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Editorial

Quantum Computation and Information: Multi-Particle Aspects

Demosthenes Ellinas [1,*], Giorgio Kaniadakis [2], Jiannis K. Pachos [3] and Antonio Maria Scarfone [4]

1 QLab, School of Electronic and Computer Engineering, Technical University of Crete, Chania 73100, Greece
2 Department of Applied Science and Technology, Politecnico di Torino, Torino 10129, Italy; giorgio.kaniadakis@polito.it
3 School of Physics and Astronomy, University of Leeds, Leeds LS2 9JT, UK; j.k.pachos@leeds.ac.uk
4 Complex System Institute (ISC–CNR) c/o Politecnico di Torino, Torino I-10129, Italy; antoniomaria.scarfone@cnr.it
* Correspondence: ellinas@ece.tuc.gr; Tel.: +30-2821-0-37747

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Abstract: This editorial explains the scope of the special issue and provides a thematic introduction to the contributed papers.

Keywords: quantum computation; quantum information; multi-particle models; quantum walks; topological quantum computing; multi-particle entanglement; quantum potential; quantum statistical mechanics

The scope of this special issue is to emphasize an aspect of the broad research area of Quantum Computation and Information which involves multi-particle models, and their associated concepts and mathematical or computational techniques. Such multi-particle models constitute a common feature of almost all genders of quantum computation and quantum information processing. The articles presented in the issue, sixteen in number, can be thematically categorized into seven titles which span an extended part of the multi-particle research discipline and are the following, with the number of papers in each given in parenthesis: remote actions on states and operators (3), quantum games (2), topological quantum computation (2), dissipative quantum systems (2), entropy (1), quantum algorithms (1), multi-particle quantum entanglement (5).

The first thematic title concerns the implementation of various remote actions on states and operators [1–3]. These actions are mediated by the help of shared quantum entanglement among agents within the framework of communication protocols such as LOCC. Special emphasis is put on the minimization of classical and quantum resources as well as on the security and feasibility of the algorithms. The first contribution in this topic is by Xie Chuanmei, Liu Yimin, Xing Hang, and Zhang Zhanjun [1], who suggest an algorithm for a probabilistic three-party sharing of an operation on a remote qubit states. The second paper is by Wang Dong, Hoehn Ross D., Ye Liu, and Kais Sabre [2], who investigate an algorithm for the generalized remote preparation of arbitrary m-qubit entangled states via genuine entanglement. Finally, Li Jian, Pan Zeshi, Sun Fengqi, Chen Yanhua, Wang Zheng, and Shi Zuozhi [3] present a paper that analyzes a cryptographic algorithm for quantum secure direct communication based on dense coding and detecting eavesdropping with four-particle genuine entangled states.

Next we have two contributions from the area of quantum games [4,5]. First, the paper by Makowski Marcin, Piotrowski Edward W., and Sładkowski Jan [4], which addresses the question of transitive/intransitive preferences in the classical context of rational choice theory, as well as in a quantum game theoretic context, and in which evidence is provided for the rationality of intransitive strategies in a one-qubit strategy game. Next, the paper by Dajka Jerzy, Łobejko Marcin,

and Sładkowski Jan [5], which investigates the role of the environment in the performance of a realistic two-player quantum game, building models based on the open quantum system mathematical methodology, and reporting on the quantum noise effect on the payoffs of the players.

The third topic concerns models in the broad area of topological quantum computation [6,7]. There are two contributions. The first one is the paper by Wootton James [6], which investigates a special form of decoder algorithm for the planar code, which is a topological error correcting code. This paper contains a numerical study which analyses and demonstrates the efficiency of the proposed decoder and compares its performance with that of other existing decoding algorithms. The second paper is by Berec Vesna [7], and studies a new family of stochastic complex information modules encoded in the hypergraph states. Particular models are introduced where the non-local correlations arise from the non-Abelian structure of topological algebraic set systems, simultaneously addressing the divergence in dimension and complexity measures of classical and quantum hypergraph representation. These results can guide the design of approximation algorithms for chip imprinted circuits in scalable quantum information systems.

