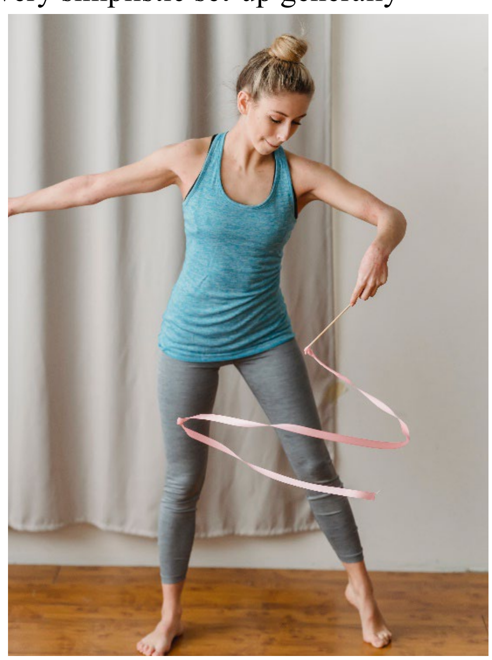
The Quantum Leap
July 24, 2023

The Quantum Leap's Beginner Guide to "Superposition"

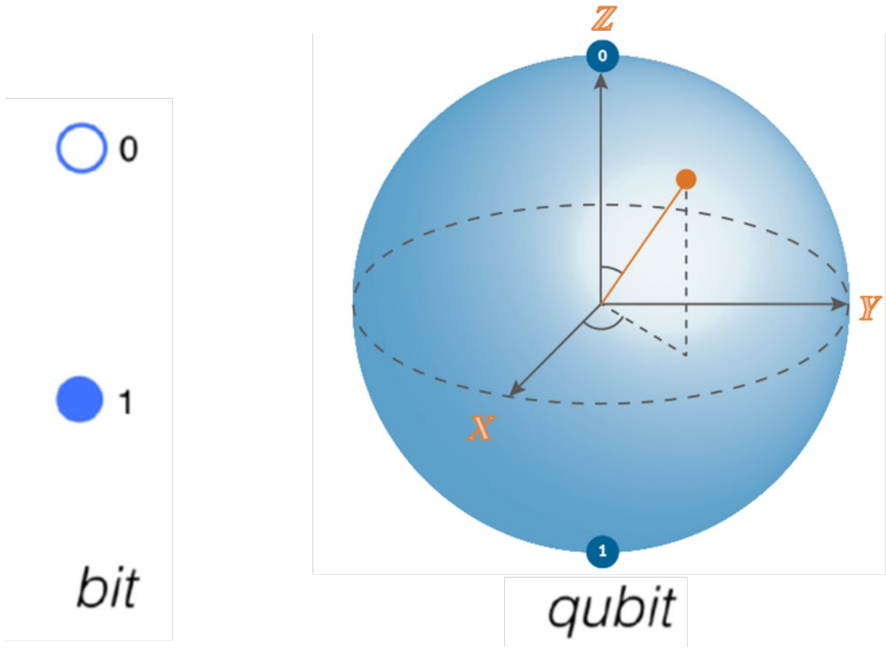
Welcome to the next installment of the "Quantum Leap Beginner Guides", aimed at audiences without physics training and using only the most basic math (and even then, only when necessary). Early on in learning about 'quantum' or 'quantum computing', the concept of **Superposition** will invariably be mentioned. If you have already been introduced to this concept but are still unclear, please try to forget everything you've heard about it to now. If this is a new term/concept for you, I hope this post gives you a foundational understanding and appreciation for why it is fundamental to quantum.

If you search for "superposition" on the Internet, nearly every resource you look at will use Schrodinger's half-dead, half-alive cat to explain it. I find it incredibly baffling why writers feel like this explains anything (fun fact, Schrodinger did NOT propose this thought experiment to explain quantum, rather he posed it to demonstrate the absurdity of quantum science at the time). We all know that animals cannot be both alive and dead, so…**please forget about Schrodinger and his unfortunate cat** as you continue to read this post.

