<u>Speed Limits of Open Quantum Systems</u>

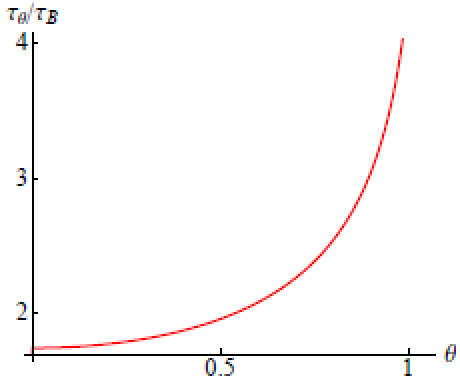

Figure 1-Ratio between the exact passage time t_θ and its bound t_B in an isotropic environment

The upper bound to the speed of evolution for an open quantum system has been found by a group of physicists at Los Alamos National Laboratory. This “quantum speed limit” dictates how fast a system can develop. These findings can be applied to fields such as chemical dynamics, metrology and computation.

Adolfo del Campo, of the Center for Nonlinear Studies, was drawn to this problem through a personal interest in the history and fundamentals of quantum mechanics. The uncertainty principle relating time and energy is well defined for closed systems but del Campo feels that it is not widely understood. He was motivated to apply it to open systems since the energy dispersion gives the speed of evolution. “I thought that extending it to open systems it was a significant step forward,” he said. “Ultimately any experimental system is an open system; it is coupled to an environment. The question arised: what plays the role of the energy dispersion then?”

In order to solve this problem del Campo *et al.* sought to find an analogous method to the one used in isolated closed systems. In such systems, the speed of evolution is bounded by passage time, the time in which an isolated state becomes orthogonal to itself through unitary dynamics. However, open systems (ones attached to the environment) are not unitary, that is the sum of all state probabilities does not equal one. They used the fidelity of two mixed states in order to measure the “distance” between them. The quantum speed limit was used to find the passage time from an initial state to a desired fidelity. This is analogous to the fact that speed limits on roads dictate the minimum time it will take a person to travel from one place to another.

Del Campo and his colleagues derived this minimum time analytically by solving the Lindblad master equation. The Lindblad equation governs the non-unitary evolution of Markovian systems, which only depend on the current state. This was done through the “purification” of the mixed states and applying unitary dynamics. Originally, they assumed the dynamics generator of the system was independent of time and that the system evolved much faster than the environment. After solving this system, the result was generalized where the field was allowed to be time dependent. The result was derived a third time using quantum channels which removed the Markovian approximation. Del Campo used this to look at the evolution of a pure state placed in a uniform environment. This system is initially pure but becomes a mixed state as time passes. Their analysis also produced an unexpected result. del Campo, “found that there are instances in which the noise of the system can increase the maximum speed of evolution. This can be done by increasing the coupling to the environment.” This phenomenon, in addition to the quantum speed limit, will have a large impact in applications.

Defining the maximum speed at which quantum systems can evolve affects a wide variety of fields, including quantum computation. The processing power of a quantum computer is limited by the maximum speed of evolution of its quantum states. Del Campo suggests that one could use coloured noise in order to improve the maximum computational speed. Quantum metrology is a field that uses the principles of quantum mechanics (especially entanglement) to develop incredibly precise measuring devices. The result of this research could lead to devices with faster detection rates and improved accuracy, and del Campo says that "Increasing the so called speed limit of one such device would allow for faster measurements which could theoretically yield more accurate results. This upper bound can be increased by the use of coloured noise (similar to the case of quantum computing). Knowledge of the upper bound also gives us the maximum precision of our measurement which is particularly useful for error analysis." Similarly, the quantum speed limit may be able to provide greater knowledge of the dynamics of chemical reactions at the quantum level.

Summary for use in RSS feeds

The upper bound to the speed of evolution for an open quantum system has been found by a group of physicists at the Los Alamos National Laboratory. This result applies to mixed states which undergo non-unitary evolution while coupled to an environment. It is also shown that the use of coloured noise can be used to increase the maximum speed of evolution. The results obtained have applications in the fields of quantum computation, chemical dynamics, and metrology.

Interview Transcript

Q: What motivated you to research open quantum systems?

A: The history of the time-energy uncertainty principle is a long and beautiful one, with results dating back to Landau, Krylow, etc. I have been familiarized with these results for years (I edited a volume in Time in quantum mechanics). The key result has been rederived and improved once and over again by different groups, no less than 20 times in the last 70 years. However, I got the feeling that not much understanding was gained out of it. I thought that extending it to open systems it was a significant step forward. Ultimately any experimental system is an open system, it is coupled to an environment. The question arised: what plays the role of the energy dispersion then? (The energy dispersion determines the velocity of evolution in close systems, in which the dynamics is unitary.)

Q: Were you driven by experiment or did you explore this to advance the field?

A: As you know I am mostly a theoretical physicist. While experiments are useful and allow us to verify our findings, it is important to do things for personal interest as well. The role of the energy dispersion was a question that had been one that I wanted to explore further and the result of that exploration is documented in this paper.

Q: What kind of response has there been to your research?

Well the paper was only published a couple of weeks ago! However there has been a positive response since we posted our work on arXiv in May. There have been a number of citations as well as groups looking to extend our work. In addition, we have been approached about the use of our work in an industrial setting but talks are still in a preliminary stage.

Q: It sounds like it has already made an impact on the scientific community. How do you think the paper will be extended?

A: It is important to note that the true impact of a paper cannot be determined until a year or two after publication. There are many promising applications that have arisen especially in the fields of quantum metrology and quantum computation. Knowledge of the upper bound on an open system allows you to determine the maximum speed of computation and the limits of physical systems. We also found that there are instances in which the noise of the system can increase the maximum speed of evolution. This can be done by increasing the coupling to the environment. One normally thinks of noise as a detrimental phenomenon however it can theoretically be used constructively to improve computation speed.

Q: I can see how this can provide more information about the limits of quantum computation and chemical dynamics (which you mentioned in the paper). I am curious how this result can be applied to quantum metrology. What advances do you see in the future of that field with respect to the upper bound of time evolution of systems?

A: As you know metrology involves building measuring devices and we can also make them using principles of quantum mechanics. Increasing the so called speed limit of one such device would allow for faster measurements which could theoretically yield more accurate results. This upper bound can be increased by the use of coloured noise (similar to the case of quantum computing). Knowledge of the upper bound also gives us the maximum precision of our measurement which is particularly useful for error analysis.

Q: I noticed on your website that you have a wide variety of research interests. Do you expect to apply this knowledge to other areas of your own research?

The results of this paper could be useful for areas such as quantum gases or non-equilibrium dynamics. Again it was mostly for personal interest so we will see what the future holds.

Q: Thanks again for doing this and best of luck with your future research!

A: It was a pleasure and thank you for being interested in my research. Cheers!