.7 million quantum application programs.

IBM will also be displaying at SC 2017 specialty programs built for simulating chemical reactions on quantum computers, for everything from new catalyst development to drug discovery. It claims the key to its success was perfecting error-detecting fault tolerance code for that work on prototypes with up to 56-qubits.

In more detail, IBM's Q Systems cannot attain coherence times (the time before the quantum states relax into an answer) of over 90 microseconds, allowing their 20-to-50 qubit systems the time to solve extremely complex applications impossible for conventional supercomputers.

IBM first launched its first free-to-try cloud-based working 5-to-16 qubit quantum computer in May 2016, and now just 18 months has upgraded the IBM Q experience to 20-qubits with 50-qubits next in line. IBM's 60,000 beta-testers included 1,500 universities, 300 high schools and 300 private-sector participants.

IBM Data Science Experience, a compiler that maps desired experiments onto the available hardware, has worked examples of quantum applications. It has also worked quantum computing concepts and application development principles into its QISKit tutorials. And besides its chemistry simulations for development of new catalysts and drug discovery, the tutorials also provided implementation details for optimization problems.

IBM describes Q as an industry-first initiative to build commercially available universal quantum computing systems for business and science applications. For more information about IBM's quantum computing efforts, visit www.ibm.com/ibmq.

IBM Q

Quora

Filipe M. Cross · Follow
Worked with computers for over 25 years ·

"It is Built around "qubits" rather than "bits" (qubits, can take the values 0 and 1 at the same time)

A lattice of 1000 tiny superconducting circuits, known as qubits, is chilled close to absolute zero to get quantum effects

Cooled to 180x colder than interstellar space (**0.015 Kelvin**)

Shielded to 50,000× less than Earth's magnetic field

In a high vacuum: pressure is 10 billion times lower than atmospheric pressure

192 i/o and control lines from room temperature to the chip

"The Fridge" and servers consume **just 25kW** of power"

"D-Wave's Colin Williams is more certain, pointing out that the company's device finds the best solution in a very different way to regular algorithms. In a classical system, the solutions are poor to begin with but rapidly improve, and then they slowly converge on the best answer. D-Wave's computer reaches the best solution almost instantly. "I've never seen anything like that in a classical algorithm before."

QC Company

Google

Google QC

Sep 2019

FORTUNE

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TECH • QUANTUM COMPUTING

Google Claims 'Quantum Supremacy,' Marking a Major Milestone in Computing

Robert Hackett September 20, 2019

Google Sycamore QC

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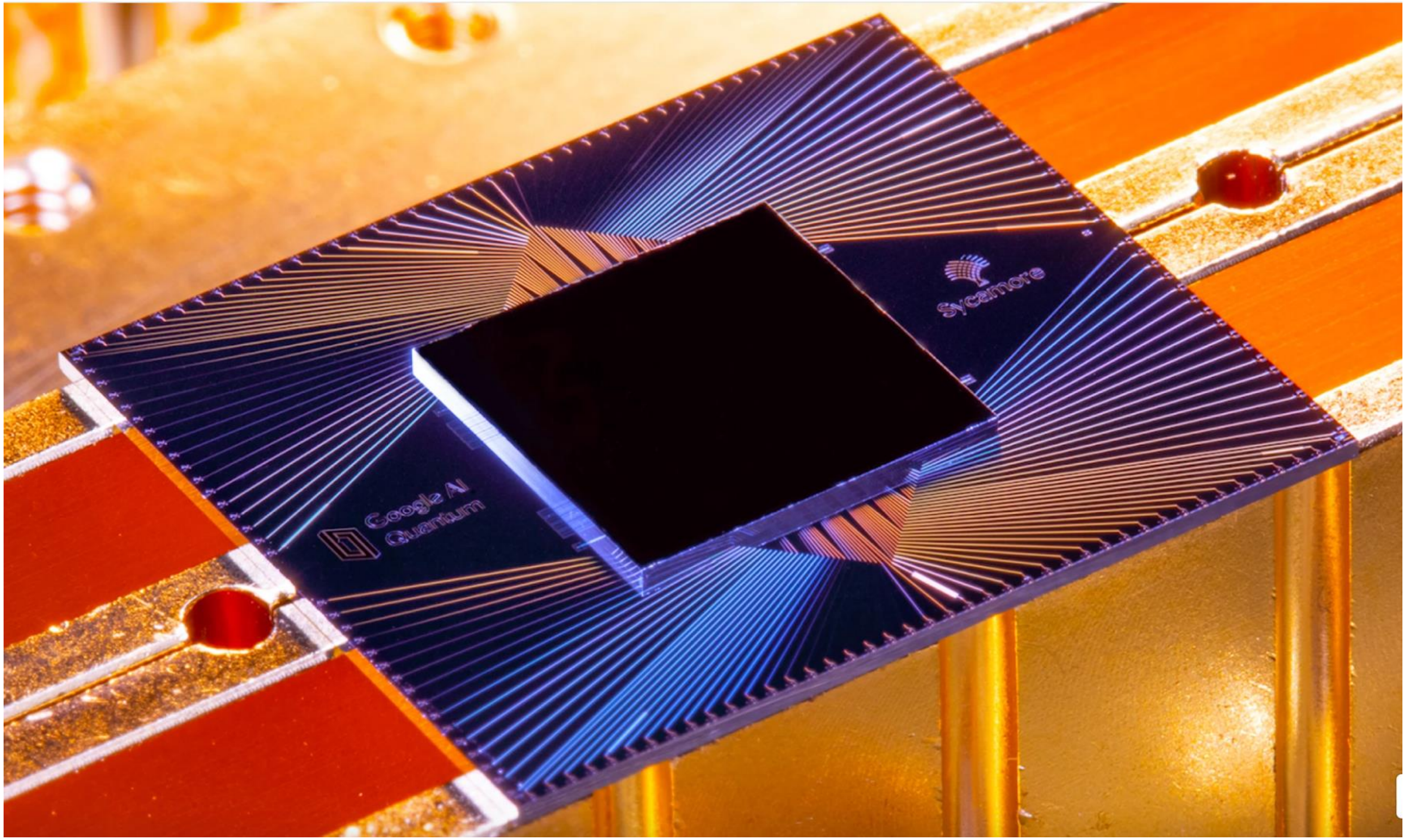
PHYSICS

Time crystals created in Google's quantum processor



Google QC

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Sep 2019

The Google team, which first wrote about their goal in a *Nature* article two years ago, appears to be more hopeful about the short-term prospects of its findings. "As a result of these developments, quantum computing is transitioning from a research topic to a technology that unlocks new computational capabilities," the researchers write.

"We are only one creative algorithm away from

applications." He added, "Quantum computers will never reign 'supreme' over classical computers, but will rather work in concert with them, since each have their unique strengths."

Google QC

53-qubits

Sep 2019

"While our processor takes about 200 seconds to sample one instance of the quantum circuit 1 million times, a state-of-the-art supercomputer would require approximately 10,000 years to perform the equivalent task," the researchers said.

Google's quantum computer, dubbed "Sycamore," contained 53-qubits, or "quantum bits," a measure of the machine's potential power. The team scaled back from a 72-qubit device, dubbed "Bristlecone," it had previously designed.

The researchers estimate that performing the same experiment on a Google Cloud server would take 50 trillion hours—too long to be feasible. On the quantum processor, it took only 30 seconds, they said.

"Quantum processors based on superconducting qubits can now perform computations…beyond the

200 sec << 10,000 years

Random number generation

"Quantum processors based on superconducting qubits can now perform computations…beyond the reach of the fastest classical supercomputers available today," the researchers write. "To our knowledge, this experiment marks the first computation that can only be performed on a quantum processor."

Server = 50T hours

Google QPU Chip

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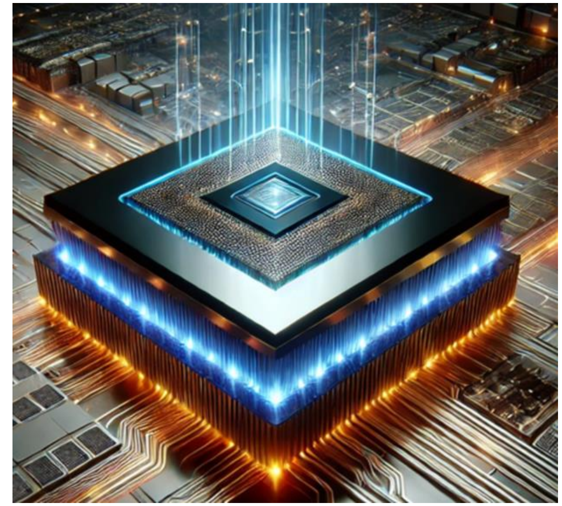


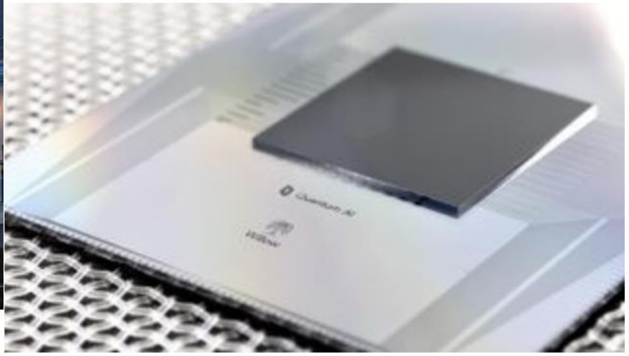
Google rises as tech giant unveils 'mind-boggling' quantum computing chip

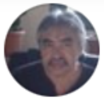
Dec 09, 2024 11:47 AM ET | **Alphabet Inc. (GOOG)** | Chris

The chip, known as Willow, is capable of handling complex calculations in a span of five minutes, while the world's most powerful supercomputers would need 10 septillion years, the tech giant said in a study published in *Nature*. "Our results present device performance that, if scaled, could realize the operational requirements of large scale fault-tolerant quantum algo-

Quora

Google QPU Chip





Kiryl Persianov · Follow

Studied PhD in Theoretical Physics & Artificial Intelligence ·

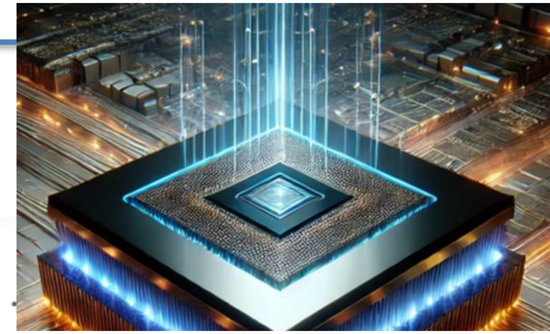
As quantum computers increase their numbers of qubits, they typically grow more powerful but also more susceptible to errors as a result of undesired interactions between qubits and the external environment.

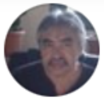
Some advance was made possible with Google's QPU, dubbed Willow, which computes using 105 qubits (the counterpart to a classical computer's bits).

By linking multiple qubits together, Willow forms a "logical qubit," a conglomerate that proved more resilient to errors than any of the chip's individual qubits. By some metrics, Willow boasts a rate of one-in-1,000 errors per computation cycle.

