A verification scheme for universal quantum computers

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Overview

Quantum Computers

What are Quantum computers?

Quantum computers are devices that perform computational tasks using quantum bits (qubits).

Qubits

Qubits are quantum binary units that exhibit properties such as superposition, entanglement etc.

Why Quantum Computers?

Quantum computers are believed to outperform classical computers in undertaking certain tasks like prime factorisation, search algorithms etc.

Need for a Verification Scheme

- One of the responsibilities of the developers of the computers is verification.
- I.e. the accuracy of the quantum computers in undertaking the assigned task.
- Quantum computers are believed to solve problems that are intractable by classical computers.
- This raises the need for verification of the results produced by the quantum computers.

Haar-Measure

Haar Measure: Uniform probability measure defined on a group which is translation invariant.

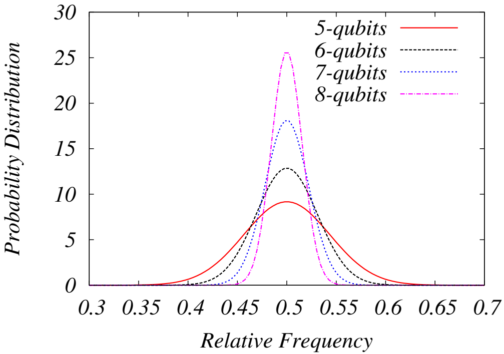
- In case of generating random matrices from $SU(n)$ based on Haar Measure, the distribution of matrices is invariant under group operation.
- $SU(n)$ is a special rotation group in complex space.
- This is equivalent to choosing points on a circle that are uniformly distributed.
- This distribution of the points on the circle does not change under the rotation of the axes.

Verification Scheme

- We present a new verification scheme for universal quantum computers.
- Our aim is finding the total number of working qubits and the error probability.
- We implement a set of random gates drawn from Haar Measure on the quantum computer.
- We make a measurement and repeat to obtain the relative frequencies (P) with which 0 and 1 occur.
- Repeating the procedure different set of gates gives us a distribution for P.

Meta Distribution

- The distribution of P is called the meta distribution p(P).
- The meta-distribution resembles a Normal distribution with standard deviation, $\sigma = \sqrt{\frac{1}{4(D+1)}}$, where $D = 2^n$.



Error Estimation and Correction for number of Qubits

- Using the standard deviation of the meta-distribution the total number of qubits in the computer can be estimated, $n \approx -2\log_2 2\sigma$.
- This does not account for the noise in the quantum computer.
- For error estimation, we implement use random gates and their inverses where the ideal output is the original state $|00...0\rangle$.
- The probability with which we recover the original state is the fidelity, f and $1 - f$ is the percentage noise.
- The standard deviation, corrected by accounting for the noise measured is given by $\sigma = \sigma_e / f$

Error Analysis

- Number of repetitions required from a single unitary is given by $N \geq \frac{10}{\sigma_e}$, ensuring the probabilities are estimated to a factor of $1/10$ the standard deviation.
- Using χ^2 analysis, we can calculate the confidence interval $(\Delta\sigma)$ of our standard deviation depending upon number of different unitaries we use.
- With help of error propagation we can write $\Delta n = -\frac{2\Delta\sigma}{\sigma \log_e 2}$.
- Such that $n \in [n_e - \Delta n/2, n_e + \Delta n/2]$, where n_e is estimated number of qubits.

Conclusion

- Our verification scheme estimates both the number of working qubits on a quantum computer and the noise in the system.
- This doesn't require assistance from classical computers in the verification of the data produced.

Thanks!