TONY KARUMBA/AFP VIA GETTY

Violence to women in protest exposed

Violence is widespread towards people protesting against harm caused by the extraction of natural resources, particularly in marginalized communities. But the impact of such violence on women is seldom documented. Writing in *Nature Sustainability*, Tran and Hanaček analyse more than 500 instances of social conflict involving environmental defenders who are women, taken from a database called the Environmental Justice Atlas. The investigation teases out nuanced correlations between forms of violence and the circumstances in which they occur (D. Tran and K. Hanaček *Nature Sustain.* https://doi.org/gsbjz3; 2023).

In 81 of the cases studied by the authors, the women involved were killed, but Tran and Hanaček also examined cases in which women were displaced, repressed or otherwise targeted in a violent manner. Their study shows that violence towards women engaged in environmental activism is most prevalent in countries that have a low regard for the rule of law. But the data also suggest that such violence occurs irrespective of the robustness of a country's legal system or how highly the nation regards gender equality.

Abigail Klopper

Quantum information

Quantum computer scales up by mitigating errors

Göran Wendin & Jonas Bylander

A post-processing technique for handling errors has enabled a quantum computer comprising 127 quantum bits to calculate the physical properties of a complex model system — a task that cannot be performed by a classical computer. **See p.500**

The idea that quantum computers might one day solve complex problems at lightning speed on microscopic chips has long been touted. But the race to show that these processors can outperform their classical counterparts is a difficult one, in which every success is cause for celebration. On page 500, Kim *et al.*[1] report a quantum-computational feat that is well beyond the capability of classical simulation: the determination, using 127 quantum bits (qubits), of the magnetization of a model quantum material. The system's fundamental advantage pertains to scale rather than speed: no classical computer has enough memory to encode the possibilities computed by the 127 qubits.

A quantum computer that can outperform a classical computer is said to display quantum advantage, but this is an elusive concept with many facets. It was once synonymous with the idea that a quantum processor could accelerate computation exponentially, by using the fact that qubits can encode a superposition of entire memories containing the 1s and 0s that store information in conventional computers. Over time, it has come to refer to more-modest quantum speed-ups in the computing times of algorithms used in chemistry, materials and logistics research[2].

Developing the full potential of quantum computers requires devices that can correct their own errors. Such errors occur all too frequently, and correcting them is a difficult task needing a large, multidisciplinary engineering effort. The resulting systems, known as fault-tolerant quantum computers, will consist of thousands of high-quality qubits, held in check by an exquisite control system. But is it possible to achieve useful quantum advantage in the interim, before accomplishing full fault tolerance?

It has been conjectured that some meaningful problems can be solved without quantum error correction, using an approach called noisy intermediate-scale quantum computation[2]. This technique encodes the problem in qubits that need not be perfect, in a state that

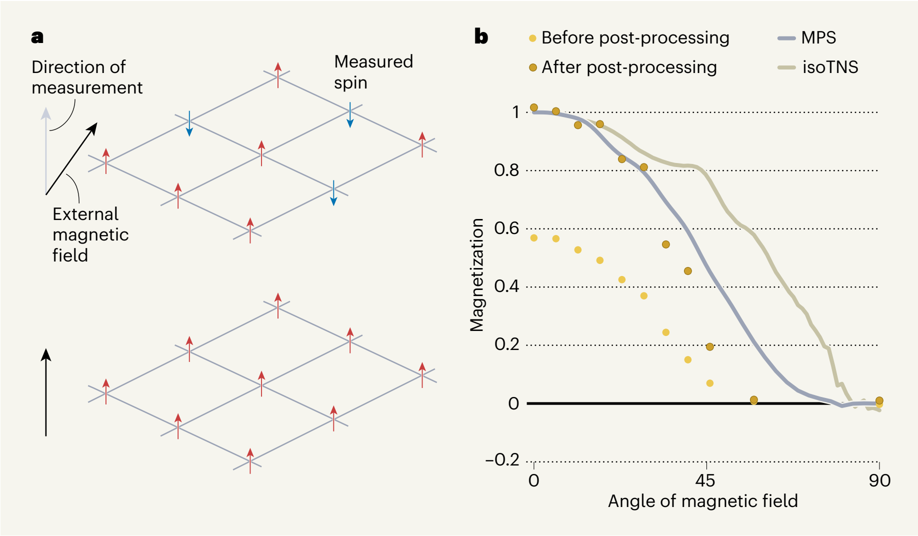

Figure 1 | Mitigating errors in quantum computation. a, Kim *et al.*[1] used a quantum computer to simulate the spin (intrinsic angular momentum) of electrons in a model quantum material. The spins are arranged on a lattice, point up or down when measured, and align in the presence of an external magnetic field, causing the material to magnetize. **b**, The authors computed the magnetization of a single spin corresponding to one quantum bit (qubit) in a simulation involving 127 qubits, and used a post-processing method to mitigate quantum errors. They compared their calculation with approximate results from two classical-simulation techniques, known as MPS and isoTNS, both of which are inaccurate when the magnetic field is oriented in a direction between those perpendicular and parallel to the spins. (Adapted from Fig. 4b of ref. 1.)

requires relatively few qubits, and these are then measured quickly, before an error can corrupt the computation. However, algorithms for solving useful problems require that, to reach sufficient accuracy, thousands of low-error operations be completed before measurement. In the end, this might not be possible without fault tolerance through quantum error correction.