[The Willow quantum computing chip, the successor Sycamore, charts the path for scaling up quantum computers thanks to error-correction technologies that eliminate more errors than are introduced. (Image credit: Google Quantum AI)]

Google QPU Chip – QECC





Kiryl Persianov · Follow
Studied PhD in Theoretical Physics & Artificial Intelligence ·

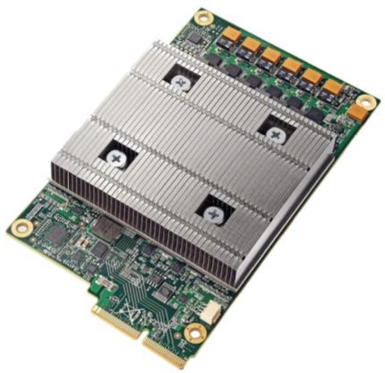
[Quantum error correction provides a path to reach practical quantum computing by combining multiple physical qubits into a logical qubit, where the logical error rate is suppressed exponentially as more qubits are added. However, this exponential suppression only occurs if the physical error rate is below a critical threshold. In this work, we present two surface code memories operating below this threshold: a distance-7 code and a distance-5 code integrated with a real-time decoder. The logical error rate of our larger quantum memory is suppressed by a factor of Λ = 2.14 ± 0.02 when increasing the code distance by two, culminating in a 101-qubit distance-7 code with 0.143% ± 0.003% error per cycle of error correction. This logical memory is also beyond break-even, exceeding its best physical qubit's lifetime by a factor of 2.4 ± 0.3.

