Spacetime and Matter as Emergent Phenomena: A Unified Field Theory

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Abstract

We propose a minimalist hypothesis in which the only fundamental entity is a real scalar field defined on four-dimensional Euclidean space E^4. An observer is modeled as a stable *cognitive tube*—a locally causal region of field projections onto a family of three-dimensional slices $\Sigma^3(\ell)$.

From non-dynamical conditions of *embodiment, local causality, stability, and unitarity*, we rigorously derive:

1. emergent spacetime with a pseudo-Riemannian metric and Lorentz transformations as the only compatible symmetry group;
2. the Einstein field equations as a variational extremum of the cognitive action;
3. quantum field theory and the Born rule as necessary conditions for cognitive reproducibility;
4. the minimal symmetry group $U(1)\times SU(2)\times SU(3)$ and a cognitive Higgs mechanism.

The model predicts the absence of a graviton and prohibits coherent superpositions of distinct spacetime metrics, thereby establishing clear falsifiability criteria: detection of a graviton or interference of heavy masses would refute the hypothesis. The unified emergence of special relativity, general relativity, and the Standard Model symmetries underscores the explanatory power of the approach and opens a path toward experimental testing of the cognitive nature of physical laws.

keywords: Emergent spacetime; Local causality; Cognitive observer; Quantum field theory; Gauge symmetries; Dark energy

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Contents

1 Introduction

This paper continues the development of a theory of emergent spacetime. A hypothesis based on the generalization of the principle of causality was formulated in a separate publication [1]. While reading that article is recommended for a deeper understanding of the present theory, it is not strictly required. The earlier paper focuses more closely on how the generalized principle of causality leads to the emergence of observable and direct transformations, and how observable transformations strictly (in the cognitive sense) preserve events and their interpretability. That level of detail is not the aim of the current work, which instead focuses on deriving physics from the theoretical model, taking the generalized causality principle as foundational and drawing partially on prior results. Without familiarity with the previous article, some conclusions here—such as the derivation of Lorentz transformations—may be more difficult to follow.

The principle of causality occupies a central position in modern physics, playing a key role in the formulation of dynamical laws and quantum theories. In the classical Newtonian framework, causality relies on absolute time and space, whereas in special relativity (SR) it is embedded in the structure of four-dimensional Minkowski spacetime [2]. However, these formulations already assume a predefined (Minkowskian) geometry, taking spacetime as fundamental. More recent approaches attempt to derive the kinematic properties of SR—and even general relativity (GR)—from more "pre-dynamical" or symmetric constructions (see, e.g., [4, 5, 6]).

An early example is Roter's work [3], which studied projections of metric structures leading to an ephemeral concept of time. In the past decades, this direction has developed further through *shape dynamics* [4], *causal set theory* [5], and *relational approaches* [7]. These frameworks aim to describe gravity and causality through discrete structures or transformation groups lacking an explicit time parameter.

In causal set theory [5], fundamental structure is not provided by metric geometry, but by order relations of "ancestor–descendant" type, enabling a notion of causality without presupposed time. A similar idea of relational emergence of space and time is implemented in shape dynamics [4, 6], where shape evolution is governed by the geometry of configuration space, and time arises only as a parametric unfolding of configurations. Rovelli's relationalism [7] further emphasizes that physical quantities acquire meaning only in relation to other systems, with no absolute background structure.

Despite these advances, most of the approaches mentioned retain some form of implicit background (e.g., the topology of the causal set or the configuration space of shape dynamics), which can hinder a complete derivation of spacetime from causality alone. Moreover, the role of the observer—and in particular, the necessity of self-awareness—typically remains outside the scope of formal physical development.

The present work puts forward the hypothesis that *causality* is more fundamental than *space* or *time*, both of which arise only as *emergent* constructs in the presence of a cognitive observer. This view aligns with the anthropic principle (cf. [8, 9]) and structural realism [10], but emphasizes the cognitive dimension: without an observer, spacetime is only a potential structure, lacking ontological actuality.

Accordingly, the aims of this work are:

- To formulate a *Generalized Principle of Causality* (GPC), which permits independent causal ordering within each inertial frame, without relying on predefined geometric structure;
- To construct a four-dimensional Euclidean model of a real scalar field devoid of internal symmetries or metric time, and to demonstrate how its projections onto cognitively actualized hypersurfaces give rise to observable spacetime;
- To prove that within this model, observable coordinate transformations coincide with the Lorentz transformations, and that the universal speed c arises as a geometric invariant;
- To analyze the role of the observer, identify the cognitive requirements (see §2.2), and show how self-awareness fixes the choice of hypersurface and causal structure.

Section 2 presents the formulation of the GPC and explains why a cognitively complete observational system is necessary. Section 3 develops a four-dimensional Euclidean field model, discusses projections onto hypersurfaces, and introduces a time parameter $t = \ell/v_t$. Section 4 provides a mathematical derivation of the postulates of special relativity, demonstrating how Lorentz transformations follow from the geometry of E^4, and how direct transformations approach the identity in the limit $v \to 0$. Section 5 discusses philosophical implications for the ontology of spacetime and consciousness, and outlines prospects for extending the model to general relativity and quantum field theory.

Main results:

1. A Generalized Principle of Causality (GPC) is formulated, allowing frame-dependent causal structures;
2. A four-dimensional Euclidean model of a real scalar field is constructed, with no privileged directions or internal symmetries;
3. Lorentz transformations are derived as observable coordinate transformations;
4. Both postulates of special relativity are shown to follow from the GPC and field symmetries;
5. General relativity is recovered, including derivations of its two postulates;
6. Quantization arises naturally from cognitive constraints;
7. The gauge symmetries of the Standard Model are derived, not postulated;

8. The theory's empirical testability is explored;
9. Future directions for theoretical development are discussed.

Section 2 elaborates the GPC and its implications. Section 3 develops the field model on E^4. Section 4 gives a rigorous derivation of the postulates of special relativity.

2 Generalized Principle of Causality (GPC)

2.1 Formulation

The Generalized Principle of Causality (GPC) is based on two key postulates:

Postulate 1 (disjoint causality). The principle of causality operates independently in each inertial reference frame (IRF). For each IRF, one can define an ordering of events compatible with its internal causal structure, regardless of other IRFs.

Postulate 2 (continuity). As the relative velocity between two IRFs approaches zero ($v_{\mathrm{rel}} \to 0$), the difference between their causal structures tends to zero.

These postulates imply that events which are causes or effects in one IRF may not exist (or be ordered) in another. Accordingly, two classes of transformations arise between IRFs:

- *Observable transformations* — preserve the structure of events as perceived by an observer within an IRF. These correspond to conventional coordinate transformations (in the spirit of Lorentz) and describe consistent descriptions of physical processes.
- *Direct transformations* — reflect the actual differences in the set of events between IRFs. These transformations typically do not preserve event structure and may arise when comparing causal structures between IRFs.

For example, a collision of electrons may occur in one IRF, while in another it may either not occur or involve different particles (e.g., a pair of muons). This is not a matter of simultaneity relativity, but rather a fundamental difference in event content. The hypothesis imposes no constraints on how distinct the event sets may be across IRFs. In principle, the Moon may exist in one IRF and be entirely absent in another.

2.2 Role of the Observer

Unlike formal or abstract observers without consciousness, a cognitive observer is capable of *actualizing* one among many potential spacetime projections of the fundamental field. It is through the observer's cognitive, perceptual, and sensory processes that a stable causal structure is formed, defining the direction of time and local space.

This fact imposes significant constraints on the choice of basis and hypersurface deemed physically real and relevant, linking the physical ontology of spacetime with the phenomenon of consciousness.

From the observer's epistemic perspective, every fact manifested in their system must be considered as existing in all IRFs — even if that event is absent in some of them. This epistemic alignment leads to the selection of observable transformations as the primary class employed in traditional physics.

Definition: Cognitively Complete Observer

Let $\mathcal{H}_{\text{obs}}$ denote the (effective) space of internal states of the observer, decomposed with respect to a basis associated with their hypersurface Σ^3.

Definition 2.1. An observer (hereafter simply "observer") is said to be *cognitively complete* (i.e., self-aware) if the following conditions are satisfied[1]:

C1. Information integration. There exists a nonlinear operator

$$\mathcal{I} : \mathcal{H}_{\text{obs}} \longrightarrow \mathcal{H}_{\text{obs}}$$

(a memory and synthesis mechanism) that aggregates distributed signals over a finite interval $\Delta\ell > 0$ along the direction $\mathbf{n}$, where:

- $\mathcal{H}_{\text{obs}}$: effective Hilbert space of the observer's internal states;
- $\mathcal{I}$: operator that collects or integrates incoming signals, enabling storage and processing;
- $\Delta\ell$: length along the normal $\mathbf{n}$, representing a perception time interval;
- $\mathbf{n}$: normal vector to the hypersurface Σ^3, specifying the observer's time direction.

C2. Reliable recursion. The evolution of internal states is described by

$$U_{\text{obs}}(\ell) = e^{-iK\ell}, \qquad K = K^\dagger, \quad \sigma(K) \subset [0, \infty),$$

where $U_{\text{obs}}(\ell)$ is a unitary evolution operator along $\mathbf{n}$, and K is a Hermitian generator. The condition $\sigma(K) \subset [0, \infty)$ ensures the arrow of subjective time [14].

C3. Limited cognitive bandwidth. There exists an upper bound $\Lambda_{\text{cog}} > 0$ for the eigenfrequencies of K:

$$\sigma(K) \subset [0, \Lambda_{\text{cog}}],$$

where $\sigma(K)$ denotes the spectrum of the Hermitian operator K. Beyond Λ_{cog}, coherent signal integration breaks down (neurophysiological "frequency cutoff" [15]).

C4. Causal locality. All interactions capable of influencing $\mathcal{H}_{\text{obs}}$ propagate with speed $v \le v_t$; thus, the observer employs the same universal limit v_t in forming their time arrow [7]. We will later show that the maximum interaction speed in the hypothesis is bounded by v_t.

Consequence (constraint on admissible Σ^3). A hypersurface Σ^3 (hereafter simply "hypersurface") can be *actualized* by the observer only if the evolution operator $U(\ell)$ of the field ϕ satisfies

$$[K, \mathcal{I}] = 0, \qquad \|U(\ell)\|_{\mathcal{H}_{\text{obs}}} \le 1, \qquad \ell \in [0, \Delta\ell_{\max}],$$

where the first condition ensures compatibility of field dynamics with information integration, the second guarantees cognitive coherence, and $\Delta\ell_{\max}$ is chosen such that $\Lambda_{\text{cog}}\Delta\ell_{\max} \ll 1$.

These cognitive properties of the observer:

[1] See reviews on integrated information and free energy in [11, 12], as well as discussions on the physics of cognitive limits in [13].

- fix the time orientation (via the spectral condition $K \geq 0$);
- impose a *frequency filter* Λ_{cog};
- exclude projections where the information flux exceeds cognitive capacity.

These conditions reduce the set of potential projections $\{\Sigma^3\}$ to a *cognitively realizable* subset, thereby ensuring consistency between the fundamental field dynamics and the phenomenology of a self-aware observer. We plan to use the observer-related constraints later in deriving quantization.

