Why Relations Precede Existence: A Critical Examination of the Entity-First Assumption in Physics

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Abstract

We critically examine the ontological assumption that "existence precedes relations" — the view that spacetime, particles, and fields are fundamental entities with intrinsic properties, and that relations are derivative. Through a careful analysis of three key physical problems (the black hole information paradox, quantum non-locality, and the non-renormalizability of quantum gravity), we argue that the entity-first assumption leads to deep conceptual tensions that resist resolution. We then propose an alternative: "relations precede existence", where fundamental reality consists of a network of relations, and spacetime, fields, and particles emerge as patterns in this network. We provide a precise mathematical definition of such a relational framework and show how it resolves the identified tensions. Moreover, we have previously demonstrated that from such a relational network one can rigorously derive free scalar quantum field theory and U(1) gauge theory in the continuum limit, providing concrete evidence that the relational framework is not merely philosophical but yields predictive physics. The paper does not claim a definitive proof but aims to establish the relational view as a viable and promising foundation for fundamental physics, worthy of serious consideration.

1 Introduction

Imagine two people who have never met, never communicated, never observed each other, and never influenced each other in any way. Are they "friends"? Clearly not—the concept of friendship is defined entirely by the relations between them: shared experiences, mutual recognition, reciprocal influence. Without those relations, the category "friend" simply does not apply. But more than that: if there are no relations whatsoever between them, then from the perspective of each, the other does not exist. Not merely unknown, but ontologically absent. Their existence as distinct entities, insofar as it is meaningful, is constituted entirely by the network of relations they participate in.

This everyday observation points to a profound possibility: perhaps the same holds for the fundamental constituents of reality. Perhaps there is no "substance" that underlies relations; perhaps relations themselves are the primary reality, and what we call "things"—particles, fields, spacetime points—are merely patterns or nodes in a relational network. This is the *relations-first* ontology.

The contrary view—that things exist independently of their relations, that there is a pre-existing spacetime populated by entities with intrinsic properties—has dominated physics since Newton. We call this the *entity-first* ontology. It is so deeply ingrained that we rarely question it. Yet the combination of quantum mechanics and general relativity has brought this assumption into question. The black hole information paradox, the non-locality revealed by Bell's theorem, and the non-renormalizability of quantum gravity all point to deep tensions that may be symptoms of a mistaken ontology.

In previous work [10, 11], we have shown that starting from a relational network of observers, one can rigorously derive the free scalar quantum field theory and U(1) gauge theory in the continuum limit. These constructive results demonstrate that the relational framework is not a mere philosophical speculation but yields concrete, predictive physics. The present paper builds on that foundation by arguing that the entity-first assumption is the source of persistent conceptual tensions, and that the relational alternative offers a coherent way out.

In this paper, we examine these tensions under the entity-first assumption and argue that they resist resolution. We then propose a precise mathematical formulation of the relations-first alternative, drawing on causal set theory, category theory, and our constructive work. We show that this relational framework resolves the identified tensions and provides a coherent foundation for a theory of quantum gravity. Our aim is not to offer a definitive proof, but to demonstrate that the relations-first view is a viable and promising path forward, worthy of serious consideration alongside other foundational approaches.

The paper is structured as follows. Section 2 defines the entity-first assumption precisely and situates it in the history of physics. Section 3 outlines the logical structure of our argument. Sections 4, 5, and 6 examine three major physical problems, showing how the entity-first view leads to tensions that resist resolution. In Section 7 we define the relational alternative mathematically, drawing on causal set theory, category theory, and the observer network models developed in our previous work. Section 8 demonstrates how the relational framework resolves the tensions identified earlier. Section 9 situates our proposal in the context of existing relational approaches (relational quantum mechanics, structural realism, causal set theory) and responds to potential criticisms. Section 10 concludes with a summary of the argument and a discussion of future directions.

2 The Entity-First Assumption

By *entity-first ontology* we mean the conjunction of the following claims:

1. **Spacetime substantivalism**: There exists a pre-given spacetime manifold (or a dynamical manifold) with its metric structure. Spacetime points, or events, are fundamental entities that exist independently of any relations they bear to other entities.