If you'll recall from the prior post in this series, quantum objects have both "wave" and "particle" features which has been proven and shown via a very simplistic set-up generally known as the "double slit experiment" (you can review that post here). The wave aspect of quantum particles can help provide an intuitive appreciation of superposition. Imagine for a minute that you are watching someone wave a streamer and imagine drawing a bold star on the ribbon with a Sharpie. If you try to describe the star's exact position while someone is waving the streamer, you'll find it difficult since it will be undulating. At any specific point in time the star will be at the top end of the ribbon's wave or the bottom end or anywhere in between. So, at any given moment that star is in a superposition of all of its possible locations. If you took a photo (with a sufficiently fast shutter speed), that star would be in one specific point, although that location would be different if you took a series of photos. So, the act of "measuring" the star's location is what determines its finite position (this is often referred to as the Observer Effect).



Now let's make a small leap from a ribbon, which you can readily observe, to a quantum object such as a photon which we will use as a qubit (see the Quantum Leap's Beginner Guide to Qubits here for a refresher). As you may recall, qubits are 3-dimensional objects as highlighted in the figure on the right in the graphic below [please make note of this “extra dimension” that qubits use versus their classical computing “bits”, it will be stressed in many future posts].



Quantum bits (qubits) are quantum’s most fundament processing unit, but there are important differences between qubits and bits including a qubit’s ability to hold information in a “superposition.” For our photon that is acting as a qubit, if “0” is the north pole and “1” is the south pole, you can rotate the qubit to point in any direction. You’ll note that for the qubit above, the orange dot is located between 0 and 1. In fact you can make that orange dot land on any point over the surface of the globe. In this case it is neither 0 nor 1 but somewhere in between. Said another way, it is partly pointing towards the north pole and partly towards the south pole.

Qubits are somewhat fickle characters. If you are not observing them, they will merrily continue to remain in a superposition[1]. But once they are observed or measured, they “pop” into either pointing north or pointing south. In other words, the position of the orange dot “collapses” to either 0 or 1 at the instant it is measured. If you begin with a qubit closer to the north pole, it is more likely it will collapse to that pole (and be measured as 0), but every now and then it will collapse to the south pole. Quantum systems are set up and measured many, many times (for quantum computing, each time the program is run is known as a “shot” and quantum computing algorithms typically involve thousands of shots, with each shot averaged to find a final solution). Averaging something that runs many times is another way of saying that the results are probabilistic.

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[1] Some more advanced readers may be familiar with decoherence, which refers to the collapse of a quantum state caused by environmental forces. The concept described here ignores effects of decoherence to focus just on the Observer Effect.

OK, so back to the basics. Quantum objects, utilizing their wave properties, generally exist in a mixture of states which can't be definitively identified until a measurement is taken. Clever quantum computer programmers can set up the qubits to point to various locations along the "globe" giving higher weighting (or probability) to 0 or 1 depending on the nature of the program. In layman's terms this is like **assigning a weighted average to differing variables**.

Said another way, we are now able to exquisitely control quantum objects such as atoms, photons and electrons. Objects at that size scale behave differently than objects we hold in our hands, and superposition is one of the quantum mechanical properties of these tiny objects. **Superposition describes a quantum system's ability to be in multiple states at the same time until it is measured.** We can use superposition to impart additional information and features on qubits, which enables quantum computers to do things that classical computers cannot. The prior post explained Wave-Particle Duality, this one covered Superposition and the next post will cover Entanglement. These series of posts hopefully lay the foundation and give readers an appreciation for why quantum computers can be so powerful. Stay tuned to the Quantum Leap to learn more.

References:

Streamer photo courtesy of Marta Wave via Pexels.com

Metwalli, Sara A., "What is Superposition?" www.builtin.com, accessed July 10, 2023.

"What is Superposition and Why is it Important," www.caltech.com, accessed July 22, 2023.

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