Quantum shortcut could speed up many quantum technologies

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A shortcut to adiabaticity (STA) offers a fast route to quantum state preparation, similar to how a toll road offers a fast route to a traveler's destination; both shortcuts involve costs, but the costs are hopefully worth the time saved. (The image depicts a road sign produced by the Swedish Transport Agency.)

(Phys.org)—Quantum technologies come in a wide variety of forms, from computers, sensors, and cryptographic systems to simulations and imaging systems. But one thing that all current and future quantum systems have in common is the need to achieve reliable control over physical systems such as atoms or photons. A frequently used method to prepare quantum systems in the desired quantum state is a quantum adiabatic process, but these processes often take so long that environmental noise causes the quantum state to decohere and lose its "quantumness."

To speed up quantum state preparation and minimize decoherence, physicists have devised so-called "shortcuts to adiabaticity" (STA), which refer to any process that prepares quantum states in a shorter time than adiabatic processes without losing the benefits of being adiabatic. Originally developed for simple systems consisting of a single particle, STA has recently been extended to many-body systems, which are more relevant for applications. However, the implementation of STA in many-body systems is still very challenging due to the inherent complexity of these systems.

In a new paper published in *Physical Review Letters*, physicists Steve Campbell, et al., at Queen's University in Belfast, UK; the University of Palermo and Scuola Normale Superiore of Pisa in Italy; and the National University of Singapore have devised a new hybrid method for preparing quantum states for many-body systems that combines STA with optimal control. The main advantage of the new method is that it can achieve nearly perfect STA performance yet allows for significant simplification by not requiring complete knowledge of the underlying mechanisms. The method shows that it's possible to speed up quantum state preparation at a low enough cost to justify the quantum shortcut.

"Our work shows that a solution exists when the quantum many-body problem is of the Lipkin-Meshkov-Glick (LMG) class, which is a very interesting case that attracts a lot of attention from various quantum communities (the solid state, the quantum information processing, and the mathematical physics ones, to name a few)," Campbell told *Phys.org*. "Our way of solving the problem is basically a 'know-your-enemy' approach, where we exploit the symmetries inherent in the problem that we want to address (the LMG one) and take advantage of them to devise a successful quantum shortcut."

As the researchers explain, this quantum shortcut or STA can also be understood in terms of a driver looking for the fastest way to get to work.

"In a nutshell, our work can be understood through a simple layman analogy," Campbell said. "Suppose you want to drive your car through the freeway from home to your office, but you do not want to go through the traffic jam of Monday morning. You will surely get to your workplace, and you do not pay anything, but you will be very slow, and it will likely imply that only half of your morning duties will be attended.

"You thus decide to go through a shortcut, which goes through a road that, however, requires a fee to be driven through. Yes, you pay a bit, but you get precisely to the parking lot of your workplace, and in a much shorter time: plenty is done in the morning, your boss is happy, and gives you a pay raise, which in the end means that the toll you paid to get to work did not really matter.

"Take now all this into the quantum world. Your car is a quantum system, prepared in a state (you being at home) and having to be transformed into a new state (you at your office). You have two choices: you can do it infinitely slowly (going through the freeway traffic), or taking the quick shortcut (i.e., implementing a shortcut to adiabaticity

[STA]) that will cost you a bit, in terms of energy, but will realize the desired transformation in a much faster way."

With a single person involved, the situation resembles a single-body problem. But, as Campbell continued, adding more commuters makes the situation more complicated and turns the situation into a many-body problem.

"Now, do the same thing when it's all of your colleagues who should get to your office at the same time, leaving their homes at the same time, and all facing the very same traffic issues," he said. "This is what we would call a many-body problem. It looks like a very difficult problem (you have to convince everybody to pay the toll!!), and indeed it is—let alone when you translate it to the quantum world. Indeed, while STA techniques are known and work for single-body problems, to date very little is known in the context of quantum many-body ones."

By showing that the STA approach can work for many-body systems, the new method could potentially have a wide variety of applications, as quantum state preparation is required for so many different future quantum technologies.

In the future, the researchers plan to further examine the true cost of the "toll," or exactly how much energy is need to implement an STA. They also plan to take the first steps toward building a quantum engine using this approach, in which many-body systems realize some thermodynamic cycles.

More information: Steve Campbell, et al. "Shortcut to Adiabaticity in the Lipkin-Meshkov-Glick Model." *Physical Review Letters*. DOI: 10.1103/PhysRevLett.114.177206