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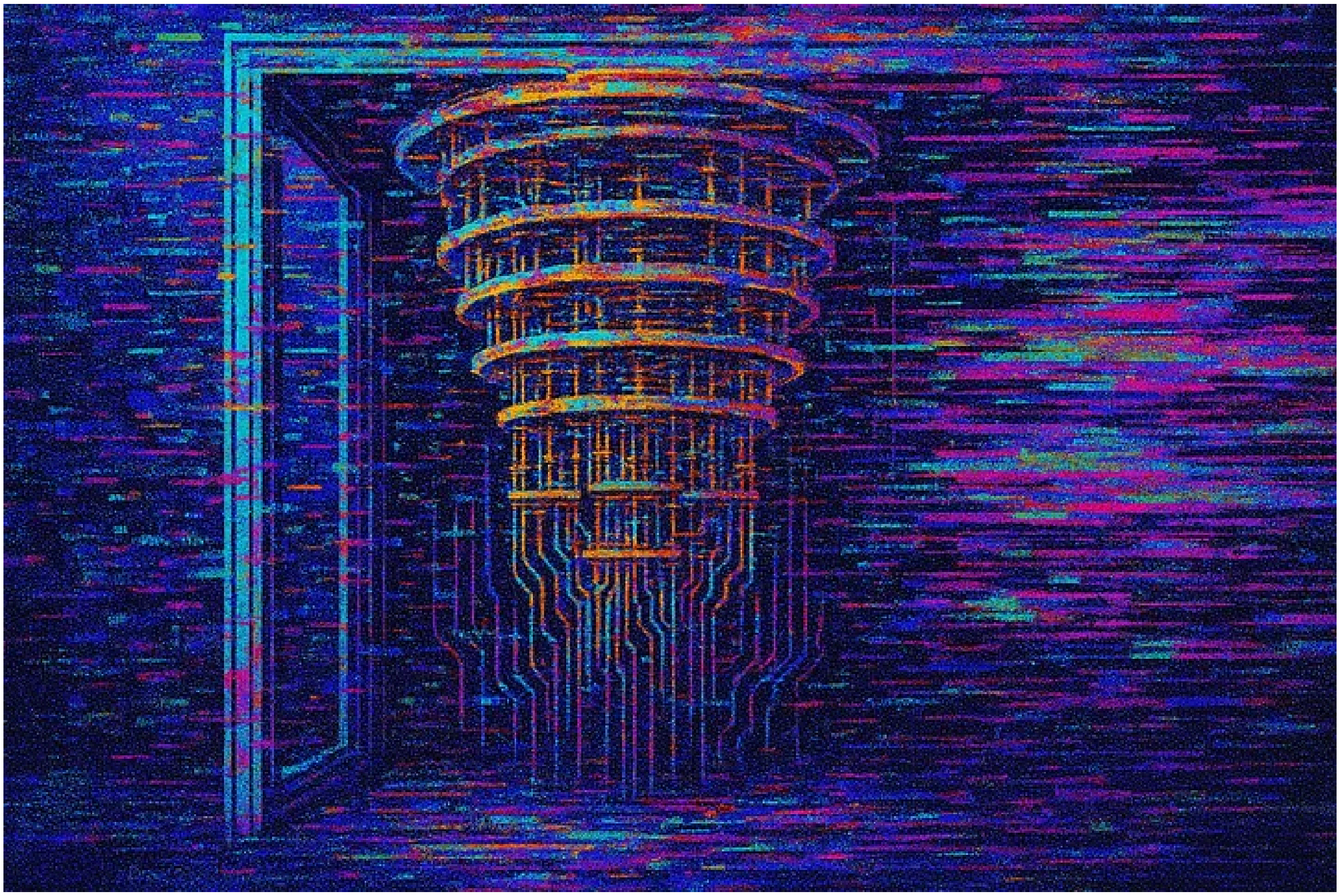
# Why quantum computers encounter more errors

A simple explanation of errors in quantum computing and the difficulty in fixing them

Jennifer Tran Follow 7 min read · 4 days ago



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Computer errors occur when mistakes or corruption in the system cause issues with transmission, computation, or unexpected behavior.

The computers we use every day (also known as classical computers) rarely encounter errors that are noticeable to users. In contrast, quantum computers often face errors that can significantly disrupt calculations, making them less practical than classical computers.

Last week, Google Quantum released a breakthrough quantum computing chip that showed fewer errors as its size increased, demonstrating the potential in making quantum computing more practical.

