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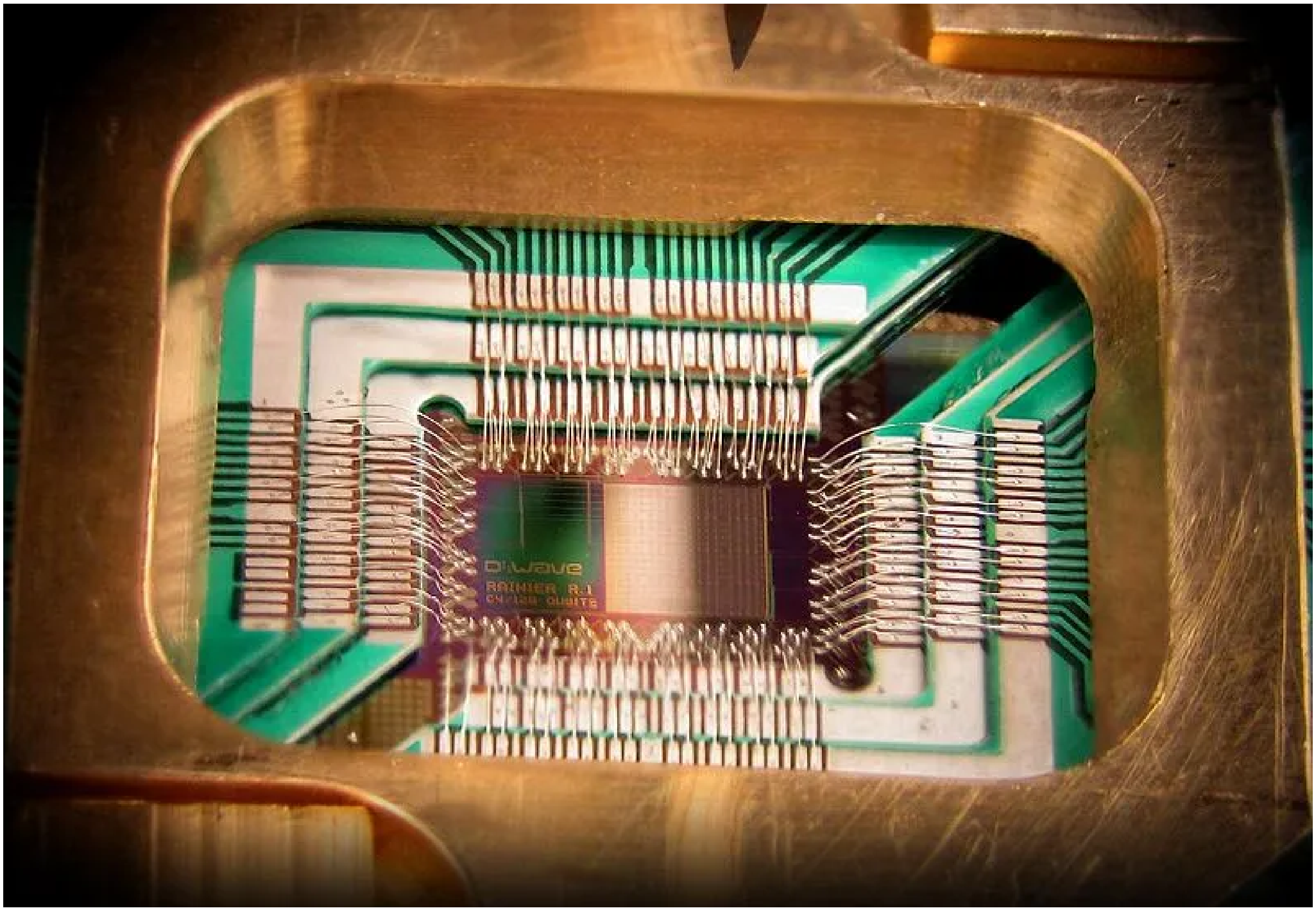


A DIY Guide to Building a Quantum Computer

April 8, 2019 / Jeronimo Martinez

Imagine a computer that doesn't use electrical devices to process information but instead uses individual atoms. These computers, called quantum computers, have the potential to solve all kinds of complex problems, from cancer to street traffic, which regular computers struggle to do. While these computers are still in development, and have been for a couple of decades, the first rudimentary versions have recently started to take form.

Quantum computers take advantage of strange properties from quantum mechanics to filter through possible solutions much more quickly than conventional computers. When someone asks about the many ways a drug can impact a cancer cell, for instance, or how to best control stop lights and direct cars to reduce traffic, there are many factors that need to be taken into account that traditional computers take a long time to sort through. For example, making a stoplight 30 seconds longer seems like a simple solution to reduce traffic on one road. But this small change means you' increased traffic for cars trying to cross which can create even more traffic overall! These com problems have so many potential solutions to check through that a traditional computer can take years to find the optimal solution. A quantum computer, on the other hand, has a unique way of sorting through possible solutions and can have an answer in a matter of minutes!

