Simulating magnetization in a Heisenberg quantum spin chain

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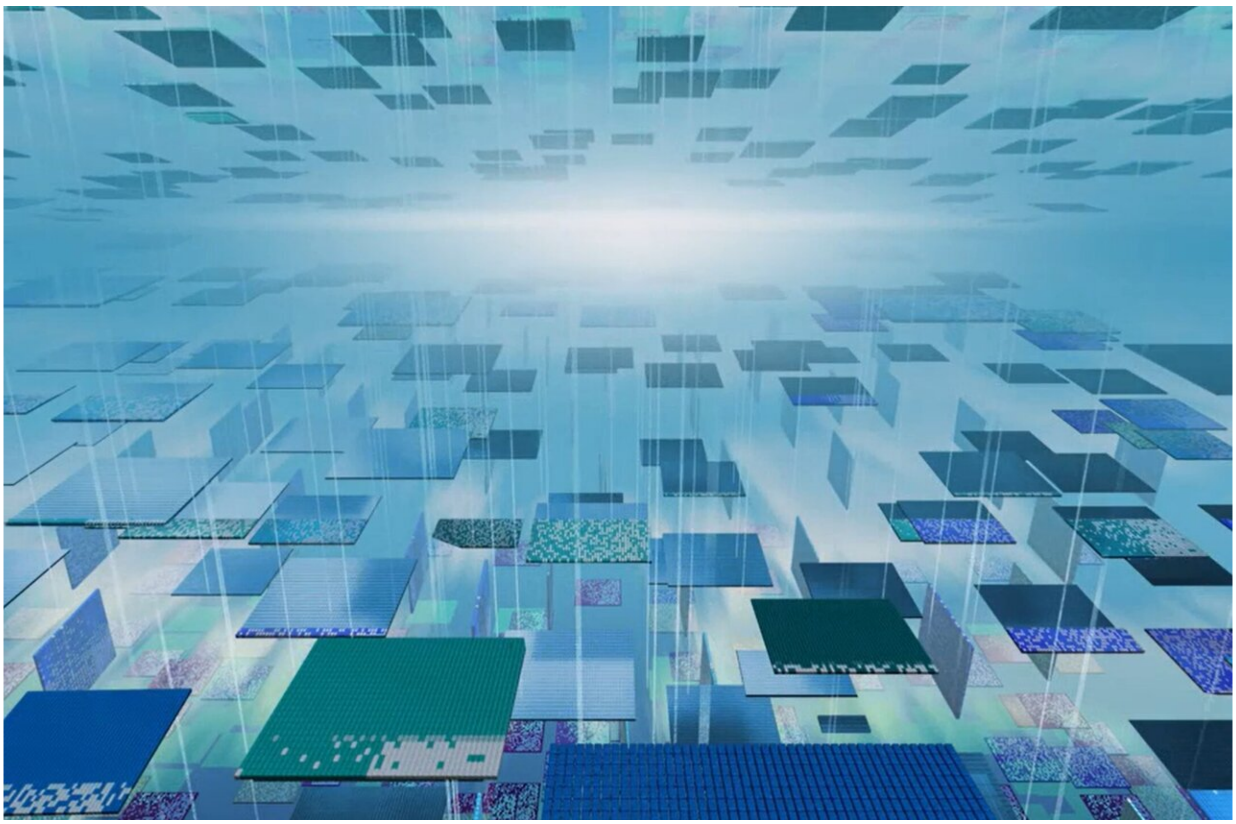

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The rapid progress of quantum simulators is now enabling them to study problems that before have been limited to the domain of theoretical physics and numerical simulation. A team of researchers at Google

Quantum AI and their collaborators showed this novel capability by studying dynamics in 1D quantum magnets, specifically chains of spin-1⁄2 particles.

They investigated a statistical mechanics problem that has been the focus of attention in recent years: Could such a 1D quantum magnet be described by the same equations as snow falling and clumping together?

It seems strange that the two systems would be connected, but in 2019, researchers at the University of Ljubljana found striking numerical evidence that led them to conjecture that the spin dynamics in the spin-1⁄2 Heisenberg model are in the Kardar-Parisi-Zhang (KPZ) universality class, based on the scaling of the infinite-temperature spin-spin correlation function.

The KPZ equation was originally introduced to describe the stochastic, nonlinear dynamics of driven interfaces and has proven to apply to a wide range of classical systems, such as growing fronts of forest fires, that belong to the KPZ universality class. It would be surprising if the spin-1⁄2 Heisenberg model were in this universality class, as conjectured by the researchers at Ljubljana, because it is linear and non-stochastic, unlike the other systems in this class.

In 2022, quantum simulations started shedding light on this question with cold atoms experiments carried out by researchers at the Max-Planck-Institut für Quantenoptik. By studying the relaxation of an initial imbalance of the magnetic spins, they found experimental evidence in support of this conjecture, which was published in *Science* in 2022.

To further explore spin dynamics in this model, the Google collaboration leveraged the ability of their superconducting quantum processor to quickly acquire large amounts of experimental data, allowing for a detailed study of the underlying statistics.

Specifically, using a chain of 46 superconducting qubits, they measured the probability distribution of how many spins crossed the center of the chain, a quantity known as the transferred magnetization. The mean and variance of this distribution showed behavior consistent with being in the KPZ universality class, in full agreement with the findings of the Max-Planck-Institut group.

It was only when they carefully examined the third (skewness) and fourth (kurtosis) moments of the transferred magnetization that they found clear deviations from the predictions for the KPZ universality class, indicating that the conjecture does not hold on the timescales probed in the experiment.

Generally, measuring the distribution of a stochastic variable with sufficient precision such that the higher moments can be resolved with sufficient signal to noise is extremely challenging; it needs rapid sampling, high level of control, and, for quantum processors, quantum coherence. This work, published in *Science* on April 5 2024, excellently represents the current exciting era of quantum simulation, in which quantum processors allow for deepening our understanding of novel physical phenomena.

More information: E. Rosenberg et al, Dynamics of magnetization at infinite temperature in a Heisenberg spin chain, *Science* (2024). DOI: 10.1126/science.adi7877

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