ERCIM “Alain Bensoussan” Fellowship Scientific Report

Fellow: Sara Felloni
Visited Location: UNIK and NTNU, Norway
Duration of Visit: 1 year

I - Scientific activity

(1 page at maximum)

I study error models capable of describing all physically possible single-qubit and two-qubit errors, in order to offer a complete and realistic description of the most general experimental situation which could happen in quantum computational or communication frameworks. General error models are achieved by analyzing general transformations of single-qubit and two-qubit density matrices.
I also study physically realistic errors in the main experimental implementations of universal two-qubit operations.

Error models allow the investigation of the qualitative behavior and noise tolerance of quantum algorithms and protocols, such as quantum privacy amplification techniques for entanglement purification in quantum cryptography, or numerical simulations of the dynamics of quantum systems. I also apply the designed error models to test quantum error correcting codes in presence of multiple single-qubit errors.

Diagrams of states are a novel method to graphically represent and analyze how quantum information is elaborated during computations performed by quantum circuits. The diagrams-of-states technique helps describe in a very intuitive way several basic quantum features and processes: the evolution of open quantum systems, the basic single-qubit transformations describing decoherence and errors, the role of entanglement in quantum information, the action of quantum copying machines, the distinctive features of renown quantum algorithms, or the working of error correcting codes.

Quantum cryptography allows secure communication by exploiting the properties of quantum information. Such communications, in theory completely secure, could be hacked in practical implementations by taking advantage of non-ideal behavior of the equipment and other kind of imperfections. In the Quantum Hacking group, I studied how it is possible to prove security even in realistic conditions and to incorporate into security proofs the imperfections that cannot be eliminated from the system.

II- Publication(s) during your fellowship

Please insert the title(s), author(s) and abstract(s) of the published paper(s). You may also mention the paper(s) which were prepared during your fellowship period and are under reviewing.

1. Felloni, S. and Strini, G., Quantum diagrams of states: Methods and applications, invited review paper to appear in "Quantum Computers: Theory, Operation and Potential", Nova Science Publishers.

2. Felloni, S. and Strini, G., Quantum algorithms by diagrams of states: Deutsch's and Grover's algorithms, to appear in the Electronic Journal of Theoretical Physics.

3. Felloni, S. and Strini, G., An error model for the Cirac-Zoller CNOT gate, A. Sergienko, S. Pascazio, and P. Villoresi (Eds.): Quantum Communication and Quantum Networking, Revised Selected Papers, QuantumComm2009 LNICST 36, (2010) 210219; arXiv:0909.3783[quant-ph].

4. Felloni, S. and Strini, G., Entanglement-based quantum computing by diagrams of states, International Journal of Applied Mathematics and Computer Sciences 5:4 2009, 202-212.

5. Felloni, S., Leporati, A. and Strini, G., Evolution of quantum systems by diagrams of states, to appear in the International Journal of Unconventional Computing; arXiv:0912.0026[quant-ph].

Authors information:
* corresponding author
1 NTNU - The Norwegian University of Science and Technology, Department of Electronics and Telecommunications, NO-7491, Trondheim, Norway
2 UNIK - University Graduate Center, NO-2027 Kjeller, Norway
3 Dipartimento di Informatica, Sistemistica e Comunicazione, Università degli Studi di Milano – Bicocca, Viale Sarca 336/14, 20126 Milano, Italy
4 Dipartimento di Fisica, Università degli Studi di Milano, Via Celoria 16, 20133 Milano, Italy

Quantum Diagrams of States: Methods and Applications

SARA FELLONI 1,2,*, GIULIANO STRINI 4

Abstract — We present Quantum Diagrams of States, a novel method to graphically represent and analyze how quantum information is elaborated during computations performed by quantum circuits.
Diagrams of states are a useful approach to analyze given quantum computations, as they offer an intuitive graphic representation of the processing of quantum information.
They also help conceive novel quantum computations, from describing the desired information processing to deriving the final implementation by quantum circuits.
Diagrams of states provide novel explorations and representations of canonical quantum operations and computations. Starting from a tutorial introduction to the method, we illustrate the basics of the graphic representation of states while providing useful examples of quantum computations: elementary operations in single-qubit, two-qubit and three-qubit systems, immersions of gates on higher dimensional spaces, generation of single and multi-qubit states, procedures to synthesize unitary, controlled and diagonal matrices.

Subsequently, diagrams of states prove to be an useful tool to investigate the main processes involved in the evolution of general quantum systems, as well as to explore entanglement in composite quantum systems and how its peculiar properties are exploited in quantum information and communication protocols. We explore partial measurements, permutations of qubits and states, quantum state representation by density matrices, partial trace operations, density matrix purification and evolution according to the Kraus representation, and we further investigate by diagrams of states a general model for single-qubit decoherence and errors. Then, we present quantum diagrams of states for Bell states generation, measurements and projections, for dense coding and quantum teleportation, for probabilistic quantum machines designed to perform approximate quantum cloning and universal NOT and, finally, for quantum privacy amplification based on entanglement purification.
Finally, diagrams of states allow for a detailed analysis of the main currently known quantum algorithms, which can be enumerated under a few classes on the basis of their common features and applications. Here we describe in detail by means of diagrams of states the functioning of two of their main representatives, Deutsch's and Grover's algorithms. A similar analysis of other main quantum algorithms will be accomplished in future works, thus completing our survey of quantum computing by the diagrams-of-states graphic representation.

