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What is the difference between classical computing and quantum computing?

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In the realm of quantum computing, the fundamental unit of information is not the classical bit that we are accustomed to in traditional computing, but rather its quantum counterpart—the qubit. The classical bit (short for binary digit) is comfortably simple to understand – as its name suggests, it only takes on binary values, 0 or 1, corresponding to electric signals being either off (binary state 0) or on (binary state 1) in our computers today. And yet, this diminutive bit is wonderfully powerful, enabling universal computing. From emails to rocket launch calculations, every computation we perform today can be represented using binary logic – a sequence of instructions to manipulate and combine bits in different ways. Our current computers are nothing more than switchboards for turnings on and off trillions of electrical signals to create the right combinations of bits for the task at hand.

So if bits are so powerful, why bother with qubits? The answer lies in thinking about computational speed and performance. While bits can do it all in principle, some computations are so complex that even supercomputers are not fast enough to solve them in a reasonable amount of time. For example, suppose you wanted to simulate a chemistry experiment on a computer instead of in the lab, in order to better understand protein folding, or create better medications. Accurately simulating every property of every electron in every atom of every molecule in your experiment is a computationally complex problem and quickly becomes intractable for any experiment with more than a few hundred atoms. As the experiment grows bigger, and involves larger molecules, more and more bits are required, leading to an exponential increase in the time and resources needed to solve the problem.

So merely building bigger computers with more bits will just not do the trick – you would still have to wait longer than the age of the universe to get to an answer.

Enter quantum computers, driven not by bits but by quantum bits (qubits), and not limited to deterministic binary logic, but using a broader probabilistic computing framework called quantum logic (or quantum information processing). One way to visualize this change is to think about the difference between horse-drawn carriages and cars as modes of transportation. Both were designed to solve the same problem of getting from point A to B, but they can take different times and different paths to reach their goal. Most importantly, they are very different technologies based on different scientific ideas. You cannot build a car by merely improving the speed of horse-drawn carriages. A car harnesses a different set of laws based on a deeper understanding of physics, thereby unlocking speed and power inaccessible to even the best horses and carts. The same is true for quantum computers compared to current classical computers. A quantum computer is a fundamentally different technology that operates using a completely new framework of computing based on the laws of quantum mechanics.

Like a car compared to a horse-and-cart, quantum computers can leave classical computers in the dust for certain tasks. From simulating large molecules to optimizing supply chain logistics, the potential of quantum computing is just beginning to be unlocked.