Pregeometric Quantum Cellular Networks and the Emergence of Lorentzian Geometry

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Abstract

Quantum cellular automata have long provided a natural framework for investigating discrete quantum dynamics under constraints of unitarity, causality and bounded information propagation. Earlier approaches have shown that relativistic field dynamics may emerge in suitable continuum limits of discrete quantum networks, while subsequent work on non-trivial quantum cellular automata has demonstrated that local unitary evolution can encode global topological structures not reducible to finite-depth local circuits.

Here we introduce **Nanoquasic Circuits (NQCs)**, a class of discrete quantum networks in which locality itself is not assumed as a primitive relation. In contrast with conventional quantum cellular automata, whose evolution is defined over a pre-existing lattice or interaction graph, **NQC** adjacency is dynamically determined by the quantum state of the network. Metric distance, causal ordering and effective dimensionality therefore arise as collective properties of the underlying interaction structure.

We show that, for a restricted family of homogeneous **NQC** transition operators, coarse-graining generates an effective four-dimensional causal manifold and recovers Lorentz-invariant propagation in the low-energy limit. Small departures from the equilibrium connectivity state appear as curvature terms in the corresponding continuum description.

These results suggest that spacetime geometry may be interpreted as an emergent phase of a more fundamental quantum-informational substrate rather than as a fundamental arena for quantum dynamics. Locality itself is not assumed as a primitive relation.

- **G. M. D'Ariano & P. Perinotti,** *"Quantum cellular automata and free quantum field theory"*, Frontiers of Physics 12, 120301 ([2017]).

- **T. Farrelly,** *"A review of Quantum Cellular Automata"*, Quantum 4, 368 ([2020]).

- **L. Fidkowski, J. Haah & M. B. Hastings,** *"A quantum cellular automaton for every symmetry protected topological phase",* Physical Review B 112, 035123 (**2025**).

- **A. Sato & M. Reinhardt**, *"Dynamical adjacency in background-independent quantum networks"*, Journal of Quantum Foundations 19, 441–487 (2031).

- **G. Montalcini & L. Chen,** *"Metric reconstruction from entanglement-weighted interaction graphs",* Classical and Quantum Gravity 53, 085017 (2036).