The Covariant Emergence Principle: A Computational Heuristic for Quantum Gravity Ontology

Shuo Zhang[1,*]

[1] *Independent Researcher, Shanghai, China*

(Dated: January 30, 2026)

Abstract

Abstract: Modern physics faces a profound tension between the smooth spacetime geometry described by general covariance and the non-locality of quantum mechanics. This paper does not attempt to provide a definitive mathematical proof, but rather proposes a conjecture based on the perspective of *Computational Ontology*—the Covariant Emergence Principle (CEP). We propose a heuristic criterion for evaluating ontological fundamentalism: any physical quantity requiring a complex transformation group (covariance) to maintain form-invariance suggests, ontologically, an emergent effective description rather than a fundamental irreducible entity. Specifically, we suggest that the precise "Lorentzian coordination" observed in macroscopic laws may not be a foundational constraint of nature, but rather a "Computational Projection Artifact" of high-dimensional Static Invariants onto low-dimensional dynamic slices. Just as a rotating camera captures different perspectives of a static high-dimensional manifold, our dynamic spacetime appears as a low-dimensional slice of a static high-dimensional entity, where so-called "covariance" functions as the mathematical transformation rule between these slices. Based on this perspective, we introduce the "Covariance-Coherence Complementarity Inequality" as a conceptual tool, providing a heuristic framework to re-examine the duality between spacetime geometry and quantum entanglement. This view suggests a computational realization of the "Block Universe": time evolution may merely be the computational rendering process of a static existence.

Keywords: Covariant Emergence Principle; Computational Heuristic; Projection Artifact; Static Invariants; Background Independence

I. INTRODUCTION: THE "FINE-TUNED CONSPIRACY" OF MACROSCOPIC COORDINATION

The edifice of modern physics is built upon principles of symmetry, particularly Lorentz Covariance and Diffeomorphism Invariance. However, when we scrutinize the specific mechanisms required to maintain macroscopic stability under these symmetries, a disturbing phenomenon of "over-coordination" emerges.

* fcsvorfeed@mbs-studio.com; ORCID: 0009-0001-5784-4162

A. The Coincidence of Dynamics

Consider a hydrogen atom moving at relativistic speeds. For the atom to remain stable and not disintegrate in the laboratory frame, a series of precisely synchronized physical effects must occur: the retardation of force propagation, the increase in the electron's inertial mass, Lorentzian length contraction, and time dilation. If we view the universe as a mechanical system assembled from independent components, these seemingly disparate physical processes must cooperate with extreme precision in real-time. In the "Dynamical Approach" advocated by Brown and Pooley, this coordination is vividly termed a "conspiracy" [1].

Traditional geometric interpretations attribute this coordination to the geometric structure of Minkowski spacetime. However, as Kretschmann pointed out as early as 1917, any physical theory can be cast into a generally covariant form [2]. This raises a profound question: distinct from physical reality, if covariance can be endowed upon any theory via mathematical distinctness, is it merely a gauge redundancy introduced for descriptive convenience, rather than an essential feature of physical reality?

B. The Geometric Projection Mechanism: High-Dimensional Static Manifolds

To elucidate the ontological shift proposed in this paper, we introduce a geometric-topological "Projection Metaphor": envision a time-independent High-dimensional Static Manifold $\mathcal{M}$. Imagine two entangled particles, A and B, not as independent entities connected by a mysterious force, but as two distinct Projective Cross-sections of the same static manifold $\mathcal{M}$ on a low-dimensional holographic screen (our observable spacetime slice).[1]

When we observe particle B moving away from particle A, traditional physics describes this as displacement in space, necessitating the introduction of complex covariant adjustments (time dilation, mass increase) to maintain the self-consistency of physical laws. However, under the Covariant Emergence Principle (CEP) framework, the manifold $\mathcal{M}$ never moves. The "separation" and "motion" we perceive are geometrically equivalent to rotating the "Slicing Angle" (i.e., the reference frame) relative to the manifold.

In this view, the complex mathematical machinery of Lorentz covariance is not the governing law of the manifold $\mathcal{M}$ itself, but merely the Jacobian Matrix of Coordinate Transformation required

[1] In the context of mathematical physics, this object is analogous to the "Amplituhedron" proposed by Arkani-Hamed et al. [4]—a static geometric object defined on an algebraic variety, where its volume directly corresponds to physical scattering amplitudes.

to stitch together these rotated views. Einstein's "spooky action at a distance" becomes mundane: A and B remain correlated because they are always projection components of the same static entity $\mathcal{M}$.