We maintain below-threshold performance when decoding in real time, achieving an average decoder latency of 63 μs at distance-5 up to a million cycles, with a cycle time of 1.1 μs. To probe the limits of our error-correction performance, we run repetition codes up to distance-29 and find that logical performance is limited by rare correlated error events occurring approximately once every hour, or 3 × 109 cycles. Our results present device performance that, if scaled, could realize the operational requirements of large scale fault-tolerant quantum algorithms.]

Google TPU 1

Google's first Tensor Processing Unit (TPU)

Google-designed chip for neural net **inference**



In production use for ~8 years: used on search queries, for neural machine translation, for speech, for image recognition, for AlphaGo match, …

2nd Gen: Google

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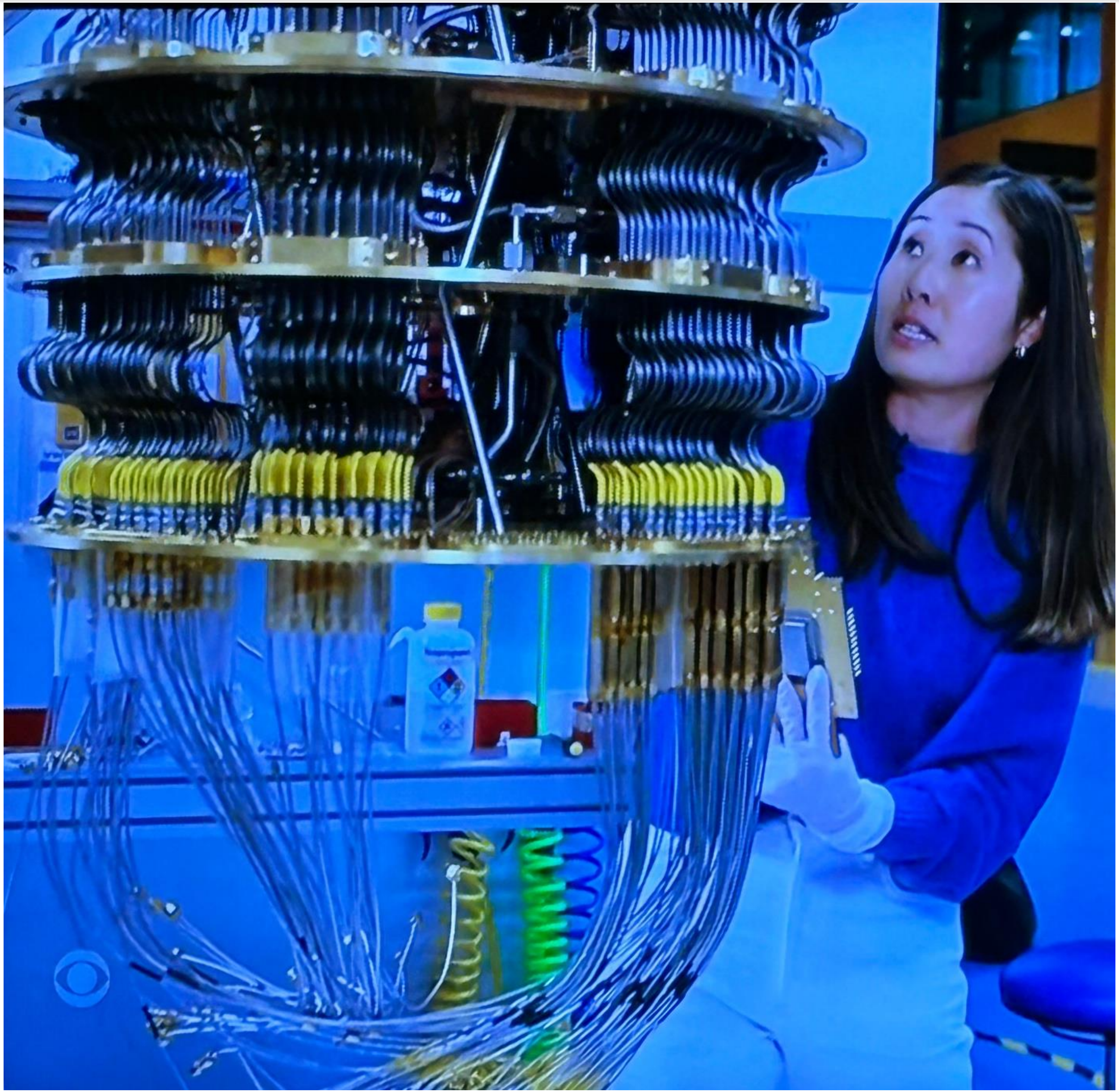

2^{nd} Gen: Google

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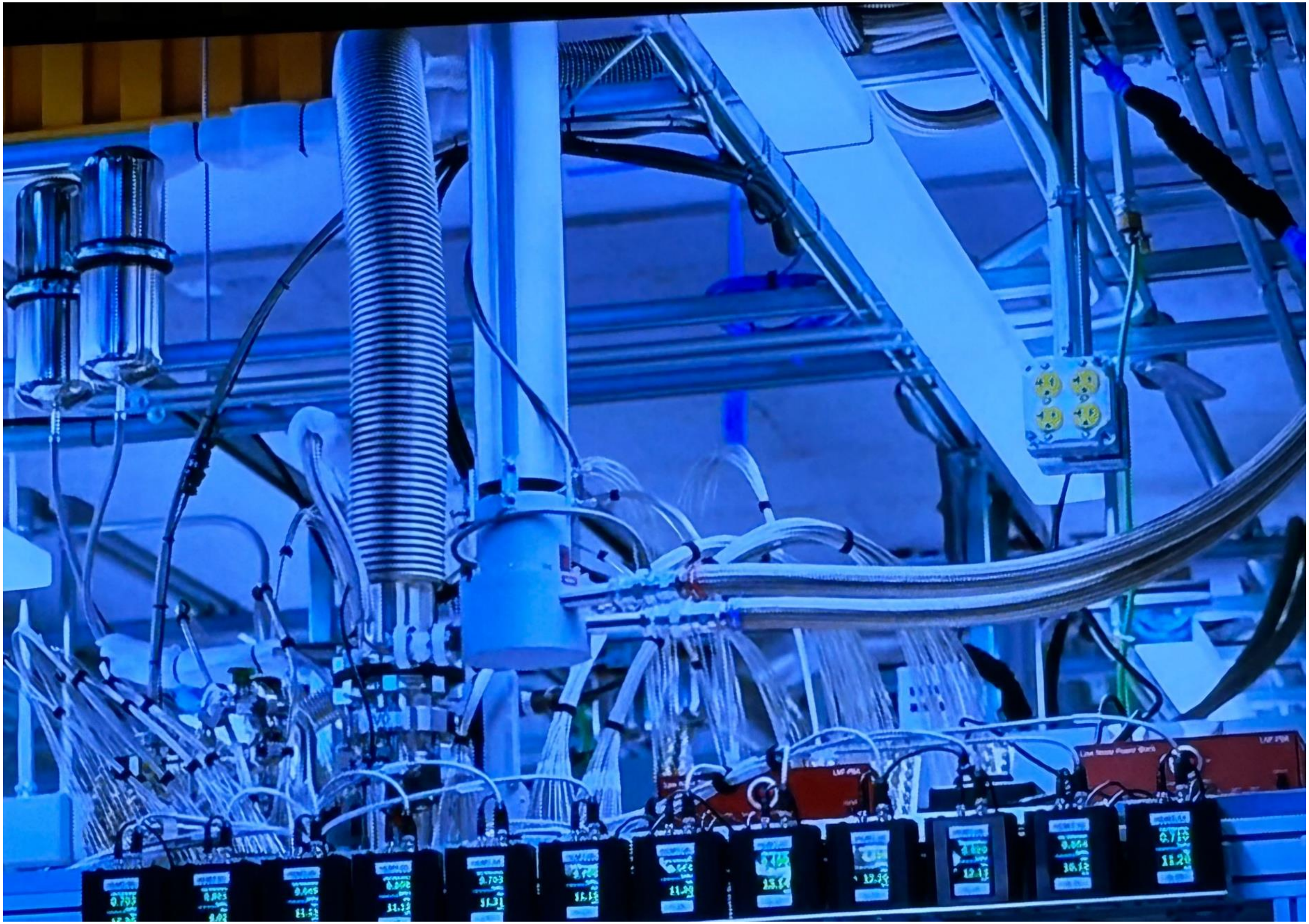
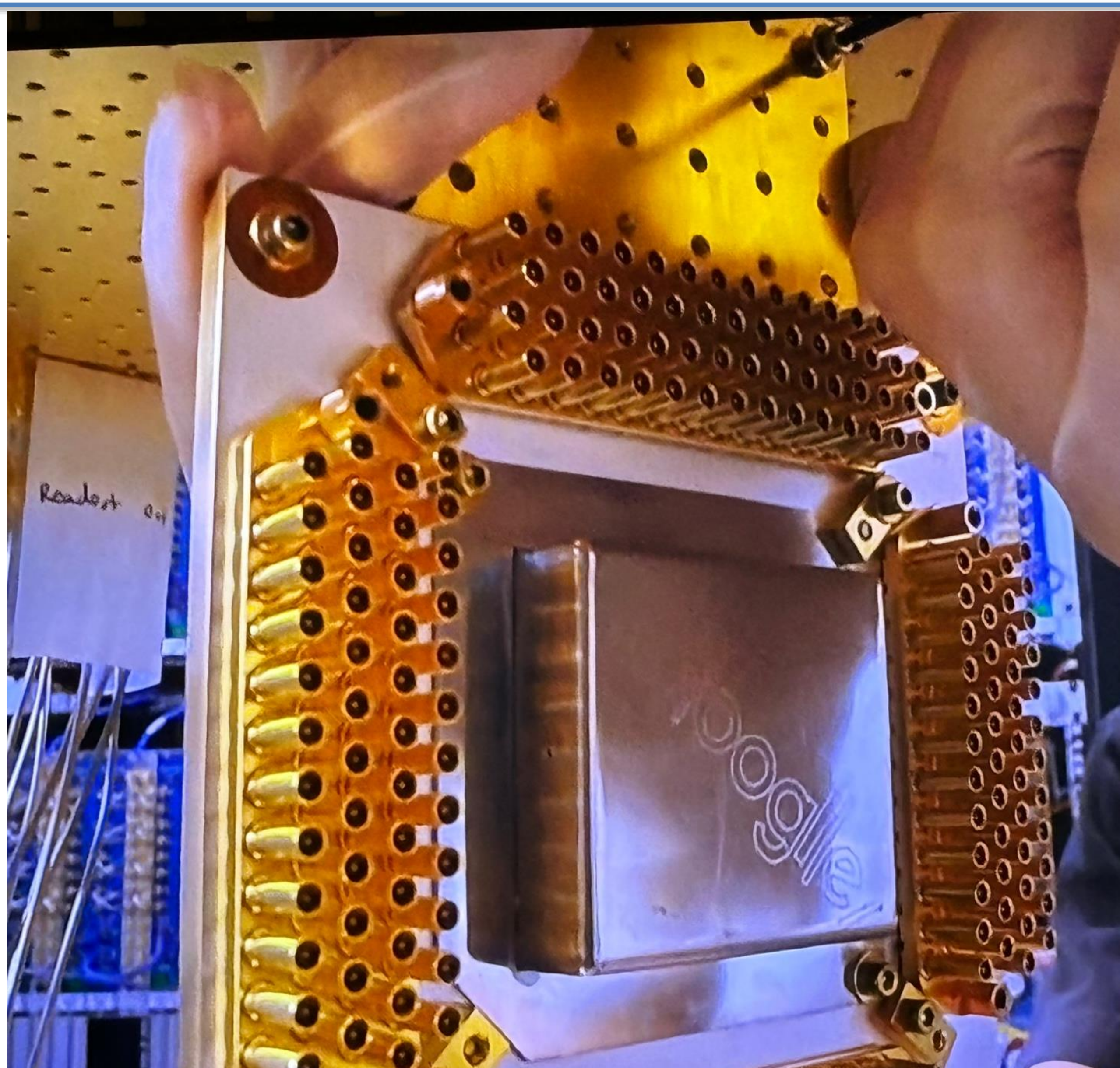
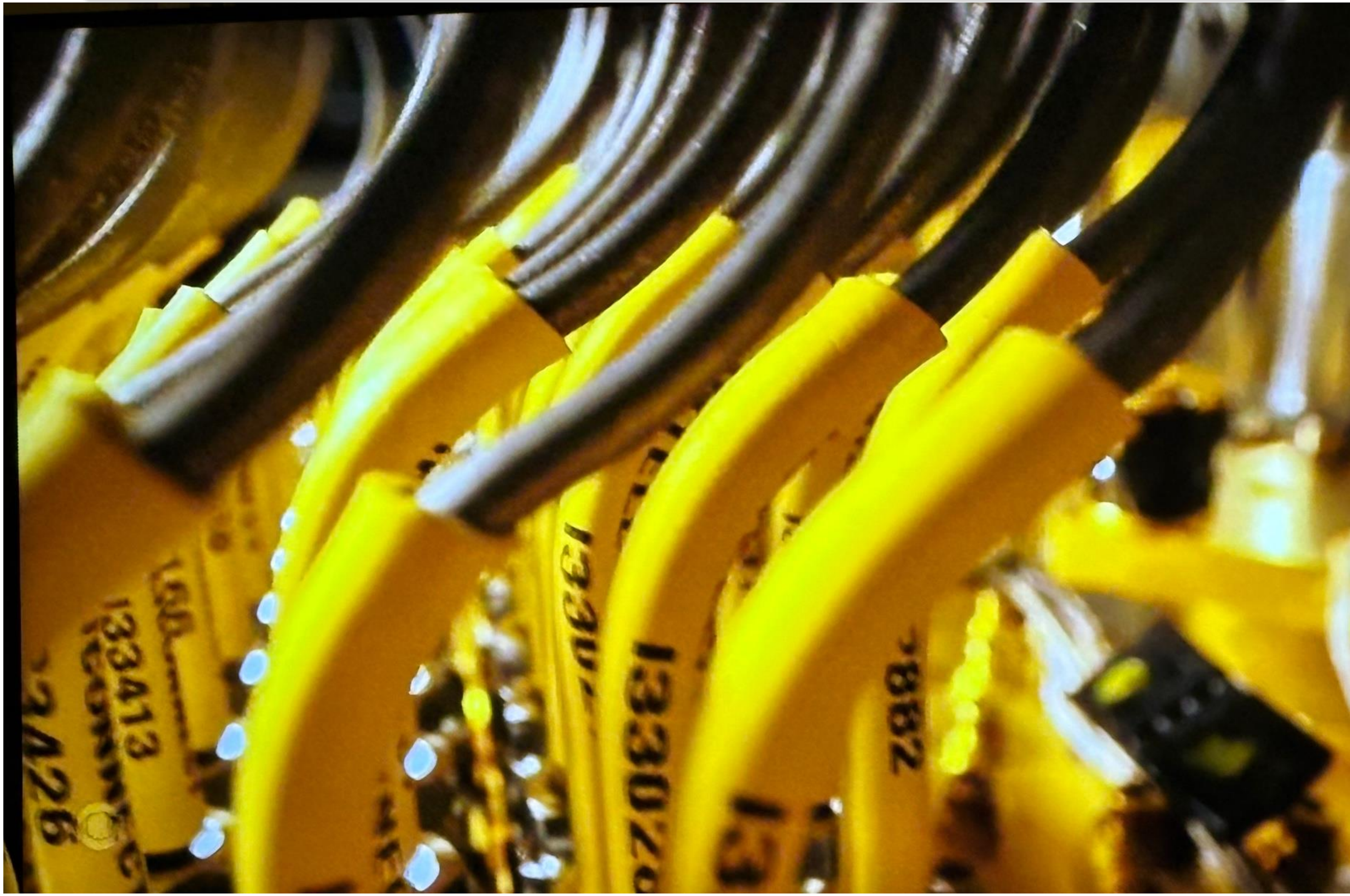