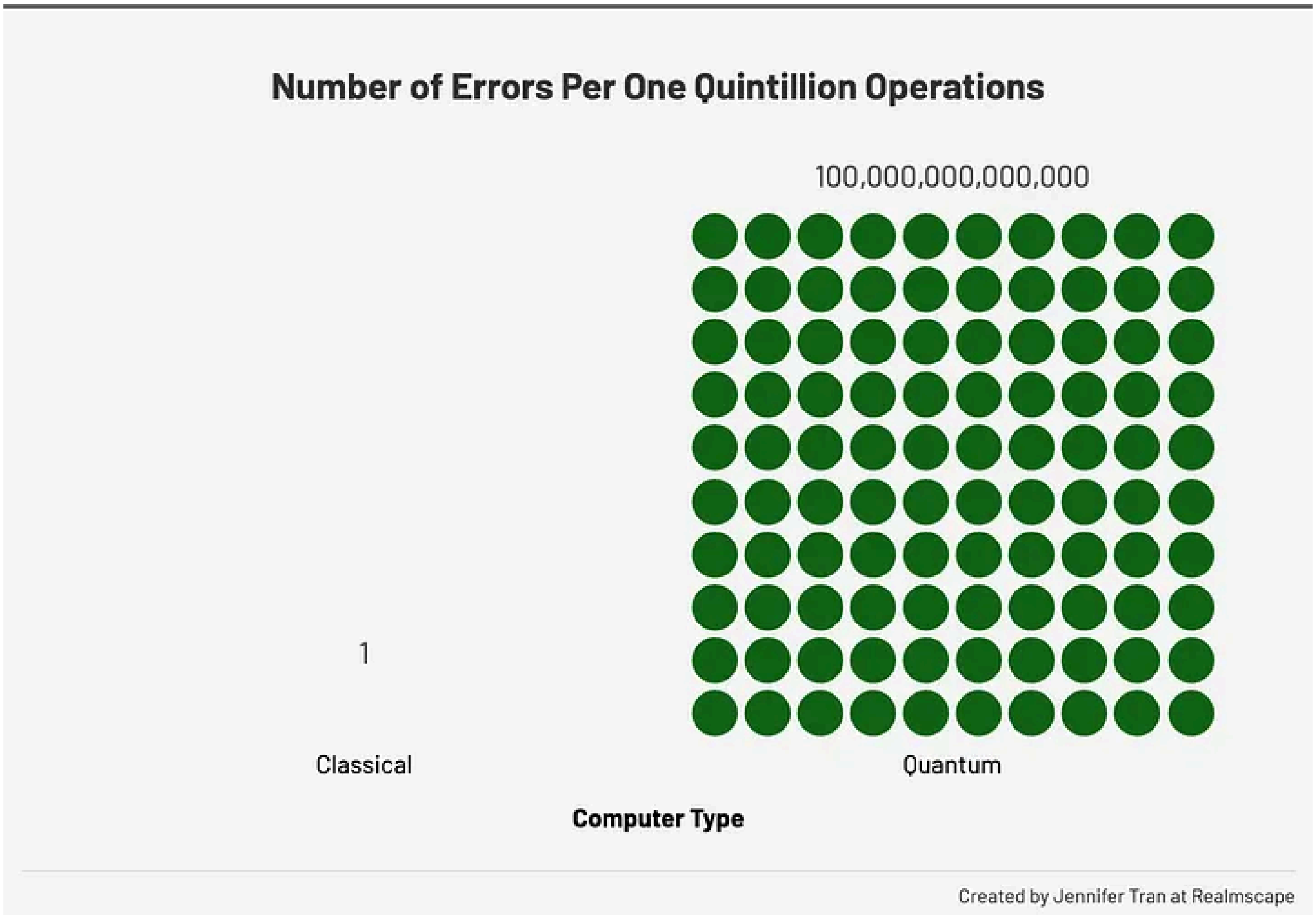
This article examines why quantum computers have impractical error rates and are more prone to errors than classical computers.

## Frequency of computer errors

Classical computers experience far fewer errors than quantum computers, making classical computers a more suitable choice for widespread use.

In general, classical computers encounter an error every $10^{18}$ (1,000,000,000,000,000,000) operations, while quantum computers face an error every $10^{4}$ (10,000) operations [1].

This means that for every quintillion ($10^{18}$) operations, a classical computer experiences only one error, whereas a quantum computer encounters one hundred trillion errors.




A pictogram graph comparing the number of errors per every quintillion operations on a classical computer (1 error) with a quantum computer (one hundred trillion errors)

Typically, a standard computer with 8GB of RAM (such as a regular laptop) would experience approximately 28 errors per year. Even in the worst-case scenario, such a computer would face 224 million errors annually, which is much less than a quantum computer would [2].

More specifically, IBM found that on their quantum processors, two qubits, or the fundamental units of a quantum computer, experienced errors ranging from at least 0.28 to 0.084 percent of the time. Even their best-performing quantum processing unit encountered errors at a rate of at least 0.0786 percent ($7.86 \times 10$^-4) of the time, which is significantly higher than the 0.0000000000000001 percent rate in classical computers [7].

| QPU name | Qubits | 2Q error (best) ↑ |
|---|---|---|
| ibm_pittsburgh | 156 | 7.86E-4 |
| ibm_kingston | 156 | 8.42E-4 |
| ibm_marrakesh | 156 | 9.62E-4 |
| ibm_torino | 133 | 1.30E-3 |
| ibm_fez | 156 | 1.52E-3 |
| ibm_brisbane | 127 | 2.88E-3 |

