Braiding may be key to using time crystals in quantum computing

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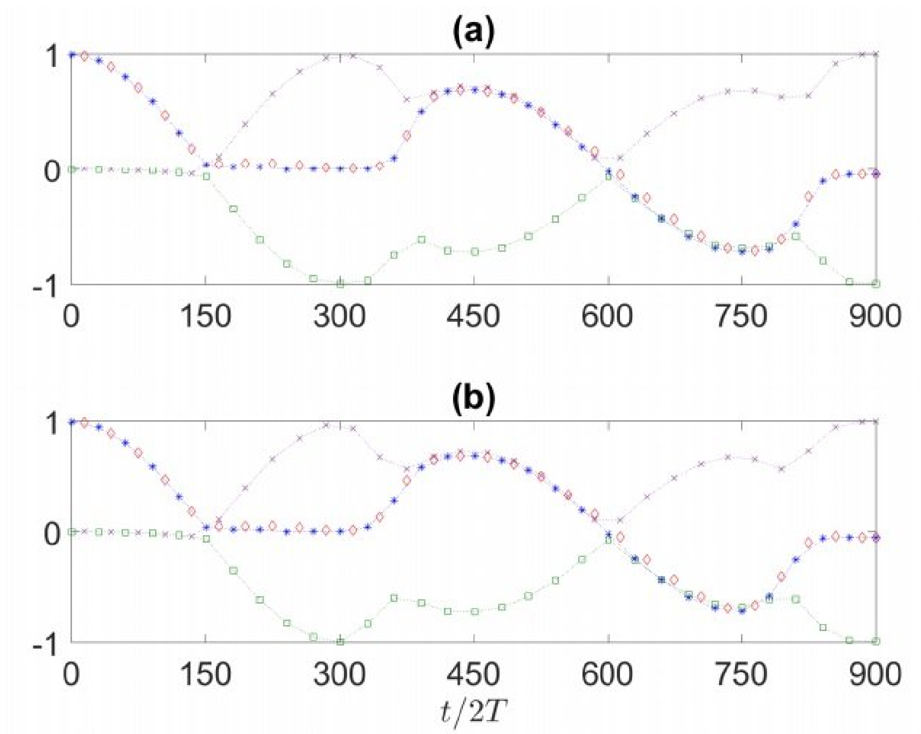

Braiding time crystals. Credit: Bomantara and Gong. ©2018 American Physical Society

Over the past few years, physicists have predicted that a new form of matter called time crystals may have potential applications in quantum computing. Now in a new study, physicists Raditya Weda Bomantara and Jiangbin Gong at the National University of Singapore have taken some of the first steps toward showing exactly how that might be done. They theoretically demonstrate that, by braiding two different modes of time crystals, it's possible to generate the states that are necessary to perform universal quantum computation.

Time crystals have attracted the attention of physicists since the concept was first proposed by Frank Wilczek in 2012. Five years later, in 2017, time crystals were experimentally realized for the first time. Just as ordinary crystals are characterized by their repeating patterns in space, time crystals—which are always moving—have the unique feature that their motion exhibits repeating patterns in time. To realize a time crystal, a periodically driven laser sets the particles in a superconducting loop in motion. When the system is manipulated in a precise way, the particles' motion collectively synchronizes in a periodic manner, resulting in a time crystal.

In the new study, Bomantara and Gong have developed a method for harnessing the unique properties of time crystals for quantum computing that is based on braiding. To do this, they turned to a particular type of time crystal called a Majorana time crystal, whose name comes from the way it's created, which is from the quantum coherence between two types of Majorana edge modes (0 and π) in a superconducting chain.

The reason for choosing Majorana time crystals is that they share similarities with a type of quasiparticle called non-Abelian anyons, which can be braided and have recently been considered as a potential component of a topological quantum computer. By making use of this connection to non-Abelian anyons, the physicists showed that it's possible to mimic non-Abelian braiding in Majorana time crystals.

"Loosely speaking, braiding refers to exchanging the location of two particles," Gong told *Phys.org*. "In order to carry out this exchange, the particles are to be systematically moved around each other in such a way that if we draw the paths traversed by the two particles in spacetime, they form a braid. We know in real life that there are different types of braids, and that converting one braid to another requires certain operations that nature cannot do by itself. As a result, by storing information in these different types of braids, we can manipulate this information (hence performing quantum computation) by changing one type of braid to another (hence called braiding) without worrying that some external disturbance may destroy them."

The braiding method in the new study consists of a four-step process that involves slowly tuning the parameters of the system that generates the Majorana time crystals. In each step, the 0 and π modes are shifted, so that at the end of the entire process, the sequence of transformations results in one complete braiding operation that resets the system to its initial configuration.

In the future, time crystals may lead to new ways to perform certain quantum computational tasks. With this goal in mind, the physicists also showed that their quantum control protocol can be applied to time crystals to generate "magic states," which are a basic requirement for quantum computing.

"Braiding time crystals is potentially useful for quantum computation because we exploit their time-domain features and thus obtain more qubits for encoding information, and hence achieve savings in hardware," Gong said.

In the future, the physicists plan to further explore the possibilities of braiding time crystals. For one thing, they expect that extending braiding from one superconducting wire to an array of wires may allow them to simulate more intricate braiding processes.

"Given that we have now shown how the time dimension can be used as a resource for performing quantum computation, one future direction we have in mind will be to explore the possibility of storing and manipulating information with even fewer physical resources by enlarging the system in the time direction and by making use of more Majorana modes in periodically driven quantum wires," Gong said. "As a long-term goal, we plan to use this idea to design a robust quantum computer architecture with an optimal amount of resources—that is, one that is relatively small in physical size, but does not take a very long time to operate."

More information: Raditya Weda Bomantara and Jiangbin Gong. "Simulation of Non-Abelian Braiding in Majorana Time Crystals." *Physical Review Letters*. DOI: 10.1103/PhysRevLett.120.230405
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