Testing the "quantum-ness" of quantum computers

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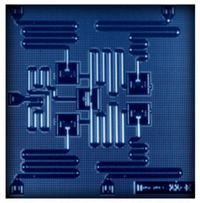
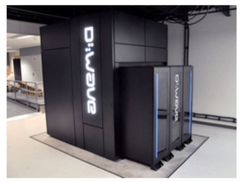
Motivation

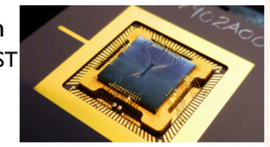




1152 superconducting qubits*, D-Wave

5 superconducting qubits, IBM

16 trapped ion qubits, UMD / NIST



quantum computers are powerful

n qubits⇒2^n dimensions

how can we verify it works correctly?

exponentially hard to test !

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

Testing dimensionality[1]

n qubits $\stackrel{?}{\Rightarrow}$ 2^n dimensions

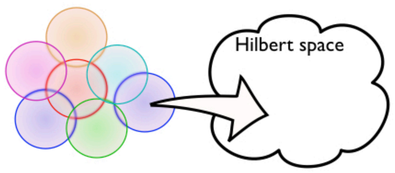
no precise test, **qubits can overlap**

Definition:

a qubit is a pair of *anti-commuting* reflections

$X = X^\dagger, Z = Z^\dagger$
$X^2 = Z^2 = I$
$\{X, Z\} = 0$

1000 qubits fit in 2^{20} dimensions!

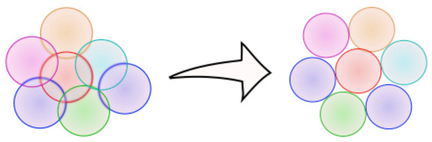


Theorem:

2^n dimensions can fit $e^{n\epsilon^2}$ overlapping qubits

s.t. $||[P_j, Q_k]|| \le \epsilon \quad \forall\, j \neq k$

low-dimensional system can't totally fool us



efficient test for n independent qubits

Protocol:

measure $X_1, Z_1, \ldots, X_k, Z_k, \ldots, X_n, Z_n, Z_k$

or $Z_1, X_1, \ldots, Z_k, X_k, \ldots, Z_n, X_n, X_k$

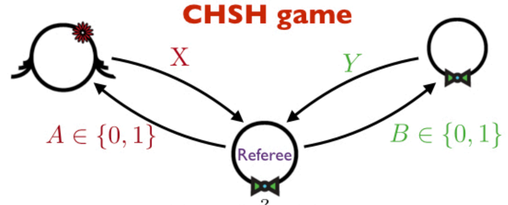
Theorem:

success 1-ϵ ⇒ dimH ≥ (1-O($n^2\epsilon$))$\times 2^n$

Testing entanglement[2]

Test for one qubit of entanglement

CHSH game

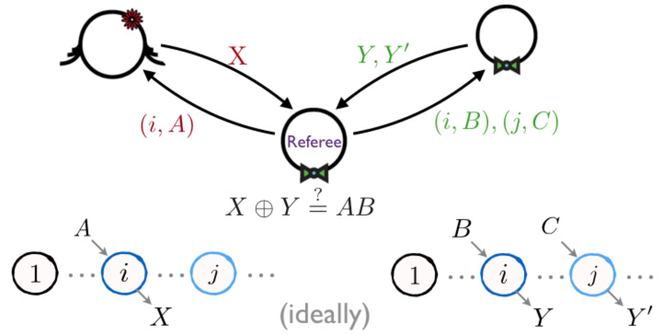


classical devices ⇒ Pr[win] up to 75%
quantum devices ⇒ Pr[win] up to 85%

Theorem:[3]

Pr[win]≥85%-ϵ ⇒ state is $\sqrt{\epsilon}$-close to $|00\rangle + |11\rangle$

Test for n qubits of entanglement



Theorem:

Pr[win]≥opt -ϵ ⇒ $\sqrt{n^{5/2}\epsilon}$-close to $|EPR\rangle^{\otimes n}$

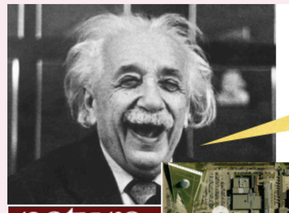
Open problems

- 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:

