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Editorial: Introduction and Motivations

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If you google for "open system" you get plenty of information about security services and consulting firms, as well as IT companies and industries. They explain about firewalls, vpn, intrusion detection, security standards, violations, protection of corporate assets, anti-spam, anti-virus, authentication, service and maintenance, proxy, and audits. Their mission is "to build and foster relationships with clients by providing dedicated, passionate and unrivaled service", to design "open and timely communications", and to this end some of them provide a full range of staffing services and solutions. Their main objective is to make one feel secure. Openness to the external world is viewed as a threat.

We pretend to be open and to like open systems, but in fact we do not. We prefer closed systems, as they are more controllable and certainly easier to deal with. Closed systems are a cradle.

I wonder whether it is not the same with quantum mechanics. Quantum mechanics originally followed the typical "Western" approach to science, based on Greek philosophy: a system is something separated from the rest of the universe and when the rest of the universe interacts with it we invent all sorts of things to describe these "interactions". We then go back to the system and analyze it. In the worst case, "external", God-given forces are time-dependent. Divide and conquer.

The gentle rocking of the cradle of closed Hamiltonian systems helped us relax peacefully for more than 50 years. Then Gorini, Kossakowski, Lindblad and Sudarshan woke us up [1, 2, 3]. Not only closed quantum systems do not exist, but the dynamical laws that govern (existing) *open* quantum systems bring to light interesting and unexpected facets of the ways Nature behaves. Entanglement and complete positivity are just two of these aspects. So "open" is not only necessary, it is also beautiful after all.

The "Symposium on Mathematical Physics" is among the oldest worldwide serial conferences in its field. It was initiated in 1969 by Professor Roman S. Ingarden and since then it is organized annually by the Institute of Physics of the Nicolaus Copernicus University in Toruń, Poland. The origin of the conference is connected with the creation of the journal Reports on Mathematical Physics (ROMP) — in fact, the first Symposium was originally the founding meeting of its Editorial Board — but soon it became a scientific event on its own. It has become a tradition that the meetings of the ROMP editorial board, as well as those of Open Systems & Information Dynamics (OSID), are held as accompanying events of the Symposium.

Although in principle devoted to general mathematical physics, the Symposium programme is usually focused around a specific, important and topical issue. In recent years the following leading subjects have shaped the Symposium programme:

- Symmetries in Nonlinear Systems (2000)
- Nonholonomic Systems and Contact Structures (2001)
- Physical and Control-Theoretic Applications of Sub-Riemannian and Finsler Geometries (2002)
- Open Systems and Quantum Information (2004)
- Quantum Entanglement and Geometry (2006)
- Geometry and Quanta (2008)
- Quantum Channels, Quantum Information — Theory and Applications (2010)
- New Developments in the Theory of Open Quantum Systems (2012)

Peer-reviewed post-conference volumes of both OSID and ROMP have been published in a few occasions. The present OSID issue continues this tradition. When I was asked by the organizers of the 2012 Conference to edit a Special Volume, I proposed that it be addressed to students, postdocs and young researchers. I wanted something that would be enjoyed by a wide readership. In fact I was being rather egoistic: since I do not particularly enjoy reading highly specialized articles myself, I found the excuse of students, postdocs and young researchers, so that *I myself* would be part of that readership. I suggested that the contributors to this Special Volume write a lecture, rather than an article. They focus on results, but also give the details of their calculations, without omitting important "technicalities", trifles and minutiae. If you read these articles, you will see that all calculations are instructive, sometimes even amusing. Some calculations are omitted, but then an effort is made to explain whys and hows.

Some of the Lectures of the Symposium are available online [4]. Have fun and look at them. Some of these articles are a completion of the oral lectures. Other articles are not and were specially selected. We gathered 9 contributions on "hot", modern topics that will certainly interest young (and hopefully less young) researchers. Let me give you an overview.

$\bowtie$ An increasingly popular approach to quantum information processing consists in encoding information in systems described by continuous degrees of freedom, such as quadratures of light. In recent years, the study of Gaussian states of continuous variable systems has arisen to a privileged position, due to manifold experimental possibilities for their highly controllable implementations, and a magnificently elegant mathematical framework. In their article "Continuous variable quantum information: Gaussian states and beyond" [5], Adesso, Ragy and Lee provide a didactic exposition of Gaussian state quantum information and its contemporary uses, including sometimes omitted crucial details. In particular, emphasis is placed on the mathematical structure combining notions of algebra and symplectic geometry fundamental to a complete understanding of Gaussian informatics. A list of open problems is included to motivate a curious student to dig deeper into the subject.

