In classic computing, uncertainty is unacceptable. With quantum computers, however, it’s an asset. Quantum computers have an innate ability to learn about the world, dealing in probability, as they explore multiple answers to come up with complex decisions.

**What is quantum computing?**

Quantum computers shine when solving involves number or data crunching with huge amounts of inputs. They are designed to tackle complex problems that would take supercomputers from days to being unable to solve. Quantum computers can simulate the universe’s subatomic particles by speaking the same language as an electron or proton. We’re at the beginning of the quantum computing paradigm that is expected to have a major impact on our grasp of chemistry, biology, and physics.

While interestingly, they are not universally faster than classical computers, they do perform specific types of calculations faster. Each operation may not be faster, however the number of operations necessary to arrive at a result using particular algorithms is exponentially small.

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*Editor's Note: This article is part of an AspenCore Network Special Project on quantum computing that aims to provide you with a starting point for assessing this emerging technology and its potential impact on your business. Other articles cover [what's next](#), [powering the quantum computer](#), and [supercomputers](#). Click the logo to see a list of other Special Projects that we’ve done thus far.*

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**How it works—The basics**

We’re all used to binary computers based on processors using transistors to perform calculations. On, off, one, zero…pretty predictable. The game changes completely however, with quantum computers. In this realm, the processing and storage of 1’s and 0’s of classical systems give way to qubits or quantum bits as the fundamental building block of quantum information, experienced as a two-state quantum-mechanical system. The power of these qubits is their inherent ability to scale exponentially so that a two-qubit machine allows for four calculations simultaneously, a three-qubit machine allows for eight calculations, and a four-qubit machine performs 16 simultaneous calculations.

The basic properties of quantum computing are superposition, entanglement, and interference.
Superposition is the ability of a quantum system to be in multiple states simultaneously. The go-to example of superposition is the flip of a coin, which consistently lands as heads or tails—a very binary concept. However, when that coin is in mid-air, it is both heads and tails and until it lands, heads and tails simultaneously. Before measurement, the electron exists in quantum superposition.

Entanglement as a quantum property is taking objects and connecting them by permanently entangling them together. When adding an additional qubit to a quantum computer, a 50-cubit quantum machine can examine two to the power of 50 states simultaneously. The increase in power plus the entanglement of qubits allows quantum computers to solve problems efficiently, finding a solution faster, with many fewer calculations.

Interference can be used to control quantum states and amplify the signals that are leading toward the right answer, while canceling signals that are leading to the wrong answer.

Coherence/decoherence: Quantum computers are extremely sensitive to noise and environmental effects. Unfortunately, information only remains quantum for so long. The number of operations that can be performed before the information is lost, therefore, is limited. Knowing in advance how long quantum information will last before it is out of coherence is critical.

Quantum chips must be kept colder than outer space to create superpositions and entanglement of qubits and retention as long as possible. Communication with qubits that are inside a dilution refrigerator is accomplished by using calibrated microwave pulses so that the qubit is put into a superposition, or the qubit’s state is flipped from 0 to 1 by applying a microwave pulse between two qubits. Microwave signals are also responsible for entanglement. In order to find a solution, parts of a problem are encoded into a complex quantum state and that state is manipulated, driving it closer to a solution—but it will take multiple operations to get to the best solution.

When quantum computers provide an answer, it is in the form of a probability. When the question is repeated, the answer changes. The more times the question is repeated, the closer the response comes to theoretical percentage or correct answer. This requires that the code be designed so that the qubits are in the correct state for a given problem. Quantum code uses wave-like properties that cancel out wrong answers and amplify the correct ones.

Applications

As the technology develops, quantum computing could lead to significant advances in numerous fields, from chemistry and materials science to nuclear physics and machine learning. Top applications include:

- Machine learning
- Super-catalyst design
- Medicine
- Chemistry
- Climate change/Earth science
- Battery chemistry
- Material science
- Engineering
- Artificial intelligence
- Information security
- Biomimetics
- Energy
- Photovoltaics
Financial services
Supply chain and logistics

Figure 1 The three known types of quantum computing and their applications, generality and computational power. Source: Carl Torres for IBM Research

Get your hands on it

So, how do you start out with quantum computing? According to Dr. Marco Pistoia, IBM’s distinguished research staff member, and senior manager, Quantum Computing Software, IBM Research, “Engineers should first familiarize themselves on the fundamentals of quantum computing, such as the concepts of superposition and entanglement.”

Online courses, including several that are free, are beginning to spring up, via the cloud. Whether you need to harness the technology for the future of your career, or you’re just curious about its capabilities, you can get involved and try the technology out. Although this is really early into the development of the technology, access to quantum computers is available globally. Here are a few to get started on.