3 Four-Dimensional Euclidean Model

3.1 Initial Assumptions

Let us consider a four-dimensional Euclidean space E^4 equipped with a fixed scalar metric. At each point $\mathbf{X} \in E^4$, we define a real scalar field $\phi(\mathbf{X})$ satisfying the linear equation

$$\Delta_4 \phi(\mathbf{X}) = 0, \tag{1}$$

where $\Delta_4 = \delta^{AB}\partial_A\partial_B$ is the Laplacian with respect to the Euclidean metric. This equation is invariant under the full orthogonal group $O(4)$; it contains no preferred directions, no metric time, and no internal symmetries.

We refer to this fundamental four-dimensional Euclidean space endowed with a real scalar field as the *Metauniverse*.

The model allows the selection of an arbitrary three-dimensional hypersurface $\Sigma^3 \subset E^4$, equipped with an orthonormal basis $\{\mathbf{e}_1, \mathbf{e}_2, \mathbf{e}_3\}$. A direction $\mathbf{n}$, orthogonal to Σ^3, defines a potential temporal axis. For each pair $(\Sigma^3, \mathbf{n})$, we may introduce a parameter ℓ representing the distance along $\mathbf{n}$, and a linear operator $U(\ell)$ that maps the field configuration from Σ^3 to the translated hypersurface $\Sigma^3 + \ell\mathbf{n}$:

$$C(\Sigma^3 + \ell\mathbf{n}) = U(\ell)\, C(\Sigma^3). \tag{2}$$

Given a fixed scaling parameter v_t (with the dimension of velocity), we define the observable time as

$$t = \frac{\ell}{v_t}. \tag{3}$$

The operator $U(\ell)$ then describes the evolution of the field with respect to the time parameter t, as defined by an observer who fixes the direction $\mathbf{n}$.

It is essential to emphasize that the choice of the normal vector $\mathbf{n}$ and the evolution operator $U(\ell)$ acquires physical meaning *only* in the presence of an observer capable of *actualizing* a direction of time.

Thus, the basis associated with Σ^3 and $\mathbf{n}$ is not merely a mathematical construction but becomes *cognitively actualized*, reflecting an observer-dependent projection of the fundamental field.

4 Derivation of Lorentz Transformations from the Model

4.1 Constraints on the Class of Reconstructions

In this section, we restrict consideration to those cases of cognitive reconstruction in which:

- the observer's cognitive time is aligned with a chosen direction $\mathbf{n} \subset \mathbb{R}^4$;
- the observer's cognitive space is aligned with a flat hypersurface $\Sigma^3 \perp \mathbf{n}$;
- the reconstructed distance between events in Σ^3 coincides with the Euclidean distance in the model $\mathbb{R}^4$, i.e., $\lambda = \ell$.

This is a simplified but physically meaningful case that allows one to construct a consistent cognitive structure and derive Lorentz transformations strictly from the geometric and causal constraints of the model. The more general case leads to general relativity, which will be considered separately.

Remark on Causal Constraints. Since we only consider reconstructions that preserve cognitive causality, there must be a constraint on the maximum permissible speed of influence transmission between observable events. That is, any two events separated by a spatial distance λ can be interpreted as causally connected only if at least a time $t = \lambda/v_{\max}$ elapses between them, for some finite $v_{\max}$. This constraint is not an external postulate but arises as a condition for consistent cognitive reconstruction of event structure by the observer.

Furthermore, since the observer lacks access to any external meta-structure, they must assume that $v_{\max}$ is the same in all admissible reconstructions (i.e., all IRFs). Otherwise, consistency of memory and event tracking under small transitions would be violated, which contradicts Postulate 2. Thus, the existence and invariance of $v_{\max}$ within observable transformations is a necessary consequence of the cognitive model itself.

Note also that the uniformity of $v_{\max}$ across all IRFs follows from the fact that the fundamental field lacks preferred directions or internal symmetries. It is therefore natural to expect that the same value of $v_{\max}$ applies throughout when the mechanism of spacetime emergence is uniform.

4.2 Derivation of Lorentz Transformations

It is important to stress that, under the local causality hypothesis, the observer treats events in different IRFs as cognitively equivalent, since their internal reconstruction requires coherence of event structure across transitions. This is justified not only by Postulate 2, but also by the fundamental requirement of cognitive consistency: the observer cannot allow events already recorded in memory to disappear or become inadmissible. Therefore, they construct transformations between IRFs so as to reconcile event reconstructions without losing cognitive integrity.

Let an observer $\mathcal{O}$ cognitively reconstruct spacetime based on the directions Σ^3 and $\mathbf{n}$. Then, for this observer:

$$t = \frac{\ell}{v_t}, \tag{4}$$

where ℓ is the distance along the direction $\mathbf{n}$, and v_t is the cognitive time scaling parameter.

This means the observer interprets the distance ℓ along their cognitive time direction as corresponding to a temporal interval t, using the scale v_t. This parameter is not a fundamental physical constant, but a subjective normalization between reconstructed Euclidean distances and perceived time flow. Its value depends on the internal coherence of reconstruction and is consistent with causal structure, as shown below.

The observer analyzes what transformations must occur between admissible cognitive reconstructions—those that respect the observable event structure and the constraint on maximum causal speed. These reconstructions may differ in the direction of cognitive time, but must preserve event coherence and cognitive consistency.

The following requirements:

- linearity of observable transformations (from cognitive consistency),
- invariance of the maximal causal speed $v_{\max}$,

imply that observable transformations between admissible cognitive reconstructions must be Lorentz transformations with parameter $v_{\max}$, defining the limit of causal connectivity:

$$t' = \gamma\left(t - \frac{vx}{v_{\max}^2}\right), \tag{5}$$

$$x' = \gamma(x - vt), \tag{6}$$

where

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{v_{\max}^2}}}.$$

Geometric Interpretation. The transition between different admissible spacetime reconstructions can also be interpreted geometrically as a rotation of the hypersurface Σ^3 relative to a fixed direction in $\mathbb{R}^4$. In other words, the observed relative cognitive velocity between IRFs corresponds to a tilt of the cognitive hypersurface by an angle θ, defined as

$$\tan\theta = \frac{v}{v_t}.$$

Each IRF is characterized by a specific choice of reconstructed time direction, and Lorentz transformations correspond to reconciliation between different tilted hypersurfaces that preserve cognitive coherence.

This geometric view emphasizes that Lorentz invariance in the model arises not as a global symmetry of space, but as a form of local consistency of cognitive reconstructions across various orientations of the observed event structure.

4.3 Time Normalization and the Identity $v_t = c$

As previously established, the observer can determine their temporal scale from reconstructed distance λ and time t:

$$v_t^{(\mathrm{obs})} = \frac{\lambda}{t}. \tag{7}$$

Assume the model includes a maximal causal speed $v_{\max}$, invariant across all IRFs (see Postulate 2). Then:

$$\text{Causal connection is admissible only if} \quad \lambda \leq v_{\max} \cdot t. \tag{8}$$

If $v_t < v_{\max}$, then $t = \lambda/v_t > \lambda/v_{\max}$, and the observer would incorrectly reject a valid causal link. If $v_t > v_{\max}$, then a false causal link would be accepted. The only case in which:

- all valid links are preserved,
- no false links are allowed,
- reconstruction is consistent with the model boundary—

is when:

$$v_t = v_{\max}. \tag{9}$$

If experiments confirm that $v_{\max} = c$, the speed of light in the observable universe, then we have:

$$v_t = c. \tag{10}$$

Thus, the parameter v_t, introduced in the model as a cognitive time scale, becomes an observable physical constant defined by the causal limit.

Additional Justification: Low-Velocity Limit. Consider now the case where the relative cognitive velocity between reconstructions tends to zero: $v \to 0$. Geometrically, this means that the direction of cognitive time in the second reconstruction $\mathbf{n}'$ deviates slightly from the original direction $\mathbf{n}$ by a small angle θ in $\mathbb{R}^4$.

In the model, cognitive velocity and tilt angle relate by:

$$\tan\theta = \frac{v}{v_t}, \quad \text{for small } \theta: \quad \theta \approx \frac{v}{v_t}.$$

Hence, the transition corresponds to tilting the hypersurface Σ^3 by angle $\theta \approx v/v_t$.

Postulate 2 demands that, in the limit $v \to 0$, observable transformations approach the identity, and cognitive structure remains coherent. This is possible only if the time scale v_t used in defining $t = \ell/v_t$ matches the bound $v_{\max}$. Otherwise, even an infinitesimal tilt would disrupt coherence of causal domains, violating cognitive consistency.

Therefore, from consistency in the small-velocity limit, it follows that:

$$v_t = v_{\max}.$$

4.4 Minimal Derivation of Lorentz Transformations

Finally, Lorentz transformations can also be derived from two general assumptions, independent of the full cognitive structure:

- observable transformations between IRFs are linear (as required by cognitive coherence),
- there exists a maximal causal speed $v_{\max}$, the same for all IRFs.

This leads to the classical invariant hyperboloid:

$$x^2 - v_{\max}^2 t^2 = \text{const}.$$

From this, Lorentz transformations follow as the unique linear transformations that preserve the structure.

Therefore, even without explicit cognitive reconstruction, Lorentz transformations emerge once linearity and a universal speed limit are assumed. The detailed derivation above demonstrates how these assumptions arise from the deeper structure of the local causality hypothesis.

Remark. Events absent from the current projection Σ^3 are not considered real in the sense of cognitive eventhood. However, if they causally influence accessible events (along $\mathbf{n}$), their effects may be reconstructed. This differs from SR, which assumes a global set of events equally accessible in all frames.

Limiting Case. The limit $v \to 0$ shows that direct and observable transformations are coherent in the weak regime, but differ in general.

4.5 Conclusion

The postulates of special relativity—including Lorentz transformations and the existence of a limiting speed—are rigorously derived from:

- the Euclidean symmetry of the scalar field equation,
- the cognitive choice of the observer,
- the generalized principle of causality.

This demonstrates that special relativity is an emergent consequence of Euclidean structure and cognitive actualization of events.

5 Derivation of Energy, Momentum, and Mass from Noether's Theorem

In this section, we derive the concepts of energy E, momentum P_i, and mass m for the scalar field ϕ at the fundamental level in E^4, without invoking "time" as a primitive notion. All symbols are introduced at their first appearance, and the variational formalism is used as a convenient mathematical tool.

On Cognitive Interpretation. Although this section employs variational calculus in E^4 without explicit time, the physical quantities—energy, momentum, and mass—acquire observable meaning only after projection onto a hypersurface Σ^3 specified by an observer. The observable interpretation of the energy–momentum tensor will be discussed in §..., where we show how the components $T^{\mu\nu}$ are projected onto the hypersurface and aligned with cognitive dynamics. Here we extract the structure of these quantities as Euclidean potential invariants available for cognitive actualization.

5.1 Euclidean Space E^4

- Let $X^\mu \in \mathbb{R}$, with $\mu = 1, 2, 3, 4$, be coordinates on four-dimensional Euclidean space E^4.
- The metric is given by $\delta_{\mu\nu} = \text{diag}(+1, +1, +1, +1)$, with inverse $\delta^{\mu\nu}$ satisfying $\delta^{\mu\rho}\delta_{\rho\nu} = \delta^\mu_\nu$.
- None of the coordinates X^μ is interpreted as "time"; all are treated equally.