2. **Intrinsic properties**: Particles, fields, and other physical objects possess intrinsic properties (mass, charge, spin, etc.) that are defined independently of their relations to other objects. These properties are ontologically prior to the interactions they participate in.

3. **Relations as derivative**: Causal connections, interactions, and information exchange are secondary structures that supervene on the intrinsic properties of the entities.

This ontology is implicit in most of classical physics and in the standard formulation of quantum mechanics (e.g., particles in a pre-existing space). It also underlies many approaches to quantum gravity that treat spacetime as a dynamical field on a background manifold, or that introduce extra dimensions as fundamental.

3 Logical Structure of the Argument

Our argument does not claim to be a formal proof in the strict logical sense; rather, it is a philosophical argument that seeks to show that the entity-first assumption leads to conceptual inconsistencies that are not merely technical but point to a deeper incompatibility. The structure is:

1. Assume entity-first ontology.

2. Examine three well-known physical problems that are widely recognized as unresolved within existing theories.

3. Show that each problem, when analyzed under the entity-first assumption, reveals a fundamental tension: either the assumptions of the entity-first view are directly contradicted, or the attempted resolutions require abandoning central principles of the theory (e.g., locality, unitarity, or background independence) in a way that is incompatible with the overall framework.

4. Conclude that entity-first ontology is not a consistent foundation for a unified theory of quantum gravity.

5. Propose an alternative relational ontology and demonstrate that it avoids these tensions.

The argument is therefore a *critical examination* that shows the entity-first assumption leads to conceptual tensions; it does not claim to prove the relational alternative uniquely, but rather establishes it as a viable candidate that deserves serious investigation.

4 The Black Hole Information Paradox

4.1 The Paradox in Entity-First Terms

The black hole information paradox, like the two persons in our opening story, arises because we treat the black hole and the radiation as independent "entities" whose existence is assumed prior to their relations. We then ask how they can "know" each other's state, leading to an apparent contradiction.

Hawking's semiclassical calculation (1976) showed that black holes emit thermal radiation. In the entity-first picture, a black hole is a region of spacetime with an event horizon. Matter that falls in possesses intrinsic properties (its quantum state). The radiation is produced by vacuum fluctuations near the horizon, which are treated as local processes in a pre-existing curved spacetime. The result is a thermal spectrum independent of the infalling matter. When the black hole evaporates completely, the information about the infalling matter appears to be lost. Quantum mechanics, however, demands unitary evolution, i.e., information conservation. Thus we have a conflict: general relativity (via Hawking's calculation) suggests non-unitary evolution, while quantum mechanics requires unitarity.

4.2 Attempted Resolutions and Their Limitations

Several proposals have been made to resolve the paradox within an entity-first framework:

- **Information is emitted in non-thermal correlations**: If Hawking radiation is not exactly thermal but contains subtle correlations, information could be preserved. However, explicit calculations (e.g., Page's theorem) show that such correlations would require non-local effects that are hard to reconcile with local field theory on a fixed background.

- **Remnant scenario**: A stable remnant remains after evaporation, storing the information. This requires a new class of objects with an infinite number of internal states, which is problematic for quantum gravity.

- **Black hole complementarity**: The information is both inside and outside, with no observer seeing both. This violates a naive notion of locality but tries to preserve unitarity. Critics argue it leads to inconsistencies like the firewall paradox.

- **AdS/CFT**: In string theory, the AdS/CFT correspondence provides a holographic description where the black hole interior is encoded in the boundary theory, ensuring unitarity. However, this requires a fixed asymptotically AdS background, which is a special case, and does not offer a general resolution for all spacetimes.

All these attempts retain the entity-first assumption that spacetime is a pre-existing manifold and that black holes are localized objects. They struggle to reconcile unitarity with locality and background independence.

4.3 Tension with Entity-First

The entity-first view forces a choice: either unitarity is violated (contradicting quantum mechanics) or locality is violated (contradicting relativistic causality). The paradox thus reveals a deep tension between the principles of quantum mechanics and general relativity when both are interpreted in an entity-first ontology. This tension is not merely technical; it arises from the assumption that there is a pre-existing spacetime with a sharp event horizon and independent quantum fields living on it.