IBM

“To make quantum computing more accessible to scientists, engineers, and even students, IBM launched the public, cloud-based IBM Q Experience, and the open source Qiskit platform, through which it is possible to access real quantum hardware. Quantum programs can be written in Python,” says Dr. Pistoia. “To date, more than 145,000 users have run more than 10 million experiments on IBM Q Experience systems and have published more than 170 related research papers. This broad, global interaction is crucial in the current so-called noisy intermediate-scale quantum (NISQ) era, where practitioners can already execute experiments on quantum computers and learn the quantum computing programming model.” Don’t be concerned about being a beginner; there are multiple user guides available, including one for beginners.
D-Wave

D-Wave Systems Inc. works on an annealer architecture rather than universal superconducting technology. D-Wave’s Leap allows anyone to sign up and access one minute of free time on a cloud-connected 2000Q each month. Since quantum computing solves problems in milliseconds, including factoring large numbers, optimizing routes, or calculating molecular structures, a minute is a generous amount of time.

Rigetti Computing

Rigetti’s Forest SDK is a lightweight, downloadable SDK that incorporates a powerful QVM and runs on your local machine. It’s a great way to get started with quantum programming and enables users to create quantum entanglement in less than 10 lines of code. Get started and access a variety of resources here.

Where are we today?

Where are we today?

Headlines consistently confirm rapid advances in the field of quantum computing. There are quantum critics in the wings and quantum supporters jumping on the bandwagon and naturally, venture capitalists have their checkbooks out even though quantum computing has yet to perform anything that could not have been done on classic computers.

Companies involved represent the who’s who in technology. IBM, Google, Intel, Microsoft, D-Wave Systems, and Rigetti Computing represent only a handful. The industry is wide open for startups as well.

D-Wave Systems Inc. offers a unique quantum annealing approach for applications requiring decision making based on high levels of reasoning. Their solution returns the lowest possible energy solutions by focusing on optimization. D-Wave recently announced their least “noisy” entry, the Pegasus, and also offers the real-time online quantum computing environment Leap. Leap is the latest addition to D-Wave Quantum Cloud Services that virtualize quantum computing for almost anyone with a computer and a broadband connection to use.

Although Intel was not an early player, it is making strides in the segment. Two recent contributions include Tangle Lake, and a full silicon wafer of test chips, each containing up to 26-qubits that rely on the spins of individual electrons being tested at Delft University of Technology, in The Netherlands.
Earlier this year, IBM announced the industry’s first commercial system, the Q System One only available to IBM Q Network organizations. The IBM Q introduces programmable universal quantum computing through the cloud-based IBM Q Experience and the commercial IBM Q Network platform for business and science applications. The company claims its Q System One is a step forward for both stability and commercial research. It is also partnering with Exxon Mobil on a network that could be used for predictive climate models and electric grid management.

On the heels of Google’s 72 qubit Bristlecone quantum processor available in the cloud and Cirq, an open-source framework for running algorithms on the quantum computers, Google also released OpenFermion, a platform for developing quantum algorithms for chemistry problems, and OpenFermion-Cirq, an open-source library which compiles quantum simulation algorithms to Cirq. Google claims that Bristlecone will soon achieve quantum supremacy, when a quantum device performs a task a classical supercomputer cannot complete in a reasonable amount of time.
Rigetti Computing’s new Quantum Cloud Service (QCS) includes Forest, a software toolkit for quantum programming in the cloud. Rigetti also unveiled what it claims is the world’s most powerful quantum processor, a 128-qubit model that tops Google’s 72-qubit Bristlecone chip. To start, QCS users will be limited to a 16-qubit chip and the service will also be limited to certain customers and partners of Rigetti, becoming widely available later in 2019. The processor enables quantum algorithms to run 20 to 50× faster on its QCS than on its current cloud setup, speeding up soon after. Rigetti also says that it found a sweet spot where qubits are less sensitive to noise, operating a two-qubit gates with fidelities to 99.2%.

Beyond supremacy

While excitement is justifiably high for the promise of quantum computers some say that a truly-relevant machine is likely decades away. Progress, however, is rapid, it may happen much faster. Moore’s Law doesn’t apply to quantum computing. Instead, quantum computers adhere to the laws of quantum physics, far from the realm of Moore, that might give us a hint to speed of development. According to a recent article in Quanta Magazine by Kevin Hartnett, Hartmut Neven, director of the Quantum Artificial Intelligence lab at Google, first coined Neven’s Law by saying whereby quantum computers are gaining computational power relative to classical ones at a “doubly exponential” rate — staggeringly fast. Neven claims that for a while it looks like nothing is happening and then suddenly you’ve entered a different world.
From understanding the Big Bang, to providing number crunching across a wide-range of industries, quantum computing will continue to evolve at breakneck speeds. The time to access it and learn as it develops is now.

—Carolyn Mathas is a freelance technology writer/editor for a number of electronics publications and corporations.

Check out all the stories in this quantum computing Special Project:

**Power supply management in quantum computers**

“The road to efficiently powering a quantum computer will require a quantum leap in power management technology.”

**What's Next in Quantum Computing?**

Quantum computing is on a steady upward trajectory, but the field is in flux with new technologies starting to come online.

**Will we need a ‘supercomputer’ on our desk?**

Cloud computing and big data analysis will require the development of ever more performant computing systems. We can imagine what these high-performance computers might look like as early as 2035.

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