Here is how to build one.

Quantum Computer DIY

The first step in building a quantum computer is figuring out how traditional computers work. At the heart of your laptop or phone are billions of tiny electrical devices called *transistors*. Transistors are used by computers to map information into the binary language of "1"s and "0's." These 1's and 0's are called "bits" and, like letters in a spoken language, they are the basic building blocks of information that a computer uses to load your apps, download your texts, stream videos, etc. By creating a dictionary that maps any unit of data on your computer- any number, letter, symbol- as a unique combination of bits (the number 29 can be represented by "11101," for example), and by following rules on how to interpret these bits, your computer can do a lot of very powerful things.

To make a quantum computer, we want to keep the language of 1's and 0's, but rather than use transistors, we use elements based on quantum mechanics- the field of physics that looks at the behavior of very small objects like atoms or the smaller particles that compose them. At this scale, particles and atoms don't behave anything like what we experience in our daily lives. By harnessing these strange behaviors, we can make computers do things we never thought were possible. Here's your step-by-step guide on how to build your very own quantum computer:

First, you need to find a property of atoms that has two discrete states that can be translated into "0" and "1." For example, atoms have different energy values based on the position of their electrons, and two of these values can be your 0 and 1, respectively. Or, you can use the fields within electric circuits, or the "spin" states of electrons.

Your next task is to limit noise. Noise is anything that bothers your quantum bits ("qubits") and randomly changes their state from 0 to 1 and vice versa, making the data indecipherable. Since atoms are incredibly tiny, any extra energy or movements will keep you from reliably controlling the state of your qubit.

One way to reduce noise is to make the quantum system cold. Very cold. As close as possible to the coldest temperature that can be physically reached. Since heat is a form of energy, heat can give your qubit unwanted energy that can erratically change the state of your qubit. Because of this, yo[illegible]d to make measurements at less than a fraction of a degree above absolute zero (-460 ºF).

Next, you will have to limit other types of energy that create noise, such as external magnetic or electric fields, or vibrations from passing cars or from you accidentally touching the computer. (Finding clever ways of reducing noise is an ongoing problem and is a big barrier for scientists developing these computers.)

Here is an example of what a quantum computer looks like. This image shows all of the shielding necessary to reach near-absolute zero temperatures and limit other sources of noise. Photo from IBM.

Once you have the physical computer working, you need to develop a way to talk to your qubits. Since you want to take advantage of the quantum mechanics, you need entirely unique computer programs that take the quantum properties into account. While some general quantum algorithms have already been made, you need to find a way to control your unique qubits to mimic the algorithms.

If you managed to reliably complete all of these steps, congratulations on making your own quantum computer!

Where Does the Language of Quantum Computers Come From?

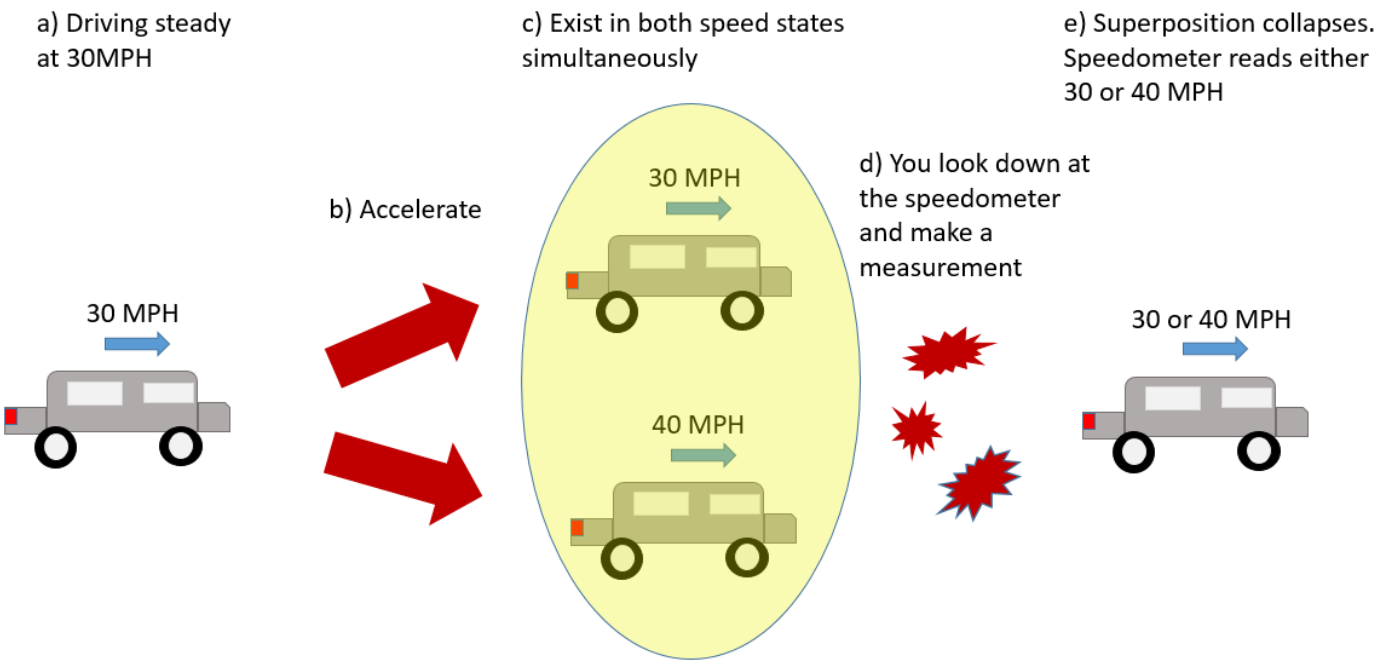
At this point, you might still be wondering why these computers are so fast. If you're going to go through the trouble of building a quantum computer, you better know how they work: It all relies on those odd quantum behaviors I mentioned earlier that form atomic "states."