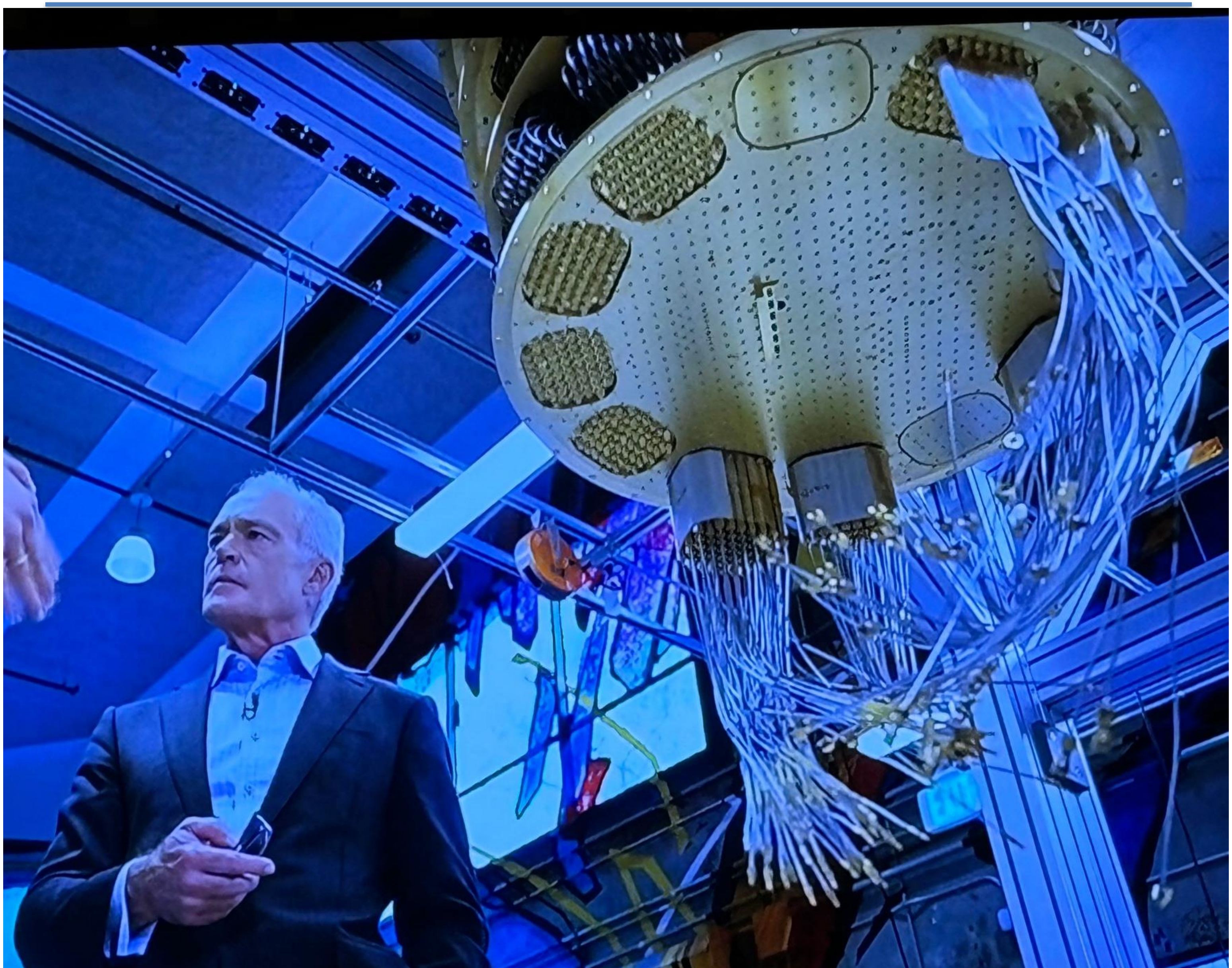
2nd Gen: Google



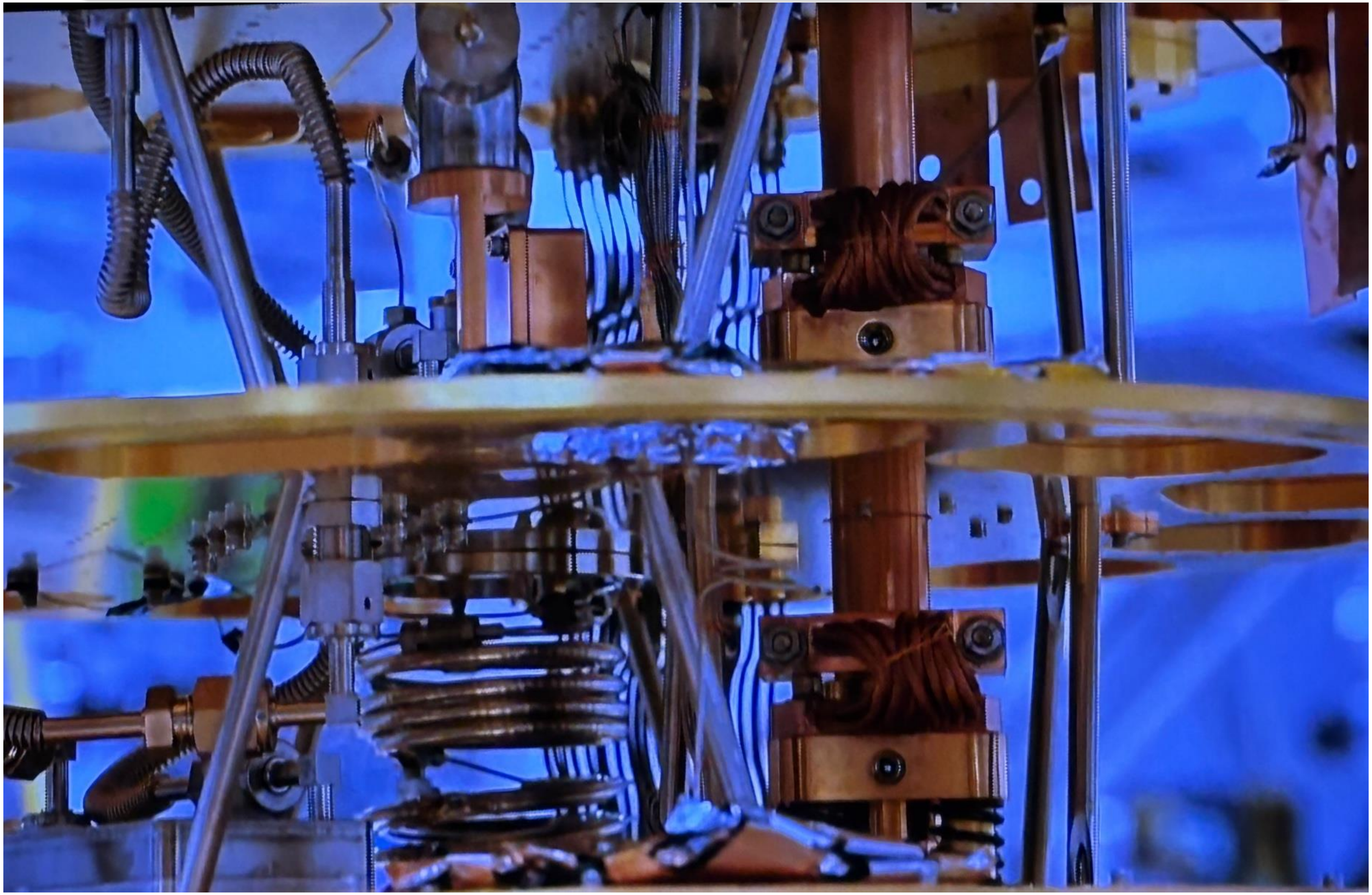
2^{nd} Gen: Google



2nd Gen: Google



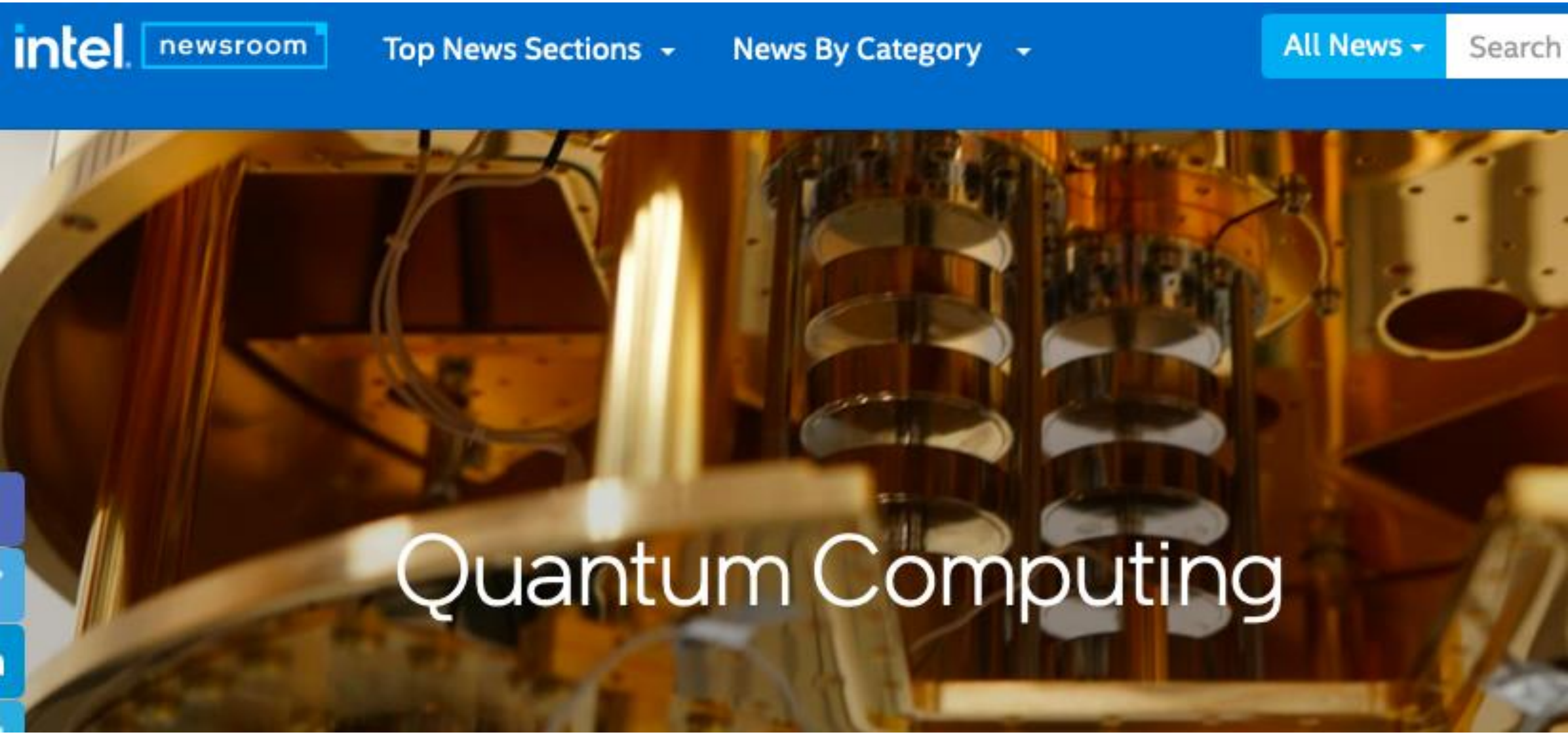
2nd Gen: Google



QC Company

Intel

Intel Photo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Intel QC

Sep 2019

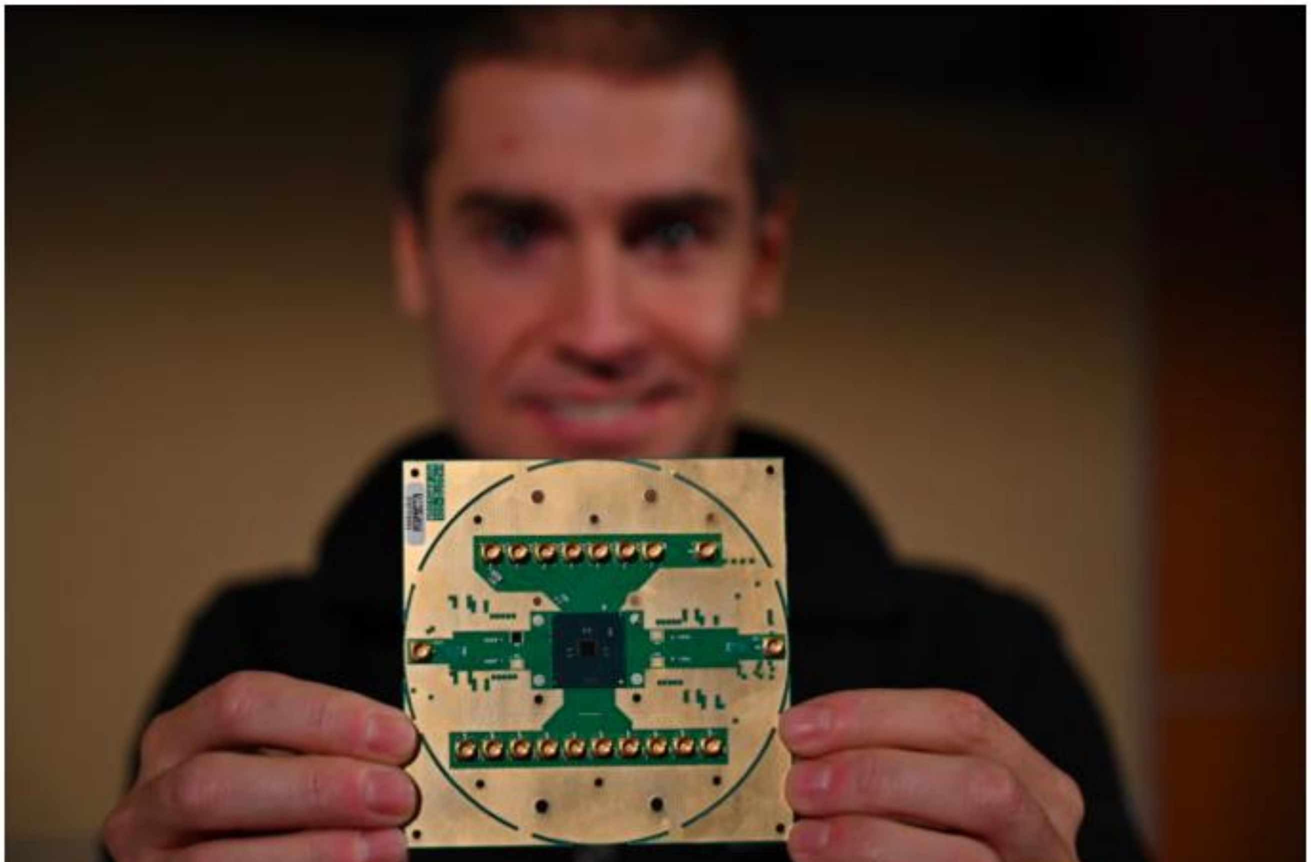
Jim Clarke, Intel Labs' director of quantum hardware, called Google's update "a notable mile marker." He said that "a commercially viable quantum computer will require" many R&D advancements before becoming a reality.

"While development is still at mile one of this marathon, we strongly believe in the potential of this technology," Clarke added.

Intel QC

Dec 2019

INTEL INTRODUCES 'HORSE RIDGE' TO ENABLE COMMERCIALLY VIABLE QUANTUM COMPUTERS



Stefano Pellerano, principal engineer at Intel Labs, holds Horse Ridge. The new cryogenic control chip will speed development of full-stack quantum computing systems, marking a

Intel QC

Dec 2019

What's New: Intel Labs today unveiled what is believed to be a first-of-its-kind cryogenic control chip — code-named "Horse Ridge" — that will speed up development of full-stack quantum computing systems. Horse Ridge will enable control of multiple quantum bits (qubits) and set a clear path toward scaling larger systems — a major milestone on the path to quantum practicality. Developed together with Intel's research collaborators at QuTech, a partnership between TU Delft and TNO (Netherlands Organization for Applied Scientific Research), Horse Ridge is fabricated using Intel's 22nm FinFET technology. In-house fabrication of these control chips at Intel will dramatically accelerate the company's ability to design, test and optimize a commercially viable quantum computer.

> *"While there has been a lot of emphasis on the qubits themselves, the ability to control many qubits at the same time had been a challenge for the industry. Intel recognized that quantum controls were an essential piece of the puzzle we needed to solve in order to develop a large-scale commercial quantum system. That's why we are investing in quantum error correction and controls. With Horse Ridge, Intel has developed a scalable control system that will allow us to significantly speed up testing and realize the potential of quantum computing."*
> *–Jim Clarke, Intel's director of Quantum Hardware*

Why It Matters: In the race to realize the power and potential of quantum computers, researchers have focused extensively on qubit fabrication, building test chips that demonstrate the exponential power of a small number of qubits operating in superposition. However, in early quantum hardware developments — including design, testing and characterization of Intel's silicon spin qubit and superconducting qubit systems — Intel identified a major bottleneck toward realizing commercial-scale quantum computing: interconnects and control electronics.

With Horse Ridge, Intel introduces an elegant solution that will enable the company to control multiple qubits and set a clear path toward scaling future systems to larger qubit counts — a major milestone on the path to quantum practicality.

