Late not great—imperfect timekeeping places significant limit on quantum computers

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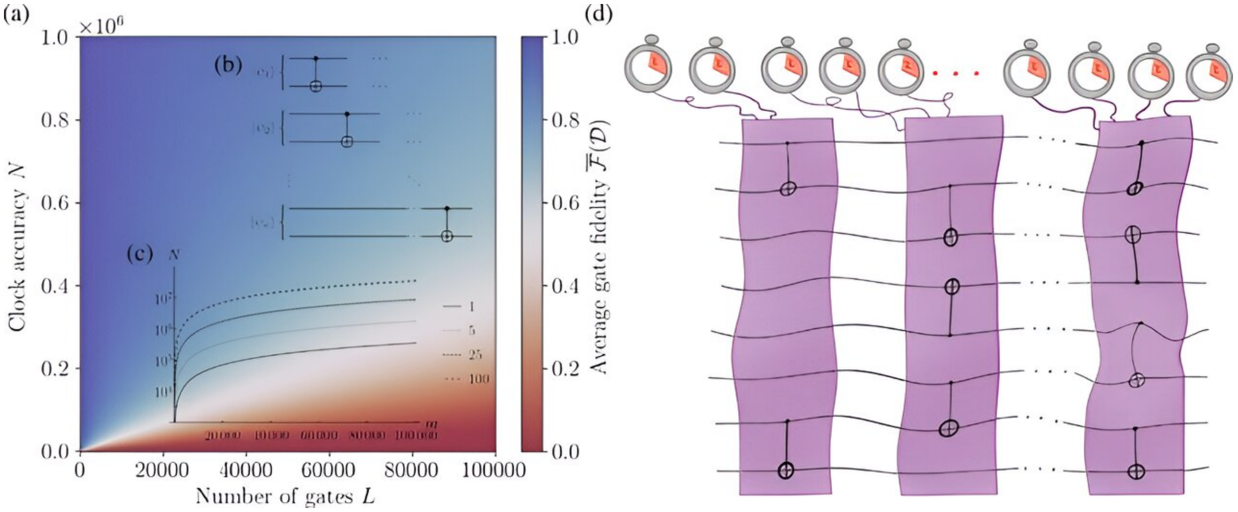

Credit: *Physical Review Letters* (2023). DOI: 10.1103/PhysRevLett.131.160204

New research from a consortium of quantum physicists, led by Trinity College Dublin's Dr. Mark Mitchison, shows that imperfect timekeeping places a fundamental limit to quantum computers and their applications. The team claims that even tiny timing errors add up to place a significant impact on any large-scale algorithm, posing another problem that must eventually be solved if quantum computers are to fulfill the lofty aspirations that society has for them.

The paper is published in the journal *Physical Review Letters*.

It is difficult to imagine modern life without clocks to help organize our daily schedules; with a digital clock in every person's smartphone or watch, we take precise timekeeping for granted—although that doesn't stop people from being late.

And for quantum computers, precise timing is even more essential, as they exploit the bizarre behavior of tiny particles—such as atoms, electrons, and photons—to process information.

While this technology is still at an early stage, it promises to dramatically speed up the solution of important problems, like the discovery of new pharmaceuticals or materials. This potential has driven significant investment across the private and public sector, such as the establishment of the Trinity Quantum Alliance academic-industrial partnership launched earlier in 2023.

Currently, however, quantum computers are still too small to be useful. A major challenge to scaling them up is the extreme fragility of the quantum states that are used to encode information.

In the macroscopic world, this is not a problem. For example, you can add numbers perfectly using an abacus, in which wooden beads are pushed back and forth to represent arithmetic operations. The wooden beads have very stable states: each one sits in a specific place and it will stay in place unless intentionally moved. Importantly, whether you move the bead quickly or slowly does not affect the result.

But in quantum physics, it is more complicated.

"Mathematically speaking, changing a quantum state in a quantum computer corresponds to a rotation in an abstract high-dimensional space," says Jake Xuereb from the Atomic Institute at the Vienna University of Technology, the first author of the paper. "In order to achieve the desired state in the end, the rotation must be applied for a very specific period of time—otherwise you turn the state either too little or too far."

Given that real clocks are never perfect, the team investigated the impact of imperfect timing on quantum algorithms.

"A quantum algorithm is like an app that runs on a quantum computer," explains Trinity's Dr. Mitchison. "It was already known that timing errors could disrupt individual quantum logic gates, which are the building blocks of quantum algorithms. Our work extends this to full quantum algorithms, showing exactly how precise the clock must be to achieve a given computational accuracy."

Since the error gets worse for more complex algorithms, it will ultimately pose a challenge for quantum computers.

"It's not a problem at the moment," said Prof. Marcus Huber who leads the research team in Vienna. "Currently, the accuracy of quantum computers is still limited by other factors, for example the precision of the hardware components or the effect of stray electromagnetic fields. But our calculations also show that today we are not far from the regime in which the fundamental limits of time measurement will play the decisive role."

The team is quick to emphasize that the message is not entirely pessimistic, because the problem could be mitigated in the future by designing clever error correction protocols.

More information: Jake Xuereb et al, Impact of Imperfect Timekeeping on Quantum Control, *Physical Review Letters* (2023). DOI: 10.1103/PhysRevLett.131.160204

Provided by Trinity College Dublin

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