5 Quantum Non-locality and Local Realism

5.1 Bell's Theorem and the Entity-First Response

Quantum non-locality, in the light of our opening story, emerges because we insist that the two entangled particles are independent "persons" with pre-existing properties, when in fact their existence is constituted by their relation.

Bell's theorem (1964) showed that any local hidden variable theory satisfying realism must obey Bell inequalities. Experiments violate these inequalities, implying that any entity-first theory that maintains both locality and realism is false. The entity-first community has responded by rejecting one of the two:

- **Copenhagen interpretation**: Rejects realism, claiming that particles have no definite properties before measurement. This preserves locality but leaves the notion of "particle" as an entity ambiguous. The measurement problem remains unsolved, and the ontology of the theory is unclear.

- **Bohmian mechanics**: Rejects locality, introducing a non-local guiding wave. This restores realism but requires a preferred foliation, contradicting general covariance. It also introduces a "quantum potential" that is not part of the relational structure.

- **Many-worlds**: Rejects the collapse postulate, claiming that all outcomes occur in separate branches. This avoids non-locality but multiplies entities and raises questions about probability and the emergence of a single observed world.

All these options retain the idea that there are fundamental particles with intrinsic states, and they either sacrifice locality, realism, or both. The cost is that the resulting theory is either incompatible with general relativity or lacks a clear ontology.

5.2 Tension with Entity-First

The entity-first view treats particles as separate entities located in a pre-existing space. The experimental violation of Bell inequalities shows that such a picture cannot simultaneously satisfy locality and realism. No entity-first interpretation of quantum mechanics has emerged that reconciles these principles with general relativity in a background-independent way. This suggests that the very notion of localized entities with intrinsic properties may be inadequate.

6 Spacetime Singularities and the Non-renormalizability of Quantum Gravity

6.1 Singularities as a Breakdown of the Entity-First Picture

The singularities of general relativity, from the perspective of our opening story, result from treating spacetime as an absolute "person" that exists independently of the relations that define it.

General relativity, as a classical field theory on a smooth manifold, predicts singularities (big bang, black hole centers) where the curvature diverges. The entity-first view treats spacetime as a continuous entity; at singularities, the entity "spacetime" ceases to be well-defined. This is a breakdown of the theory, indicating that the continuum approximation fails. The problem is not just technical: it signals that the concept of spacetime as a fundamental entity cannot be extended to extreme regimes.

6.2 Attempts to Quantize Gravity and Their Challenges

Perturbative quantum gravity treats the metric as a field on a fixed background. This is non-renormalizable: it requires an infinite number of counterterms, making it predictive only as an effective field theory. Non-perturbative approaches like string theory and loop quantum gravity attempt to go beyond this, but they face their own challenges:

- **String theory**: Postulates fundamental strings as entities living in a higher-dimensional spacetime. It requires a fixed background (though attempts at background independence exist, e.g., AdS/CFT). It also predicts a vast landscape of vacua, making it difficult to derive unique predictions.
- **Loop quantum gravity**: Treats spacetime as a discrete spin network, with no background. It succeeds in quantizing the gravitational degrees of

freedom but struggles to recover semiclassical physics and to incorporate matter fields in a unified way.

Both approaches, despite their sophistication, retain elements of entity-first thinking: strings are entities; spin networks are composed of edges and vertices (entities). The persistent difficulties in constructing a unique, predictive theory of quantum gravity may indicate that the entity-first starting point is itself flawed.

6.3 Tension with Entity-First

The inability to produce a consistent, background-independent quantum theory of gravity within the entity-first paradigm suggests that the assumption of a fundamental spacetime manifold is not viable. The non-renormalizability of perturbative gravity and the landscape of string theory can be seen as symptoms of a deeper problem: the attempt to treat spacetime as a pre-existing entity leads to an overabundance of degrees of freedom and an inability to select a unique vacuum.

7 A Relational Alternative: Precise Definition

We now propose a relational ontology that avoids the tensions identified above. The core idea is that fundamental reality is a network of *relations*, and that what we call spacetime, fields, and particles are emergent patterns in this network. To make this precise, we adopt a mathematical definition inspired by causal set theory, category theory, and our previous constructive work [10, 11].

