Towards a Unified Dynamic Network Theory of Space, Time and Matter: A Conceptual and Philosophical Exploration

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Abstract

This article develops a deterministic interpretation of quantum mechanics based on a universal dynamic network (UDN). The model is grounded in the hypothesis that physical reality consists of nodes and links evolving according to simple rules of splitting and joining. Space, time, matter, and quantum phenomena emerge from this network, with apparent randomness reinterpreted as the result of deterministic complexity. Matter arises as self-sustained dynamical structures, while quantum fields correspond to extended oscillations in the network. In particular, quantum entanglement is reinterpreted as the manifestation of direct nonlocal links within the network, rather than as mysterious correlations across spacetime. The resulting framework offers a unified perspective in which quantum physics and relativity appear as emergent aspects of an underlying deterministic dynamics.

Keywords: Deterministic microdynamics, Emergent geometry, Discrete spacetime, Network theory, Quantum foundations

1. Introduction

String theory, despite its mathematical elegance and promise of unifying gravity with quantum mechanics, remains fundamentally background-dependent. It assumes a fixed spacetime geometry upon which strings propagate, rather than allowing spacetime itself to emerge dynamically from the theory. This reliance on a pre-defined geometric backdrop stands in contrast with general relativity, which is fully background-independent. Furthermore, string theory lacks predictive power due to the enormous 'landscape' of possible vacua ($\sim 10^{500}$), making it difficult to identify a unique low-energy limit

corresponding to our universe. It also fails to offer direct experimental evidence after decades of development [1–3] Loop Quantum Gravity (LQG) [4] presents a bold attempt to quantize general relativity in a background-independent manner by replacing the smooth geometry of spacetime with discrete quantum states of geometry, so-called spin networks. While this is conceptually appealing, LQG also faces unresolved issues in dynamics, notably with the Hamiltonian constraint and the semiclassical limit [5,6]. Other approaches include causal dynamical triangulations [7], group field theory [8], and asymptotic safety [9]. While mathematically rich, none yet provide a complete account of low-energy physics or matter couplings. Quantum Graphity [10,11] tries to derive geometry from a pre-geometric network, but struggles with node creation and embedding matter.

One guiding theme in physics is unification: Maxwell's unification of electricity and magnetism, Einstein's unification of space and time, the electroweak theory [12,13]. Yet geometry and matter remain distinct in general relativity. A deeper theory may need to unify both as emergent aspects of one substrate. In this work we propose the Unified Dynamic Network Theory (UDNT), a deterministic local-rule-based model where both space and matter emerge from node-link dynamics. Matter can emerge from this network as a self-sustained dynamic structure of the network.

Apparent randomness arises from deterministic complexity, not indeterminacy. Recent work supports this line: tensor-network holography shows spacetime emerging from entanglement [14,15]; deterministic cellular-automation approaches [16] pursue similar goals; and information-theoretic gravity emphasizes spacetime as emergent from quantum information [17,18]. These reinforce the plausibility of deterministic microdynamics yielding the quantum world. In most random tensor-network approaches, geometry emerges from entanglement, while matter typically appears as excitations or defects of the underlying network. For instance, in [20] localized "hologron" excitations in a multiscale entanglement renormalization ansatz (MERA) tensor network are interpreted as matter-like disturbances within an emergent AdS-like bulk geometry. This resembles the hologron excitations of MERA, which are part of the network itself but interpreted as disturbances of an underlying background geometry. In contrast, in the present model particles are conceived as self-sustained configurations of the node–link fabric, co-generating geometry rather than emerging as excitations upon it. Whereas tensor-network approaches encode local structure in high-rank tensors with thousands of parameters, the present model assigns only simple link relations to each node, shifting the burden of complexity from local objects to the global dynamics of the network.

2. Unified Dynamic Network Theory (UDNT)

2.1. Nodes and links as fundamental entities

The network consists of nodes and links. Links connect nodes but carry no intrinsic metric, orientation, or weight. Nodes likewise have no predefined properties but are assigned two binary states: a creation bit (c) determining whether splitting is allowed, and a destruction bit (d) determining whether merging is allowed. This parallels creation and annihilation operators in quantum field theory, but here it arises from network dynamics itself. All physical properties of space, matter, and fields are emergent from this evolving relational structure.

2.2. Network rules

The network evolves through deterministic rules governing node splitting and merging: A node may split into two, provided local connectivity rules are respected (no node may fall below three links).