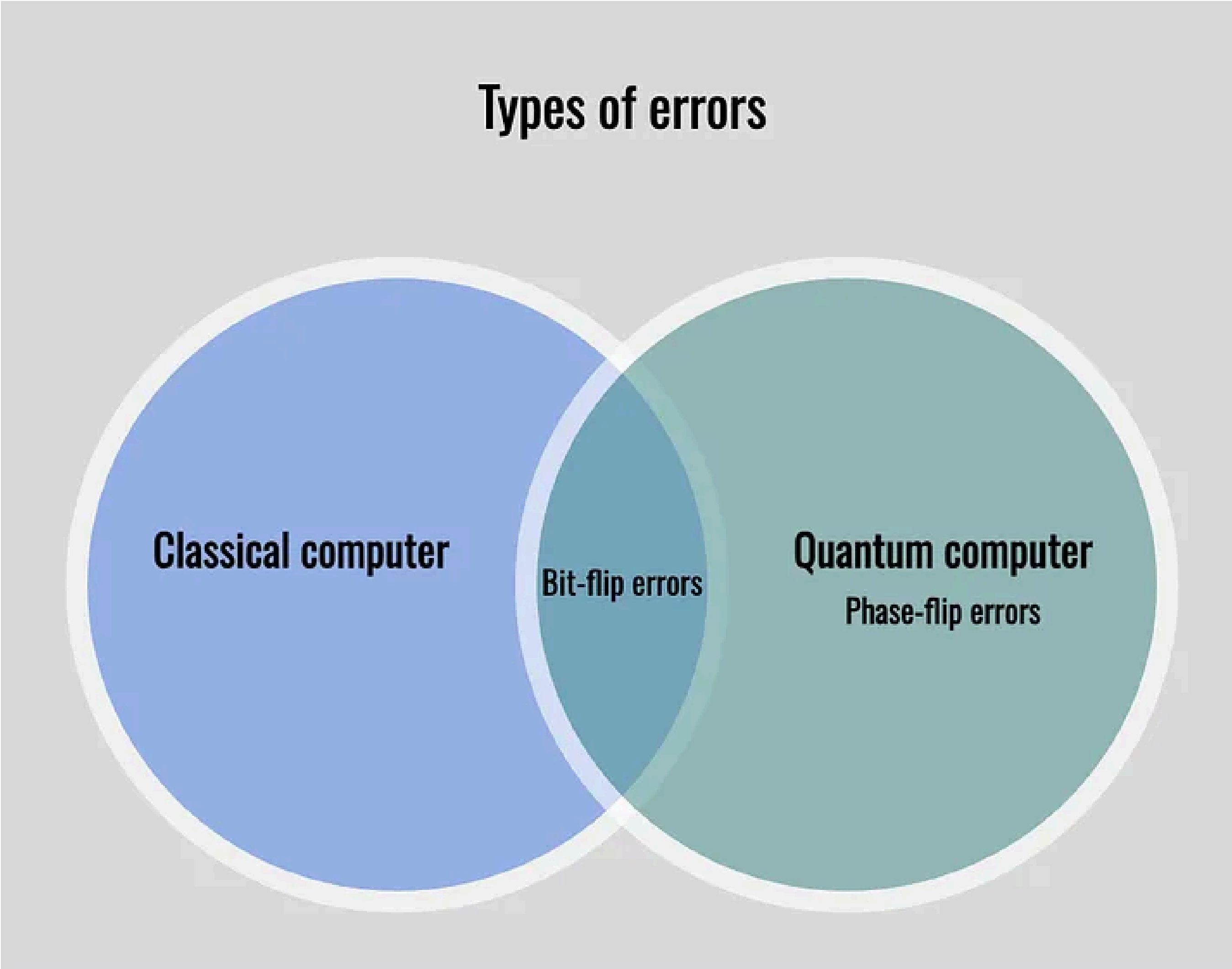
A graph displaying the minimum error rates for operations on each IBM quantum processor. Source: [7]

## Types and causes of errors

Quantum computers are more susceptible to errors because of their complex composition and delicate nature.

### Types of errors

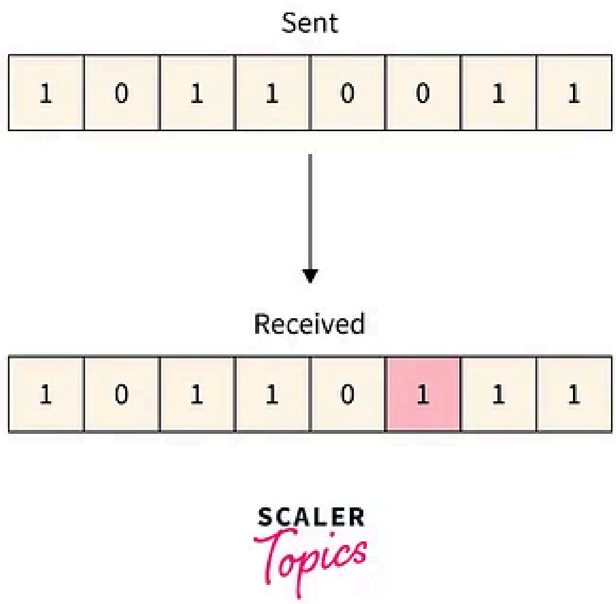
Classical computers experience only a single type of error, while quantum computers are susceptible to two types, increasing the overall error rate. Classical computer errors are also more logical, making it easier to identify and fix them compared to errors in quantum computers.




A Venn diagram illustrating how quantum computers experience an additional type of error — phase-flip errors.