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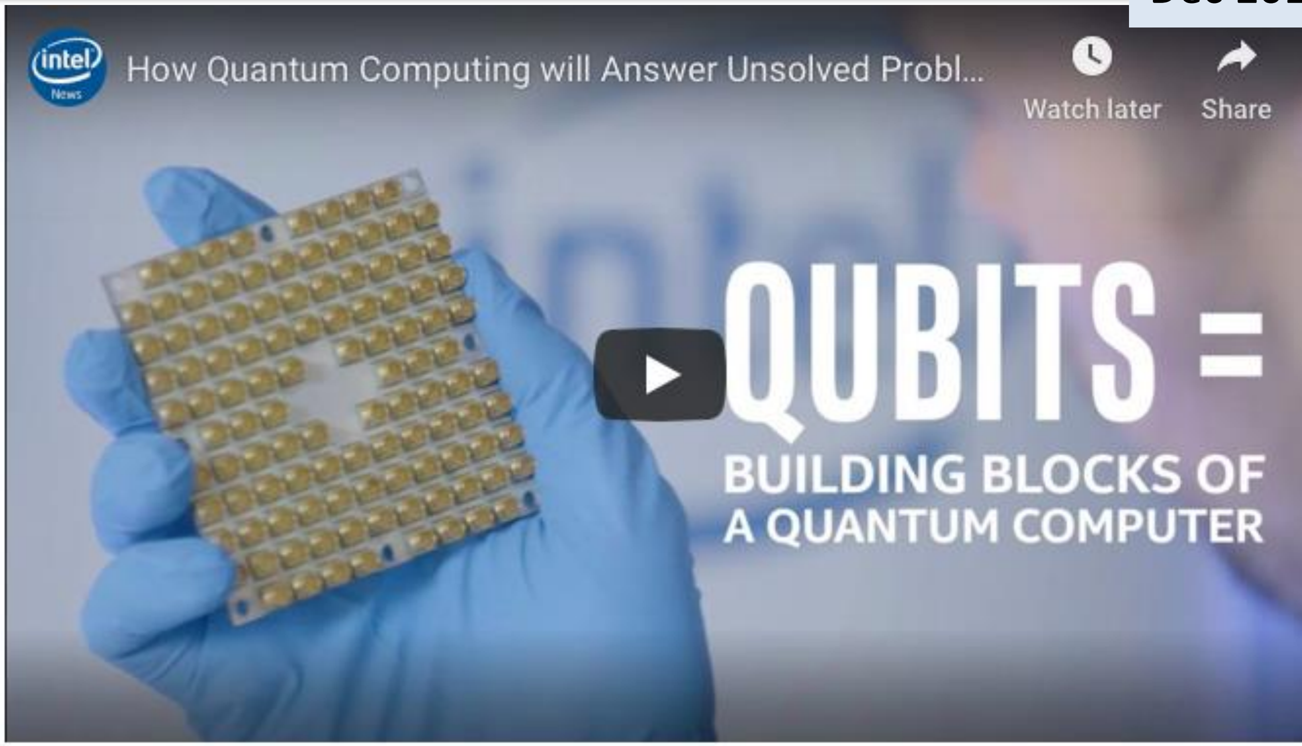

What Quantum Practicality is: Quantum computers promise the potential to tackle problems that conventional computers can't handle by leveraging a phenomena of quantum physics that allows qubits to exist in multiple states simultaneously. As a result, qubits can conduct a large number of calculations at the same time — dramatically speeding up complex problem-solving.

The quantum research community is still at mile one of a marathon toward demonstrating quantum practicality, a benchmark against which the quantum research community can determine whether a quantum system can deliver game-changing performance to solve real-world problems. Intel´s investment in quantum computing covers the full hardware and software stack in pursuit of the development and commercialization of a practical, commercially viable quantum system.

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News Byte

December 9, 2019

Contact Intel PR

More About Horse Ridge: Horse Ridge is a highly integrated, mixed-signal SoC that brings the qubit controls into the quantum refrigerator — as close as possible to the qubits themselves. It effectively reduces the complexity of quantum control engineering from hundreds of cables running into and out of a refrigerator to a single, unified package operating near the quantum device.

Designed to act as a radio frequency (RF) processor to control the qubits operating in the refrigerator, Horse Ridge is programmed with instructions that correspond to basic qubit operations. It translates those instructions into electromagnetic microwave pulses that can manipulate the state of the qubits.

Named for one of the coldest regions in Oregon, the Horse Ridge control chip was designed to operate at cryogenic temperatures — approximately 4 Kelvin. To put this in context, 4 Kelvin is only warmer than absolute zero — a temperature so cold that atoms nearly stop moving.

This feat is particularly exciting as Intel progresses its research into silicon spin qubits, which have the potential to operate at slightly higher temperatures than current quantum systems require.

Today, a quantum computer operates at in the millikelvin range — just a fraction of a degree above absolute zero. But silicon spin qubits have properties that could allow them to operate at 1 Kelvin or higher temperatures, which would dramatically reduce the challenges of refrigerating the quantum system.

As research progresses, Intel aims to have cryogenic controls and silicon spin qubits operate at the same temperature level. This will enable the company to leverage its expertise in advanced packaging and interconnect technologies to create a solution with the qubits and controls in one streamlined package.

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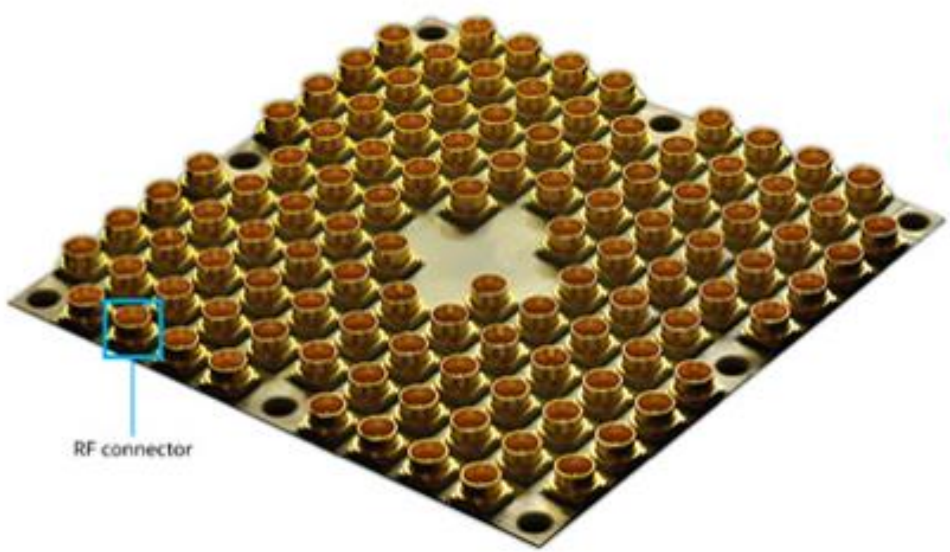
Tangle Lake	49 qubit	Dec 2020

49-Qubit Processor

INTEL'S 49-QUBIT PROCESSOR

During his keynote at CES 2018 in January, Intel CEO Brian Krzanich unveiled our 49-qubit superconducting quantum test chip, code-named "**Tangle Lake**." The 3-inch by 3-inch chip and its package is now in the hands of Intel's quantum research partner QuTech in the Netherlands for testing at low temperatures. Quantum computing is heralded for its potential to tackle problems that today's conventional computers can't handle. Scientists and industries are looking to quantum computing to speed advancements in areas like chemistry or drug development, financial modeling, and even climate forecasting.

TOP



WORTH ITS WEIGHT IN GOLD

There are 108 radio frequency (RF) connectors on Tangle Lake that carry microwave signals into the chip to operate the quantum bits (qubits). They are made of gold, which is excellent for anti-corrosion and signal transmission.

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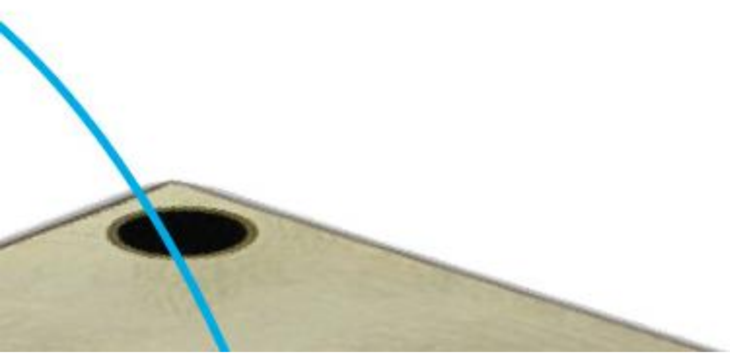
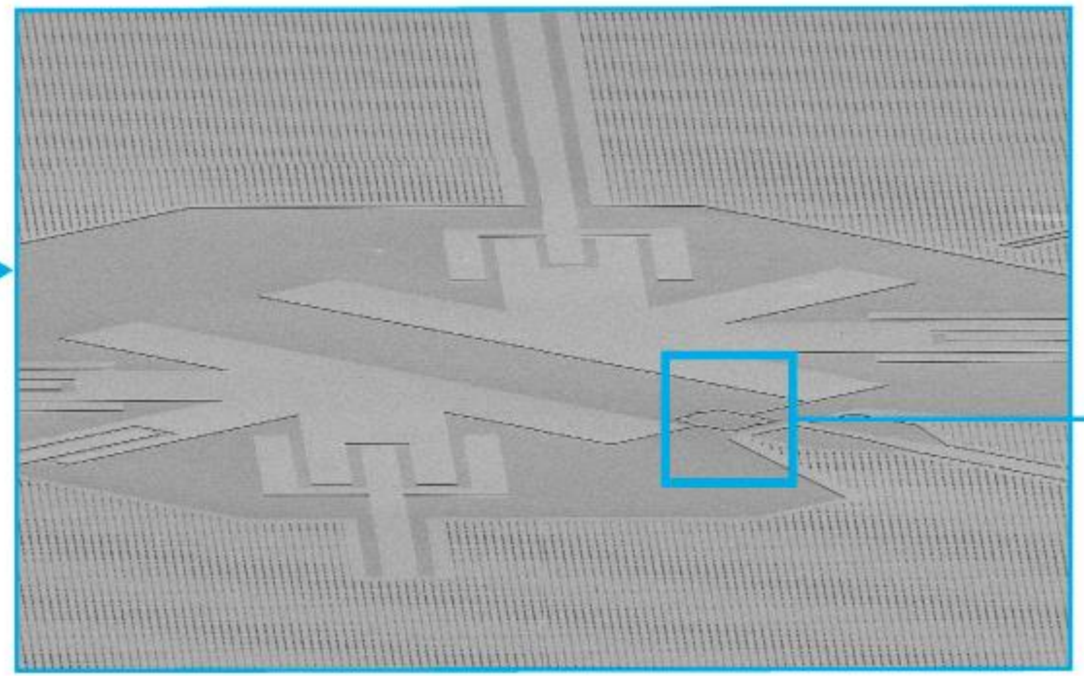
Tangle Lake | 49 qubit | Dec 2020

A single qubit





Enlarged qubit taken with an electron microscope.

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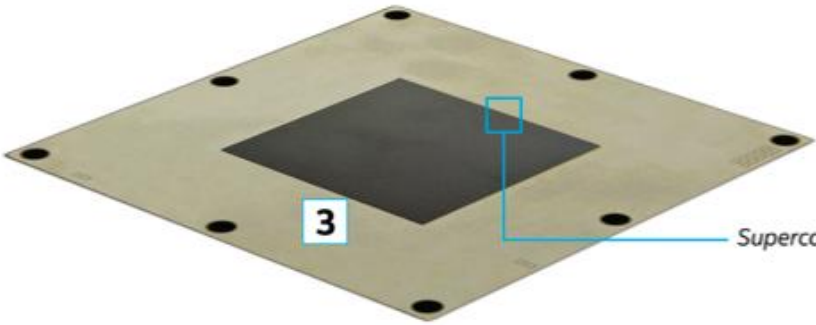
Tangle Lake	49 qubit	Dec 2020

BOTTOM

CONNECTING THE QUBIT CHIP



3 The package

The qubit chip is attached to the package by the Flip-Chip technique. The qubits are patterned onto a silicon substrate and attached to the multi-layer package by superconducting metal balls.

