Quantum Computation in T6: Achievements of FY96

The T6 Quantum Computation effort consists of:

1) W. H. Zurek, Laboratory Fellow
2) R. Laflamme, Oppenheimer Fellow
3) B. Schumacher, Consultant
4) J. Anglin, Post-Doctoral Fellow
5) J. P. Paz, Post-Doctoral Fellow
6) C. Miquel, GRA
7) I. Chuang, GRA

In the coming fiscal year, three new postdoctoral fellows who have expressed interest in quantum computation will join the T-6 effort (I. Chuang, who will convert from a GRA appointment, C. Jarzynski, and B. Resnik).

Financial profile for this effort for FY96

National Security Agency $ 60 K

(PI - W. H. Zurek; R. Laflamme, J. Anglin, as well as E. Knill (CIC-3) are the key co-investigators).

Papers for FY 96

1) "Quantum Computer, Factoring and Decoherence"; I.L.Chuang, R.Laflamme,P.Shor & W.H.Zurek, quant-ph/9503007, Science 270, 1633, 1995.
2) "Decoherence and a Simple Quantum Computer", I.L. Chuang, R.Laflamme and Y.Yamamoto, published Quantum Cohenrece ad Decoherence, Foundations of Quantum Mechanics in the Light of New Technology, Edited by K.Fujikawa and Y.A. Ono North Holland Delta Series, Elsevier 1996.
3) "Quantum Error Correction by Coding", I.L. Chuang and R. Laflamme, quant-phys/951003, Los Alamos National Laboratory Report LA-UR-95-3641, submitted to Physica Review Letters.
4) "Perfect Quantum Error Correcting Code"; R.Laflamme, C. Miquel, J.P. Paz & W.H.Zurek, quant-ph/9602019, Physical Review Letters, 98, 77, 1996.
5) "Quantum Logical Operations on Encoded Qubits"; W.H.Zurek and R.Laflamme to appear in Physcal Review Letters, LAUR-96-1810.

6) "A Theory of Quantum Error Correcting Codes"; E.H.Knill and R.Laflamme submitted to Physical Review A, April 1995, LA-UR-96-1266.

7) "Decoherence Bounds on Quantum Computation with Trapped Ions"; R. Hughes, D.F. James, E.H.Knill, R.Laflamme and A. Petschek, Physical Review Letters, XXX, 77, 1996.

8) "Quantum Logic with Qubytes"W. H. Zurek and R. Laflamme. Extended Abstract for *Physics of Computation 96* (accepted).

9) "Concatenated Quantum Codes" E. Knill and R. Laflamme, quant-ph/9608012, LAUR-96-2808.

10) "Factoring in a dissipative quantum computer", Cesar Miquel, Juan Pablo Paz, and Roberto Perazzo, to appear in *Phys.Rev.A*.

11) "Quantum Coding",B. Schumacher, Phys.Rev.A51,2738,1996.

12) "Quantum Data Processsing and Error Correction" M. Nielsen and B. Schumacher, LANL e-print quant-ph/9604022.

13) "Decoherence of quantum fields: Pointer states and predictability" J. R. Anglin and W. H. Zurek, Phys.Rev.D53,7327,1996.

14) "Deconstructing Decoherence", J. R. Anglin, J. P. Paz, and W. H. Zurek, Phys.Rev.D, submitted.

Quick Overview

Within the past two years, quantum communication and computation have undergone a dramatic evolution. From being subjects of essentially academic interest, they have become fields with an enormous potential to revolutionize computer science, a possible impact on issues of national security, and a conceivable economic promise. This has occurred as a result of the development of new algorithms such as quantum factoring which can be used for factoring large numbers in a polynomial time.

Quantum Computers will be much more powerful than their classical counterparts only if they can use the tremendous parallelization inherent in quantum mechanics. The most important problem in quantum computation and communication at present is the understanding and reduction of the effects of noise, decoherence and unreliable operations on the desired state of the system. This is the main thrust of T6's endeavor. In this we are collaborating with colleagues from other groups and divisions (the collaboration with E. Knill of CIC-3 has been particularily helpful; discussions and collaborations with the laboratory wide quantum computation community have been useful and stimulating;

we have extensive contacts and/or on-going collaborations with colleagues at ATT, IBM, Caltech, Oxford, Ecole Normale Superieure,...).

Our effort is based on the long tradition of the research on decoherence and the physics of information, where many of the ideas presently discussed in the context of quantum computation and communication have originated. In terms of the goals, our aims are similar to these of the research conducted at IBM and ATT, where the implications of quantum computers and strategies for error correction as well as the analysis of error sources is conducted in complete generality, so that it may be used as a basis for quantum computational strategies regardless of the specifics of the physical implementations.

The first part of our research [1,2,10,12-14] investigates the phenomena of decoherence (the propensity of losing quantum information) and its importance for quantum computation. In [1], the importance of decoherence for quantum factoring has been assessed. [10] gives a detail implementation of the factoring algorithm and studies the influence of spontaneous emission on the results of the computation. The effect of decoherence is ananlysed in [2] on a simple quantum computer where photons carry the quantum information, while in [13] and [14] general laws governing decoherence in quantum systems are investigated.

The second part of our research has focused on finding ways to reduce the effect of decoherence, noise and errors during quantum computation. We have worked on a general theory of error correction for quantum computers and communication [6]. This has laid the groundwork to understand the basics properties for such a theory. We have also focused on different types of codes for error correction. In [4], we have presented the most compact code (the perfect 5-bit code), which preserves 1 qubit of information against 1 general qubit error. In [9], we have shown how codes can be combined in a such way (concatenation) that once a certain bound is achieved for the error rate, we can preserve a quantum state as long as desired.

This long-standing leadership has been recognised outside of the laboratory in the form of invited talks and invitations to seminars. Moreover, one of us (W. H. Zurek) has been chosen to organise the "Quantum Computation and Quantum Coherence" program at the Institute for Theoretical Physics (ITP, UC Santa Barbara, July-December 1996) and in the future at the Isaac Newton Institute (planned for May-August, 1999, and just approved). This will facilitate contacts for the entire Los Alamos quantum computing community.