The next two papers deal with the topic of dissipative quantum systems [8,9]. The first paper, by Luca Magazzù, Davide Valenti, Angelo Carollo, and Bernardo Spagnolo [8] deals with a particle in a bistable potential interacting with a sub-Ohmic broadband environment. In the strong coupling regime, the authors find a crossover dynamic regime with damped intra-well oscillations and incoherent tunneling and a completely incoherent regime. In the second paper the authors Claudio Guarcello, Davide Valenti, Angelo Carollo, and Bernardo Spagnolo [9] consider the stabilisation effect of noise in long Josephson junctions. They find that the mean lifetime of the superconductive metastable state as a function of the noise intensity is characterized by nonmonotonic behavior.

The topic of classical versus quantum entropy is a pivotal one in the theory of quantum information processing. It is presented in this special issue by a paper contributed by Hatzinikitas Agapitos [10]. The paper provides rigorous proofs of two maximization problems that submit the alpha-order Renyi entropy as a solution, and also demonstrates the concavity property of its entropy power.

Quantum algorithms constitute a core topic in the science of quantum computation that utilizes quantum entanglement in powerful ways in order to achieve computation tasks un-accessible by corresponding rival classical algorithms. The contribution by Ellinas and Konstandakis [11] demonstrates how the Grover search algorithm is extended to be a collective search algorithm among many agents. For n collaborative agents, the search complexity is proved to be reduced by order $O(\sqrt{n})$.

The topic of multi-particle quantum entanglement and quantification is represented in this special issue by a collection of five papers [12–16]. These investigations use both advanced theoretical tools and numerical techniques. They direct their efforts to special multiparticle models. Firstly, the paper by Canosa Norma, Ciliberti Leonardo, and Rossignoli Racal [12], which undertakes the task of examining the behaviour of quantum discord and other standard entanglement measures, such as information deficit of spin pairs in the ground state of finite anisotropic cyclic XY chains. Results and comparisons are reported for the behaviour of these measures around the critical field of the model, as well as about the local minimizing measurements that define those measures. The following paper is by Peng Hsuan Tung and Ho Yew Kam [13], and studies some entropic aspects in the so-called mutiparticle Moshinsky model. Specifically, they obtain an analytic expression of the Shannon entropy in position and momentum picture for the ground state of the model. These entropies are evaluated for the total system and its subsystems. Then, the following three topics are discussed: statistical classical and quantum correlations between partitions of the model, test of the entropic uncertainty principle, and finally, comparison of classical and quantum mutual information between partitions of the model. The next paper in the group is by Bao Lina, Pan Feng, Lu Jing, and Draayer Jerry P. [14]. It investigates the Dicke model from the point of view of quantum entanglement between atoms and afield in the presence of the phase transition known to take place for critical values of the model's coupling constant. The analytic tool of progressive diagonalization

is utilized. It is thus shown that, in addition to ground state properties and level statistics that are manifesting changes at the critical point of the quantum phase transition as it is known, the quantum entanglement quantified by values of the reduced density matrix of the atomic subsystem is sensitive to the onset of a quantum phase transition where the system is most chaotic.

The next paper, written by Enriquez Marco, Puchała Zbigniewm, and Ż yczkowski Karol [15] investigates the q-Rényi–Ingarden–Urbanik (qRIU) entropy of pure states of quantum multipartite qudit systems and its minimization over local unitary parametrized by q. Numerical and analytic results are derived for 3,4-qubit cases and compared with results from the PARAFAC algorithm. Asymptotic results from 3-qudit states are also investigated, and the role of q in qRIU is analysed to obtain connections with other special entropic measures. The last paper of that group, by Panas Itai [16], deals with the low-energy instabilities in the hole-doped cuprates. They include, in addition to short range antiferromagnetic fluctuations and superconductivity, ubiquitous translational and rotational symmetry breaking. By employing Density Functional Theory to study these systems, a generalisation is offered to articulate high-critical temperature superconductivity from a normal state where a crystal field causes states related to two non-hybridizing bands to coalesce at Fermi energy.

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