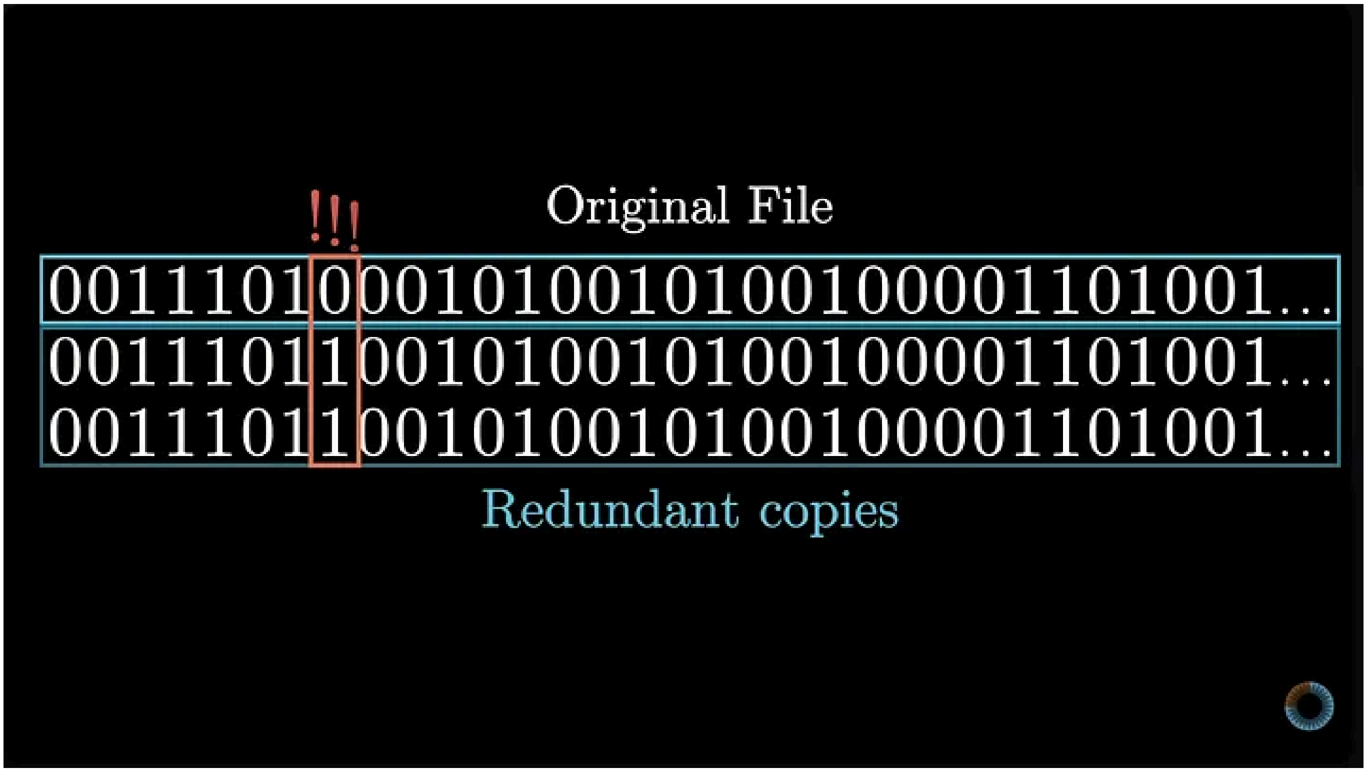
Classical computers have only a single type of error because of their simple, logical on/off design. They operate with millions of transistors, which are semiconductors that regulate current or voltage via on/off switches. These on/off switches are represented in bits, using binary to show zero as off and one as on.

Errors in classical computers occur when a zero is incorrectly represented as a one, and a one is incorrectly represented as a zero. Binary-based errors, also known as bit-flip errors, are well standardized and easier to identify and resolve because they involve only two states.




An example of a system experiencing a bit-flip error, where zero was sent but one was received. Source: Scaler

A simple way to fix bit-flips is to store multiple copies of the dataset, compare each copy with the others, and revert any data that doesn't match the other copies. For example, if a dataset is returned as 000 but the previously stored copies were 010 and 010, then it is inferred that the correct set is 010. The faulty bit, which is either zero or one, can only be the number that it is not.




An example showing three copies of a file, where one part is zero and the other two identical parts are one. The system should determine that the correct result is zero. Source: 3Blue1Brown (Grant Sanderson)

In contrast, quantum computers use binary and an additional state that is not as standardized as zeroes and ones — phases. Quantum computer errors are even more complicated because both bit-flip and phase-flip errors can coincide.

Phases describe how qubits, the basic units of quantum computing, interact with each other and their patterns, and serve as one of the key measurements for defining the quantum state. Unlike bits, which are based on either zero or one, phases have a more extended numerical range.

The quantum state is described using complex numbers with α (alpha) and β (beta). Phases are represented as $\theta_1$ (theta one) and $\theta_2$ (theta two), which form α and β, and are approximately between zero and one, including zero but not including one [3].