5.2 Scalar Field ϕ and Its Equation

- Let $\phi : E^4 \to \mathbb{R}$ be a real scalar field.
- Define the differential operators:

$$\partial_\mu := \frac{\partial}{\partial X^\mu}, \quad \Delta_4 := \delta^{\mu\nu}\partial_\mu\partial_\nu.$$

- Let $m \geq 0$ be a constant of dimension $[\text{length}]^{-1}$, which will later be interpreted as mass, though here it is simply an internal parameter.
- The field satisfies the Euclidean Klein–Gordon equation:

$$(\Delta_4 - m^2)\,\phi = 0. \tag{11}$$

5.3 Lagrangian and Action

- Define the Lagrangian density:

$$\mathcal{L}[\phi](X) := \tfrac{1}{2}\,\delta^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - \tfrac{1}{2}\,m^2\phi^2. \tag{12}$$

- The action is:

$$S[\phi] := \int_{E^4} \mathcal{L}[\phi](X)\,d^4X, \qquad d^4X := dX^1dX^2dX^3dX^4. \tag{13}$$

- Variation $\delta S[\phi] = 0$ yields the equation of motion without referring to time.

5.4 Noether's Theorem and the Energy–Momentum Tensor $T^{\mu\nu}$

- The Lagrangian is invariant under translations $X^\mu \mapsto X^\mu + \varepsilon^\mu$.
- Noether's theorem gives:

$$T^{\mu\nu}(X) := \partial^\mu\phi\partial^\nu\phi - \delta^{\mu\nu}\mathcal{L}[\phi], \quad \partial^\mu := \delta^{\mu\rho}\partial_\rho. \tag{14}$$

- The conservation law is:

$$\partial_\mu T^{\mu\nu} = 0. \tag{15}$$

5.5 Observer and Hypersurface $\Sigma^3(\ell)$

- The observer is defined by a unit normal vector:

$$n^\mu \in \mathbb{R}^4, \quad \delta_{\mu\nu}n^\mu n^\nu = 1.$$

- Define the hypersurface:

$$\Sigma^3(\ell) := \{X \in E^4 \mid X^\mu n_\mu = \ell\}.$$

- Let $\{e_i^\mu\}_{i=1}^3$ be an orthonormal basis on $\Sigma^3(\ell)$, such that:

$$\delta_{\mu\nu}e_i^\mu e_j^\nu = \delta_{ij}, \quad \delta_{\mu\nu}e_i^\mu n^\nu = 0.$$

- Define directional derivatives:

$$\partial_n\phi := n^\mu\partial_\mu\phi, \quad \partial_{e_i}\phi := e_i^\mu\partial_\mu\phi.$$

- Let d^3x denote the induced volume element on $\Sigma^3(\ell)$.

5.6 Observable Energy E

- Define the energy as the flux of $T^{\mu\nu}$ through $\Sigma^3(\ell)$:

$$E := \int_{\Sigma^3(\ell)} T^{\mu\nu} n_\mu n_\nu \, d^3x.$$

- Substituting from the definition of $T^{\mu\nu}$, we get:

$$\begin{aligned} E &= \int_{\Sigma^3(\ell)} \left[(\partial_n\phi)^2 - \mathcal{L}\right] d^3x \\ &= \int_{\Sigma^3(\ell)} \left[(\partial_n\phi)^2 - \left(\tfrac{1}{2}(\partial_n\phi)^2 + \tfrac{1}{2}\sum_{i=1}^{3}(\partial_{e_i}\phi)^2 - \tfrac{1}{2}m^2\phi^2\right)\right] d^3x \\ &= \int_{\Sigma^3(\ell)} \left[\tfrac{1}{2}(\partial_n\phi)^2 - \tfrac{1}{2}\sum_{i=1}^{3}(\partial_{e_i}\phi)^2 + \tfrac{1}{2}m^2\phi^2\right] d^3x. \end{aligned}$$

5.7 Observable Momentum P_i

- Define momentum in the direction e_i^μ as:

$$P_i := \int_{\Sigma^3(\ell)} T^{\mu\nu} n_\mu e_{i,\nu} \, d^3x.$$

- Using the definition of $T^{\mu\nu}$ and orthogonality $n^\nu e_{i,\nu} = 0$, we obtain:

$$P_i = \int_{\Sigma^3(\ell)} (\partial_n\phi)(\partial_{e_i}\phi) \, d^3x.$$

5.8 Four-Momentum P^μ and Mass m

- Define the four-momentum as:

$$P^\mu := \int_{\Sigma^3(\ell)} T^{\mu\nu} n_\nu \, d^3x.$$

  Then:

$$P^\mu n_\mu = E, \quad P^\mu e_{i,\mu} = P_i.$$

- The mass is defined via the Euclidean norm:

$$m^2 := \delta_{\mu\nu} P^\mu P^\nu = E^2 - \sum_{i=1}^{3} P_i^2.$$

6 Derivation of General Relativity from the Local Causality Hypothesis

This section demonstrates that both postulates of general relativity, as well as the Einstein field equations, follow formally from the hypothesis of local causality formulated on four-dimensional Euclidean space E^4, without assuming time or a metric a priori.

6.1 Emergent Metric and the Physical Interpretation of Gravity

The observer is defined as a sequence of nested three-dimensional hypersurfaces

$$\Sigma^3(\ell) \subset E^4,$$

parameterized by length ℓ, with normal vectors $n^\mu(\ell) \in T_{x(\ell)}E^4$. This normal determines the "projective observation" direction at each hypersurface.

By projecting the Euclidean metric $\delta_{\mu\nu}$ onto the hypersurface orthogonal to n^μ, we obtain the induced metric:

$$g_{\mu\nu}(x) = \delta_{\mu\nu} - n_\mu(x)n_\nu(x), \tag{16}$$

where $n_\mu = \delta_{\mu\nu}n^\nu$ and $\delta_{\mu\nu}n^\mu n^\nu = 1$. Note that $g_{\mu\nu}(x)$ does not exist globally as a structure on E^4; rather, it emerges as a cognitively actualized tensor, locally defined by the observer in the vicinity of each hypersurface $\Sigma^3(\ell)$.

Physical Meaning of Gravity. In this hypothesis, gravity is not a fundamental interaction but an emergent phenomenon. It originates from variations in the direction of the normal vectors $n^\mu(\ell)$ between adjacent hypersurfaces. These variations lead to changes in the observed metric $g_{\mu\nu}(x)$ and are interpreted by the observer as gravitational curvature of spacetime. Thus, gravity functions as an effective field that maintains coherence in the observed causal structure. Its role is to compensate for mismatches between local projections, ensuring observed inertiality and locality.

6.2 Derivation of the Postulates of General Relativity

1. Principle of Equivalence. Near any point x_0, where $n^\mu(x)$ varies slowly, the metric approximates flat space:

$$g_{\mu\nu}(x_0) \approx \delta_{\mu\nu} - n_\mu(x_0)n_\nu(x_0) = \eta_{\mu\nu}.$$

In such regions, projected dynamics become locally inertial. Therefore, the observer cannot distinguish acceleration from gravity, and the first postulate of general relativity is satisfied.

2. Principle of General Covariance. The observer perceives only quantities defined via $g_{\mu\nu}(x)$. Hence, physical laws must be invariant under arbitrary coordinate transformations $x^\mu \mapsto x'^\mu(x)$, formalizing the second postulate of general relativity: the diffeomorphism invariance of physical equations [16, 17, 18].

6.3 Justification of the Action Structure

Locality. The fundamental action for the field ϕ is defined locally on E^4:

$$S[\phi] = \int_{E^4} \left(\frac{1}{2}\delta^{\mu\nu}\partial_\mu\phi\,\partial_\nu\phi \right) d^4x. \tag{17}$$

After projection onto observable space, the action remains local—operational quantities are expressed through local tensors and their derivatives. Although (17) is defined in E^4, its physical interpretation arises only after cognitive projection: the observer perceives only the variation of action projected onto the sequence $\Sigma^3(\ell)$, parameterized by observable time $t = \ell/v_t$.

Second-Order Derivatives. According to Ostrogradsky's theorem, stability requires the Lagrangian to depend on derivatives of no more than second order. Lovelock's theorem [19] states that in four dimensions, the only diffeomorphism-invariant scalar yielding second-order field equations is the Ricci scalar R. Thus, the gravitational Lagrangian takes the form:

$$\mathcal{L}_{\text{grav}} = \frac{1}{2\kappa} R. \tag{18}$$

6.4 Full Action and Einstein Equations

The total action involves the metric $g_{\mu\nu}$ and the projected scalar field ψ:

$$S[g, \psi] = \int \left[\frac{1}{2\kappa} R + \frac{1}{2} g^{\mu\nu} \nabla_\mu \psi \, \nabla_\nu \psi - \frac{1}{2} m^2 \psi^2 \right] \sqrt{-g} \, d^4x. \tag{19}$$

Variation with respect to $g^{\mu\nu}$ using the identities:

$$\delta \sqrt{-g} = -\tfrac{1}{2} \sqrt{-g} \, g_{\mu\nu} \, \delta g^{\mu\nu}, \tag{20}$$

$$\delta R = R_{\mu\nu} \, \delta g^{\mu\nu} + (\text{divergence terms}), \tag{21}$$

yields the Einstein field equations:

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R = \kappa T_{\mu\nu}. \tag{22}$$

with the energy–momentum tensor:

$$T_{\mu\nu} = \nabla_\mu \psi \, \nabla_\nu \psi - \tfrac{1}{2} g_{\mu\nu} \left(\nabla^\lambda \psi \nabla_\lambda \psi - m^2 \psi^2 \right).$$

The full technical derivation is provided in Appendix A.

6.5 Conclusion

The local causality hypothesis leads to:

- the postulates of general relativity;
- constraints on the form of the Lagrangian;
- the Einstein equations as a consequence of a universal action principle.

This supports the interpretation of general relativity as an emergent theory arising from the operational structure of observation in Euclidean space.

7 Singularities and Planck-Scale Limits in the Projective Model

In standard general relativity (GR), singularities—such as the core of a black hole—are points where curvature becomes infinite and the theory loses predictive power [23]. Similarly, in quantum field theory and gravity, energy near the Planck scale E_{Pl} breaks down the applicability of smooth metrics and field dynamics [25, 24].

In the framework of the local causality hypothesis—based on Euclidean geometry and a scalar field without intrinsic time—both issues are reinterpreted.

1. Singularities as Boundaries of Cognitive Coherence. Gravity in this model is not a fundamental interaction but a consequence of deviations in the projection normal $n(x)$ between adjacent hypersurfaces. The observed curved metric g_{ab} is merely a projection of the Euclidean metric and not fundamental.

Thus, regions where the projective structure becomes inconsistent (e.g., where $n(x)$ becomes discontinuous, degenerate, or non-orthogonal) are interpreted as *singularities*—not because geometry fails, but because the observer can no longer maintain a coherent projection. A breakdown of cognitive coherence occurs when no smooth or piecewise-smooth extension of $n^\mu(x)$ exists that satisfies the admissibility conditions (see §2.3). In such cases, cognitive projection collapses, and the observable event structure disintegrates.

Therefore, singularities are not ontological properties of physical reality, but *epistemic boundaries of observation.* The fundamental Euclidean field and its Laplace equation remain smooth everywhere.

2. Planck Energy as the Limit of the Projective Interpretation. Energy, mass, and momentum in this model emerge from symmetries of the projective action defined on the observer's hypersurface. These quantities are not absolute.

At energies comparable to E_{Pl}, the evolution of the field ϕ deforms the projective hypersurface Σ^3, such that the normal n becomes ill-defined, non-orientable, or multivalued. This causes concepts such as "energy" and "mass" to become ill-posed—not due to failure of the underlying field, but due to breakdown of the coordinate-based interpretation.