When a node splits, deterministic update signals propagate to its neighbors, altering their c/d states accordingly. Links are conserved: they may only vanish through the merging of the nodes they connect. Although the rules are simple and local, their interplay produces complex, seemingly random global behavior. This is akin to a ball bouncing on waves at sea: the ball follows deterministic laws, but the sea's chaotic surface makes its motion appear unpredictable. UDNT replaces intrinsic randomness with deterministic complexity that mimics stochasticity. Importantly, no Hamiltonian or Lagrangian is imposed;

evolution follows directly from the rules. Matter and fields are emergent coherent structures stabilized by deterministic dynamics rather than by imposed potentials.

In the network considered here, nodes are not only connected to their immediate neighbors but also by direct links to distant nodes. These links ensure the symmetry of relative motion (Section 2.6) and provide global synchronization of updates (see next paragraph), so that the network evolves as an indivisible whole. While such links permeate the substrate, their physical role becomes apparent only through the behavior of excitations, where they manifest as correlations such as entanglement.

A well-known difficulty in deterministic cellular-automaton–like models is the definition of updates: if nodes are advanced sequentially, different orders of updating can lead to different results. This threatens consistency and could introduce a preferred frame. In the present model, this problem is resolved by the assumption that direct links provide synchronization channels, ensuring that local node operations are not independent but coordinated. As a result, the final network configuration is invariant under different update sequences, and the dynamics remain consistent without the need for an external ordering. Although direct links imply that a local update participates in a global synchronization, this does not mean that signals or information are transmitted instantaneously across the network. Rather, the links enforce consistency of the overall update, so that observers embedded in the emergent geometry still experience causal structure and relativistic signal constraints. The presence of direct links between all nodes implies that network evolution is not a sum of independent local events, but a globally coordinated process. In this sense, the universe acts as an indivisible whole, with local changes understood as expressions of a single underlying dynamics.

2.3. No background space or geometry
Distance is defined as the minimal number of links between nodes. Since nodes split and merge, paths constantly fluctuate, making length inherently probabilistic in appearance. Geometry thus emerges from the evolving network rather than being presupposed. Global symmetries such as SU(3)×SU(2)×U(1) are expected to arise from intrinsic network symmetries, constraining allowable configurations and interactions.

2.4. Time as emergent network activity
Time is defined as the cumulative count of local network transitions (split/merge operations). Temporal duration corresponds to the number of such events in a region. Time dilation arises from suppressed fluctuation rates, and time may halt in regions where network dynamics freeze. The arrow of time emerges statistically from imbalances between splitting and merging, especially in expanding regions.

2.5. Mass, energy, and fields as emergent network quantities

Matter corresponds to stable structures that suppress local fluctuations. Energy represents loss of dynamical freedom relative to the vacuum. Fields are extended oscillatory modes of the network. Particles arise as localized, self-sustaining excitations of these fields, stabilized through resonance and constructive interference. Spin is interpreted as a cyclic network pattern; charge arises from persistent asymmetries or topological constraints. In this framework, the wavefunction represents a real distributed configuration of network connections. Quantum behavior thus reflects deterministic connectivity patterns rather than fundamental indeterminacy.

2.6. Movement of particles

Particle motion is not translation through a pre-existing background, but the directed propagation of an excitation pattern across the network. Motion arises as a statistical bias in node splitting and merging that makes a localized excitation persist and advance. The de Broglie wavelength corresponds to the periodicity of this advancing excitation pattern. In the double-slit experiment, this means that the particle propagates deterministically along multiple network paths, with interference resulting from the superposition of phases assigned to those paths.

Relativity requires that no preferred frame of motion emerges from network dynamics. This condition is preserved only if excitations propagate in a way that is symmetric between the "leading" and "trailing" ends of the particle. A joint operation that advances one end of the structure without advancing the other would select a preferred frame, and is therefore forbidden. Instead, motion requires that both ends of the structure act in concert, which is made possible by the presence of direct network links. These links act as information channels that synchronize the evolution of distant nodes within a particle's structure. Unlike tensor-network models, where each tensor connects only locally and long-range correlations are mediated indirectly, the present framework allows for direct nonlocal links, providing zero-length paths that enable synchronized propagation.

