Testing the “quantum-ness” of quantum computers

Motivation

Quantum computers are powerful

\[ n \text{ qubits} \approx 2^n \text{ dimensions} \]

how can we verify it works correctly?

exponentially hard to test!\[\]

is it really quantum, or classical, or even more powerful…?

Testing entanglement

\[ \begin{align*}
&\text{Test for one qubit of entanglement} \\
&\text{CHSH game} \\
&A \in \{0,1\} \\
&B \in \{0,1\} \\
&X \oplus Y = AB \\
&\text{classical devices } \Rightarrow \Pr[\text{win}] \text{ up to } 75\% \\
&\text{quantum devices } \Rightarrow \Pr[\text{win}] \text{ up to } 85\% \\
\end{align*} \]

**Theorem:**

\[ \Pr[\text{win}] \geq 85\% - \epsilon \Rightarrow \text{state is } \sqrt{\epsilon}\text{-close to } |00\rangle + |11\rangle \]

Testing quantum physics

Is quantum theory complete?

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Einstein, Podolsky, Rosen, '35
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Motivation

Testing entanglement

**Open problems**

- More powerful tests
- More practical tests
- Test functionality as well as dimensionality and entanglement
- Separate quantum from k-local non-signaling correlations
- Experimental implementation in ion traps

References:


- R. Chao, B. Reichardt, C. Sutherland, T. Vidick.

- Submitted to QIP '17.

[2] Test for a large amount of entanglement, using few measurements.

- R. Chao, B. Reichardt, C. Sutherland, T. Vidick.


- B. Reichardt; F. Unger; L. Vazirani. Nature '13

[4] A test to separate quantum theory from non-signaling theorems.


Protocol:

- Measure \( X_i, Z_j, \ldots, X_k, Z_k \)

- \( \text{or } Z_1, X_1, \ldots, Z_k, X_k, Z_k, X_k \)

Theorem:

success \( 1 - \epsilon \Rightarrow \dim H \approx (1-O(\epsilon)) \cdot 2^n \)