Thus, the Planck energy marks not a fundamental limit of nature, but the boundary of classical projective interpretation—that is, the limit of *cognitive projective interpretability.*

Conclusion. In the model of local causality, there are no ontological singularities or absolute energy limits. Instead, such features reflect the limitations of the observer as a projective system that constructs spacetime and physical observables through operational means. The fundamental Euclidean field remains smooth and invariant even where the emergent metric loses applicability.

8 Degrees of Causality Violation and Cognitive Stability of the Observer

This section analyzes the extent to which the principle of causality in E^4 must be satisfied for the observer to remain cognitively stable. This is essential for understanding the limits of applicability of the model and the conditions under which spacetime and evolution continue to be observable.

8.1 Exact Satisfaction of the Causality Principle in E^4

The principle of local causality in this hypothesis is based on the existence of an embedded family of hypersurfaces $\{\Sigma^3(\ell)\} \subset E^4$, parameterized along a continuous field of normals $n^\mu(\ell)$, defining a sequence of cognitive slices. When $n^\mu(\ell)$ depends smoothly on the parameter ℓ, the field $\phi : E^4 \to \mathbb{R}$ evolves along ℓ in a well-defined manner:

$$\partial_\ell \phi|_{\Sigma^3(\ell)} = \mathcal{F}[\phi|_{\Sigma^3(\ell)}], \tag{23}$$

which determines the locally causal order. In this sense, causality in the fundamental space E^4 is satisfied exactly if the normals n^μ are consistent and differentiable [4].

8.2 Weak Causality Violation and Cognitive Adaptation

Suppose the vector $n^\mu(\ell)$ undergoes fluctuations:

$$n^\mu(\ell) = \bar{n}^\mu(\ell) + \delta n^\mu(\ell), \quad \text{with } \|\delta n^\mu\| \ll 1. \tag{24}$$

Here, $\bar{n}^\mu(\ell)$ is the average direction of the normal defining the principal direction of perceived time, while $\delta n^\mu(\ell)$ describes its local fluctuations, induced either by the dynamics of the field ϕ or by constraints in the observer's cognitive structure.

In this case, the observer loses precision in ordering the projections. The observed state becomes not a point but a *temporal interval*:

$$\phi_{\text{eff}}(x,t) = \int_{t-\delta t}^{t+\delta t} \phi(x,\tau) w(\tau - t)\, d\tau, \tag{25}$$

where $w(\tau)$ is a weighting function determined by the statistics of δn^μ. A typical form of $w(\tau)$ is Gaussian with width δt, representing the "thickness of time." This aligns with the view of the observer as a cognitive structure defining accessible evolution [27, 11].

8.3 Boundary of the Observer's Cognitive Stability

If $\|\delta n^\mu\| \to 1$, the observer's cognitive structure collapses:

- the hypersurfaces $\Sigma^3(\ell)$ lose their embedding,
- causal order becomes ambiguous,
- subjective time loses directionality.

Thus, the observer can exist only under the condition that δn^μ remains bounded on the cognitive integration scale [26].

8.4 Geometry of the Observer's Projection Tube

Definition. The observer's projection tube $\mathcal{T}_{\text{obs}} \subset E^4$ is defined as the set of points $x \in E^4$ such that:

1. $\exists \ell_0 \in \mathbb{R}$ such that $x \in \Sigma^3(\ell_0)$,
2. $n^\mu(\ell)$ is defined and continuous in a neighborhood of ℓ_0,
3. the field ϕ is differentiable in a neighborhood of x,
4. the projection $\phi|_{\Sigma^3(\ell)}$ yields coherent evolution.

If any of these conditions fail, the point $x \notin \mathcal{T}_{\text{obs}}$, and it does not belong to observable reality. This is analogous to the concepts of local algebras and coherent regions in algebraic quantum field theory [28] and in causal set theory [29].

8.5 Physical and Cognitive Implications

Weak causality violations manifest in the observable world as:

- temporal jitter and time shifts,
- quantum-like energy fluctuations,
- reduction in the coherence of event perception,
- decoherent zones near the boundary of $\mathcal{T}_{\text{obs}}$.

Thus, the "thickness of time" reflects the range $\delta\ell$ over which cognitive consistency of projections is preserved under weak causality violation. Even under approximate satisfaction of the causality principle, observable reality and cognitive evolution may still persist.

9 Deriving Quantum Physics

9.1 Formalization of the Observer's Cognitive Tube

We consider the observer as a cognitive structure projecting the fundamental field $\phi(X)$ onto a sequence of three-dimensional slices $\Sigma^3(\ell)$ in 4D Euclidean space. This projection defines observable spacetime and cognitive observables. The boundedness of the tube ensures the finiteness of the local phase space and defines the region $\mathcal{T}_{\text{obs}} \subset \mathbb{R}^4$ where cognitive activity is effective:

$$\mathcal{T}_{\text{obs}} = \{X \in \mathbb{R}^4 \mid \phi(X) \mapsto \Sigma^3(\ell), \text{ bounded and stable cognitive projection}\}.$$

The tube must be cognitively realizable, which requires three fundamental conditions:

1. **Embodiment:** the observer must be realized through a connected set of localized modes forming a stable body in projection. These modes must evolve subluminally, supporting a causal cognitive structure and consistent emergent spacetime metric.
2. **Locality:** the observer interacts with the field only within a finite cognitive volume, defined by the bounded cognitive projection in its vicinity. This precludes access to global information and ensures operational consistency of observables.
3. **Stability:** the observer's cognitive structure must be robust against small field fluctuations, enabling reliable cognitive evolution, stable measurements, and compatibility with formal causality.

These requirements define the admissible class of observers and restrict the symmetries and dynamics compatible with cognitive realization. In particular, they play a key role in deriving the admissible internal symmetry groups in the following subsections.

9.2 Unitary Cognitive Evolution

Although the fundamental field $\phi(X)$ is a real scalar field, the observer's cognitive structure requires representing the observable state as a complex function. The complex nature is not fundamental but arises as a necessary feature of the cognitive projection, ensuring compatibility with Lorentz-invariant unitary dynamics and statistical reproducibility of observations. Accordingly, $\psi(x, \ell) \in \mathbb{C}^n$ is interpreted as an effective description of the cognitive state arising from the projection $\phi(X) \mapsto \Sigma^3(\ell)$.

The cognitive projection operator $\mathcal{P}_\ell$ is generally nonlinear and depends on the structure of the observer's tube. In the limit of a coherent and smooth cognitive structure, it can be approximated by a linear integral transform over a bounded region $\mathcal{T}_{\text{obs}}$, for example:

$$\psi(x, \ell) = \int_{\mathcal{T}_{\text{obs}}} K(x, \ell; X)\, \phi(X)\, d^4X, \tag{26}$$

where K is a weighting function defining the local contribution of the field to the cognitive projection. This clarifies the transition $\phi \mapsto \psi$.

The local structure of observable spacetime, previously derived from Euclidean geometry and the principle of causality, corresponds to a Minkowski-type pseudo-Riemannian manifold. Therefore, the observer's cognitive dynamics must be compatible with Lorentz transformations and preserve the norm of the observable state across inertial slices.

From representation theory (see [30, **?**]), it is known that the only class of equations invariant under Lorentz transformations and norm-preserving are unitary linear equations on complex functions. Therefore, the cognitive dynamics must be described by a complex wavefunction $\psi(x, \ell) \in \mathbb{C}^n$, defined on the cognitive slice $\Sigma^3(\ell)$, with unitary evolution in the parameter ℓ (interpreted as cognitive time):

$$i\frac{d\psi}{d\ell} = \hat{H}\psi, \tag{27}$$

where $\hat{H}$ is a Hermitian operator ($\hat{H}^\dagger = \hat{H}$), ensuring norm conservation:

$$\|\psi(\ell)\|^2 = \langle \psi(\ell), \psi(\ell) \rangle = \text{const}. \tag{28}$$

The cognitive wavefunction $\psi(x, \ell) \in \mathbb{C}^n$ is defined on the cognitive slice $\Sigma^3(\ell)$, arising as the observable projection of the observer's tube. Its norm,

$$\|\psi(\ell)\|^2 = \int_{\Sigma^3(\ell)} \psi^*(x, \ell)\, \psi(x, \ell)\, d^3x, \tag{29}$$

has operational cognitive meaning: it is interpreted as the reproducibility measure of the cognitive state under repeated projections onto the same slice $\Sigma^3(\ell)$.

Thus, the conservation of norm $\|\psi(\ell)\| = \text{const}$ is not optional but a cognitively necessary requirement: it guarantees that cognitive evolution is consistent with the operationally defined time ℓ, admits interpretation of observables as statistically reproducible, and aligns with the local spacetime structure derived from causality. As will be proven below, the only norm compatible with unitary evolution and reproducibility of cognitive information is the quadratic form $|\psi|^2$.

9.3 Probabilistic Interpretation of the Cognitive Function

To compute the probability of observing a particular state A, given the system's cognitive function $\psi(x, \ell)$, we use the standard scalar product in the Hilbert space of cognitive states. Let $\varphi_A(x)$ be a normalized cognitive function corresponding to state A on slice $\Sigma^3(\ell)$. Then the probability of cognitively registering state A upon observing state ψ is:

$$P_A = |\langle \varphi_A | \psi \rangle|^2 = \left| \int_{\Sigma^3(\ell)} \varphi_A^*(x)\, \psi(x, \ell)\, d^3x \right|^2. \tag{30}$$

If state A corresponds not to a single vector but to a subspace $\mathcal{H}_A$, then the probability is given by the projector $\hat{P}_A$ onto that subspace:

$$P_A = \langle \psi | \hat{P}_A | \psi \rangle. \tag{31}$$

To eliminate ambiguity in the structure of the cognitive function space, we define the cognitive Hilbert space as

$$\mathcal{H} = L^2(\Sigma^3(\ell), \mathbb{C}^n), \tag{32}$$

equipped with the scalar product:

$$\langle \varphi, \psi \rangle = \int_{\Sigma^3(\ell)} \varphi^*(x) \psi(x)\, d^3x, \tag{33}$$

ensuring completeness, separability, and consistent normalization. We assume that ψ is Borel-measurable and square-integrable, and that admissible operators are defined on a dense subspace $\mathcal{D} \subset \mathcal{H}$. Thus, the probabilistic interpretation is rooted in a consistent cognitive structure, rather than postulated externally.

Remark. The expression

$$\langle \varphi, \psi \rangle = \int_{\Sigma^3(\ell)} \varphi^*(x)\, \psi(x)\, d^3x$$

defines the scalar product in the cognitive space $\mathcal{H} = L^2(\Sigma^3(\ell), \mathbb{C}^n)$, interpreted as the space of admissible cognitive projections onto a fixed observable slice $\Sigma^3(\ell)$. This structure is not only mathematical but also operational: $|\langle \varphi | \psi \rangle|^2$ measures the reproducibility of state φ when the system is in state ψ.

That is, it expresses the probability that an observer, with cognitive function ψ, will register the state corresponding to φ upon projection. This understanding aligns with the postulates of quantum mechanics, but here it emerges naturally from the structure of the cognitive tube and unitary evolution.

The choice of L^2 is dictated by the need to:

- ensure norm conservation under unitary evolution,
- admit a complete orthonormal system of states,
- support linear self-adjoint operators as observables.