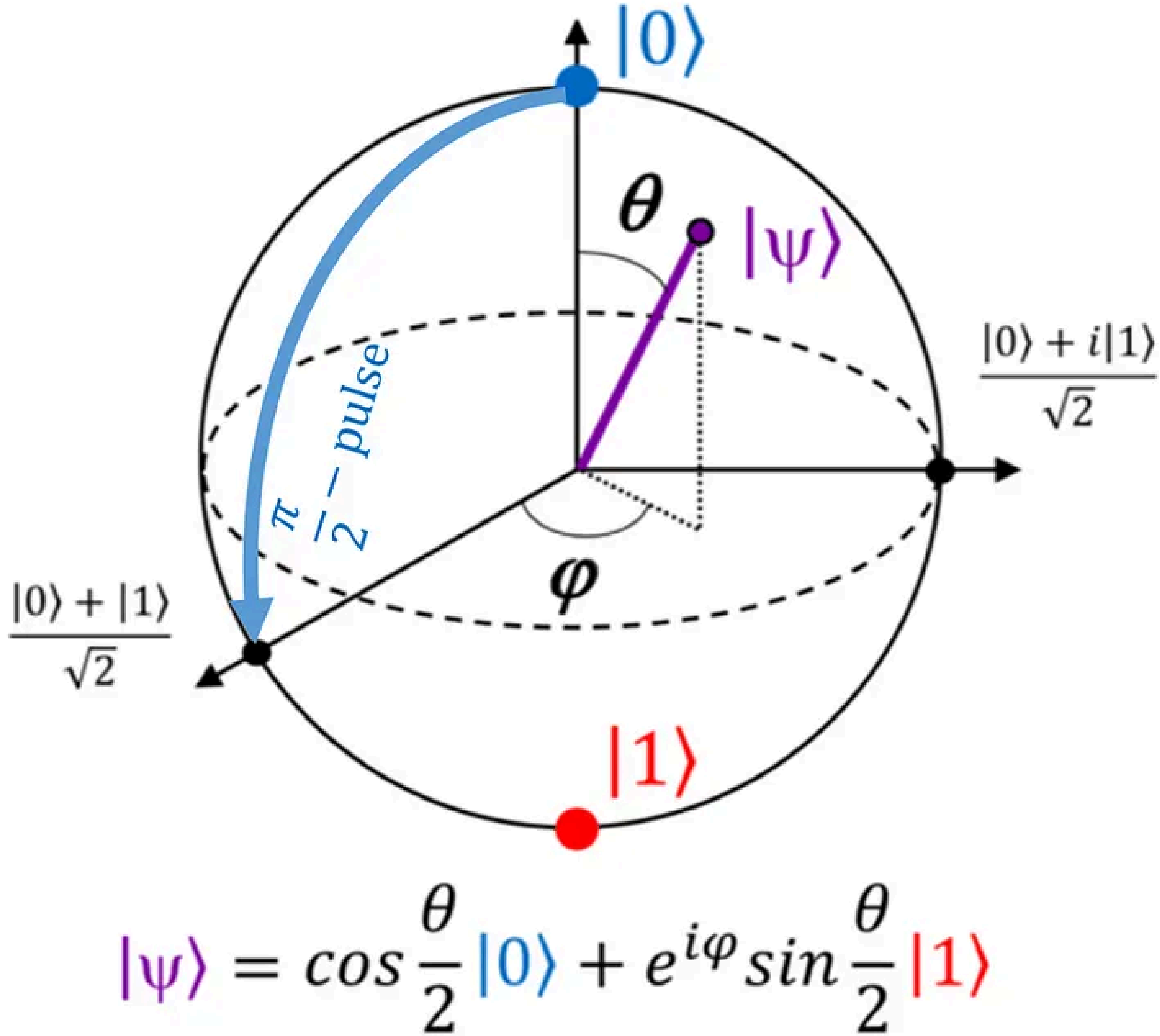
```
** Formula representing state **
|ψ >= [ αβ ]

α = r₁e^(iθ₁)
β = r₂e^(iθ₂)
```

An example of a phase calculation is the fraction below, where *y* can equal 0 to *2^m — 1*, which is more complex than a simple pure zero or one.

```
** Phase represented as θ **
θ = y / 2^m
```

The complexity of phase values can also be shown as angles $\theta$ (theta) and $\phi$ (phi) on the Bloch sphere, a 3D sphere that visualizes a qubit. The angles, which range from zero to one, can take infinitely many values.




A visual representation of a qubit using a Bloch sphere, where $|\psi$ is a state that is made up of angles $\theta$ and $\phi$, representing the phase. Source: Ecole Polytechnique Federale de Lausanne and University of Utah

Changes in phase, also known as phase-flip errors, in quantum computers are more specific, making them harder to identify and correct.

