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"Quantum Supremacy" and the Complexity of Random Circuit Sampling

Adam Bouland
Electrical Engineering and Computer Sciences, University of California, Berkeley, 387 Soda Hall
Berkeley, CA 94720, U.S.A.
abouland@berkeley.edu
https://orcid.org/0000-0002-8556-8337

Bill Fefferman
Electrical Engineering and Computer Sciences, University of California, Berkeley, 387 Soda Hall
Berkeley, CA 94720, U.S.A.
Joint Center for Quantum Information and Computer Science (QuICS), University of
Maryland/NIST, Bldg 224 Stadium Dr Room 3100, College Park, MD 20742, U.S.A.
wjf@umiacs.umd.edu
https://orcid.org/0000-0002-9627-0210

Chinmay Nirkhe
Electrical Engineering and Computer Sciences, University of California, Berkeley, 387 Soda Hall
Berkeley, CA 94720, U.S.A.
nirkhe@cs.berkeley.edu
https://orcid.org/0000-0002-5808-4994

Umesh Vazirani
Electrical Engineering and Computer Sciences, University of California, Berkeley, 387 Soda Hall
Berkeley, CA 94720, U.S.A.
vazirani@cs.berkeley.edu

Abstract

A critical goal for the field of quantum computation is quantum supremacy – a demonstration of any quantum computation that is prohibitively hard for classical computers. It is both a necessary milestone on the path to useful quantum computers as well as a test of quantum theory in the realm of high complexity. A leading near-term candidate, put forth by the Google/UCSB team, is sampling from the probability distributions of randomly chosen quantum circuits, called Random Circuit Sampling (RCS).

While RCS was defined with experimental realization in mind, we give strong complexity-theoretic evidence for the classical hardness of RCS, placing it on par with the best theoretical proposals for supremacy. Specifically, we show that RCS satisfies an average-case hardness condition – computing output probabilities of typical quantum circuits is as hard as computing them in the worst-case, and therefore #P-hard. Our reduction exploits the polynomial structure in the output amplitudes of random quantum circuits, enabled by the Feynman path integral. In addition, it follows from known results that RCS also satisfies an anti-concentration property, namely that errors in estimating output probabilities are small with respect to the probabilities themselves. This makes RCS the first proposal for quantum supremacy with both of these properties. We also give a natural condition under which an existing statistical measure, cross-entropy, verifies RCS, as well as describe a new verification measure which in some formal sense maximizes the information gained from experimental samples.

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