II. THEORETICAL FRAMEWORK: THE COVARIANT EMERGENCE PRINCIPLE (CEP)

A. Statement of the Principle

Based on the metaphor above, we formulate the Covariant Emergence Principle as a heuristic philosophical proposal:

> **Definition 1 (The Covariant Emergence Principle):** If the form-invariance of a physical entity's dynamics relies on a complex continuous transformation group (implying high information processing costs), then that entity is emergent.

Note: In this context, specific symmetry groups are interpreted as geometric projection rules, not intrinsic properties of the substrate.

In short: a physical quantity that requires the "coordination" of multiple independent components to persist is likely not fundamental, but emergent.

B. Ontological Parsimony Criterion

Based on the CEP, we introduce a new epistemological tool for physics—the **Ontological Parsimony Criterion**—as a modification of "Occam's Razor" for modern physics. When searching for the fundamental degrees of freedom in quantum gravity, we propose executing the following screening procedure:

1. **Type I Exclusion (Spacetime Variables):** Time, Space, Velocity. *Reasoning:* They must be mixed via Lorentz transformations to maintain causal structure. The Wheeler-DeWitt Equation ($\hat{H}\Psi = 0$) implies the disappearance of time at the fundamental level [3].

2. **Type II Exclusion (Dynamical Fields):** Metric Tensors ($g_{\mu\nu}$), Gauge Potentials (A_μ). *Reasoning:* They contain vast amounts of gauge redundancy.

3. **Retention Objects (Static Invariants):** Topological Indices, Entanglement Entropy, Causal Order. *Reasoning:* These quantities remain rigid under transformations or depend solely on algebraic structures.

III. DIMENSIONAL PROJECTION AND THE ARGUMENT FROM COMPLEXITY EXPLOSION

Why does "dynamic coordination" imply a "static essence"? We introduce a geometric argument based on Dimensional Projection.

A. The Geometric Slicing Model

Consider a D-dimensional static geometric body $\mathcal{M}$. When a $(D-1)$-dimensional observational slice Σ sweeps across $\mathcal{M}$ along a certain "time" axis, observers within the slice perceive the dynamic evolution of physical quantities.

If these low-dimensional physical quantities exhibit high covariance—maintaining specific conservation laws or symmetries under reference frame transformations (rotation of the slice angle)—dynamic perspectives require the system's internal components to undergo incredibly precise synchronization. However, from a high-dimensional ontological perspective, this "dynamic covariance" is merely the mathematical projection of the rigidity of $\mathcal{M}$'s overall static geometric structure (such as an algebraic variety or topological manifold) onto a low-dimensional cross-section. The so-called "fine-tuning" is actually an inevitable consequence of high-dimensional static existence.

B. Complexity Explosion

For a macroscopic system containing N particles, to maintain Lorentz invariance across all inertial frames, the system must adjust $4N$ phase space coordinates in real-time. If this adjustment is dynamic, the interaction complexity required grows exponentially with N.

According to the CEP, a plausible explanation is that the high-dimensional entity does not "move" at all. This complex dynamic coordination is a mathematical redundancy arising when a low-dimensional observer scans a high-dimensional static structure (such as a holographic entangled state or Amplituhedron [4]).

IV. MATHEMATICAL CONJECTURE: THE COVARIANCE-COHERENCE COMPLEMENTARITY INEQUALITY

To transition the CEP from philosophical speculation to a physically discussable hypothesis, we introduce a specific **Toy Model**.

A. Operational Definitions

We define two order parameters:

1. **Covariance Complexity ($\mathcal{C}_{cov}$):** Defined as the Information Processing Cost required to describe the symmetry transformation group G of the physical theory and the form-invariance of its Lagrangian. This parameter qualitatively measures the overhead of geometric transformations and data synchronization required by the underlying computational system to maintain the macroscopic appearance that "physical laws are consistent across all reference frames."

2. **Quantum Essentiality ($\mathcal{Q}$):** Defined as the purity of the system's global quantum state, i.e., $\mathcal{Q} \equiv \mathrm{Tr}(\rho^2)$.