In 2019, a programmable superconducting quantum computer was reported to have outperformed the most powerful conventional computers[3,4]. But the processor was benchmarked with a task designed solely for this purpose — sampling the output of a random circuit containing quantum logic gates. Instead, Kim *et al.* sought to simulate the dynamics of a system that is perhaps more appealing to physicists: a two-dimensional Ising model, which is now used across many areas of physics, but was originally devised to describe magnetic materials. The approach is in the spirit of US physicist Richard Feynman's idea of simulating one quantum system (the Ising model) by using another (the quantum computer)[5].

The Ising model conceives of the 'spins' (intrinsic angular momenta) of electrons in a magnetic material as discrete variables: each spin can point in any direction, but a measurement will cast it as either up or down. These spins are arranged on a lattice and, when subjected to an external magnetic field, they align, resulting in the collective magnetization of the material. Kim and colleagues' goal was to accurately measure the average magnetization for selected clusters of spins — rather than the more challenging problem of determining the exact state of the entire system.

The authors modelled the way that the system changes in time as a sequence of operations on qubits and pairs of qubits, configured as 2,880 two-qubit gates. Their quantum hardware and control system were both state-of-the-art devices, but estimating the average magnetization still required advanced techniques to mitigate any errors[6,7]. Quantum error mitigation is a post-processing method that uses software to compensate for the noise generated during a calculation, and should not be confused with quantum error correction. The idea is that a quantum computation that uses a 'small' number of qubits (up to 68) can be verified with brute-force classical simulation, lending credibility to the idea that errors are similarly mitigated for larger systems that cannot be verified classically.

Kim *et al.* verified their error-mitigation scheme by computing the magnetization of a single spin in a simulation involving all 127 qubits. Before mitigating the errors, the authors' results were strongly affected by noise, but their post-processing technique restored the correct magnetization (Fig. 1). They also compared their calculation with approximate results from two classical-simulation techniques. Both methods are known to break down when the external magnetic field is oriented in a direction between those perpendicular and parallel to the spins, a situation in which the quantum nature of the system is particularly important.

The quantum-computational advantage that Kim *et al.* demonstrated is one of scale. In implementing a quantum processor with 127 qubits, the authors showed that a quantum computer could go beyond a previous experiment with 27 qubits[8] and thereby decisively exceed the limits set by classical methods. In terms of the computational time, the quantum speed-up reported was very modest — only two to three times faster than a classical simulation method called isoTNS, which produces inaccurate results (see Fig. 1b).

So does this advance improve the prospects for applying quantum computation to industrially relevant problems? The answer is most probably no: such algorithms must involve a much larger number of qubits and many more consecutive gate operations to be competitive with high-performance classical supercomputers, and these quantum computations would inevitably drown in noise arising from qubit errors.

Instead, Kim and co-workers' results herald further opportunities for quantum processors to emulate physical systems that are far beyond the reach of conventional computers. As quantum hardware improves, processors will be capable of longer computations than those currently possible, and such computations will require advanced post-processing and quantum error-mitigation methods that can handle large data sets[9]. Techniques such as Kim and colleagues' error-mitigation method will drive the development of device technology, control systems and software by providing applications that could offer useful quantum advantage beyond quantum-computing research — and will pave the way for truly fault-tolerant quantum computing.

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1. Kim, Y. *et al. Nature* **618**, 500–505 (2023).
2. Wendin, G. Preprint at https://arxiv.org/abs/2302.04558 (2023).
3. Arute, F. *et al. Nature* **574**, 505–510 (2019).
4. Oliver, W. D. *Nature* **574**, 487–488 (2019).
5. Feynman, R. P. *Int. J. Theor. Phys.* **21**, 467–488 (1982).
6. Temme, K., Bravyi, S. & Gambetta, J. M. *Phys. Rev. Lett.* **119**, 180509 (2017).
7. Kandala, A. *et al. Nature* **567**, 491–495 (2019).
8. Kim, Y. *et al. Nature Phys.* **19**, 752–759 (2023).
9. Quek, Y., França, D. S., Khatri, S., Meyer, J. J. & Eisert, J. Preprint at https://arxiv.org/abs/2210.11505 (2022).

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