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 unified 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: Emergent geometry, Discrete spacetime, Network theory, Quantum foundations, Quantum Gravity, Entanglement

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 (Smolin, 2006; Witten, 1996; Ellis & Silk, 2014). Loop Quantum Gravity (LQG) (Rovelli, 2004) 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 (Nicolai & Zamaklar, 2005; Dittrich & Thiemann, 2009). Other approaches include causal dynamical triangulations (Ambjørn & Loll, 2005), group field theory (Oriti, 2009), and asymptotic safety (Niedermaier & Reuter, 2006). While mathematically rich, none yet provide a complete account of low-energy physics or matter couplings. Quantum Graphity (Konopka & Smolin, 2008; Caravelli & Markopoulou, 2011) 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 (Weinberg, 1967; Salam, 1968). 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 (Swingle, 2012; Sahay & Cotler, 2025); deterministic cellular-automation approaches ('t Hooft, 2016) pursue similar goals; and information-theoretic gravity emphasizes spacetime as emergent from quantum information (Van Raamsdonk, 2010; Cao & Carroll, 2018). 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 (Sahay & Cotler, 2025) 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). For the case of a non-expanding space, the average number of nodes must remain constant. This means that for every node which splits, there must be a corresponding pair of nodes which merge. The continuous splitting and merging of nodes correspond to the zero-point fluctuations of the vacuum. Further, we require that links are not allowed to "snap", reflecting the conservation of information.

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. Time as emergent network activity

In UNET, time is not introduced as an external parameter or imposed background structure. Instead, it emerges from the intrinsic dynamics of the underlying node-link network. Specifically, time is associated with the fluctuating behavior of local network configurations, where links may transiently shift, and nodes may split and merge in reversible processes. In regions of the network that are spatially stable, i.e. not undergoing net expansion or large-scale structural change, such activity does not result in permanent alterations to geometry or connectivity. However, these fluctuations still represent physical processes, and their cumulative count serves as a natural candidate for measuring the passage of time. Just as spatial distance is defined by the number of links connecting two nodes, temporal duration is defined by the number of local network transitions (e.g., oscillatory split-merge cycles) that occur within a given region. This approach offers a relational and quantized concept of time, grounded in the network's internal evolution rather than imposed from outside. Time is effectively a count of change, and it only "progresses" where such change occurs. This has several immediate consequences: Time dilation can be interpreted as a local reduction in the frequency of network fluctuations, understood as fewer transitions per external comparison interval. In extreme cases (e.g., frozen regions or bound states), time may effectively "stop" if network dynamics are suppressed. In special and general relativity, local clocks (as well as rulers) play an essential role in the understanding of physical laws and the understanding if spacetime in general. Within out theory, these local clocks are now represented by local fluctuations.

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

In the UNET framework, mass and energy are not introduced as external parameters but are instead understood as emergent properties of network dynamics. Two guiding principles support this interpretation:

(1) Local Suppression of Network Fluctuations

Matter configurations are understood as stable patterns in the network that restrict or reduce the range of allowed local fluctuations. In this sense, energy is identified with a loss of dynamical freedom in the vicinity of a structure: the presence of matter limits the set of accessible link rearrangements, effectively creating a low-entropy zone within the network. This aligns with the view that energy reflects deviation from a maximally fluctuating "vacuum" state and that structures with greater internal coherence (or rigidity) correspond to higher energy densities.

(2) Interaction with Surrounding Network

A second, complementary interpretation links energy and mass to the influence a structure exerts on its surroundings. A persistent configuration may alter connection probabilities, reorganize link directions, or suppress the formation of nearby nodes. This external "field-like footprint" mirrors how mass in general relativity curves the geometry of space. In UNET, however, this influence arises not from curvature but from the structure's redistribution of network activity around itself. The larger or more disruptive this footprint, the greater the associated mass-energy. These principles were anticipated in earlier proposals linking energy to the suppression of quantum degrees of freedom in space itself (Van Nieuwenhove, 1992) and find natural expression in the dynamic, discrete setting of UNET. This perspective opens a path toward understanding gravity not as a fundamental force, but as a secondary effect emerging from how matter modulates the network's intrinsic dynamics.

Einstein's Field Equations describe mathematically how matter curves spacetime. However, a major shortcoming is that no physical mechanism is provided. UNET on the other hand, provides a clear mechanism in line with (Van Nieuwenhove, 1992)).

