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The Role of Quantum Interference in Quantum Computing

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Quantum interference is proposed as a tool to augment Quantum Computation.

KEY WORDS: quantum computing.

1. CAN QUANTUM INTERFERENCE AUGMENT QUANTUM COMPUTATION?

1.1. The dilemma

The power of quantum computing lies in the quantum ability to have a linear superposition of all possible states (Hadamard spread), so that one could produce the following, non-entangled, 3 qubit state (we ignore the normalizations throughout for simplicity).

$$
\begin{aligned}
|\psi\rangle &= (|0\rangle + |1\rangle)(|0\rangle + |1\rangle)(|0\rangle + |1\rangle) \\
&= |000\rangle + |001\rangle + |010\rangle + |011\rangle + \cdots + |111\rangle
\end{aligned}
$$

A function f applied to this one state results in the evaluation of this function for each component, and herein lies the exponential parallelism of quantum computing.

This information, however, is not directly accessible, as the act of measurement picks out only one of the components, and therein lies the dilemma of quantum computing.

1.2. The response

Let us start with the same state as above, and like Grover's algorithm, apply the decision function to mark the invalid solutions by changing their sign. For the

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sake of argument let us suppose that solutions 001 and 010 satisfy the function, which yields the state:

$$-|000\rangle + |\mathbf{001}\rangle - |010\rangle + |\mathbf{011}\rangle + \cdots - |111\rangle$$

which has got us nowhere at all, *unless* one were to bring in the mechanism of Young's double slit or the beam splitter interferometer, with the marking function being applied to one of the two arms alone. Then interference would yield:

$$\begin{gathered} -|000\rangle + |\mathbf{001}\rangle - |010\rangle + |\mathbf{011}\rangle - \cdots - |111\rangle \\ +|000\rangle + |\mathbf{001}\rangle + |010\rangle + |\mathbf{011}\rangle + \cdots + |111\rangle \end{gathered}$$

to expose the desired solutions

$$|\mathbf{001}\rangle + |\mathbf{011}\rangle$$

one of which will be seen upon measurement, and can be confirmed on a classical computer, if so desired. The two arms are brought into overlap and not sent through a final beam splitter as is typical of an interferometer.

To locate the remaining solution, one can start over, and exclude the known solution by also flipping its sign in one of the two interference arms. Eventually all solutions will be located and removed, so the final run will expose either a non-valid solution or a previously found solution from the remnants of the wave-function.

Concerns over lost unitarity can be allayed by noting that a quantum computer typically starts by transforming a sharp (ground) state into a superposition, and that this is a unitary change. All that is happening here is the inverse, and so the process is also unitary.

In practice, due to imperfect cancellation, this process may need to be repeated a few times.

2. IMPLICATIONS FOR ERROR CORRECTION

The amplitudes are analogue and the states digital in nature; so errors in the amplitude, no matter how small, might be expected to affect all qubits in an error correction scheme, which so could not be completely removed. In contrast, small errors in the state would only flip one qubit of a state, which is amenable to correction.

Since the approach to quantum computing being proposed here is insensitive to small changes in amplitude, this technique may benefit from digital robustness.

3. CONCLUSION

By explicitly introducing an interferometer, a generic exponential speedup seems possible, and the system may be more robust to error correction.

After completion of this work (arXiv:cs.CC/0507003) it was discovered that Finkelstein and Castagnoli had also been working on using quantum interference to achieve a milder generic speed up of a quantum computer, under the name quantum interferometric computation (QUIC),[2] as well as a similar proposal by Gui Lu Long (arXiv:quant-ph/0512120) achieving the full exponential speedup.

[2] Private Communication 2nd Dec 2005: Professor David Finkelstein.