In tensor-network approaches, motion is described as the local propagation of excitations through stepwise tensor-to-tensor updates, with effective dynamics generated by time-evolution operators acting on the state. Formally, translation symmetry of the Hamiltonian ensures global consistency, but the synchronization of local hops is imposed externally rather than arising from the network itself. In the present model, motion likewise arises from stepwise actions such as node joining and splitting, but these local processes are coordinated by direct nonlocal links that act as zero-length paths. This coordination enables synchronization across arbitrary separations, allowing relative motion between any two particles in the universe, not just those connected by a local chain of interactions.

This picture is admittedly counterintuitive, but it provides a natural explanation for how motion, relativity, and entanglement can coexist in a deterministic network framework.

The assumption that every node can in principle be directly linked to every other node implies that separations are emergent rather than fundamental. At the most basic level, the network is therefore characterized by an intrinsic unity, with geometry and distance arising only from the relative density of intermediate links. While this paper develops the idea in physical terms, such an all-to-all connected substrate has also been interpreted in broader philosophical contexts as expressing a fundamental oneness of nature.

2.7. Apparent randomness, phases, and the Born rule

Quantum superposition is reinterpreted in UDNT as the coexistence of multiple deterministic propagation routes. Each route carries a phase, assigned to nodes and links. When several routes connect source and detector, their contributions add coherently with these phases. The probability of an outcome is then given by the squared magnitude of the total amplitude, reproducing the Born rule [19]. As an example, consider two possible deterministic routes for a particle. If their phases align, the amplitudes add constructively and the detection probability increases. If their phases are opposite, the contributions cancel, yielding destructive interference. This is precisely the logic of the double-slit experiment: the apparent randomness of detection events arises not from indeterminacy in the rules, but from our ignorance of the underlying microstate. Thus, UDNT explains probabilities as emergent from interference of deterministic histories, with randomness only apparent.

2.8. Relativity and nonlocality

Bell's theorem [21] shows that no theory of local hidden variables can reproduce the correlations of quantum mechanics. UDNT circumvents this constraint because its links are not restricted to ordinary geometric adjacency. Long-range connections in the network provide a deterministic mechanism for correlations that appear 'nonlocal' in emergent spacetime. In this sense, entanglement is encoded by deterministic but non-geometric structures. Relativity remains preserved because no preferred frame arises: excitations propagate across the entire network structure in a relational manner. Thus, nonlocality and relativity coexist naturally in this framework, entanglement corresponds directly to the presence of nonlocal links: what appears in emergent spacetime as mysterious correlations is, at the network level, simply the deterministic synchronization of distant nodes through zero-length connections. These synchronization channels do not carry signals in the relativistic sense, but enforce consistency across distant nodes, so that apparent nonlocal correlations arise without enabling faster-than-light communication.

3. Open Questions and Outlook

Several open challenges remain:

- Formalization of rules: Can deterministic network rules be captured in an algorithmic framework, analogous to spin networks and spin foams?

- Connection to the Standard Model: How exactly do known particle species and gauge groups arise from network symmetries?
- Simulation: While the rules of UDNT are deterministic and could in principle be implemented on classical computers, the exponential growth of configurations makes large-scale exploration infeasible. Because phase assignments and interference are naturally represented in quantum circuits, simulation on quantum computers may ultimately be the only practical way to investigate emergent behavior.

UDNT challenges the assumption that the universe 'obeys equations.' Instead, nature may follow simple deterministic rules, with equations serving as approximations. Apparent randomness emerges from complexity, not indeterminism.

4. Conclusions

We have proposed a Unified Dynamic Network Theory in which space, time, and matter emerge from deterministic rules applied to a network of nodes and links. Geometry, fields, and particles are realized as self-sustained structures within this substrate, while apparent quantum randomness is reinterpreted as the interference of deterministic histories. By assigning phases to nodes and links, the Born rule arises naturally. Bell's theorem is satisfied through non-geometric long-range connections, which account for apparent nonlocality without violating relativistic causality.

The framework is necessarily speculative, but it illustrates how quantum mechanics and relativity could both emerge from a deeper deterministic foundation. A central implication is that the network does not evolve as a collection of independent local events, but as a globally coordinated process in which direct links act as synchronization channels, correlating distant regions without transmitting information. In this sense, the universe acts as an indivisible whole, and local phenomena are expressions of a single underlying dynamics. The value of the model lies not in providing a final theory, but in pointing to the possibility that the deep unity of space, time, matter, and information reflects deterministic microdynamics whose complexity gives rise to the quantum world we observe.

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