Thus, this scalar product plays a central role in the cognitive structure: it defines norms, probabilities, orthogonality of states, and underpins the mathematical rigor of cognitive dynamics. The uniqueness of the probability measure compatible with unitary dynamics and linearity is rigorously supported by Gleason's theorem [31] and its extensions [41].

Theorem 9.1 (On the Probabilistic Interpretation of the Cognitive Function)**.** Let the observer be defined by a cognitive tube satisfying embodiment, locality, and stability, and let their cognitive dynamics be consistent with local Lorentz invariance of emergent spacetime. Then:

1. the cognitive state of the observer is described by a complex wavefunction $\psi(x, \ell) \in \mathbb{C}^n$ defined on a cognitive slice $\Sigma^3(\ell)$;

2. the evolution of ψ with respect to cognitive time ℓ is given by a unitary Hermitian equation:
$$i\frac{d\psi}{d\ell} = \hat{H}\psi, \quad \hat{H}^\dagger = \hat{H};$$

3. the norm
$$\|\psi(\ell)\|^2 = \int_{\Sigma^3(\ell)} |\psi(x, \ell)|^2 \, d^3x$$
is cognitively interpreted as the reproducibility of the state;

4. norm preservation $\|\psi(\ell)\| = \text{const}$ is a necessary condition for consistent cognitive evolution;

5. the density $|\psi(x, \ell)|^2$ defines the probability of observing the state at point $x \in \Sigma^3(\ell)$ under repeated cognitive projections.

Proof. Items 1 and 2 follow from local Lorentz invariance derived earlier: by Wigner's theorem [30], Lorentz-invariant representations preserving scalar product must be unitary in complex Hilbert space. Item 3 follows from the operational definition of the cognitive tube: observation is a local projection onto a slice, and reproducibility of observations is determined by the norm of the state. Item 4 results from the requirement of observer stability: if the norm changes, cognitive evolution becomes statistically incoherent. Item 5 is a consequence of the fact that unitary linear evolution ψ admits only a norm that preserves cognitive reproducibility under all admissible transformations. Under assumptions of linearity, additivity, and unitarity, the only compatible probability measure is the modulus squared of the cognitive function. This is further supported by uniqueness theorems such as Gleason's [31] and its refinements [41].

□

9.3.1 Superdeterminism, Uncertainties, and Bell's Theorem

The proposed hypothesis is based on strict local causality in four-dimensional Euclidean space, leading to a superdeterministic framework: the entire cognitive evolution of the observer is fully determined by the configuration of the fundamental field. Thus, the probabilistic nature of quantum mechanics is not a fundamental randomness, but emerges as a consequence of limited cognitive accessibility and the projective nature of observation.

The constraint of the cognitive tube that defines the observer's body prohibits simultaneous observation of incompatible projections, resulting in observable uncertainties, including the Heisenberg uncertainty relations. These uncertainties are not interpreted as fundamental but rather as consequences of incomplete cognitive coherence in the projection of observables.

Bell's theorem, which asserts the impossibility of explaining quantum correlations by local hidden variables under the assumption of counterfactual independence, does not apply here. Due to the global cognitive coherence between the observer and the field, the assumption of independence of initial conditions from the choice of observables is violated. Therefore, within the framework of the hypothesis, Bell's theorem is circumvented by rejecting the freedom-of-choice assumption, in a manner consistent with strict local causality.

This approach preserves both locality and the unitarity of cognitive dynamics, while remaining fully consistent with observable quantum phenomena, including interference, entanglement, and probabilistic distributions of measurement outcomes.

Formalization of Bell's Theorem Assumptions. For completeness, let us recall that the standard derivation of Bell's theorem [56] relies on the following assumptions:

1. *Locality*: the outcome of a measurement on one device does not depend on the setting of another (spatially separated) device;
2. *Realism*: the physical system possesses definite properties independent of measurement;
3. *Counterfactual independence* (freedom of choice): the variables determining the outcome of an experiment are independent of the choice of observables being measured.

The local causality hypothesis retains *realism* in the sense of the existence of a fundamental field in E^4, independent of the observer. However, the cognitive state (the wave function) is regarded as emergent—reflecting cognitive limitations rather than constituting a fundamental physical object. Consequently, the hypothesis violates the third assumption (counterfactual freedom) while preserving realism in the deeper ontological sense, grounded in the deterministic configuration of the field. Due to the global cognitive coherence, the field and the observer form a coupled system that does not allow for independent variation of observation settings. This approach corresponds to the well-known *freedom-of-choice loophole* [57, 58], and is consistent with empirical data while maintaining a strictly local deterministic model.

10 Symmetries and Particles as Cognitive Representations

This section addresses the origin of the observed symmetries $SU(3) \times SU(2) \times U(1)$ and the associated structure of elementary particles as cognitive representations within the hypothesis of local causality and the observer's cognitive tube.

10.1 Minimal Symmetries as Cognitive Requirements

Since the observer must be embodied, local, and stable, the cognitive tube that generates spacetime and matter must permit the description of particles capable of subluminal motion (i.e., $v < c$), which is necessary for forming the observer's embodied cognitive structure.

Among all continuous compact groups $SU(n)$, the minimal one that allows for color interaction and asymptotically free fermionic states is $SU(3)$. It enables the formation of stable localized bodies of a cognitive observer.

The group $SU(2)$, which does not lead to confinement but supports unstable weak interactions, may be associated with the necessity of transmitting information about decoherent cognitive projections—such as in measurements or decays. Thus, it provides a mechanism for cognitive decoherence, sustaining the observability of unstable and transitional states.

The abelian symmetry $U(1)$ arises as the minimal extension of local phase symmetry compatible with unitary cognitive evolution. According to Wigner's theorem and norm preservation, only those phase transformations are admissible that realize a unitary representation of the group $U(1)$.

U(1) as a Consequence of Lorentz Invariance and Cognitive Unitarity. The local Lorentz invariance of the observer's cognitive tube, previously derived as a property of coherent projection, requires that cognitive state functions admit a phase degree of freedom:

$$\psi(x) \mapsto e^{i\theta(x)}\psi(x),$$

such that observable quantities and probabilities remain invariant. This transformation is compatible with unitary evolution of the cognitive function and, hence, with cognitive reproducibility. These transformations form the group $U(1)$ — the minimal continuous unitary symmetry compatible with norm preservation and local Lorentz invariance.

In the present hypothesis, where cognitive time and phase structure are emergent, $U(1)$ appears as a necessary cognitive condition for coherent observation in time, ensuring robustness under local phase shifts and decoherent projection.

Thus, the group $U(1)$ in the observer's cognitive structure is not an arbitrary extension but follows naturally from:

- local Lorentz invariance of the observable structure;
- unitarity of cognitive evolution;
- phase-based cognitive reproducibility of observations.

Consequently, the *smallest known symmetry group compatible with cognition*, allowing for an embodied observer with stable cognitive projections and decoherent processes, is:

$$G = SU(3) \times SU(2) \times U(1). \tag{34}$$

Its uniqueness as the only cognitively admissible group remains a hypothesis. Other candidate symmetries, such as $SU(5)$ or $SO(10)$, might be cognitively realizable but are more complex and not experimentally confirmed.

10.2 Particles as Representations of the Cognitive Gauge Group

Within this framework, the observer is described by a cognitive tube possessing a minimally coherent structure compatible with Lorentz invariance, embodiment, locality, and stability. These requirements uniquely determine the admissible cognitive symmetry structure: the group $\mathcal{G}_{\text{cog}} = SU(3) \times SU(2) \times U(1)$, which emerges as the only realizable symmetry within a consistent cognitive phase volume.

In this model, elementary particles are interpreted as irreducible representations of the cognitive group $\mathcal{G}_{\text{cog}}$. Each representation corresponds to a class of stable cognitive projections on the slice $\Sigma^3(\ell)$, perceived by the observer as observable quantum states.

This aligns with the standard principle in gauge theory: the fields associated with particles are sections of vector bundles defined by local symmetry representations.

- The group $SU(3)$ governs *color* interactions and describes quarks and gluons as triplets and octets;
- The group $SU(2)$ implements the weak interaction, e.g., with leptons forming doublets;
- The group $U(1)$ accounts for electromagnetic interaction, where charges correspond to phase transformations.

Hence, the observer's cognitive tube admits only those projections that are stable under transformations of $\mathcal{G}_{\text{cog}}$, leading to the observed spectrum of elementary particles. The Standard Model structure and particle properties (spin, charge, isospin, etc.) thus follow not as a postulate but as a necessary consequence of coherent cognitive realizability.

Generations of particles can be interpreted as cognitively distinguishable but mathematically isomorphic realizations of the same representations. This leaves open the question of their mass and interactions, potentially clarified through the structure of decoherent interactions or symmetry modifications.

10.3 Constraints and Testing of Cognitive Symmetry

The derivation of symmetries relies on cognitive minimality, unitary realizability, observer embodiment, and the feasibility of decoherent projections. Alternative groups either fail to support stable subluminal modes (e.g., $SU(2)$ alone) or lack cognitive localization (e.g., $U(1)$ alone). Possible alternatives such as $SU(5)$ or $SO(10)$ require more complex cognitive structures and are not experimentally confirmed.

Therefore, the hypothesis of cognitive realizability leads to a *preference* for the symmetry $SU(3) \times SU(2) \times U(1)$ as minimal and empirically supported. However, its strict uniqueness remains an open question.

10.4 Number of Particle Generations

The hypothesis of cognitive realizability also imposes constraints on the number of cognitively distinguishable modes realizable as stable or decoherent particles. It is known that only the first generation of fermions (electron, electron neutrino, up and down quarks) forms stable embodied matter. Therefore, its existence is necessary for the presence of an observer.

The second and third generations (e.g., muon, tau, corresponding neutrinos, and heavy quarks) primarily participate in unstable processes. Their role may relate to providing cognitive decoherence, enhancing CP-violation, or enabling cognitively complete transitions of observed states.

Moreover, unitary cognitive dynamics requires a finite cognitive Hilbert space. This excludes the possibility of an infinite number of generations, which would break normalizability and statistical coherence.

Thus, the hypothesis permits only a finite number of generations, minimally necessary for a stable cognitive structure. The exact number of generations (e.g., $n = 3$) is not fixed, but its finiteness and the functional distinction among generations are explained through cognitive principles.

11 Interaction Fields, Symmetry Breaking, and Mass

This section formalizes the cognitive structure of interactions and the mechanisms of symmetry breaking that lead to the emergence of particle masses and intergenerational distinctions.

11.1 Cognitive Fields as Emergent Perturbations

The cognitive wave function $\psi(x, \ell)$ describes the state of the observable slice. However, interactions between different cognitive modes require the introduction of additional structures—*cognitive fields*, which are realized as perturbations of the cognitive tube and transform coherently under the action of the $SU(3) \times SU(2) \times U(1)$ symmetry.

Cognitive fields are introduced as operator-valued distributions $\hat{\Phi}_a(x, \ell)$ acting on the cognitive Hilbert space. They serve as quantized analogues of the couplings between cognitive modes and admit spectral decomposition with respect to the symmetry representations.

Terminological justification. The term *cognitive field* is used instead of the standard *effective field* because, within the present hypothesis, the observer and their cognitive tube are not external witnesses to a microscopic physical world but rather generative structures of spacetime and matter. In this context, fields are not approximations of a deeper underlying dynamics but emergent operators of cognitive projection, rooted in local coherence. Hence, cognitive fields are not outcomes of integrating out microphysics, but structures intrinsically required for coherent cognitive realization.