$\surd$ Alicki wrote an article on "Quantum thermodynamics. An example of two-level quantum machine" [6]. The main question is whether the principles of thermodynamics are applicable to quantum systems. To this end, many models of quantum machines have been recently investigated. Alicki discussed what is perhaps the simplest model of microscopic thermal machine based on a two-level system interacting with two heat baths. The system can work as a heat engine or refrigerator and serves as a tutorial introduction to quantum thermodynamics, showing that with the proper definitions of the fundamental thermodynamical notions, the standard formulation of the laws of thermodynamics remains valid also in the quantum domain.

$\sharp$ Benatti, Floreanini and Titimbo focus on the "Entanglement of identical particles" [7]. Entanglement usually concerns correlations among properties of different particles; when these are identical (Fermions) Bosons, one cannot say which particle has which property. Entanglement need be re-tought: in their contribution the authors compare the "particle" point of view, based on (anti-)symmetrized states, with the "mode" point of view, based on the second quantization formalism.

$\clubsuit$ In his article "On time-local generators of quantum evolution" [8], Chruściński gives a basic introduction to the dynamics of open quantum systems, based on local-in-time master equations. This approach provides a natural generalization of the Markovian semigroup dynamics: one replaces the constant generator of the quantum evolution by a time-dependent one. The properties of time-local generators are characterized and give rise to legitimate completely positive trace preserving quantum evolutions. The analysis of Markovian and non-Markovian quantum dynamics is presented as well and the whole discussion is illustrated by a family of instructive examples.

♢ Haikka and Maniscalco wrote on "Non-Markovian quantum probes" [9]. They review the most recent developments in the theory of open quantum systems, that are quantum systems interacting with their surrounding environment. They focus on situations in which the memory effects, due to long-lasting and non-negligible correlations between system and environment, play a crucial role. Within this framework they study how the open quantum system can be seen as a quantum probe to infer information about the environment. Examples range from ultracold gases to spin chains, and trapped ion crystals.

♡ Modi's contribution is entitled "A pedagogical overview of quantum discord" [10]. Quantum discord is widely studied these days, but still to many it is not clear why. This even includes some of us who have done a great deal of work on this notion of quantum correlation. However, quantum discord can be understood in a similar manner to quantum entanglement by defining discord-less states. In that way it is easy to see why discord is an interesting quantity to study and what applications may use it.

♠ The article by Pascazio, "All you ever wanted to know about the quantum Zeno effect in 70 minutes" [11] focuses on the general features of the quantum decay law of an unstable system. Such a decay law is exponential only at sufficiently long times. There is a precursor, at short times, that is called Zeno region. The classical allusion is to an Eleatic philosopher, who argued that a sped arrow does not move, if observed. In quantum mechanics the act of observation profoundly disturbs the system, so one finds that Zeno was right: quantum arrows do not move, if properly observed. The Zeno region heralds not only the exponential law, but also dissipation, markovianity, memory losses and the like.

♯ Typically, open quantum systems are described with the help of master equations, which are evolution equations for the density matrix of the open systems. Equivalently, open systems can be described by stochastic Schrödinger equations (SSEs), which are stochastic differential equations for the wave function of the reduced system. The great advantage of the SSE is that it allows to include the description of measurements in continuous time, to generalize the dynamical description to the non-Markovian case (memory effects are included), to allow for numerical simulations. The aim of the paper by Semina, Semin, Petruccione and Barchielli, "Stochastic Schrödinger equations for Markovian and non-Markovian cases" [12], is to present the general features of the theory, to show how to get non-Markovian models by using coloured noises, and to illustrate approximation techniques and numerical simulation schemes in a couple of concrete examples.

◎ The last contribution is due to Tanaka and Nakazato and is entitled "Measurement of purity, the simplest nonlinear functional of density matrix" [13]. Physical quantities are always expressed as *linear* functionals of the density matrix. However, there exist physically important quantities in quantum mechanics that are *not* linear functionals of the density matrix and one may wonder whether it is possible to measure such nonlinear functionals within the framework of quantum mechanics. The purity is a typical example, and Tanaka and Nakazato present a way to measure it without resorting to quantum state tomography. The general scheme is then revisited within the framework of the Bloch vector (and its generalization), the algebra of SU(D) generators and the S-matrix theory, all from a very elementary level. This helps one get a deeper understandings of the phenomenon.

Let me end this note by thanking D. Chruściński, A. Jamiołkowski, J. Jurkowski, A. Kossakowski and M. Michalski for organizing the 44th Symposium on Mathematical Physics on "New Developments in the Theory of Open Quantum Systems" (Toruń, Poland, in June 20–24, 2012) and for proposing that I venture in the organization of this Special Volume. Modern research should be curiosity driven and should also focus on possible applications. These two aspects are not contradictory and in fact nicely complement each other. I see no research field nowadays that is more fertile than that of open quantum systems.

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