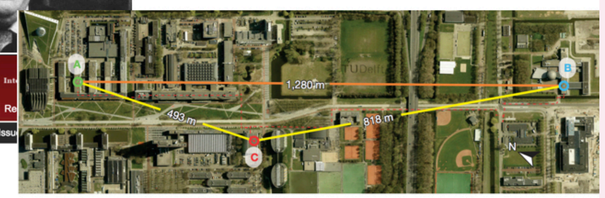
[1] Overlapping qubits.
R. Chao, B. Reichardt, C. Sutherland, T. Vidick.
Submitted to QIP '17.
[2] Test for a large amount of entanglement, using few measurements.
R. Chao, B. Reichardt, C. Sutherland, T. Vidick.
Submitted to QIP '17. arXiv:1610.00771 [quant-ph].
[3] Classical command of quantum systems.
B. Reichardt, F. Unger, U. Vazirani. Nature '13
[4] A test to separate quantum theory from non-signaling theories.
R. Chao, B. Reichardt. In preparation.

Testing quantum physics[4]



Is quantum theory complete?

Einstein, Podolsky, Rosen, '35



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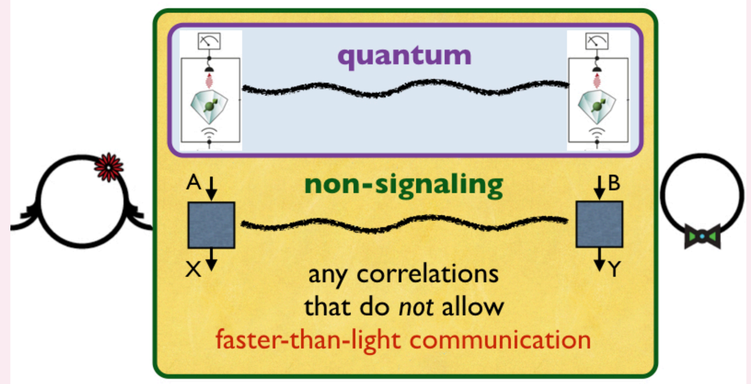
B. Hensen, H. Bernien, A. E. Dréau, A. Reiserer, N. Kalb, M. S. Blok, J. Ruitenbe
Vermeulen, R. N. Schouten, C. Abellán, W. Amaya, V. Pruneri, M. W. Mitchell, M
D. J. Twitchen, D. Elkouss, S. Wehner, T. H. Taminiau & R. Hanson

Affiliations | Contributions | Corresponding author

Nature **526**, 682–686 (29 October 2015) | doi:10.1038/nature15759

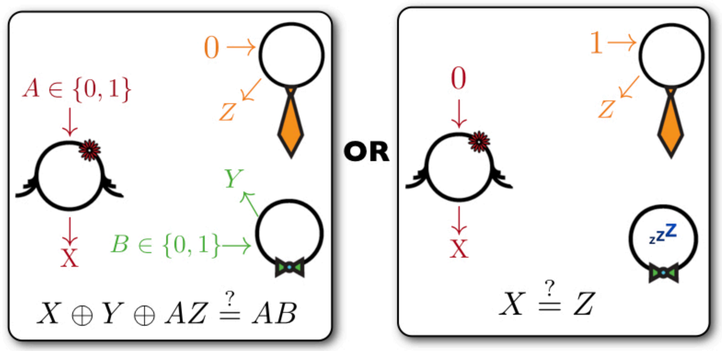
reality is **non-local**

"action at distance" is real



e.g., Pr[XY|AB]=$\begin{cases} 1/2, & \text{if } X\oplus Y=AB \\ 0, & \text{otherwise} \end{cases}$

is non-signaling
Pr[win]=1 !
quantum≤85%



Theorem:

Quantum devices (using $|000\rangle + |111\rangle$)
can win w.p. **5% more than**
any classical devices sharing two-local non-signaling boxes