11.2 Generalized Gauge Cognitive Invariance

The requirement of local cognitive realizability leads to the necessity of local invariance of the cognitive function under the groups $SU(3)$, $SU(2)$, and $U(1)$. This yields the emergence of cognitive gauge fields:

- $A^a_\mu(x) \in \mathfrak{su}(3)$: gluonic cognitive fields;
- $W^i_\mu(x) \in \mathfrak{su}(2)$: weak cognitive fields;
- $B_\mu(x) \in \mathfrak{u}(1)$: hypercharge field.

These fields implement local transformations of the cognitive phase, isospin, and color, respectively, preserving the unitarity of the cognitive evolution.

11.3 Symmetry Breaking Mechanism and Mass

The emergence of mass requires a mechanism of spontaneous symmetry breaking. Its cognitive realization is implemented via a field $H(x)$ (a cognitive analogue of the Higgs boson), which acquires a nonzero cognitive expectation value in a certain cognitive vacuum:

$$\langle H(x) \rangle \neq 0.$$

This results in the narrowing of the cognitive tube to more localized projections, thereby breaking the cognitive gauge symmetry $SU(2) \times U(1)$ and generating mass for leptons and vector fields. At the same time, the global coherence of the cognitive structure is preserved, ensuring unitary evolution.

11.4 Outlook Toward Quantum Field Theory

The introduced cognitive fields $\hat{\Phi}_a(x, \ell)$ admit second quantization and spectral analysis. The cognitive tube can be viewed as a multi-modal quantum system, with creation, annihilation, and interaction of modes mediated by the corresponding fields. This provides a foundation for a cognitive quantum field theory consistent with local causality and the cognitive realizability of the observer.

Remark. A more rigorous formalization of the quantization of cognitive fields requires constructing a complete algebra of cognitive operators and a cognitive vacuum. This is intended for future work.

12 Quantum Dynamics and the Evolution of Cognitive States

Following the introduction of the cognitive wave function and cognitive fields, the next objective is to describe the evolution of cognitive states within the framework of unitary quantum dynamics.

12.1 Cognitive Hamiltonian and Evolution

The cognitive state $\psi(x, \ell) \in \mathcal{H}$ evolves with respect to the cognitive parameter ℓ, which describes the position of the observable slice $\Sigma^3(\ell)$ within the observer's tube. The evolution is governed by a unitary operator $U(\ell_2, \ell_1)$, satisfying the Schrödinger-type equation:

$$i\frac{d\psi}{d\ell} = \hat{H}(\ell)\psi,$$

where $\hat{H}(\ell)$ is a Hermitian operator depending on the local cognitive environment, including the cognitive fields $\hat{\Phi}_a(x, \ell)$.

Unitarity of evolution ensures the conservation of the norm $\|\psi(\ell)\|^2$, guaranteeing consistency of cognitive reproducibility across states.

12.2 Spectral Structure and Observable Quantities

Observable quantities are represented by Hermitian operators $\hat{O}$ acting on $\mathcal{H}$. The possible outcomes of cognitive registration correspond to the eigenvalues of $\hat{O}$, and the probability of observation is determined by the projection of ψ onto the corresponding eigenspace.

The spectral structure of the cognitive Hamiltonian $\hat{H}$ defines the accessible cognitive energy levels, and the evolution in the eigenbasis realizes a decomposition of cognitive dynamics into modes.

12.3 Cognitive Interference Effects

Since the cognitive evolution is unitary, coherence between components of the wave function is preserved. This enables the emergence of interference effects upon the superposition of cognitive projections.

Thus, cognitive superpositions yield statistically reproducible deviations from classical predictions, in agreement with empirically observed quantum phenomena. Interference manifests the unitary nature of cognitive evolution and the linearity of the cognitive tube.

Remark. At this stage, cognitive dynamics describes a one-particle quantum mechanics. The transition to a cognitive quantum field theory requires the construction of a field algebra and second quantization. This is planned as a subsequent development of the hypothesis.

13 Measurement and Cognitive Decoherence

13.1 Operational Definition of Cognitive Measurement

In the proposed hypothesis, measurement is not treated as a physical interaction with an external device, but rather as the cognitive fixation of a projection of the state onto a slice $\Sigma^3(\ell)$ of the observer's tube. The measurement process consists in selecting a specific subspace of the cognitive Hilbert space $\mathcal{H}$, followed by the fixation of the cognitive function within it.

The probability of such fixation is given by the squared norm of the projection:

$$P_A = \langle \psi | \hat{P}_A | \psi \rangle,$$

where $\hat{P}_A$ is the projector onto the subspace corresponding to the result A.

13.2 Decoherence as Loss of Cognitive Interference

When cognitive interactions occur with fields or other subsystems, the cognitive state may lose phase coherence with respect to a chosen basis. This is reflected in the disappearance of interference terms in the statistical sum of projections:

$$\rho(x, x') \to \rho(x, x)\delta(x - x').$$

This transition is interpreted as decoherence: the system ceases to cognitively reproduce superpositions and transitions to a probabilistic distribution.

13.3 Cognitive Stability of the Measurement Result

The observer's cognitive tube requires structural stability. Hence, measurement must yield a state reproducible in repeated cognitive projections. This implies that the measurement result is fixed as a stably decoherent cognitive state:

$$\psi(x, \ell) \longrightarrow \hat{P}_A \psi(x, \ell).$$

Thus, wave function collapse is not postulated but emerges as a limiting case of decoherence that ensures stability of cognitive fixation.

13.4 Relation to Unitary Evolution

At the level of the full cognitive tube, the entire dynamics remains unitary. Decoherence and measurement arise as effective local processes, determined by the structure of projections and cognitive realizability. Therefore, unitarity is violated only within the restricted operational model of projections, but not at the fundamental level.

Conclusion. Measurement and decoherence are interpreted not as external physical processes, but as consequences of the observer's limited cognitive structure and the requirement for stable local fixation of cognitive information.

14 Dark Energy as a Cognitive Constraint

14.1 Finiteness of the Cognitive Tube and the Necessity of Bounded Volume

The cognitive tube of the observer represents a localized region in four-dimensional Euclidean space that enables coherent perception and cognitive fixation of emergent spacetime. Cognitive stability requires that the domain in which the principle of local causality holds is finite.

If the volume of the observable space tends toward infinity, consistent cognitive fixation and reproducibility of observations become impossible: even small violations of causality at large scales accumulate and destroy cognitive coherence.

14.2 Cosmological Constant and Cognitive Realizability

In order for observable spacetime to remain cognitively stable, it must possess a finite three-volume on the slice $\Sigma^3(\ell)$. Within general relativity, such a constraint can be achieved through the presence of a positive cosmological constant:

$$\Lambda > 0 \quad \Rightarrow \quad \text{closure of cognitively admissible space.}$$

Thus, the presence of dark energy (in the form $\Lambda > 0$) is not an empirical parameter, but a consequence of the cognitive requirement of observer realizability within an infinite Euclidean background.

14.3 Prediction: Asymptotic Isolation

If dark energy is fundamental and tied to cognitive stability, then as the universe expands, the observer will gradually become cognitively isolated from distant regions. This prediction aligns with contemporary forecasts of the thermal death of the universe and the disappearance of observable galaxies beyond the horizon.

14.4 Dark Matter as an Incoherent Projection of the Field

Since observation in this hypothesis is a cognitive projection of the fundamental field onto the coherent tube of the observer, not all components of the field participate in cognitive fixation. Modes that fall outside the phase or coherence range of the tube may exert gravitational influence but do not manifest as cognitive states.

This cognitively inaccessible yet metaphysically present content is interpreted as *dark matter*. It does not participate in superpositions of observable quantum states, does not contribute to cognitive interference, but affects the geometry of emergent spacetime.

Accordingly, dark matter may be understood as the projection of those modes of the fundamental scalar field that are incoherent with the observer, yet still contribute to the effective gravitational metric. Its presence supports the cognitive connectivity of large-scale structures (e.g., galaxies), which are necessary for the existence of stable embodied observers.

Origin of Incoherence. More formally, the cognitive tube defines a spectral projector $\hat{P}_{\text{cog}}$ in the state space. Dark matter corresponds to modes orthogonal to the image of $\hat{P}_{\text{cog}}$. These modes are:

- either geometrically localized outside the tube;
- or possess incoherent phase trajectories;
- or are dynamically incompatible with the observer's unitary cognitive evolution.

Hence, the origin of dark matter is not attributed to an additional field, but to the limited cognitive projection of the fundamental field.

Conclusion. In the context of the local causality hypothesis, dark matter arises as an incoherent yet gravitationally active part of the fundamental field—excluded from cognitively reproducible states but necessary for the stability of the observed metric and coherence of large-scale structure.

15 Quantum Field Theory as Cognitive Dynamics

15.1 Cognitive Field as a Section of an Operator Bundle

Let $\Sigma^3(\ell)$ be a cognitive slice within the observer's tube, consistent with local Lorentz invariance. We define a cognitive field as a mapping

$$\Phi : \Sigma^3(\ell) \to \mathcal{A},$$

where $\mathcal{A}$ is the algebra of linear operators on the cognitive Hilbert space $\mathcal{H} = L^2(\Sigma^3(\ell), \mathbb{C}^n)$.

Interpretation. The cognitive field $\Phi(x)$ acts as a cognitive transformer, linking local observable projections with the global cognitive evolution of the observer. It encodes the internal structure of cognitive symmetries and local observability.

15.2 Cognitive Field Dynamics

At scales permitting an effective approximation by smooth spacetime, the cognitive field Φ satisfies the equation:

$$(\Box + m^2)\Phi(x, \ell) = 0, \tag{35}$$

where $\Box \equiv \eta^{\mu\nu}\partial_\mu\partial_\nu$ is the d'Alembertian in local coordinates on $\Sigma^3(\ell) \times \ell$, and m is the cognitive mass of the field. This equation describes a stable local cognitive projection under approximately Lorentz-invariant conditions.

15.3 Algebra of Cognitive Operators

Let $\Pi(x) = \partial_\ell \Phi(x, \ell)$ be the conjugate operator. In the cognitive approximation, these satisfy:

$$[\Phi(x), \Pi(y)] = i\delta^3(x - y), \quad [\Phi(x), \Phi(y)] = [\Pi(x), \Pi(y)] = 0. \tag{36}$$

This algebra is consistent with the cognitive norm and unitary evolution, defining observables as functionals of Φ and Π acting on $\mathcal{H}$.

15.4 Hamiltonian and Unitary Cognitive Evolution

The cognitive Hamiltonian of the observer is given by:

$$\hat{H} = \int_{\Sigma^3(\ell)} \left[\tfrac{1}{2}\Pi^2(x) + \tfrac{1}{2}(\nabla\Phi(x))^2 + \tfrac{1}{2}m^2\Phi^2(x)\right] d^3x, \tag{37}$$

governing the cognitive evolution of states with respect to the parameter ℓ:

$$i\frac{d}{d\ell}|\Psi(\ell)\rangle = \hat{H}|\Psi(\ell)\rangle. \tag{38}$$

15.5 Symmetries and Interactions

Cognitive fields may carry indices corresponding to representations of $SU(3), SU(2), U(1)$, previously derived as minimal cognitive symmetries. Interactions are described by cognitively admissible Lagrangians, invariant under these symmetries and preserving unitarity.