UNTANGLING A NAME

Tangle Lake is named after a chain of lakes in Alaska, a nod to the extreme cold temperatures and the entangled state of qubits that gives quantum computing the ability to scale exponentially. Qubits are extremely fragile—they're kept at about 20 millikelvin, 250 times colder than deep space.

intel

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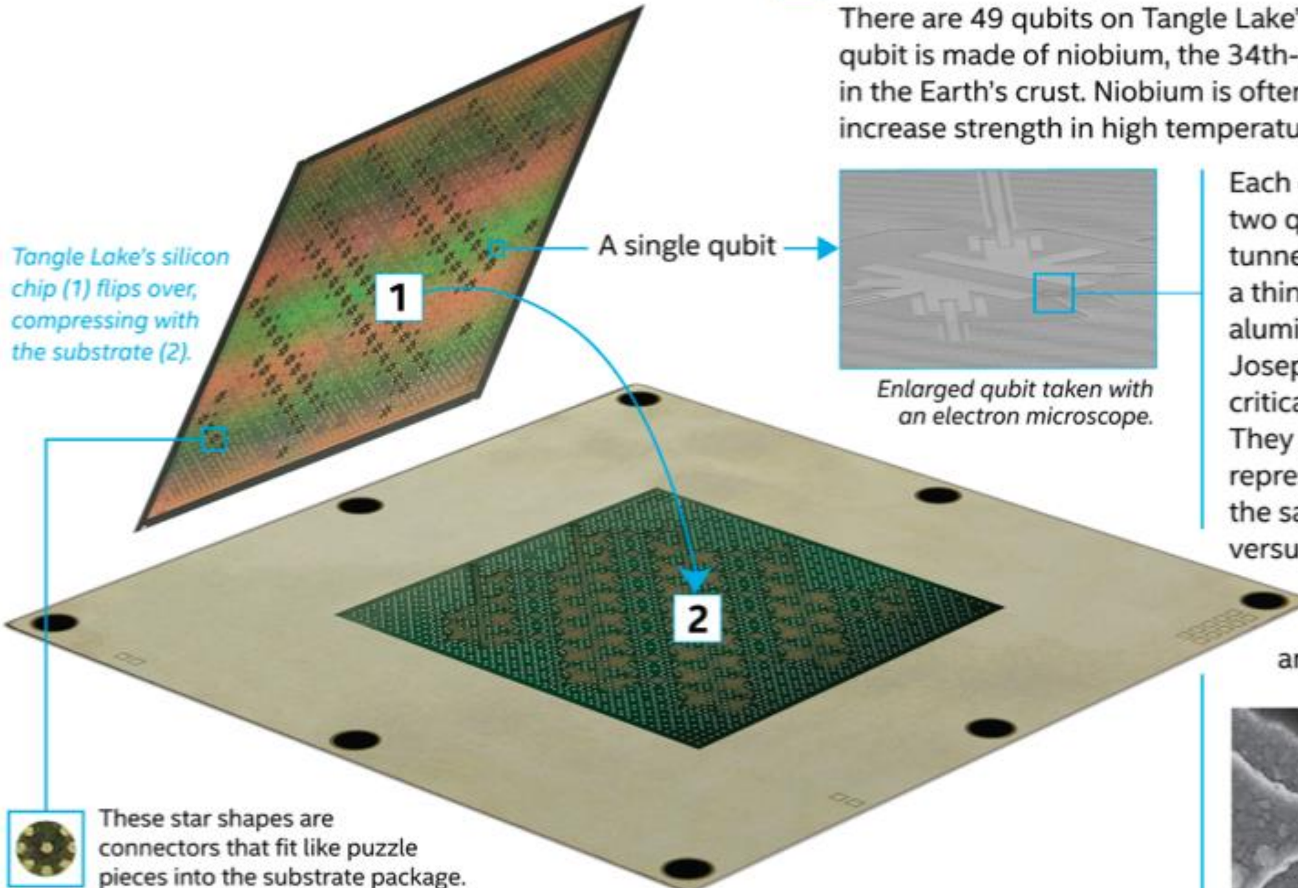
THE MAGIC INSIDE



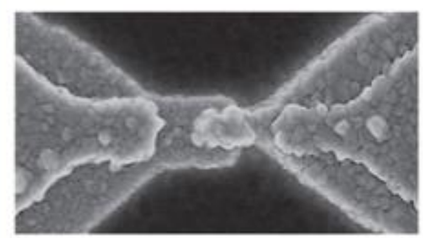
These star shapes are connectors that fit like puzzle pieces into the substrate package.

1 The silicon chip

There are 49 qubits on Tangle Lake's silicon chip (1). Each qubit is made of niobium, the 34th-most common element in the Earth's crust. Niobium is often added to steel to increase strength in high temperature applications.

Enlarged qubit taken with an electron microscope.

Each qubit in Tangle Lake has two quantum mechanical tunnels, which are comprised of a thin oxide film between two aluminum wires. Known as Josephson junctions, they are critical to quantum computing. They allow for a qubit to represent both a 1 and a 0 at the same time (superposition) versus classic computing where information is encoded in bits as a string of 1s and 0s.



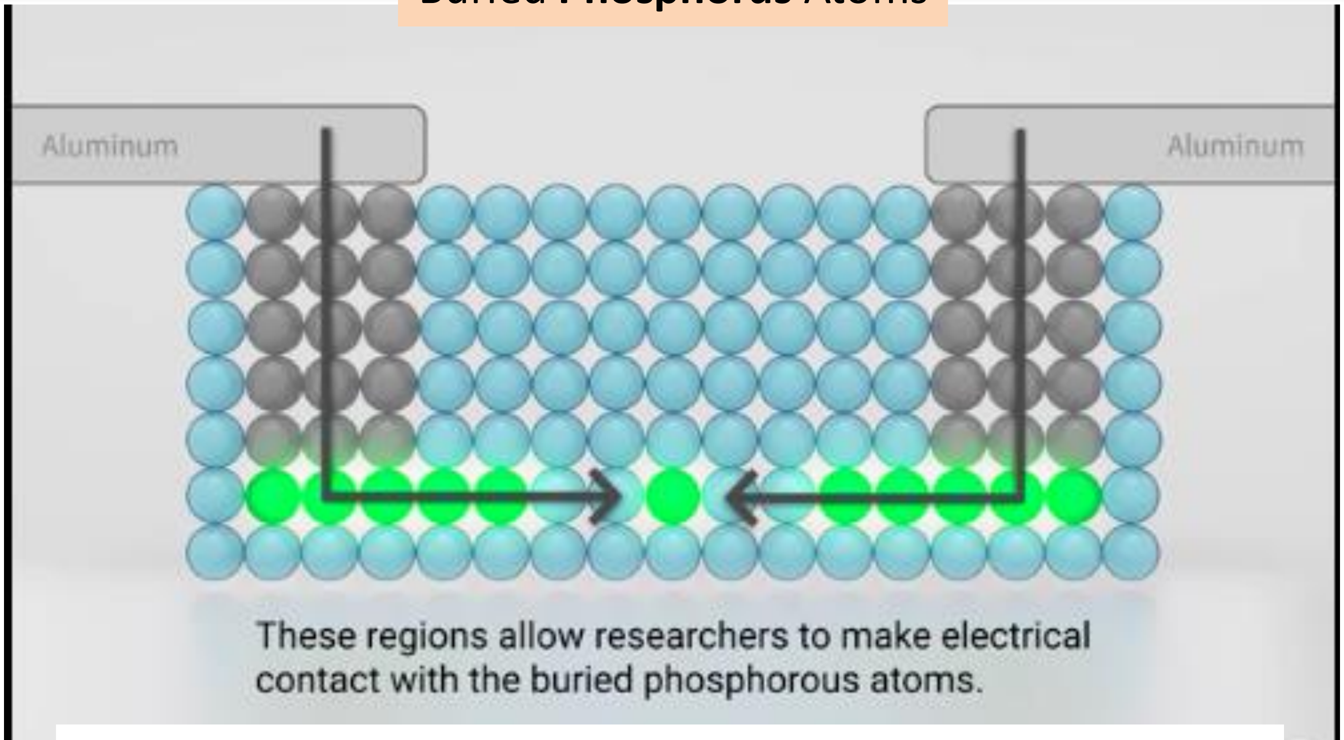
Magnified view of the qubit on Tangle Lake showing the Josephson junction.

2 The substrate

The substrate (2) is grounded by superconducting spheres that offer mechanical strength and transmission of RF/microwave signals from package to chip.

Single Atom Qubits

Buried **Phosphorus** Atoms



In the lab, the research team produced a series of seemingly identical single-atom transistors. However, each one featured different-sized tunneling gaps. By augmenting the size of the tunneling gap by distances less than a nanometer, scientists were able to precisely control the flow of single electrons through the transistor.

"Because quantum tunneling is so fundamental to any quantum device, including the construction of qubits, the ability to control the flow of one electron at a time is a significant achievement," Wyrick said.

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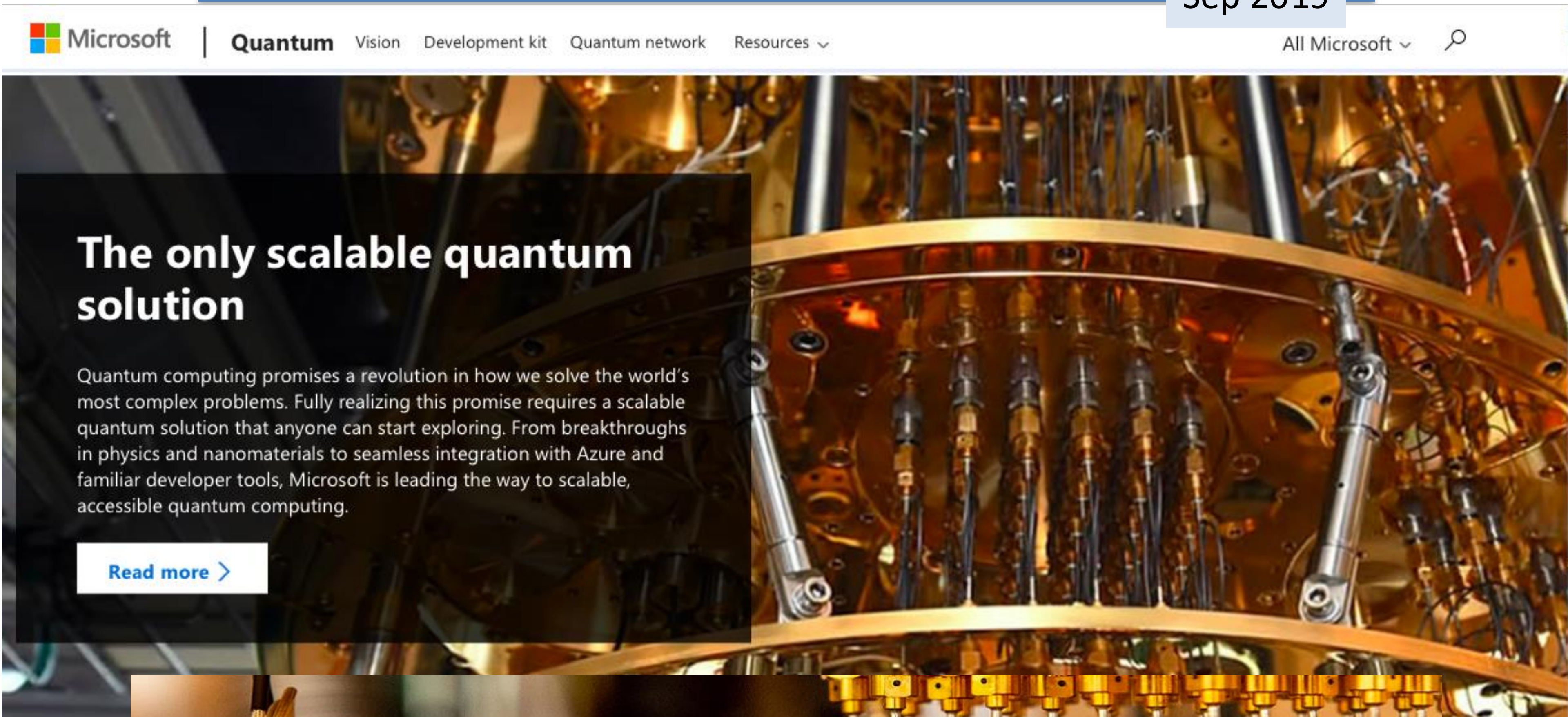
Microsoft

Microsoft QC

Sep 2019



Microsoft QC

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Realizing a quantum future

Building a quantum cloud platform

Our complete quantum stack approach includes familiar tools, provides development resources to build and simulate quantum solutions, and continues with deployment through Azure for a streamlined combination of both quantum and classical processing.

