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Einladung zum Physikalischen Kolloquium

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New frontiers for quantum information processing: from topological invariants to the theory of formal languages

A novel realm of applications of quantum information processing is discussed, grounded on quantum algorithms that can be designed to efficiently evaluate all significant quantities – partition functions and observables – of the SU(2) topological quantum field theory (TQFT) of Chern-Simons-Witten. Efficiently means here polynomial time on a quantum computer – a feature that reflects the intrinsic field-theoretic solvability of the theory – at finite values of the coupling constant.

It had been long conjectured that non-Abelian TQFT's might exhibit the properties necessary to support a model of computation capable of solving **#P** problems in polynomial time. For a wide class of systems realistically described by finite TQFT's, a discrete universal representation exists, the "Spin Network Quantum Simulator" (SNQS), where coding of quantum information is based on the angular momentum (re-)coupling scheme. The SNQS has three crucial features: i) its combinatorial structure – induced by the intrinsic $SU(2)_q$ co-algebra – allows us representing any computation process as a path over a graph, as in the classical case. Here the graph is in fact the base space of a fibre bundle which sustains the simulator dynamics as well as information coding; ii) in view of such structure, the simulator naturally implements holonomic quantum computation; iii) the ensuing computational scheme is to a large extent independent on the details of the physical system. The SNQS models bridge standard circuit schemes of quantum computation and notions from TQFT, and they are the natural setting of a quite general and far-reaching formal quantum automaton model, whose structure makes it possible to perform the evaluation of quantum topological invariants. In particular, the Jones polynomial of coloured oriented links can be obtained in such framework, with a quantum algorithm derived by the use of known results in conformal field theory, whereas the invariants of 3-manifolds can be evaluated by the q-deformed spin network model, equivalent to a more general object than the quantum automaton – a quantum recognizer in the sense of K. Wiesner and J.P. Crutchfield – where each basic unitary transition function can be efficiently processed by a standard quantum circuit.

Another leading idea of the talk is to argue that quantum information manipulation tools may allow us to explore wider fields than mere computation, reaching beyond its boundaries to touch the very roots of the universal structure of languages. Building on the conceptual framework induced by the SNQS topological approach to quantum information processing, the technical details necessary to pursue this general argument are touched, showing how a complex blend of notions coming from formal language theory, finite group theory, and topological quantum information theory may lead to a novel perspective in the science of formal languages. As working study-case the problem of quantum combing finite groups is addressed, which bridges language theoretical with structural and quantum algorithmic issues.

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