Falsifying Local Realism

L.K. Shalm¹, Y. Zhang², P. Bierhorst¹, K. Coakley¹, S. Glancy¹, S.W. Nam¹, E. Knill¹

¹. National Institute of Standards and Technologies, Boulder, CO, USA
². Institute for Quantum Computing and Department of Physics and Astronomy, University of Waterloo, 200 University Ave. West, Waterloo, ON N2L 3G1, Canada

Bell’s inequality highlights the incompatibility between the predictions of local realism and quantum mechanics. This inequality has profoundly shaped our understanding of the foundations of quantum mechanics, and underpins many of the advances made in quantum information, quantum cryptography, and quantum computing. To date there has not yet been a full loophole-free test of Bell’s inequalities, but a number of efforts are underway world-wide to perform such an experiment. The goal is to rule out local realism as a viable description of nature—not to prove quantum mechanics. Even if such an experiment can be performed the standard analysis techniques are not robust enough to certifiably rule out local realism [1–2].

The standard method is to measure the Bell parameter and then quote how many standard deviations it lies from the Bell boundary. Such an approach makes Gaussian assumptions about the data and says nothing about how close a local realistic theory can come to explaining a given measurement record. It is easy to end up with a false level of confidence in a violation this way—something that is dangerous when using Bell tests for cryptographic applications. Here we present a robust method, based on hypothesis testing, that avoids the analysis pitfalls of the standard approach [3–4]. By falsifying the hypothesis that local realism can explain our measurement results we are then able to bound the probability that a local realistic theory can explain a particular measurement record. Our approach is not subject to memory loopholes and can be thought of as a powerful generalization of a standard Bell test. This provides a method for falsifying local realism, and has important applications to the certification of quantum random number generators and in cryptography.

Fig 1: In a Bell test the results allowed by local realism form a convex space. The boundaries of this space are composed of the different measurement settings and outcomes made by the parties carrying out the Bell test—any local hidden variable theory can be described as a linear combination of these vertices. In our analysis method we use hypothesis testing to certify the probability with which local realism is compatible with the experimental data record.

References