Empowering the future quantum workforce

Because quantum computing has great potential to positively impact lives and societies, we're working hard to develop tools and educational opportunities, creating job skills that will apply to a future quantum economy.

Achieving scalability through innovation

The topological approach to quantum computing requires far fewer physical qubits than other quantum systems, making scalability much more achievable. Providing a more solid foundation, the topological approach offers robust, stable qubits, and helps to bring the solutions to some of our most challenging problems within reach.

Secure our data in a quantum future

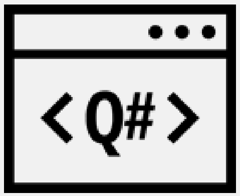
Microsoft is building post-quantum cryptography solutions to ensure our data remains safe once quantum computers become mainstream in years to come.

Check out this podcast >

Microsoft QC Tools

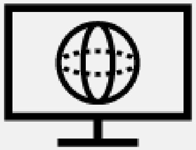
Sep 2019

Q# Powering a new generation of development



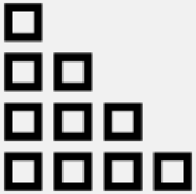
A groundbreaking quantum-focused language

The first of its kind, Q# is a new high-level quantum-focused programming language. Q# features rich integration with Visual Studio and Visual Studio Code and interoperability with the Python programming language. Enterprise-grade development tools provide the fastest path to quantum programming on Windows, macOS, or Linux.



Code optimization in a simulated environment

Set breakpoints, step into the Q# code, debug line-by-line, and estimate the real-world costs to run your solution. Simulate quantum solutions requiring up to 30 qubits with a local simulator.



Open source license for libraries and samples

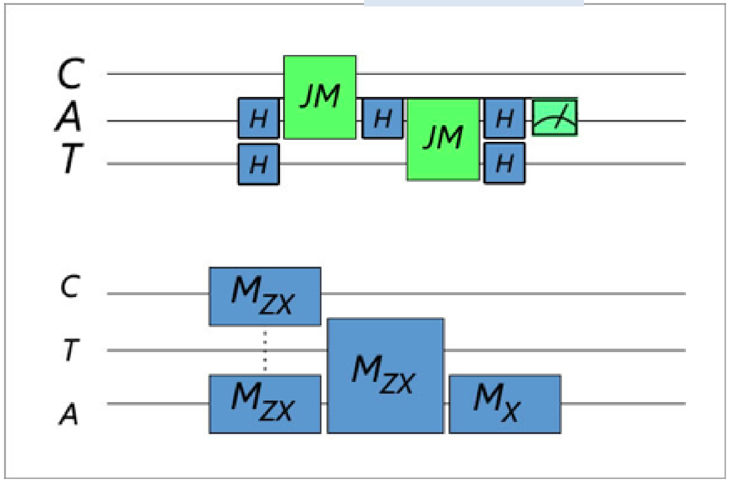
Developed by top industry experts, a collection of ready-to-use building blocks take you from being a beginner to building your first quantum solution. The open source license allows development libraries and samples to be used in your applications, while also enabling you to contribute your own enhancements to the growing Q# community.

Visual Studio + Python

Supports ***quantum inspired*** algorithms that *simulate <= 30* **Qubits**

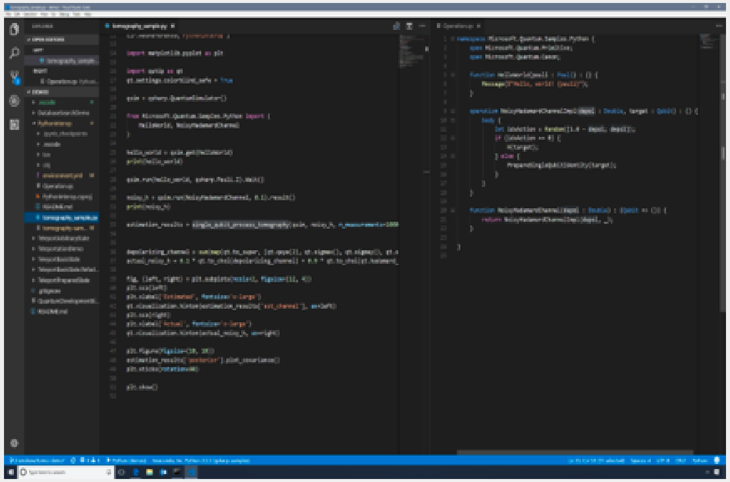
Microsoft QC Tools

Sep 2019



Runtime

To solve problems on a quantum computer, you need a runtime that executes a quantum algorithm while maintaining the state of the machine, operating the control system in a parallel real-time environment, and communicating from the device to the outside world. The runtime layer is the firmware and operating system of the quantum computer.



Quantum development tools

To help quantum developers build applications and algorithms, we've designed the **Quantum Development Kit**—a set of enterprise-grade tools to write, debug, and optimize quantum code. Microsoft has been focused on providing an integrated software experience for as long as we've been working on the hardware itself, and this kit includes everything you need to get started. Microsoft will also create quantum services in Azure, giving you a fast path from simulation to optimization to deployment on quantum hardware.

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Amazon

Amazon Q1

Amazon Q1

Amazon Braket – Get Started with Quantum Computing

by Jeff Barr | on 02 DEC 2019 | in Amazon Braket, AWS Re:Invent, Launch, News, Quantum Technologies | Permalink | Comments | Share

00:00 -00:00

Voiced by Amazon Polly

Nearly a decade ago I wrote about the Quantum Compute Cloud on April Fool's Day. The future has arrived and you now have the opportunity to write quantum algorithms and to run them on actual quantum computers. Here's what we are announcing today:

Amazon Braket – A fully managed service that allows scientists, researchers, and developers to begin experimenting with computers from multiple quantum hardware providers in a single place. Bra-ket notation is commonly used to denote quantum mechanical states, and inspired the name of the service.

AWS Center for Quantum Computing – A research center adjacent to the California Institute of Technology (Caltech) that will bring together the world's leading quantum computing researchers and engineers in order to accelerate development of quantum computing hardware and software.

Amazon Quantum Solutions Lab – A new program to connect AWS customers with quantum computing experts from Amazon and a very select set of consulting partners.

Amazon Q1

DR JEFF SOFTWARE
INDIE APP DEVELOPER

Amazon Braket

This new service is designed to let you get some hands-on experience with qubits and quantum circuits. You can build and test your circuits in a simulated environment and then run them on an actual quantum computer. Amazon Braket is a fully managed AWS service, with security & encryption baked in at each level.

You can access Amazon Braket through a notebook-style interface:

```
    'ZZ']

In [3]: bell = Circuit().h(0).cnot(0, 1)
        print(bell)
        print(f"\nserialized_circuit: {bell.to_ir().json()}")

T  : |0|1|

q0 : -H-C-
        |
q1 : ---X-

T  : |0|1|

serialized_circuit: {"instructions": [{"target": 0, "type": "h"}, {"control": 0, "target": 1, "type":
"cnot"}]}

In [4]: result = simulator.run(bell, s3_destination_folder).result()
        print(f"measurement_counts: {result.measurement_counts}")
        print(f"measurement_probabilities: {result.measurement_probabilities}")

        data = ["".join([str(bit) for bit in shot]) for shot in result.measurements]
        plot = plt.hist(data)

measurement_counts: Counter({'00': 50, '11': 50})
measurement_probabilities: {'00': 0.5, '11': 0.5}
```

Amazon Q1

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Looking Ahead

Today's implementations of public key cryptography are secure because factoring large integers is computationally intensive. Depending on key length, the time to factor (and therefore break) keys ranges from months to forever (more than the projected lifetime of our universe). However, when a quantum computer with enough qubits is available, factoring large integers will become instant and trivial. Defining "enough" turns out to be far beyond what I can cover (or fully understand) in this blog post, and brings in to play the difference between logical and physical qubits, noise rates, error correction, and more!

You need to keep this in mind when thinking about medium-term encryption and data protection, and you need to know about post-quantum cryptography. Today, s2n (our implementation of the TLS/SSL protocols) already includes two different key exchange mechanisms that are quantum-resistant. Given that it takes about a decade for a new encryption protocol to become widely available and safe to use, it is not too soon to look ahead to a time when large-scale quantum computers are available.

Quantum computing is definitely not mainstream today, but that time is coming. It is a very powerful tool that can solve certain types of problems that are difficult or impossible to solve classically. I suspect that within 40 or 50 years, many applications will be powered in part using services that run on quantum computers. As such, it is best to think of them like a GPU or a math coprocessor. They will not be used in isolation, but will be an important part of a hybrid classical/quantum solution.

Here We Are

Our goal is to make sure you know enough about quantum computing to start looking for some appropriate use cases and conducting some tests and experiments. We want to build a solid foundation that is firmly rooted in reality, and to work with you to move into a quantum-powered future.

Ok, with that as an explanation, let's get into it!

Amazon Braket

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Apple

Apple Post-QC Sec

And Apple in February said it was introducing PQ3, a "post-quantum" cryptographic protocol with the ability to restore the cryptographic security of a conversation even if a given key becomes compromised.

Chinese QC/Optical

Quora 187 636 Search Quora

On the other hand, this is a rather limited "quantum computer." And one can imagine that it took an army of graduate students to keep all the optics tweaked up.

Jeff Drobman

Just now

hmmm. seems to me this is an "optical computer", not a quantum one, and is not programmable, so not universal.