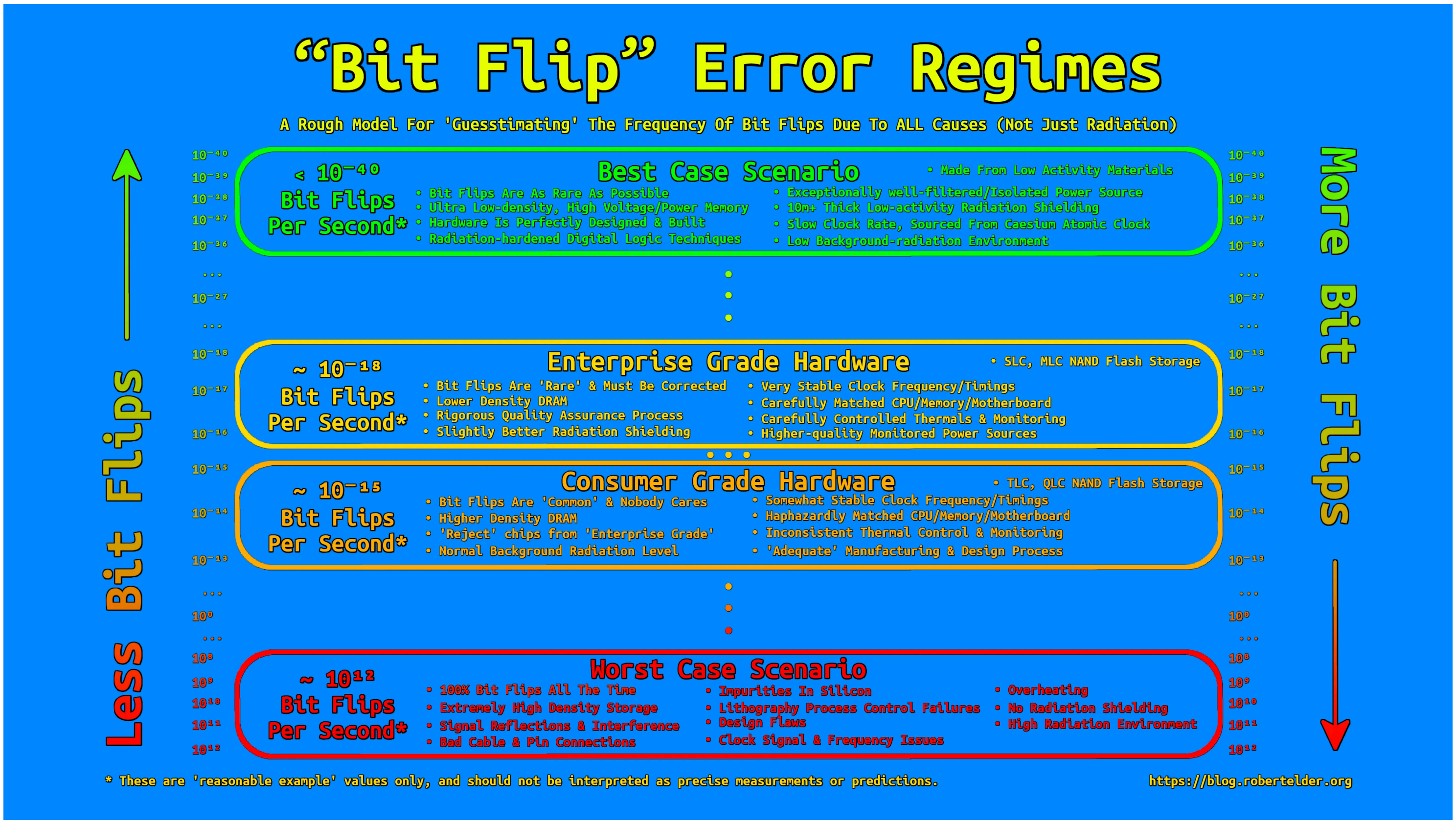
Fixing errors in quantum computers, or quantum error correction, is not as straightforward as storing multiple copies of data and referencing them, as is the case in classical computing. Direct copying or cloning of data in quantum computers is impossible because quantum states cannot be cloned. Reproducing data requires new methods and additional qubits for every qubit that must be stored. Measuring the attributes of qubits might compromise their quality and performance, or even change their previous state [4].

The added complexity of qubits versus bits, along with an additional type of error, makes error prevention particularly challenging, resulting in a higher error rate in quantum computers.

### Causes of errors

Quantum computers are more susceptible to errors because their powerful quantum physics causes even greater distortions. The more qubits there are, the more the physics can harm the hardware, making it challenging to scale quantum computing.

Environmental factors and human error can cause errors in both classical and quantum computers. Overheating, power supply issues, and incorrect part assembly are all common issues that can affect any computer.