Fields in UNET are understood as fluctuating modes of the network, extending across its dynamic structure. These modes behave analogously to ensembles of coupled harmonic oscillators, with different types of fields corresponding to different allowed dynamical excitations of the network. Interactions between fields arise through specific configurations or resonances within the network's local connectivity, enabling couplings between, for example, electromagnetic and fermionic modes. Each field encodes, at every location, the relevant quantum numbers (such as charge, spin, etc.) associated with its corresponding particle, such as for instance, a photon, gluon, or electron. Importantly, during the detection process of a particle, all the necessary information to "reconstruct" the particle from the field is already present locally in the network.

Although these fields are inherently extended, particles appear as localized excitations within them during interactions or measurements. In the UNET framework, such localization arises naturally from the network dynamics itself. It reflects a temporary concentration of activity; a self-sustaining pattern of oscillations stabilized within a small region. This can occur through constructive interference of modes, resonance effects, or dynamic constraints imposed by the surrounding network topology. Thus, the particle is not an independent object but an emergent, sharply peaked field excitation, a coherent configuration in an otherwise fluctuating medium. Localization is therefore not imposed externally but emerges as a natural consequence of the network's internal dynamics, reconciling the wave-like nature of fields with the observed particle-like behavior.

In the UNET framework, particles are not localized defects, but stable excitations of global fields encoded in the network's dynamic structure. Spin is interpreted as a cyclic localized pattern in the network. This naturally accounts for quantized spin behavior (such as spin-½) without invoking substructure.

Charge is attributed to persistent asymmetries or topological features in the excitation's configuration, possibly connected to internal symmetries of the network rules. These properties determine how excitations interact with specific fields and may reflect deeper conservation laws inherent in the network dynamics.

The present approach naturally supports the view that the wave function represents a real physical structure, rather than merely a computational tool for predicting measurement outcomes. In standard quantum mechanics, only the squared norm of the wave function is directly observable as a probability density, but the full complex-valued wave function contains phase and interference information essential for describing physical phenomena such as tunneling, superposition, and entanglement. This tension between formalism and interpretation has long been recognized in foundational discussions. Several authors have argued for an ontological status of the wave function, including in the context of pilot-wave theory (de Broglie–Bohm), objective collapse models, and certain many-worlds interpretations. Yet no consensus has emerged as to what the wave function actually represents in physical terms. Within a network-based framework, however, the wave function may be interpreted more directly as a manifestation of the underlying network connectivity as a distributed configuration of links, phases, or topological constraints, that governs how a quantum object interacts with space and other systems. This view restores a form of physical realism to quantum theory and invites reinterpretation of wave phenomena as emergent features of discrete dynamical structure. In this framework, the wavefunction represents a real distributed configuration of network connections. Quantum behavior thus reflects deterministic connectivity patterns rather than fundamental indeterminacy.

2.5. Meaning of distance

In the present framework, distance is not defined as the minimal number of links between two nodes, since this would be trivialized by the presence of long-range connections. Instead, distance is understood *operationally*: it is the effective separation experienced by a propagating network structure (particle). Such a structure cannot arbitrarily "jump" along distant links without losing its internal organization. To preserve coherence, the particle must propagate mainly through successive, locally consistent merge–split steps in the network. The succession of these local transitions defines what we perceive as motion, and the number of such steps provides a meaningful notion of distance. In this sense, geometry is not a pre-given background but emerges from the rules of motion themselves: space is the relational pattern of transitions that self-sustained excitations can follow while maintaining their internal order.

An everyday analogy may help clarify this point. Imagine a city with both narrow alleyways and wide highways. For a bicycle, the alleys are accessible, so the shortest route between two squares may be a winding path through backstreets. For a car, however, the alleys are blocked, and the same journey must follow a different route along main roads. The "distance" between the two squares is therefore not absolute: it depends on the kind of traveler and the paths available to them. Likewise, in the network picture, a particle cannot jump arbitrarily across distant links without losing its coherence. Its motion is restricted to sequences of locally consistent steps, and the effective distance it experiences emerges from those allowed paths.

Global symmetries such as SU(3)×SU(2)×U(1) are expected to arise from intrinsic network symmetries, constraining allowable configurations and interactions.

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 (Born, 1926). 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 (Bell, 1964) 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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