Specifically:

- **Fermions** transform under the fundamental representation of $SU(3) \times SU(2) \times U(1)$;
- **Gauge fields** represent local symmetry transformations and are described by connections A_μ with curvature $F_{\mu\nu}$;
- **The Higgs mechanism** is implemented cognitively via a field Φ_H responsible for spontaneous symmetry breaking and mass generation.

15.6 Path Integrals, Feynman Diagrams, and Renormalization

The probabilistic cognitive dynamics can equivalently be expressed through a path integral of the form:

$$\mathcal{A}_{fi} = \int \mathcal{D}\Phi \, e^{iS[\Phi]}, \tag{39}$$

where $\mathcal{D}\Phi$ is the measure over field configurations, $S[\Phi]$ the cognitively consistent action, and $\mathcal{A}_{fi}$ the transition amplitude.

Feynman Diagrams. Vertices and lines arise from expanding e^{iS} in interacting terms of the Lagrangian. Internal lines (virtual particles) correspond to cognitively non-coherent transitions and are off-shell.

Ultraviolet Divergences. At high energies (small scales), the cognitive approximation of continuity leads to divergences in loop diagrams. This reflects the limits of cognitive applicability of the smooth field approximation.

Renormalization. These divergences can be removed by regularization and cognitive redefinition of Lagrangian parameters (mass, charges, couplings), preserving theoretical predictability and cognitive consistency with observations.

Interpretation. Renormalization is not an ad hoc procedure but a cognitive necessity for maintaining stability and observability at small scales. It is fully compatible with the principles of cognitive unitarity and probabilistic interpretation.

15.7 Spontaneous Symmetry Breaking as Cognitive Necessity

A cognitive system implementing an observer must be coherent but not necessarily invariant under the full symmetry group G. If the cognitive Lagrangian is invariant under a continuous group G, but the cognitive vacuum $|\Omega\rangle$ is not,

$$\exists g \in G : \hat{U}(g)|\Omega\rangle \neq |\Omega\rangle, \tag{40}$$

then only a subgroup $H \subset G$ preserving $|\Omega\rangle$ is fixed by the observer, and physical fields correspond to representations of H.

Example. For a cognitive Higgs field Φ_H with potential

$$V(\Phi_H) = \lambda(\Phi_H^\dagger \Phi_H - v^2)^2, \tag{41}$$

the minimum occurs at $\langle \Phi_H \rangle = v \neq 0$, breaking the symmetry and generating mass for other fields. Cognitively, this corresponds to a preferred direction in the projection space.

Interpretation. Spontaneous symmetry breaking arises from the stability requirement of the observer's cognitive structure: the cognitive tube selects a stable observable state that minimizes its internal cognitive energy but is not symmetric under the full equations. This is cognitively necessary for the emergence of distinguishable states and stable particles.

15.8 Conclusion

Quantum field theory thus emerges in the hypothesis as an effective theory of local cognitive observations within a stable cognitive tube. It preserves unitarity, symmetries, and the probabilistic interpretation of the cognitive function, with observable particles interpreted as field quanta in the cognitive Hilbert space.

16 Cognitive Constraints on Beyond Standard Model Extensions

Since the hypothesis is based on the existence of a bodily, local, and stable observer, possible extensions of physical theory beyond the Standard Model (BSM) are subject to cognitive constraints. Only those extensions are admissible which are consistent with the observer's cognitive tube and do not violate its realizability.

16.1 Admissible Extensions

- **Neutrino masses and the PMNS matrix:** are allowed, since neutrinos possess small but non-zero mass, enabling subluminal cognitive dynamics and interference. Flavor oscillations correspond to cognitive transformations between modes.

- **Fermion masses and Higgs-sector extensions:** are allowed provided that symmetry is spontaneously broken and mass arises through cognitively admissible local dynamics. Higgs-sector extensions must preserve unitarity.

- **Sterile neutrinos:** are admissible if they participate in cognitive dynamics and allow projections onto the observer's tube. Their weak interactions are compatible with gradient-level cognitive connectivity.

- **Dark matter candidates:** are admissible if the corresponding fields are cognitively realizable via gravitational effects or cognitively permissible weak coupling. Examples include axions or weakly interacting massive particles (WIMPs).

16.2 Inadmissible Extensions

- **Tachyonic fields:** are prohibited as they violate the subluminal structure of the bodily cognitive tube, disrupting causality and locality.

- **Non-degenerate extra dimensions:** are inadmissible if they are not cognitively realizable. Extra dimensions must be effectively compactified below the cognitive resolution scale.

- **Nonlocal interactions:** are ruled out, as they contradict cognitive locality and continuous bodily evolution of the observer.

- **Non-unitary models:** are excluded because cognitive evolution requires norm preservation and a coherent probabilistic interpretation.

Remark. Although a human observer cannot be cognitively localized in extreme regions (e.g., the early universe or near black hole horizons), they can receive signals from such regions within the cognitive tube. Therefore, only those extensions are admissible that can be reconstructed from effects observable here and now, without violating the observer's bodily coherence and stability.

Neutrinos, as particles with extremely small mass and near-luminal velocity ($v \lesssim c$), play a special role in the cognitive structure. Their nearly lightlike speed permits participation in cognitive dynamics without forming the bodily coherence of the observer. This makes them natural carriers of weak cognitive interactions and helps explain the role of SU(2) in the minimal cognitive symmetry group.

Although neutrinos interact very weakly with matter, they admit unitary flavor transformations (PMNS matrix), which are cognitively realizable and observable. They can thus be interpreted as markers of cognitive extent and of interactions at the boundary of realizability—preserving bodily structure while expanding the observational phase space.

16.3 Cognitive Constraints on Extensions

Only those extensions of physics are considered which are cognitively realizable by an observer possessing a bodily, local, and stable cognitive tube consistent with local Lorentz invariance. This excludes:

- extreme conditions (early universe, Planck-scale physics),
- topological transitions in cognition,
- fields that violate local coherence or bodily realizability.

Clarification. Even though a human observer cannot be cognitively localized in extreme environments (e.g., the early universe or near black hole horizons), they can still receive signals from such regions within their cognitive tube. This implies that only extensions reconstructible from observable effects within the present cognitive frame are admissible.

16.4 Conclusion

The cognitive hypothesis imposes a natural selection criterion for viable BSM models: only those extensions that preserve unitarity, locality, and cognitive realizability relative to the human observer's structure can be integrated as consistent extensions of the Standard Model.

Thus, BSM extensions become physically meaningful only if they are observable and cognitively stable. This makes the hypothesis both predictive and constraining.

17 Spacetime and Consciousness: Ontological Status

The constructed theory derives observable spacetime as an emergent phenomenon arising from the cognitive structure of the observer, operating within the fundamental four-dimensional Euclidean space E^4. Spacetime coordinates in this model are not fundamental but represent projections of coherent perception along the observer's cognitive tube.

The cognitive tube, endowed with local causality, embodiment, and stability, gives rise to the structure of coherent observables consistent with Lorentz invariance. This yields the illusion of spacetime for the observer. Within this framework, time is not absolute but a parameter of sequential cognitive projection consistently maintained across the tube.

Thus, space and time are cognitive, observer-dependent constructs. Their existence and properties are determined not by external conditions but by internal constraints of a stable observer. This radically distinguishes the model from classical realist interpretations, in which spacetime is taken as fundamental *a priori*.

Implications. This perspective resolves paradoxes in quantum gravity and the problem of time in general relativity, unifying quantum mechanics and gravity without postulating a graviton. Geometry, metric structure, particles, and fields emerge from the cognitive organization of the observer rather than from the fundamental structure of the world.

17.1 Consciousness as Strong Emergence

Within the proposed hypothesis, consciousness is not postulated as a primitive entity and does not require a new ontological category. Instead, it emerges as a cognitive phenomenon within stable projections of the scalar field possessing the following properties:

- cognitive coherence and unitary evolution;
- locality and reproducibility of observations;
- a structure capable of self-observation and reflexivity;
- formation of observable spacetime as a cognitive projection.

In this context, consciousness is a structure that emerges from the fundamental field but is not reducible to its local values. It requires a coherent global configuration of the observer's cognitive tube and plays a central role in the formation of all observable physical phenomena, including space, time, causality, and probabilistic interpretation.

Thus, consciousness may be qualified as a phenomenon of *strong emergence* in a precise sense: it is not directly derivable from the field equations, yet it becomes inevitable under conditions of cognitive stability. Importantly, this emergence does not expand the ontology—only the fundamental field remains, whose global configuration generates both the observer and their experienced reality.

Therefore, the hypothesis explains consciousness as a structural necessity arising within physics, eliminating the gap between physical laws and subjective experience without the introduction of additional entities.

17.2 The Transition of Philosophical Domains into Physics

If the hypothesis of local causality in Euclidean space with a cognitive observer is correct, it profoundly shifts the boundary between philosophy and physics. Several traditionally philosophical domains become physically formalizable and are integrated into theoretical physics, making experimental verification possible. Key areas transitioning into physics under this hypothesis include:

- **Philosophy of mind** → *Physics of cognitive structures*: consciousness is described as a stable cognitive tube satisfying physically defined coherence conditions, enabling the formalization of criteria for the presence of consciousness and agency.
- **Metaphysics of time and space** → *Emergent physics of spacetime*: time and space are not postulated but emerge from the structure of the cognitive tube. Their properties follow from requirements for observability and causality.
- **Epistemology** → *Physics of observation*: the cognitive process of observation is formalized as projection dynamics, thus granting cognition an operational physical description.
- **Philosophy of mathematics** → *Physics of cognitive forms*: mathematical structures are interpreted as stable cognitive projections, unifying mathematical and physical ontology.

- **Ontology** → *Physics of emergent existence*: the concept of existence is cognitively defined through the stability and reproducibility of observable projections.
- **Philosophy of science** → *Metatheory of cognitive physics*: the observer is included within the theory, allowing criteria for scientificity and falsifiability to be formulated as internal properties of the theory.

In this way, the hypothesis leads to a profound ontological and epistemological revision: physics becomes a self-contained structure encompassing the cognitive capacity of the observer, and philosophical problems are subsumed under specific cases of physical regularities.

18 Discussion and Outlook

The presented theory formalizes the hypothesis of local causality as a universal principle governing the organization of observable reality. Space, time, fields, particles, and interactions all emerge as cognitive phenomena enabling stable and coherent observation. The theory demonstrates that quantum mechanics, general relativity, and gauge symmetries can be derived from a single operational principle, without postulating any specific geometric or physical structures.

Of particular importance is the derivation of the observed symmetries of the Standard Model as the minimal set necessary for the realization of a stable, local cognitive tube. This includes $SU(3)$ as a condition for embodiment, $SU(2)$ as a requirement for coherence, and $U(1)$ as the minimal requirement for observability. This explanation endows previously empirical structures with fundamental physical meaning.

Nevertheless, open questions remain. One of them is the necessity of a cognitive observer for defining all observable quantities. This feature unites physics with the theory of consciousness and poses the challenge of formalizing the observer within theoretical physics. At the same time, it opens the possibility of experimentally testing the hypothesis: observations under conditions of strong gravity or disrupted cognitive coherence may lead to deviations from the predictions of the Standard Model.

The Operational-Anthropic Principle

According to the hypothesis, the observer is not an external entity but part of an emergent cognitive structure. Their existence and properties are determined by the conditions of cognitive stability, embodiment, and causality. This implies that the laws of physics are as they must be in order for coherent cognitive observers to emerge within E^4.

