PHYSICS

To see the world in a grain of spins

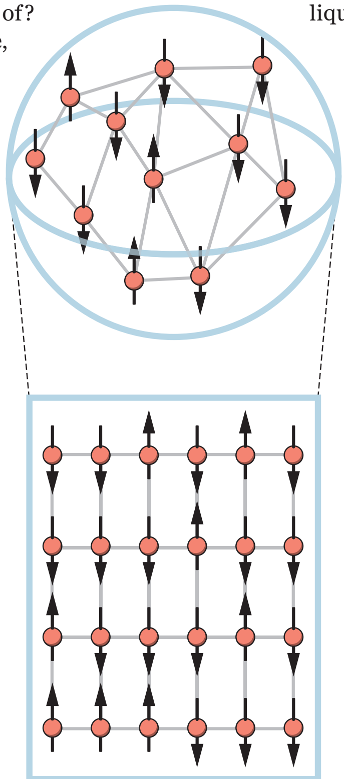
A universal simulator is developed that can model the workings of any classical spin system

By **Stephanie Wehner**

Grappling with our desire to understand nature, we construct models of the specific systems that we wish to study. Unsurprisingly, such models are generally highly tailored to the system of interest. But are all these models really that distinct? Or, could there be a universal model that can somehow describe the behavior of any system we could think of? On page 1180 of this issue, De las Cuevas and Cubitt (*1*) venture out to weave ideas from physics and computer science in an attempt to answer this question for all classical spin models.

Although spin models affect many areas of science, they have their origin in condensed-matter physics, where quantum-mechanical spin is a property of particles. In oversimplified terms, we may think of spin as a direction for each particle that is either "up" or "down." A particular model will describe how such spins can interact with each other. A possible interaction between two spins, for example, may indicate that if one spin changes its state to "up," the other spin will become "down." We usually consider systems in which the spins are arranged in some geometry, such as on a line, a two-dimensional (2D) plane, or in three dimensions (3D). For example, one model may specify that we can only have interactions between nearby spins, whereas other models may include long-range interactions between distant spins.

We could write down a daunting number of such models. However, when we zoom out and focus on the macroscopic behavior to which all these spins together give rise, then simplifications can arise. It has long been known that models can be grouped into certain classes (*2*), and for all models within the same class, even unrelated materials behave in a very similar fashion in the vicinity of a phase transition (a point at which a material changes its macroscopic behavior dramatically, such as the transition of water from a liquid to ice).



A universal spin simulator. A complicated spin model in 3D can be mapped onto the simpler 2D Ising model with fields, which De las Cuevas and Cubitt find to be a universal simulator for all classical spin models.

In contrast, De las Cuevas and Cubitt zoom into the microscopic regime, where such known simplifications do not apply. Intriguingly, they find simple models that are universal simulators. A model is termed a universal simulator if we can tune its parameters to simulate the entire physical behavior of all other classical spin models, even at the microscopic scale. Though at first glance a universal simulator might be expected to be very complicated, it turns out that one of the simplest and most well-studied models, known as the 2D Ising model (*3*) (with fields), does the trick. Perhaps surprisingly, this means that even though in the 2D Ising model spins are arranged on a 2D plane, it can thus be used to simulate the physics of any model in 3D, even one with long-range interactions. Stashed away in the low-energy sector of the universal model rests the entire physics of the one we wish to simulate (see the figure).

Unsurprisingly, the 2D simulation requires more spins than the original 3D one, but that number of additional spins remains manageable. Furthermore, De las Cuevas and Cubitt map the original model onto the universal simulator explicitly and efficiently. This makes the simulation useful, allowing us to apply techniques known for the simpler universal model to study the more complex one that we would actually want to simulate.

The possibility of realizing such a simulation is appealing for our ability to probe the physics of certain models experimentally. It may be the case that a 2D model may be easier to realize than a 3D one. Indeed, we could think of an experiment realizing a universal model with tunable parameters as a universal spin simulator that can reproduce the physics of any classical spin model. Just as a universal classical computer (*4*) can be programmed to run any algorithm, the universal spin simulator can be programmed to simulate any classical spin model.

Crucially, the universal spin simulator goes beyond the use of a computer to perform simulations as a means to do calculations. To draw a rough analogy, we could use a computer simulation to try and calculate how a magnet behaves, but this is quite different from actually creating something that behaves like one. It may be tempting to conclude that the relation between universal spin models and the universal classical computer stops here—that the brief encounter between physics and computer science merely inspired the idea of universal simulation. But, that would be incorrect. To establish their result, De las Cuevas and Cubitt not only need ideas from physics, but make use of technical results developed in computer science, starting with an encoding of the computer science question of whether a formula can be transformed into a Hamiltonian (the quantum-mechanical description of the system). We thus see quantum information at work—the long-standing affair between physics and computer science, which continues to shed new light on our understanding of nature. ■

QuTech, Delft University of Technology, Delft 2628 CJ, Netherlands. E-mail: s.d.c.wehner@tudelft.nl

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