Effects of Decoherence and Imperfections for Quantum Information Processing (EDIQIP)

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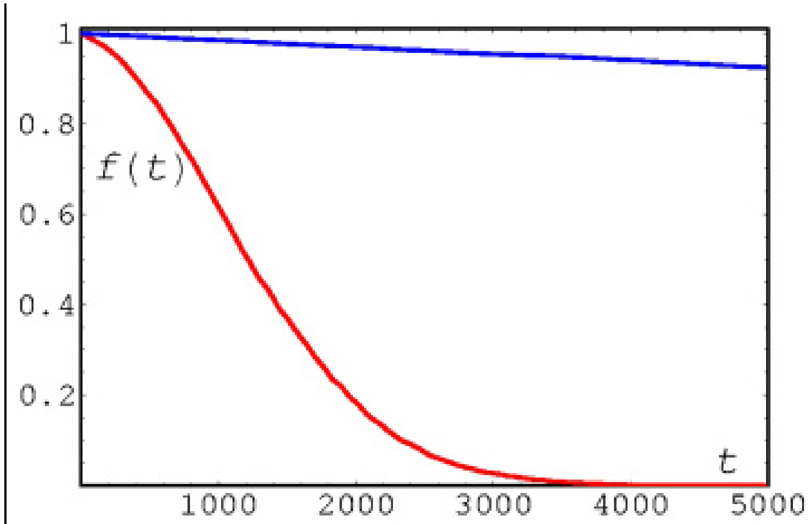
Objective

• Effects of realistic imperfections on quantum computer operability and accuracy
• Decoherence and quantum chaos induced by inter-qubit couplings
• New efficient algorithms for simulation of quantum and classical physical systems
• Numerical codes with up to 30 qubits
• Development and test of error-correcting codes for quantum chaos and noisy gates



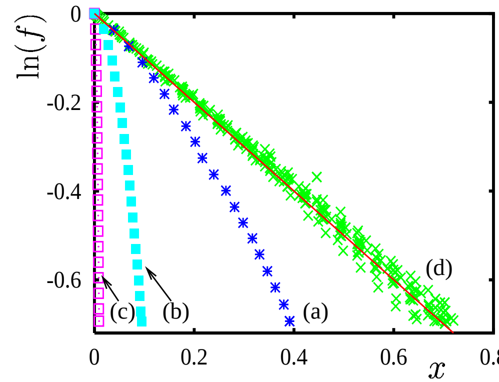
Objective Approach

• Analytical methods developed for many-body systems (nuclei, atoms, quantum dots)
• Random matrix theory and quantum chaos
• Large-scale numerical simulations of many qubits on modern supercomputers
• Stability of algorithms to quantum errors

Success Story

• Quantum chaos due to static imperfections with energy shifts and inter-qubit interactions
• Polynomial algorithms for complex dynamics
• Universal law for fidelity decay given by random matrix theory, more rapid than random errors in quantum gates, 20 qubits numerics
• Pauli random error correction method

Universal fidelity decay law in quantum chaos algorithms



Static quantum computer hardware (DLS, Georgeot (2000)):

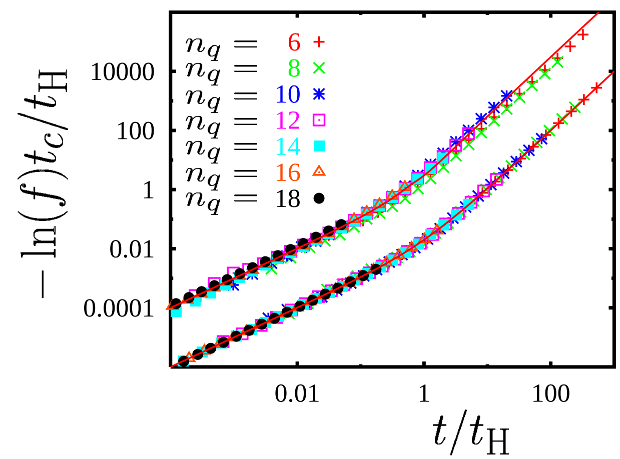
$$H_{\mathsf{S}} = \sum_i (\Delta_0 + \delta_i)\sigma_i^z + \sum_{i<j} J_{ij}\sigma_i^x\sigma_j^x,$$

$(\delta_i \sim \delta,\ J_{ij} \sim J,\ \Delta_n \sim \delta/N,\ N = 2^{n_q})$

Emergence of quantum chaos for: $J > \delta/n_q \gg \Delta_n$

Quantum algorithms for quantum chaos maps:

($n_g \approx 9{n_q}^2/2$ elementary gates for vector size N in tent map)