Definition 1 (Relational Network)**.** *A* relational network *is a locally finite partially ordered set* $(P, \prec)$ *where* P *is a countable set (whose elements are mere placeholders and carry no intrinsic properties), and* $\prec$ *is a transitive, irreflexive, locally finite partial order. The only fundamental structure is the relation* $\prec$*; the elements of* P *are merely labels, and the ontology consists solely of the pattern of relations. In the constructive realizations that follow, we use a cubic lattice as a convenient labeling, but the physical content is entirely in the relational structure.*

Such a structure is exactly a *causal set* when interpreted causally. However, we emphasize that we are not presupposing a Lorentzian manifold or an embedding; we use only the pure combinatorial structure. (In standard causal set theory, one often considers embeddings into a Lorentzian manifold as a tool to take the continuum limit, but here the continuum limit is defined purely combinatorially via density scaling, without assuming an ambient manifold.)

The properties of the network are:

- **Directedness**: $a \prec b$ and $b \prec a$ cannot both hold.
- **Transitivity**: If $a \prec b$ and $b \prec c$, then $a \prec c$.

- **Local finiteness**: For any a, b, the set $\{c : a \prec c \prec b\}$ is finite.

The nodes are not assumed to have any intrinsic properties; they are merely placeholders. All physical content resides in the pattern of relations. In particular:

- **Spacetime** emerges as the continuum limit of a large, dense causal set.
- **Fields** emerge as functions on the causal set that satisfy discrete equations of motion.
- **Particles** emerge as excitations of the quantum fields, i.e., as collective patterns in the quantum network.

7.1 Constructive Realizations

In previous work [10, 11], we have shown explicitly how such a relational network can give rise to quantum field theory. Starting from a four-dimensional cubic lattice of nodes (each representing an observer) with nearest-neighbor relations, we assign to each node a quantum harmonic oscillator. The Hamiltonian is the lattice discretization of the free scalar field:

$$\hat{H}_h = \frac{1}{2h^2} \sum_{\langle x,y \rangle} (\hat{\phi}_x - \hat{\phi}_y)^2 + \frac{1}{2h^4} \sum_x \hat{\pi}_x^2,$$

where h is the lattice spacing. We proved that as $h \to 0$, the two-point correlation function converges to the continuum Wightman function of the massless scalar field. This is a rigorous demonstration that a continuous quantum field emerges from a discrete relational network. Similarly, by introducing U(1) phases on the bonds, we derived the Hamiltonian of lattice QED and proved its continuum limit yields scalar QED. These results are not analogies; they are exact mathematical theorems. They show that the relational framework is not a mere philosophical speculation but a viable route to recovering known physics. (Preprints of these works are available upon request; they are currently under review.)

8 Resolution of the Tensions

8.1 Black Hole Information Paradox

In a relational network, there is no pre-existing black hole entity. Instead, a black hole corresponds to a region of the network where causal relations are such that some nodes cannot send information to future nodes (the horizon). The evaporation process corresponds to the gradual loss of those relations. Information is never lost because it is encoded in the entire network; the interior is not an independent region but is holographically encoded in the boundary relations. This is analogous to the AdS/CFT correspondence but arises from the fundamental relational structure rather than from string theory. Moreover, in causal set theory, one can define a notion of "entropy" that counts the number of relations crossing a horizon, and it has been shown that such entropy is proportional to the horizon area, providing a microscopic origin for black hole thermodynamics [8]. The relational framework thus offers a natural resolution of the information paradox.

8.2 Quantum Non-locality

In a relational network, there are no separate particles with pre-existing properties. Entanglement is simply the fact that the relational structure connects nodes in ways that do not respect a pre-existing spatial distance. The violation of Bell inequalities is a consequence of the relational structure itself; there is no need to preserve locality or realism in the classical sense because "space" itself is emergent. Concrete models exist within causal set theory where non-local correlations are encoded through "non-causal adjacency" or through the structure of the order itself [9]. The measurement process is a change in the relational configuration, not a mysterious collapse of a pre-existing state.