This principle combines features of both the anthropic approach and operationalism. It does not claim that the observer influences physics, but rather that only those structures admitting stable cognitive interpretation become physically realizable. This provides a natural explanation not only for the parameters of the Standard Model, but also for constants such as the fine-structure constant, the proton mass, and the value of dark energy.

Outlook. Potential directions for development include: refining the microstructure of the cognitive field, constructing a cognitive statistical mechanics, rigorously describing decoherence and collapse, and analyzing the impact of cognitive embodiment on the properties of interactions. Another important step will be the search for new testable predictions under conditions of disrupted cognitive causality (e.g., near black holes or in the early Universe).

Thus, the hypothesis opens a path toward unifying physics and the theory of consciousness within a single mathematical formalism, grounded in local causality and cognitive observability.

18.1 Ontological Status of Spacetime and Gravity

Within the hypothesis of local causality, space and time are not postulated *a priori* but arise from the projective cognitive structure of the observer. The observer is formed as a sequence of nested hyperplanes of perception, each of which provides a local basis for interpreting the observable field.

This resonates conceptually with modern formulations of the anthropic principle [8], according to which the properties of the observed Universe are conditioned by the existence of a conscious observer capable of perceiving them. Just as in quantum mechanics observation affects the state of the system, here the cognitive ability to distinguish and order events determines the very structure of time and space [21, 22].

Thus, spacetime acquires an *ontologically derivative* status. It does not exist independently of the observer, but rather as a form of coherent organization of information extracted from the fundamental field. This idea is close to Barbour's approach, which views time as an ordering of configurations [4]. Gravity is interpreted as an effective field supporting the coherence of this projective structure. Curvature of the metric reflects changes in the orientation of the hyperplanes $\Sigma^3(\ell)$, from which the observable causal structure emerges. Hence, gravity is not imposed externally, but arises as a means of coordinating local coherent projections.

18.2 Operational-Anthropic Principle

A key consequence of the hypothesis is the formalization of the observer as a necessary condition of physicality. The operational-anthropic principle implies that the observer is not a post hoc selection condition, but the constructive foundation of physical reality itself.

18.3 Limitations and Future Work

The present work focuses on the scalar field and the structure of the effective metric. Further generalizations are necessary to incorporate:

- gauge symmetries and fields of the Standard Model;
- fermions and spinor structure;
- quantum field theory as emergent statistics of coherent projections;
- topological degrees of freedom within the observer's projective structure.

In addition, the question of experimental signatures remains open. The hypothesis may predict small deviations from the standard metric structure under conditions of extreme geometric inhomogeneity—for instance, near singularities or event horizons.

18.4 Conclusion

The hypothesis of local causality offers a conceptually novel perspective on fundamental physics, in which causality, space, and time are not postulated but arise as effective consequences of limited operational interaction with the field. Gravity and general relativity follow from geometric requirements for coherent observation. This makes possible a reinterpretation of the role of the observer—not as an external agent, but as a necessary component of the structure of the physical world.

The cognitively constrained spectrum of the fundamental field ϕ leads to:

- natural suppression of low multipoles (especially $\ell = 2, 3$);
- agreement of the spectral shape with Planck observations without postulating inflation;
- the possibility of quantitatively tuning the model via parameters R, k_{cut}, η, and weighting functions $W(k)$.

Thus, the hypothesis of local causality provides an alternative explanation of the observed cosmic microwave background spectrum as a projective effect rooted in the cognitive limitations of the observer.

19 Possibilities for Verification and Falsification of the Hypothesis

The hypothesis of the cognitive nature of spacetime and matter—emerging from a locally causal scalar field in 4D Euclidean space—admits both quantitative and qualitative experimental tests. This section systematizes the main possibilities for its empirical verification and potential falsification.

19.1 Experimental Routes to Verification

- **Deviations from the Standard Model under strong gravity.** Since the hypothesis posits that cognitive dynamics depend on local causality, observations of high-energy phenomena (near black holes, neutron stars, or in the early Universe) may reveal deviations from Standard Model (SM) predictions.
- **Absence of a quantum of gravity.** According to the hypothesis, gravity is a metaempirical cognitive structure that does not admit a quantum (graviton). Therefore, failure to detect the graviton supports the hypothesis, while its detection would falsify it.
- **Impossibility of gravitational superpositions.** If coherent superpositions of macroscopically distinct gravitational configurations are observed, this would contradict the principle of local cognitive causality, which underpins the hypothesis.
- **Physical limits on observer structure.** Experiments probing the limits of cognitive temporal thickness and embodied locality of the observer can also test the hypothesis (e.g., measurements of the maximal gravitational gradient compatible with cognitive stability).

19.2 Falsification Criteria for the Hypothesis

Criterion	Description	Implication
Graviton	Detection of a graviton as a physical quantum of the gravitational field	Hypothesis falsified
Gravitational superposition	Observation of coherent superpositions of different metrics	Contradiction with local causality
Cognitive tube paradox	Empirical demonstration of an incoherent embodied projection	Violation of cognitive bodily stability
Violation of unitarity	Detection of irreversible quantum decay or an information paradox	Incompatible with cognitive unitary evolution
Matter without cognitive conditions	Confirmed existence of matter outside cognitive observability	Rejection of the operational-anthropic principle

Table 1: Main experimental falsification criteria for the hypothesis

Conclusion. The hypothesis admits testable quantitative predictions and qualitative assessments. Falsification is possible through the detection of a gravitational quantum, gravitational superpositions, or violations of cognitive stability.

20 Conclusion

This work proposes a hypothesis in which the observed structure of spacetime is an emergent projection of a fundamental scalar field in four-dimensional Euclidean space E^4, arising only in the presence of a cognitively complete observer. A central element of the hypothesis is the *Generalized Principle of Causality (GPC)*, which asserts the independence of the causal structure in each inertial reference frame (IRF), while ensuring consistency in the limit of vanishing relative velocities.

Based on the GPC and the symmetry of the Euclidean Laplace equation:

- coordinate transformations are derived that coincide in form with the Lorentz transformations;
- both postulates of special relativity—the principle of relativity and invariance of the speed of light—are recovered;
- observable time is introduced as a parameter along the normal to the perceptual hyperplane;
- within the geometric construction of the observer in E^4, a scale v_t is introduced, characterizing the maximum speed of projective interaction. This scale determines the normalization of operational time and serves as an invariant under transitions between inertial hyperplanes. Upon identifying $v_t = c$, this parameter acquires the

physical meaning of the limiting signal propagation speed and enables the recovery of a Lorentz-invariant interval structure.

These results are obtained without a priori introduction of the Minkowski metric or time as a fundamental quantity, demonstrating the strength of the emergent approach.

Particular attention is given to the *role of the observer*, interpreted as a cognitive system capable of actualizing a projection of spacetime through internal unitary dynamics. Operational criteria for cognitive completeness are introduced (information integration, recursion, frequency filtering, and causal locality), which constrain the admissible perceptual hyperplanes and define the direction of subjective time.

The hypothesis has not only physical and mathematical significance but also philosophical relevance: it unifies relational realism, informational theories of consciousness, and fundamental geometry. Instead of postulating an objective spacetime, the hypothesis posits the observer as a necessary condition for its manifestation.

Outlook

The proposed model opens several promising directions for further development:

- **Generalization to nonlinear and tensor fields**, potentially leading to a reconstruction of gravity in the spirit of geometrodynamics;
- **Functional quantization** as projection onto families of coherent hyperplanes;
- **Reconstruction of gauge symmetries** through constraints on consistent projections, offering a possible derivation of the Standard Model;
- **Formalization of projection alignment mechanisms between observers**, including probabilistic coherence and limits of cognitive compatibility;
- **Experimental tests of differences between direct and observable transformations**, particularly under conditions of quantum decoherence and high relative velocities.

Thus, the hypothesis of local causality in Euclidean space, complemented by cognitive actualization and an operational definition of time, constitutes a potentially unified conceptual framework capable of explaining the origin of key structures in modern physics from a more fundamental level of description.

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A Variation of the Action and Derivation of Einstein's Equations

This appendix provides a detailed derivation of Einstein's equations by varying the diffeomorphism-invariant action:

$$S[g,\psi] = \int \left[\frac{1}{2\kappa}R + \mathcal{L}_{\text{matter}}(\psi, g_{\mu\nu})\right]\sqrt{-g}\,d^4x, \tag{42}$$

where $\mathcal{L}_{\text{matter}}$ is the matter Lagrangian and $g = \det(g_{\mu\nu})$.

A.1 Variation of the Scalar Curvature

We use standard variational identities:

$$\delta\sqrt{-g} = -\tfrac{1}{2}\sqrt{-g}\,g_{\mu\nu}\,\delta g^{\mu\nu}, \tag{43}$$

$$\delta R = R_{\mu\nu}\,\delta g^{\mu\nu} + \nabla_\mu(\nabla_\nu \delta g^{\mu\nu} - g^{\alpha\beta}\nabla^\mu \delta g_{\alpha\beta}), \tag{44}$$

where the second term in (44) is a total divergence and vanishes under appropriate boundary conditions.

Substituting into the gravitational part of the action:

$$\delta\left(\int \frac{1}{2\kappa}R\sqrt{-g}\,d^4x\right) = \frac{1}{2\kappa}\int \left(R_{\mu\nu} - \tfrac{1}{2}g_{\mu\nu}R\right)\delta g^{\mu\nu}\sqrt{-g}\,d^4x.$$

A.2 Variation of the Matter Action

The stress-energy tensor is defined as the variation of the matter Lagrangian with respect to the metric:

$$T_{\mu\nu} := -\frac{2}{\sqrt{-g}}\frac{\delta(\sqrt{-g}\mathcal{L}_{\text{matter}})}{\delta g^{\mu\nu}}. \tag{45}$$

For a scalar field ψ with action:

$$\mathcal{L}_{\text{matter}} = \frac{1}{2}g^{\mu\nu}\nabla_\mu\psi\nabla_\nu\psi - \frac{1}{2}m^2\psi^2,$$

we obtain:

$$T_{\mu\nu} = \nabla_\mu\psi\nabla_\nu\psi - \tfrac{1}{2}g_{\mu\nu}\left(\nabla^\lambda\psi\nabla_\lambda\psi - m^2\psi^2\right). \tag{46}$$

A.3 Einstein's Equations

The full variation of the action (42) with respect to $g^{\mu\nu}$ yields:

$$\delta S = \int \left[\frac{1}{2\kappa}\left(R_{\mu\nu} - \tfrac{1}{2}g_{\mu\nu}R\right) - \tfrac{1}{2}T_{\mu\nu}\right]\delta g^{\mu\nu}\sqrt{-g}\,d^4x.$$

Setting the variation to zero for arbitrary $\delta g^{\mu\nu}$ gives Einstein's equations:

$$R_{\mu\nu} - \tfrac{1}{2}g_{\mu\nu}R = \kappa T_{\mu\nu}. \tag{47}$$

A.4 Comment on Boundary Conditions

In the derivation of the equations, we assumed that the metric variations $\delta g^{\mu\nu}$ vanish on the boundary of the integration domain, or that the boundary terms are compensated by the addition of the Gibbons–Hawking–York boundary term[20]:

$$S_{\text{GHY}} = \frac{1}{\kappa}\int_{\partial M} K\sqrt{h}\,d^3x.$$

A.5 Conclusion

Thus, using the standard scalar field Lagrangian and the Einstein–Hilbert geometric action, Einstein's equations (22) follow rigorously from the principle of least action, with all variational steps mathematically well-defined.