Quantinuum | Glossary

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Quantum Computing Explained: Terms to Know

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Not long ago, discussions about quantum computing occurred primarily in technical journals or at scientific conferences.

Today, mainstream media outlets and business publications are covering quantum topics and speculating about "quantum advantage" — the point at which quantum computers can perform calculations that today's computers cannot.

Quantum computing will transform industries. Quantinuum already is collaborating with JPMorgan Chase, Merck, DHL, BMW, Samsung, and other global organizations to do just that.

Here are definitions to help explain quantum computing and Honeywell's trapped-ion technology:

Bit flips and phase flips

In classical computing, bit flip errors occur when a binary digit or bit inadvertently switches from a zero to one or vice versa. Quantum computers experience this error as well as phase flips. Both errors cause qubits to lose their quantum state – or decoherence. Classical computers get around this by cloning data to correct errors. However, this method does not work in quantum computing.

Break-even

As noted above, creating logical qubits, and applying quantum error correction codes can add errors into a quantum system. The breakeven is the point at which the error rate that occurs after logical qubits are created and quantum error correction cycles are applied is lower than the error rate that exists before they are.

Codes

Once a logical qubit is formed, researchers apply codes to detect and correct errors, which reduces noise. This is not the same as writing software code. These are mathematical protocols or processes that help protect quantum information. Some of the more popular quantum error correction codes are the color code and surface code.

Coherence

In quantum computing, coherence refers to qubits being entangled in the quantum state necessary to complete a calculation. Maintaining this quantum state longer is essential for running more complex calculations.

Entanglement

Generally, it is impossible to be in two places at once – except in quantum physics. Thanks to a phenomenon called entanglement, quantum particles can link across large distances and share a quantum state. Changing the state of one quantum particle automatically changes the state of the other. Quantum computers utilize this phenomenon by entangling qubits and then encoding them with information to run calculations while they share a quantum state.

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Fault-tolerant computing

Fault tolerance is a design principle that prevents errors from cascading throughout a system and corrupting circuits. Today's supercomputers are fault-tolerant and quantum computers must be as well to handle complex calculations.

Fidelity

Computers perform calculations by manipulating the states of bits — changing the bits from 0s to 1s and 1s to 0s, like flipping a switch. Quantum computers must similarly be able to manipulate qubits from 0s to 1s, and so on. The accuracy of the calculation depends on our ability to perform these "bit-flips" with very high success rate, or "fidelity." Fidelity is the measure of how often an attempted flip results in the correct qubit state. The higher the fidelity the better. Our individual qubit operation fidelities of 99997 percent, currently the best reported performance of any addressable qubit technology.

Logical qubit

To get around these issues, researchers create "logical" qubits. A logical qubit is a collection of entangled physical qubits on which quantum information is distributed, stored, and protected. Logical qubits are structured in such a way that researchers can detect errors on outlying physical qubits known as ancillas without disrupting the qubits encoded with information and that are running calculations.

Magic state

The process of quantum error correction is essential to initializing and creating what is known in quantum computing as a magic state. Magic states are what enable quantum computers to do things or run the complex calculations that classical computers can't. It's like the secret sauce or special ingredient in a recipe except that it's hard to define. We can't see it. We just know it's there and that it is essential to quantum computing. Yes, it's abstract. But what is important is that applying quantum error correction and reducing noise are necessary for creating magic states.

Mid-circuit measurement

With this feature, qubits can be selectively measured at a point other than the end of a quantum circuit. The quantum information of a measured qubit collapses to a classical state (zero or one), but the non-measured qubits retain their quantum state. Based on the measured qubit, users can decide what actions to take further in the circuit, enabling much more dynamic and flexible quantum computer programming than would otherwise be possible. We were the first to incorporate this type of measurement into our commercial offerings.

NISQ

Articles about quantum computing sometimes reference this current phase of quantum computing as the "NISQ era." Pronounced "nis-k," this acronym stands for Noisy Intermediate-Scale Quantum Computing. It refers to near-term quantum computers on which full quantum error correction cycles have not been applied. All commercial quantum computers operating today are considered NISQ-era machines.

Noise

Quantum bits or qubits are the smallest unit of data in quantum computers. Qubits are delicate and fragile and tend to interact with their environment and one another, which creates "noise" or interference. This noise causes errors to accumulate, corrupts information stored in and between physical qubits, and disrupts the quantum state in which qubits must exist to run calculations. This phenomenon is called decoherence.

Post-processing

There are different methods of removing "noise" from quantum data. One is called post processing where results from a quantum calculation are compared against data from classical computers so "noise" can be identified and removed after a computation is completed. This is a useful technique during this early stage of quantum computing to verify and validate calculations. But this will not be feasible as quantum computers scale and begin tackling calculations too complex for classical computers.

Quantum error correction cycle

Quantum researchers have developed a multi-step process known as a quantum error correction cycle to detect and correct errors and eliminate noise as calculations are running. The QEC cycle starts with 1) measuring what are known as syndromes to pinpoint errors; 2) sending these error measurements to a decoder that identifies a mathematical correction; 3) updating these syndromes and implementing corrections. Applying full cycles of quantum error correction is tricky. This process can inject noise into the system and applying this directly to physical qubits causes them to lose their quantum state.

Quantum volume

Remember the old saying "you can't judge a book by its cover?" The same is true in quantum computing. You can't judge a quantum computer solely on the number of qubits it has. Other factors such as number of operations, fidelity, and qubit connectivity also affect performance. The Quantum Volume (QV) benchmark was developed to measure performance in a comparable way across all quantum computing technologies. QV is measured through a series of carefully designed tests. The higher the quantum volume the more powerful the system. Our 10-qubit System Model H1 achieved a record quantum volume of 512 in March 2021.

Qubit

In classical computing, the smallest unit of data is a binary digit or bit. A bit is a stream of electrical pulses that each exist in either a "0"- off – or "1" -on- position. A quantum bit or qubit is the smallest unit of data in quantum computing. Qubits can exist as 0s and 1s simultaneously, a phenomenon called superposition, or anything in between. This ability to be in multiple positions at once is one of the reasons quantum computing is potentially so powerful.

Trapped-ion technology

At Honeywell Quantum Solutions, we develop trapped-ion quantum technologies. Our systems "trap" charged ytterbium atoms (ions) with electromagnetic fields so they can be manipulated and encoded with information using microwave signals and lasers. Our latest technology, the System Model H1, offers some distinct advantages, including high fidelities and longer coherence times (qubits maintain their quantum state longer) than other quantum computing technologies.

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