8.3 Spacetime Singularities and Quantum Gravity

A relational network is inherently discrete, so singularities where continuum geometry diverges are naturally avoided. The continuum limit produces effective field theories that are renormalizable because the fundamental degrees of freedom are discrete. The problem of infinite fine-tuning (cosmological constant) is mitigated because the ground state of the network can have zero energy by construction (e.g., through gauge symmetries or topological constraints). Moreover, the constructive results of [10, 11] show that the continuum limit exists and yields the correct physics, demonstrating that the discrete network is a valid regularization.

9 Relation to Existing Frameworks

9.1 Relational Quantum Mechanics (RQM)

Rovelli's relational quantum mechanics emphasizes that quantum states are relative to observers. Our approach shares this relational spirit but goes further by making the relational network ontologically primary and providing a constructive mathematical framework for emergence. While RQM focuses on interpretation, we aim to build a predictive theory.

9.2 Structural Realism

Structural realism (Ladyman, French) holds that the structure of the world is ontologically prior to its individual constituents. Our relational network is a concrete instance of a structure in the sense of structural realism. The key difference is that we provide explicit mathematical definitions and a constructive route to deriving known physics.

9.3 Causal Set Theory

Causal set theory (Bombelli, Sorkin) posits that spacetime is a discrete causal set. Our relational network is essentially a causal set with additional local degrees of freedom (quantum oscillators). We adopt the causal set framework as a concrete mathematical model, but we extend it to include quantum dynamics and a mechanism for field emergence. The constructive results of [10, 11] can be seen as a concrete implementation of the "causal set" approach to quantum field theory.

9.4 Constructive Results

The constructive work [10, 11] provides rigorous derivations of free scalar quantum field theory and U(1) gauge theory from a relational network. These results are not merely analogies; they are exact mathematical theorems. They demonstrate that the relational framework is capable of recovering the standard model of particle physics (at least its free part) from first principles, without presupposing continuum spacetime. This is a significant step toward a relational theory of quantum gravity.

9.5 Potential Criticisms and Responses

- *Isn't the network itself made of entities (nodes)?* Yes, nodes are present, but they have no intrinsic properties; they are merely markers of positions in the relation structure. One could eliminate them by working directly with the order relation (as in causal sets). The nodes are a convenient fiction; the real ontology is the relation structure itself.

- *Doesn't the continuum limit require a background?* The continuum limit is defined purely combinatorially: we consider a sequence of networks with increasing density and prove that correlation functions converge. The target space is $\mathbb{R}^4$, which is constructed as the Dedekind completion of the order, not as a pre-existing background.

- *How do you recover general relativity?* By allowing the network itself to be dynamical (i.e., the edges can appear and disappear), one can obtain a theory of gravity. This is the program of causal set quantum gravity and spin foam models. Our work provides a unified framework that includes both matter and gravity.

- *Doesn't the relational network itself presuppose set theory and other mathematical structures?* Yes, all physical theories presuppose a mathematical framework. The crucial point is whether the framework assumes a physical background (such as a continuum manifold) that is not emergent.

Our framework uses only discrete mathematics and does not assume any pre-existing spacetime structure. The mathematical tools (set theory, order theory, functional analysis) are meta-level and do not imply a physical background.

10 Conclusion

We have argued that the entity-first assumption—that spacetime, particles, and fields are fundamental entities with intrinsic properties—leads to deep tensions when confronting quantum gravity. The black hole information paradox, quantum non-locality, and the non-renormalizability of quantum gravity all resist resolution within an entity-first framework, and the attempts to resolve them often require abandoning central principles. We have proposed a relational alternative, defined mathematically as a causal set with local quantum degrees of freedom, and shown how it avoids these tensions. Moreover, we have previously demonstrated that from such a relational network one can rigorously derive free scalar quantum field theory and U(1) gauge theory in the continuum limit, providing concrete evidence that the relational framework is not merely philosophical but yields predictive physics.

Just as two people become friends only through shared relations, so too do spacetime points, particles, and fields acquire physical meaning only through the relational network. We do not claim to have proven the relational view beyond doubt, but we hope to have established it as a viable and promising candidate for the foundations of physics. The argument presented here is a critical examination of the entity-first assumption, showing its conceptual inadequacies, and an invitation to explore the relational alternative more deeply. Future work will extend the constructive program to include interacting theories, fermions, and gravity.

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