A Computer Instructor Explains Quantum Computing

By Frank Rotering
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As someone who taught computer courses for over 30 years, I understand the core principle of classical computing. Electronic representations of bits - zeroes and ones - are manipulated by logic gates to implement a set of instructions called a program. Classical computers are fast because electronic signals and their manipulations are fast. I had expected that, given this understanding, I would have no trouble grasping the core principle of quantum computing and its superior speed in certain applications. Until recently, however, my investigations left me confused and frustrated.

Why? Because the explanations offered by the experts are muddled, misleading, and incomplete. An example is this video by IBM, which informs us that quantum bits, or qubits, are similar to classical bits, but they can represent a zero, a one, or both at the same time. The video then claims that, because of this capability, qubits can act as highly sophisticated logic gates and solve difficult problems. One viewer summarized my reaction by commenting that, "This is the third non-explanation I've seen from IBM people. How does a qubit's ability to be a 1 and a 0 simultaneously help it to solve anything?"

The IBM video is a lazy repetition of the standard story about quantum computing in that it uses the same three-step approach employed by almost all experts: cite the quantum concepts of superposition and entanglement, vaguely describe qubits using a sphere and some arrows, and then rave about the awesome computational potential of this combination. This is meaningless arm-waving, and it is insulting to the many people who want a basic understanding of the computer revolution that is now unfolding. Let me put on my (retired) instructor hat and see if I can do better.

We're trying to understand how quantum computing differs from classical computing, so let's start with computing. What is it? The term refers to the processing of human inputs to produce useful outputs. Someone might input the number 625, run a program that extracts square roots, and get the useful output 25. Another might input financial figures, run a banking program, and get useful account updates. Computing can thus be represented by the following sequence:

HUMAN INPUTS → **PROCESSING** → USEFUL OUTPUTS

All computing begins with human inputs and ends with useful outputs, but processing can vary in a fundamental way. Programs to extract square roots and update accounts are written by human programmers to apply human logic. However, it is also possible to present human inputs to the natural world, have nature's logic do the processing, and then extract useful outputs when it's done. Slime molds are a well-known example. These organisms can accept human inputs in the form of dispersed food sources, apply their survival logic, and produce highly optimized routes between them. See this brief video.

What this implies is that computing is - or should be - divided into two categories: classical computing, which applies human logic, and *natural computing*, which applies nature's logic. Classical computing can thus be represented by this sequence:

HUMAN INPUTS → **HUMAN LOGIC** → USEFUL OUTPUTS

And natural computing by this one:

HUMAN INPUTS → **NATURE'S LOGIC** → USEFUL OUTPUTS

The next step is to recognize that nature comprises both living and non-living entities. If natural computing is performed by a living organism, the logic derives from its efforts to efficiently find sustenance, communicate, reproduce, etc. If a non-living entity is used instead, the logic derives from the inherent properties of the physical world.

Given this classification, *quantum computing is a mode of natural computing that uses non-living entities to implement nature's logic*. This is the understanding that most of us need, and that the experts consistently fail to provide.

Of course, much more knowledge is required to understand quantum computing in depth and detail. This is where PhD-level expertise comes in, but given the experts' abysmal performance in explaining the basics, let me present what I've gleaned from various sources.

The crucial point is that a qubit - a subatomic particle such as an electron or photon - is NOT analogous to a classical bit. The latter is a logical unit of *information*, whereas a qubit is a physical unit of *processing* - like a slime mold finding the best route to yummies. What appears to happen in a quantum computer is that a number of associated ("entangled") qubits receive human input through a carefully calculated disturbance. The qubits then interact and modify their combined state, which is captured as the output. With some advanced mathematics, the relationship between this subatomic input and output can provide useful knowledge in the human realm.

This knowledge is of two kinds. The first is about quantum reality itself: how do subatomic particles behave when we prod and poke them? This was Richard Feynman's aim in proposing the principles of quantum computing in 1981. His classical computer was far too slow to simulate this reality, so he adopted a new idea: use the quantum world to simulate the quantum world.

The second kind of knowledge derives from the information processing outlined above. When a human problem can be represented by qubit state changes, a cleverly constructed algorithm can exploit this similarity. Just as a slime mold can optimize the routes between food sources, a set of entangled qubits can - indirectly, with the algorithm's help - factor huge numbers and break encryptions. Such processing is extraordinarily fast because qubit state changes are extraordinarily fast.

If the above works as a rudimentary explanation of quantum computing, I have three suggestions for any brainiacs who may attempt more sophisticated versions in the future.

First, get the categorization right. It's not classical computing vs. quantum computing, but rather classical computing vs. *natural computing*. Quantum computing is in the latter category under the non-living sub-category.

Second, never start with quantum mechanics. This theory is a pragmatic success because it mathematically describes physical reality with remarkable precision. Conceptually, however, it is an embarrassing failure because no-one truly understands what the math represents. Any explanation that begins with a mystery will inevitably be mysterious.

Third, and speaking of math: forget that stuff. Quantum math is incomprehensible to all but the deeply initiated, and it allows the experts to mystify us by substituting arcane symbols for meaningful explanations. And we really don't need any more of that.

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