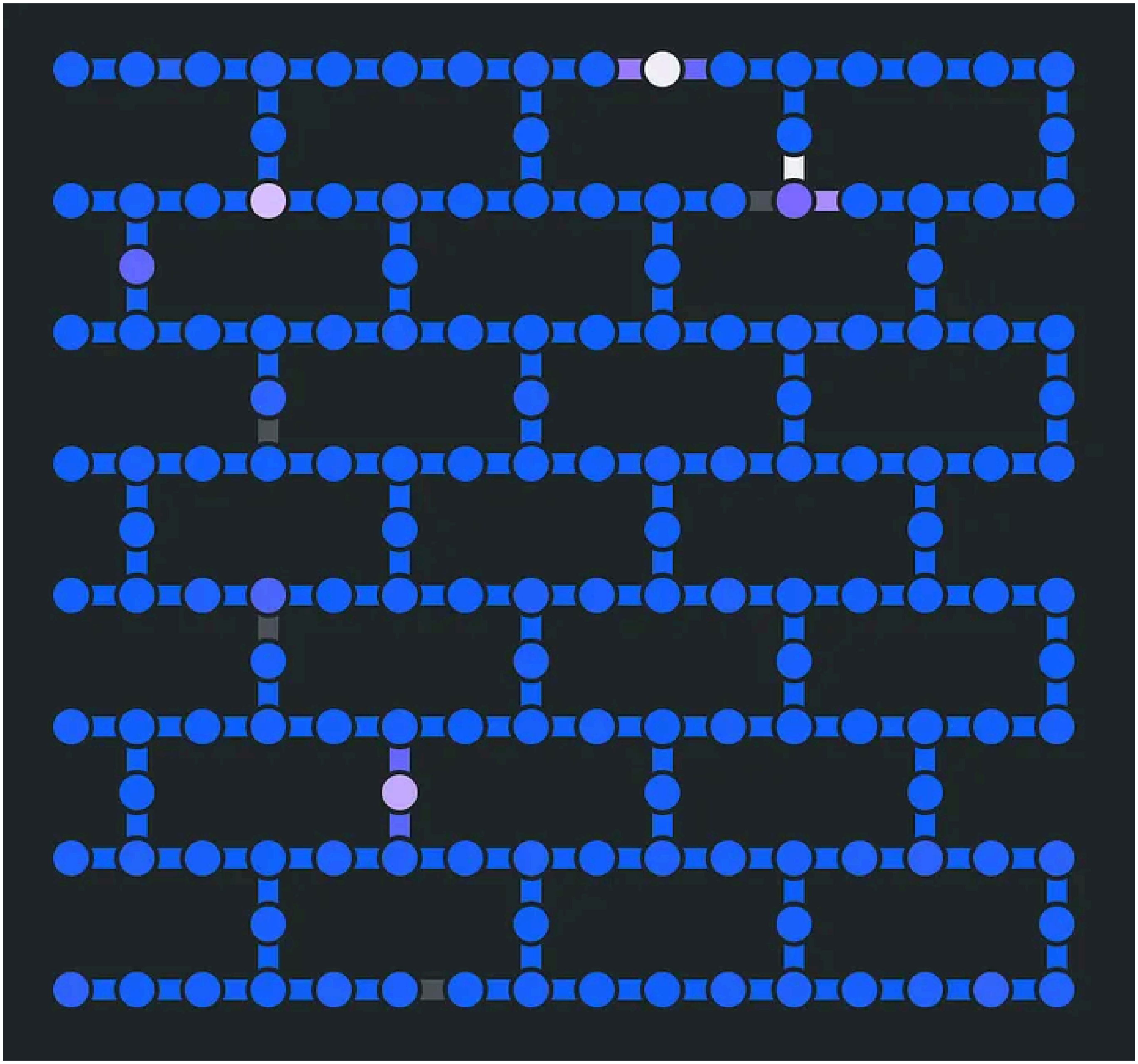



A graph listing common causes of bit-flips that are well-defined and known, including overheating, bad cable issues, poorly matched motherboard, and more. Source: Robert Elder

Although classical computers also experience errors due to physical events, quantum computers are more sensitive to their quantum physical environment.



delicate. The unpredictable nature of quantum physics makes it challenging to keep a stable, desired state for computing tasks. Quantum physics phenomena occurring in one qubit can also interfere with another qubit. Measuring other qubits and unintended magnetic interactions between qubits can alter the state of neighboring qubits. Errors can happen when the state of a qubit is not maintained correctly [5].



A diagram showing 156 qubits (shaped as circles) connected in a quantum processing unit. The non-blue qubits are experiencing readout assignment errors, which are due to unstable state conditions. Source: [7]

The most minor changes in temperature, exposure to air at room temperature, and a vacuum can cause decoherence, or deform qubits, within milliseconds.

A University of Portland research study shows that a large molecule loses its quantum properties within 0.0000000000000000001 seconds (10^-19) of exposure to air at standard pressure and within 0.01 seconds (10^-2) of exposure to a high-quality laboratory vacuum [6].

| Environment | Dust grain | Large molecule |
|---|---|---|
| Cosmic background radiation | 1 | $10^{24}$ |
| Photons at room temperature | $10^{-18}$ | $10^{6}$ |
| Best laboratory vacuum | $10^{-14}$ | $10^{-2}$ |
| Air at normal pressure | $10^{-31}$ | $10^{-19}$ |

A graph from a University of Portland research study showing how fast a dust grain and a large molecule lose their quantum properties when exposed to specific environments. Source: [6]

The delicate nature of qubits makes them highly sensitive to their environment, increasing the risks of problems.

## Conclusion

Quantum computers are more susceptible to errors due to their complex composition and fragility, which makes them less practical compared to classical computers.

Quantum computers encounter the same type of error as classical computers, as well as an additional kind of error. The additional type of error — phase-flip errors — can have an infinite number of values, making it more difficult to detect and fix.

The delicate nature of qubits means that even slight environmental exposure, such as air or minor temperature shifts, can cause issues. No cloning of qubits is allowed, and any measurement of their data could alter them, rendering traditional error detection and correction methods irrelevant.

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Alex Mylnikov

What are your thoughts?

JoChronicles he/him
3 days ago

This was a clear and accessible explanation of a complex issue. Quantum errors are such a fundamental hurdle — thanks for shedding light on how researchers are tackling them.

9 2 replies Reply

NextGenStories
2 days ago

Nice explainer! The funny twist is that those same fragile qubits might **one day** be replaced by anyons — the "in-between" particles that could finally make quantum computers error-proof.