Random matrix theory for fidelity decay $f(t)$:

$f(t) = \exp(-[t/t_c + t^2/(t_c t_{\mathrm{H}})])$

two time scales: $t_c \approx 1/(\varepsilon^2\, n_q\, n_g^2)$, $t_{\mathrm{H}} \approx 2^{n_q}/3$

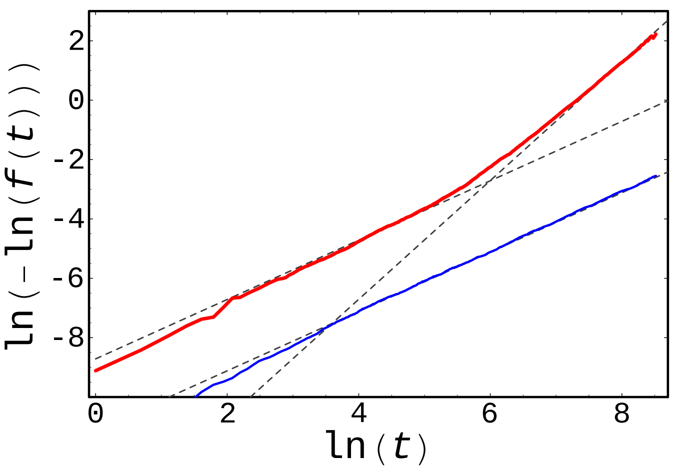
Coherent errors give more rapid fidelity decay compared to random errors in quantum gates

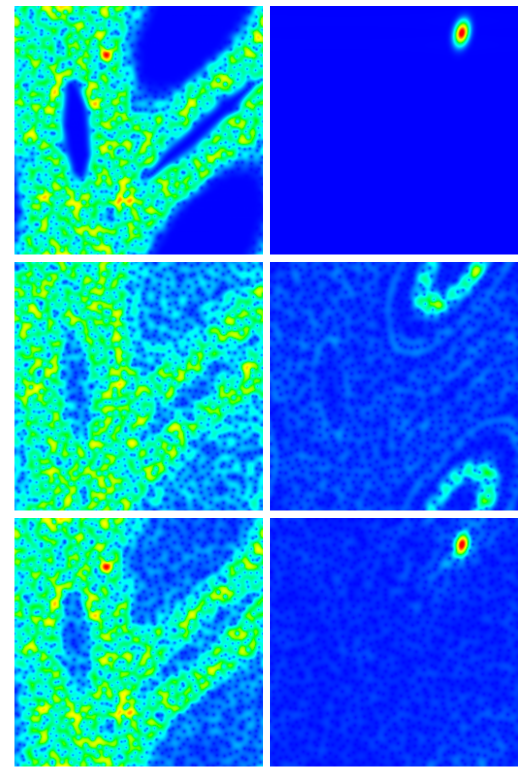
Pauli random error correction method (PAREC)

Static imperfections → coherent errors $n_q = 10, K = 1.7, \epsilon = 5 \cdot 10^{-6}$

PAREC: application of random Pauli rotations after certain number of gates makes random re-ordering of computational basis following the programmer order

NO REDUNDANCY





DRASTIC INCREASE OF FIDELITY

“Enrico Fermi” School on Quantum Computers, Algorithms and Chaos

Villa Monastero, Varenna, Como Lake, Italy, July 5th-15th, 2005

Directors: G. Casati (Como), D.L. Shepelyansky (Toulouse), P. Zoller (Innsbruck)
Scientific Secretary: G. Benenti (Como)
Lecturers: D. Averin (Stony Brook), C.W.J. Beenakker (Leiden) I. Bloch (Mainz), D. Bouwmeester (Santa Barbara), H.J. Briegel (Innsbruck), N. Davidson (Weizmann), R. Dum (Brussels), J. Eschner (Barcelona), D. Esteve (Saclay), H. Everitt (ARO), R. Fazio (Pisa), B. Georgeot (Toulouse), M. Grassl (Karlsruhe), R. Laflamme (Waterloo) H. Mabuchi (Caltech), A. Steane (Oxford), P. Tombesi (Camerino), L.M.K. Vandersypen (Delft), G. Vidal (Caltech)
Topics: Introduction to quantum computing, Quantum logic, information and entanglement, Quantum algorithms, Error-correcting codes for quantum computations, Quantum measurements and control, Quantum communication, Quantum optics and cold atoms for quantum information, Quantum computing with solid state devices, Theory and experiments for superconducting qubits, Interactions in many-body systems: quantum chaos, disorder and random matrices, Decoherence effects for quantum computing, Future prospects of quantum information processing

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