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Quantum Topology / Hopf Algebra Seminar

Quantum walks on Cayley graphs: free quantum field theory derived from simple algorithmic principles.

Giacomo Mauro D'Ariano (Dipartimento di Fisica, via Bassi 6, I-27100 Pavia, Italy)

Abstract: Last year I reviewed the derivation of quantum theory of abstract systems from informational theoretical principles. This year I will show how relativistic quantum field theory (QFT) can be derived from additional information-theoretic axioms. The information-theoretic paradigm has the special power of allowing an axiomatization of physics without physical primitives in the axioms (including any mechanical notion, space-time, special relativity, etc.) allowing for a thorough logically coherent foundation toward the solution of the VI Hilbert problem, and with the potential of solving the clash between our current major theories: general relativity (GR) and QFT. The derivation of QFT starts from simply considering countably many quantum systems in interaction, with the requirements of locality, homogeneity, and isotropy of the interactions. This corresponds to a theory of quantum cellular automata on a Cayley graph of a group G. The restriction to linearity of the evolution leads to a quantum-walk theory. The further restriction to quasi-isometric embedding of the graph in Euclidean space (corresponding to virtually Abelian G) in the limit of "small" wave-vectors (so-called relativistic limit) gives Weyl, Lorentz, and Maxwell QFT in Euclidean space. Relaxing linearity one could extend the derivation to interacting QFT, whereas relaxing Abelianity of G would correspond to QFT in curved space. The theory is purely mathematical, and as such is adimensional, yet it contains the standards for mass, space, and time through the nonlinearities intrinsic to the

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theory—i.e. maximum wave-vector, a maximum frequency, and a maximum mass (the latter following from unitarity). The relativistic limit connects these standards to the speed of light and the Planck constant, whereas at the maximum value for the particle mass the dispersion relation becomes flat, with interpretation as a mini-black hole, thus setting the scale at Planck's (therefore "small" wave-vector means much smaller than Planck). All the three standards are in principle measurable with current technology (e.g. the Fermi telescope) from a weak dispersion of vacuum which affects the arrival time of deep-space ultra-high energy cosmic rays. Interestingly the photon comes out as a pair of entangled Fermions, similarly to the de Broglie neutrino theory of radiation, however, Fermionic saturation effects are not visible with current laser technology. How Einstein relativity principle is restated without using space-time? The inertial reference frames are just the "representations" of the quantum algorithm that leave its "eigenvalue equation" invariant, whereas the invariance itself is the restatement of the relativity principle. The inherent discreteness of the algorithmic description leads to distortions of the Lorentz transformations that would be visible at huge energies. However, the usual special relativity is perfectly recovered at energies even much higher than those ever tested, e.g. those of the observed ultra-high energy cosmic rays. In addition to allowing the theory to provide its own physical standards for space, time, and mass, the discreteness of the theory introduces new phenomenology predicted by GR, e.g. a maximum value for the particle mass, and De Sitter invariance.

Very recently the interacting theory has been addressed, starting with the one-dimensional case which satisfies the locality axiom, corresponding to an Hubbard Fermionic automaton which is analytically solved by the Bethe ansatz. I will show some numerical evaluations of the free and the interacting walk/automaton theories, along with exact path-sum evaluation of the propagator and a simple asymptotic analytical approach that allows to derive a general dispersive Schroedinger equation holding in all regimes for narrow-band states describing quantum particles. Follow-ups and next planned researches about the interacting theory will be discussed at the end of the talk, along with the presentation of a list of open problems.

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Giacomo Mauro D'Ariano Professor of Theoretical Physics Quantum Foundations and Quantum Information

Dipartimento di Fisica, via Bassi 6, I-27100 Pavia, Italy

email:dariano@unipv.it tel:+39 0382 987 484 fax:+39 0382 987 793 mobile:+39 347 0329998 skype: giacomo_mauro_dariano AIM: dariano13

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