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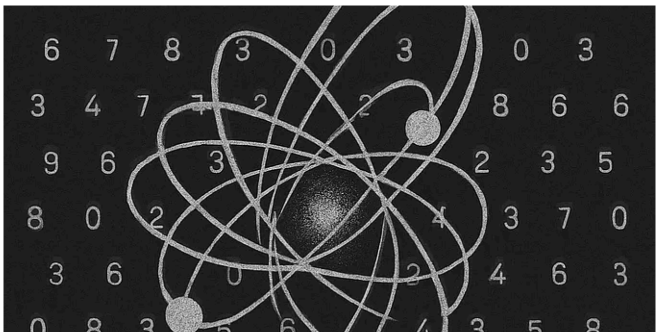


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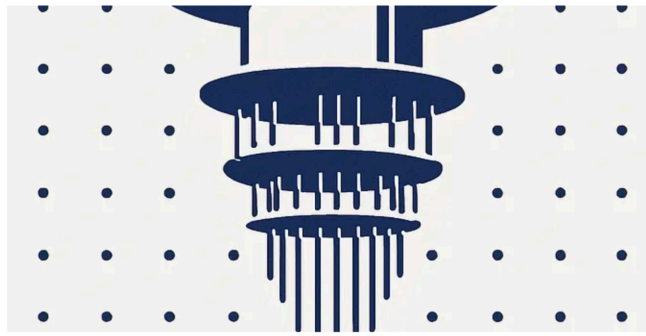

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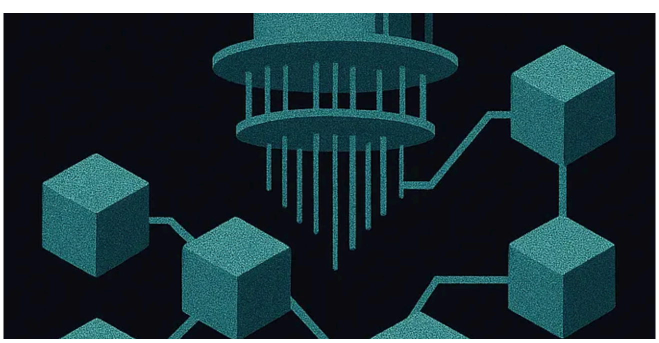

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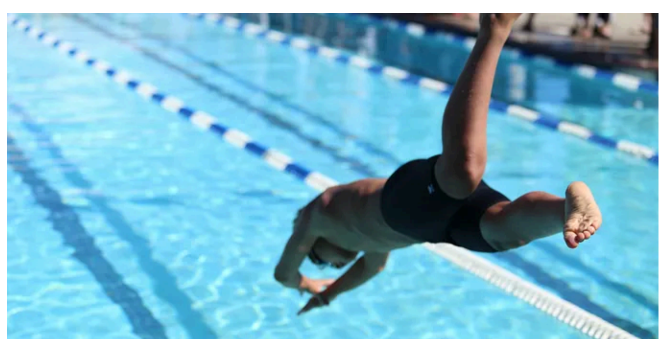

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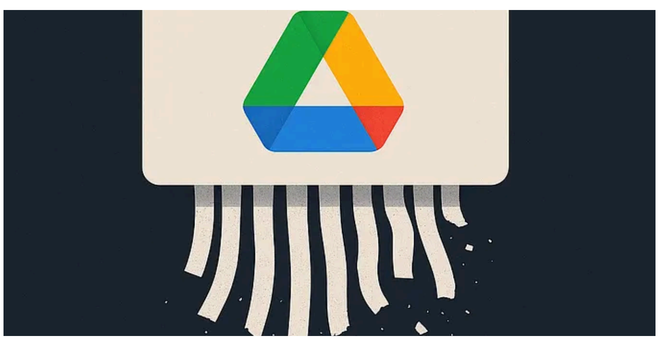

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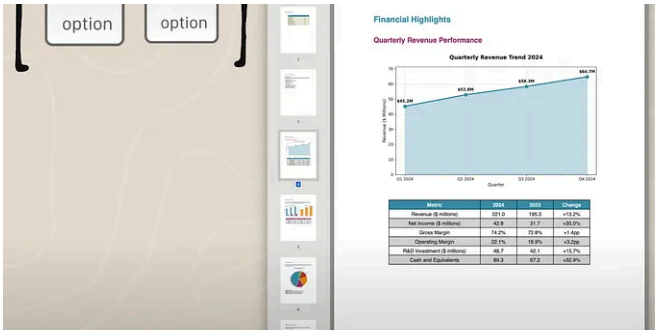


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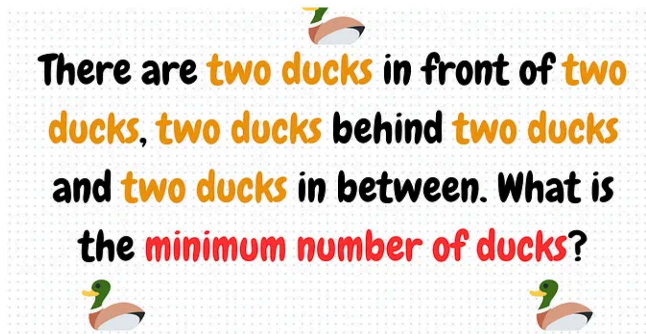


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