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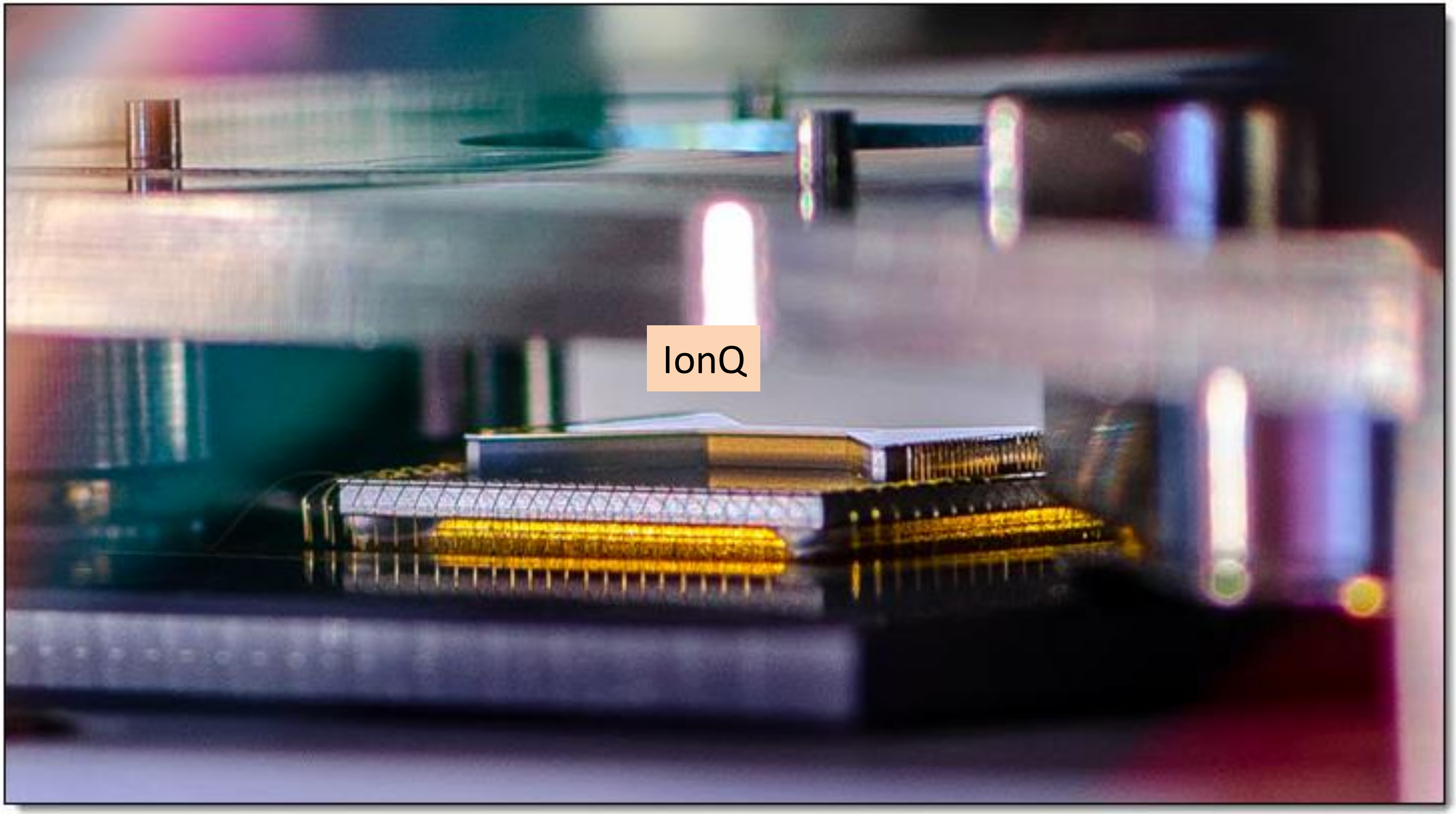
IonQ

IonQ

And the IonQ linear ion trap:



Quantum

IONQ

➢ Ion Trap tech

IonQ to Increase Performance and Scale of Quantum Computers with Photonic Integrated Circuits in Collaboration with imec

November 7, 2024, 4:00 PM Eastern Standard Time

COLLEGE PARK, Md.--(BUSINESS WIRE)--IonQ (NYSE: IONQ), a leader in the quantum computing industry, announced today that it is developing photonic integrated circuits (PICs) and chip-scale ion trap technology for trapped ion quantum computing in partnership with imec, a world-renowned R&D center in nanoelectronics and digi-

Quantum

IONQ

IonQ to Advance Hybrid Quantum Computing with New Chemistry Application and NVIDIA CUDA-Q

IonQ uses the NVIDIA CUDA-Q platform alongside IonQ Forte to demonstrate an end-to-end application workflow

The work reaffirms IonQ's focus on making quantum acceleration as simple and ubiquitous as GPU acceleration for on-prem and hybrid deployments

Quantum

IONQ

Dec 2024

IonQ Unveils Its First Quantum Computer in Europe, Online Now at a Record #AQ36

IonQ's quantum computer Forte Enterprise has achieved the record-breaking milestone of #AQ36

In partnership with QuantumBasel, IonQ Forte Enterprise will provide European Enterprise Customers, Industries, government entities, and research institutes with local access to IonQ's most powerful quantum systems

IonQ has opened its First European Innovation Center at the uptownBasel campus in Arlesheim, Switzerland

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D-Wave

D-Wave

Quora

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Worked with computers for over 25 years ·

Will quantum computers eventually replace classical computers any time

Lets see... D-Wave, a company based in Burnaby, Canada, has been selling quantum computers since 2011,

The one you can buy today has a few requirements you may find difficult to get in your home. But it is not impossible.

Now based in Santa Clara, CA

D-Wave

Quora

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Worked with computers for over 25 years ·

"It is Built around "qubits" rather than "bits" (qubits, can take the values 0 and 1 at the same time)

A lattice of 1000 tiny superconducting circuits, known as qubits, is chilled close to absolute zero to get quantum effects

Cooled to 180x colder than interstellar space (**0.015 Kelvin**)

Shielded to 50,000× less than Earth's magnetic field

In a high vacuum: pressure is 10 billion times lower than atmospheric pressure

192 i/o and control lines from room temperature to the chip

"The Fridge" and servers consume **just 25kW** of power"

"D-Wave's Colin Williams is more certain, pointing out that the company's device finds the best solution in a very different way to regular algorithms. In a classical system, the solutions are poor to begin with but rapidly improve, and then they slowly converge on the best answer. D-Wave's computer reaches the best solution almost instantly. "I've never seen anything like that in a classical algorithm before.""

Quantum: D-Wave

Recent performance benchmarks demonstrate that the 4,400+ qubit Advantage2 processor is computationally more powerful than the current Advantage system, solving a range of problems – including 3D lattice problems common in materials science – 25,000 times faster. The processor

Compared with the current Advantage system, the 4,400+ qubits Advantage2 processor delivers significant improvements in:

- **Qubit coherence time:** doubled, which drives faster time to solution
- **Energy scale:** increased by 40% to deliver higher-quality solutions
- **Qubit connectivity:** increased from 15 to 20-way connectivity to enable solutions to larger problems

QC Company

Rigetti

Rigetti

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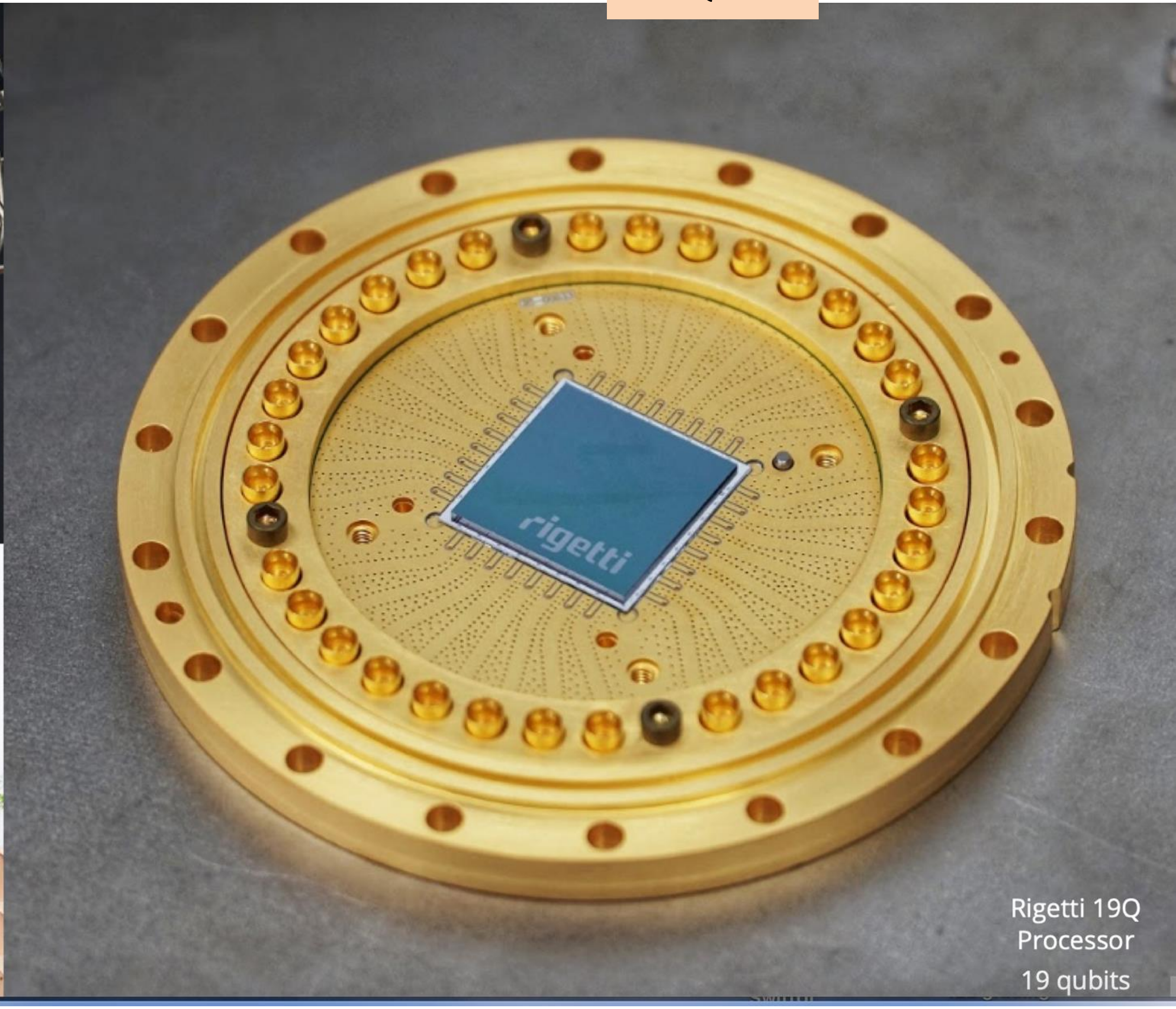
The Rigetti 16Q Aspen-4:

QC's

19 Qubits

Rigetti Computing



Rigetti 19Q Processor
19 qubits

Rigetti

12-23-24

Rigetti Computing Launches 84-Qubit Ankaa™-3 System; Achieves 99.5% Median Two-Qubit Gate Fidelity Milestone

Ankaa-3 features a broad hardware redesign enabling superior performance. Enhancements across the technology stack include a new cryogenic hardware design, an overhaul of the qubit circuit layout, precise qubit frequency targeting with Alternating-Bias Assisted Annealing, and flexible gate architecture with precise controls. Ankaa-3 has achieved a 99.5% median two-qubit gate fidelity.

BERKELEY, Calif., Dec. 23, 2024 (GLOBE NEWSWIRE) -- Rigetti Computing, Inc. (Nasdaq: RGTI) ("Rigetti" or the "Company"), a pioneer in full-stack quantum-classical computing, announced today the public launch of its 84-qubit Ankaa-3 system. Ankaa-3 is Rigetti's newest flagship quantum computer featuring an extensive hardware redesign that enables superior performance. Rigetti also celebrates major two-qubit gate fidelity milestones with Ankaa-3: successfully halving error rates in 2024 to achieve a median 99.0% iSWAP gate fidelity, as well as demonstrating 99.5% median fidelity fSim gates.

All new cryogenic hardware design - F

Improved qubit chip -

Josephson junction fabrication with Alternating-Bias Assisted Annealing (ABAA) -

QC Company

Apple

Apple QC

And Apple in February said it was introducing PQ3, a "post-quantum" cryptographic protocol with the ability to restore the cryptographic security of a conversation even if a given key becomes compromised.