To appear

Quantum Algorithms by Diagrams of States: Deutsch and Grover's Algorithms

SARA FELLONI 1,2,*, GIULIANO STRINI 4

Abstract — We investigate quantum algorithms by means of Diagrams of States, a method to graphically represent and analyze how quantum information is elaborated during computations performed by quantum circuits.
In previous works we introduced the diagram-of-states graphic representation and applied it to describe how general quantum systems evolve and how entanglement can be exploited in quantum information to perform otherwise impossible tasks.
Quantum algorithms can be enumerated under a few classes on the basis of their common features and applications. Here we describe in detail the functioning of two of their main representatives, Deutsch and Grover's algorithms, by means of diagrams of states. A similar analysis of other main quantum algorithms will be accomplished in future works, which will complete our survey by the diagrams-of-states graphic representation.
Diagrams of states prove to be a useful approach as they offer an intuitive representation of quantum information processing.
They can also help in conceiving novel elaborations of quantum information, from describing the desired information processing to deriving the final implementations by quantum circuits.

To appear

An Error Model for the Cirac-Zoller CNOT gate

SARA FELLONI 1,2,*, GIULIANO STRINI 4

Abstract - In the framework of ion-trap quantum computing, we develop a characterization of experimentally realistic imperfections which may affect the Cirac-Zoller implementation of the cnot gate.

The cnot operation is performed by applying a protocol of five laser pulses of appropriate frequency and polarization. The laser-pulse protocol exploits auxiliary levels, and its imperfect implementation leads to unitary as well as non-unitary errors affecting the cnot operation.
We provide a characterization of such imperfections, which are physically realistic and have never been considered before to the best of our knowledge. Our characterization shows that imperfect laser pulses unavoidably cause a leak of information from the states which alone should be transformed by the ideal gate, into the ancillary states exploited by the experimental implementation.

QuantumComm2009 LNICST 36, (2010) 210219

Entanglement-based Quantum Computing by Diagrams of States

SARA FELLONI 1,2,*, GIULIANO STRINI 4

Abstract — We explore entanglement in composite quantum systems and how its peculiar properties are exploited in quantum information and communication protocols by means of Diagrams of States, a novel method to graphically represent and analyze how quantum information is elaborated during computations performed by quantum circuits.
We present quantum diagrams of states for Bell states generation, measurements and projections, for dense coding and quantum teleportation, for probabilistic quantum machines designed to perform approximate quantum cloning and universal NOT and, finally, for quantum privacy amplification based on entanglement purification.
Diagrams of states prove to be a useful approach to analyze quantum computations, by offering an intuitive graphic representation of the processing of quantum information. They also help in conceiving novel quantum computations, from describing the desired information processing to deriving the final implementation by quantum gate arrays.

International Journal of Applied Mathematics and Computer Sciences 5:4 2009

Evolution of Quantum Systems by Diagrams of States

SARA FELLONI 1,2,*, ALBERTO LEPORATI 3, GIULIANO STRINI 4

Abstract - We explore the main processes involved in the evolution of general quantum systems by means of Diagrams of States, a novel method to graphically represent and analyze how quantum information is elaborated during computations performed by quantum circuits. We present quantum diagrams of states for representations of quantum states by density matrices, partial trace operations, density matrix purification and time-evolution by Kraus operators. Following these representations, we describe by diagrams of states the most general transformations related to single-qubit decoherence and errors.
Diagrams of states prove to be a useful approach to analyze quantum computations, by offering an intuitive graphic representation of the processing of quantum information. They also help in conceiving novel quantum computations, from describing the desired information processing to deriving the final implementation by quantum gate arrays.

To appear

III -Attended Seminars, Workshops, and Conferences

Please identify the name(s), date(s) and place(s) of the events in which you participated during your fellowship period.

1. Organizer and chair of the Quantum Communication Workshop 2010 at UNIK, Kjeller, NO; talk: Quantum errors in quantum communication [01/02/2010]

2. Contributed Talk: An error model for the Cirac-Zoller CNOT gate, First International Conference on Quantum Communication and Quantum Networking - QuantumComm2009, Naples, IT [30/10/2009]

3. Seminar Talk: Quantum information processing and diagrams of states, Academic Forum on Security - AFSecurity meetings, UNIK, Kjeller, NO [17/09/2009]

4. Invited Talk: Diagrams of states and error models in quantum information processing, World Congress on Science, Engineering and Technology, Oslo, NO [29/07/2009]

IV – Research Exchange Programme (12 month scheme)

Please identify the name(s), date(s) and place(s) of your Research Exchanges during your fellowship period and detail them.

1.
Visit to the Quantum Information Theory groups at the Institute of Theoretical Computer Science and Institute of Theoretical Physics, ETH Zurich, Zurich, CH
(ERCIM 1st Research Exchange Programme) [11-25/01/2010].
Participation to the international conference QIP2010, tutorial and scientific programs.
Scientific contacts:
Prof. Renato Renner, Quantum Information Theory group at the Institute of Theoretical Physics, ETH Zurich;
Prof. Stefan Wolf, Quantum Information Theory group at the Institute of Theoretical Computer Science, ETH Zurich.

2.
Visit to the Quantum Information group at TelecomParisTech and INRIA, Paris, FR
(ERCIM 2ndResearch Exchange Programme) [11-16/02/2010].
Participation to the COCQ project meeting, and presentation of my activities at UNIK & NTNU to the INRIA and TelecomParisTech groups.
Scientific contacts:
Dr. Eleni Diamanti, Quantum Information group, TelecomParisTech;
Dr. Jean-Pierre Tillich, INRIA.