SAND2010-5928P

Workshop: Control and optimization of open quantum systems

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A Sandia-organized workshop entitled "Control and optimization of open quantum systems for information processing" was held at the American Institute of Mathematics (AIM) in Palo Alto, California from June 21st to June 25th, 2010. Matthew Grace (8961) originated the idea after participating in an earlier AIM workshop. The co-organizers, Constantin Brif (8961), Wayne Witzel (1435), and Andrew Landahl (1412), brought their expertise in optimal control, dynamical decoupling, and quantum error correction, respectively. AIM solicits proposals for workshops and fully funds the selected participants.
The goal of the workshop was to bring together a focused cadre of world experts in the areas represented by the co-organizers to tackle the challenge of quantum control, with an especial emphasis on quantum information processing (QIP) applications. The ability to control technology at the quantum-mechanical level opens entirely new areas of science and engineering, with QIP applications ranging from quantum teleportation to quantum cryptography to quantum computation. Because real quantum systems are "open" to their environment, controlling them requires more than just experimental finesse—it requires carefully designed protocols to minimize the impact of system-environment interactions. This is precisely what the approaches of optimal control, dynamical decoupling, and quantum error correction aim to do, but in very different ways.

To appreciate how disparate these approaches to quantum control are, consider how widely their mathematical underpinnings vary. Optimal control is based on variational calculus and uses gradient methods or genetic algorithms to search for time-dependent classical controls that, subject to whatever constraints exist, protects quantum information against environmental decoherence as well as possible. Dynamical decoupling, on the other hand, is based on Lie algebra theory and reduces the effective coupling of a quantum system to its environment to arbitrary orders in perturbation theory. Finally, quantum error correction is based on linear-algebraic coding theory and distributes quantum information across multiple subsystems so that local environmental disturbances can be detected and corrected. While these approaches are quite different, their goal is the same: to control quantum systems, preferably in a way that is fault-tolerant, namely in a way that is robust to imperfect knowledge of the system and imperfect mastery of the controls.

The informal "structure-the-workshop-as-you-go" format allowed for adequate time to educate each community's experts on the other's approaches, with ample time for interactive questioning. It also generated lively discussions about what the most important open problems are and where some of the greatest areas for cross-fertilization of ideas may lie. While some progress was made on these questions during the workshop, the most lasting impact of the workshop will likely be the new collaborations that were begun across communities that historically have not interacted much. As quantum technology becomes more and more pervasive, the demand to control it for information-processing tasks grows—hopefully some practical new solutions will be able trace their origins to this workshop.

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