Consider, for a moment, driving a car at 30 MPH and accelerating to 40. Naturally, you first go 31 MPH, 32, 33, and so forth until reaching 40 MPH. If your car behaved like an atom, it might only be able to go either 30 or 40 MPH and nothing in between. In quantum mechanics, these possible values are what we call "states." Naturally, you might be asking yourself, "how can you go from one state to the other without going through the values in between?"

This is where things get weird. When you accelerate your quantum car, rather than going 31 or 32 MPH, you are actually going both 30 and 40 MPH simultaneously! We would say that the car is in a *superposition* of two states. But when you decide to look down at your speedometer to check your speed, the superposition collapses, and your car will "choose" one of the

This is what is underne shielding. The quantum systems are two states. Superposition is part of what allows quantum computers to be so fast. Rather than looking at solutions one by one, the computer can be in a superposition of solutions and exist in all possible solutions simultaneously.

in a small section by the bottom that the wires connect to.



This works alongside the property of *entanglement*. Entanglement means that if you have many quantum cars on the road, the speed of one of them will affect the speed of the others. If two cars are entangled, then if you look at the speedometer of one car and see that it is going 30 MPH, the other will automatically be going 40 MPH, and vice versa.

Entanglement allows all of the individual atoms in the quantum computer to talk to each other so that they can represent all possible solutions.

Putting it All Together

At face value, it looks like you just built an unnecessarily complicated, expensive, and fragile computer that uses the same 1's-and-0's of a classical computer. What specifically is it about quantum mechanics that makes these computers so innovative?

It's impossible to directly attribute the speed of quantum computers to single characteristics of quantum mechanics. However, superposition and entanglement seem to be key features that, when incorporated into programs, have been shown to be much faster than classical computers.

Beyond their very fast processing speed, they are optimal for simulating nature at its most fundamental levels. How a drug will interact with a tumor, for instance, involves quantum mechanical interactions. In order to properly simulate them, we need to use quantum mechanics, which is exactly what a quantum computer can do best.

Unfortunately, as great as these computers seem, engineers and physicists still have many years or even decades of research and innovation ahead of them until these computers are ready to tackle the problems they are set to solve. Today, the technology is still in its early stages. IBM, for example, recently released a computer with 20 qubits (much less impressive than the billions of bits on your phone).

Although there are general ideas of what these computers can be used for, we are just starting to scratch the surface. If you're interested in learning more about quantum computers but the task of building one seems daunting… don't worry. Right now, you can connect to IBM's computer or Rigetti's quantum computer remotely and help discover what new questions quantum computers could solve!

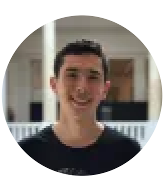
Further Reading:

If you want to read more about quantum mechanics and are interested in its applications for communication, read this blog posted just a few weeks ago by a fellow student of mine!

Author

Jeronimo Martinez is an undergraduate student studying physics at the University of Chicago. He works at a research lab on campus under David Schuster focusing on fabricating superconducting qubits. In his free time, he enjoys rock climbing and, if the weather is warm enough, slacklining or skateboarding. You can contact him at jemartinez@uchicago.edu or find him on LinkedIn.

Jeronimo's article is part of a collaboration between the Illinois Science Council and the University of Chicago.



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