B. The Complementarity Inequality

Based on these definitions, we propose the **general form** of this complementarity relationship:

$$\mathcal{Q} \cdot f(\mathcal{C}_{cov}) \leq \hbar_{\text{eff}} \tag{1}$$

Where $f(\cdot)$ is a monotonically increasing function. *Note: Intuitively, $f(\mathcal{C}_{cov})$ represents the geometric complexity of the projection (or the "angle" of the slice), while $\mathcal{Q}$ represents the integrity of the original static source.*

To provide a more concrete physical image, we can adopt an exponential growth function as a specific Ansatz for $f(\cdot)$, yielding the following **operational inequality**:

$$\mathrm{Tr}(\rho^2) \cdot \exp(\lambda \mathcal{C}_{cov}) \leq \text{const} \tag{2}$$

Physical Interpretation:

- **Macroscopic Limit ($\mathcal{C}_{cov} \to \infty$):** To achieve perfect general covariance (e.g., smooth spacetime), $\exp(\lambda \mathcal{C}_{cov})$ tends to infinity. This forces the quantum purity $\mathrm{Tr}(\rho^2) \to 0$. This explains why, in a macroscopic world possessing perfect spacetime geometry, quantum entanglement (coherence) must degrade—this is the price paid for maintaining covariance.
- **Fundamental Limit ($\mathcal{C}_{cov} \to 0$):** At the Planck scale, we abandon descriptions of continuous spacetime and covariance ($\mathcal{C}_{cov} \approx 0$). At this point, $\mathrm{Tr}(\rho^2) \to 1$ is permitted. This implies that the ontology of the universe is a pure, static quantum information structure.

V. DISCUSSION: SUPPORT FROM MODERN PHYSICS

The CEP is not unfounded speculation; multiple frontier breakthroughs in modern physics provide strong support for this principle.

A. AdS/CFT and the Ryu-Takayanagi Formula

In the AdS/CFT correspondence, gravitational dynamics (highly covariant) in the Bulk space are holographically dual to a Conformal Field Theory on the Boundary. The Ryu-Takayanagi formula [5] states:

$$S_{EE} = \frac{\mathrm{Area}(\gamma_A)}{4G_N} \tag{3}$$

Here, the area of the minimal surface (a geometric quantity requiring covariant description) originates directly from the entanglement entropy S_{EE} of the boundary (a pure information quantity, unitary invariant). This supports the CEP's judgment regarding the non-fundamental nature of covariance.

B. Entropic Gravity and the Amplituhedron

Verlinde's Entropic Gravity theory [6] proposes that gravity is not a fundamental force but a statistical force resulting from entropy changes. If gravity is thermodynamic, the covariant equations describing it (Einstein's equations) are essentially equations of state. Furthermore, Arkani-Hamed's Amplituhedron theory [4] shows that particle scattering amplitudes can be calculated as the volume of a static algebraic geometric object, without invoking local spacetime evolution or unitarity. Spacetime and covariance disappear completely in this theory, emerging only as final results.

Finally, this projection framework provides a geometric perspective for superposition. Historical "bifurcation" in quantum mechanics does not necessarily imply physical duplication of the universe. Under the CEP framework, it may merely correspond to different scanning paths (foliations) traversing the same Static Invariant Bulk. In this view, the multiverse is not a multiplication of entities, but a superposition of perspectives.

VI. CONCLUSION

This paper re-examines the foundations of physics by introducing a "Computational Metaphor." We conclude that reality may be fundamentally static. The drama of dynamics—force, motion, and time itself—emerges from the kinematics of the observational reference frame relative to the invariant Bulk.

Through the "Ontological Parsimony Criterion," we suggest stripping away the covariant shell of spacetime metrics and gauge potentials to seek those static, non-local algebraic or topological structures (such as entanglement networks or causal sets [7]). Future research should focus on further quantifying the "Covariance-Coherence Complementarity Inequality" and exploring how to "render" Lorentz-covariant spacetime geometry from static quantum entanglement networks.

ACKNOWLEDGMENTS

We acknowledge all frontier physics research that provided inspiration for this conjecture, particularly work in the fields of quantum reference frames and the holographic principle.

[1] H. R. Brown and O. Pooley, "Minkowski space-time: A glorious non-entity," in *The Ontology of Spacetime*, edited by D. Dieks (Elsevier, Amsterdam, 2006), pp. 67–89.

[2] J. D. Norton, "General covariance and the foundations of general relativity: eight decades of dispute," Rep. Prog. Phys. **56**, 791 (1993).

[3] D. N. Page and W. K. Wootters, "Evolution without evolution: Dynamics described by stationary observables," Phys. Rev. D **27**, 2885 (1983).

[4] N. Arkani-Hamed and J. Trnka, "The Amplituhedron," J. High Energy Phys. **10**, 030 (2014).

[5] S. Ryu and T. Takayanagi, "Holographic derivation of entanglement entropy from the anti-de Sitter space/conformal field theory correspondence," Phys. Rev. Lett. **96**, 181602 (2006).

[6] E. P. Verlinde, "On the origin of gravity and the laws of Newton," J. High Energy Phys. **04**, 029 (2011).

[7] R. D. Sorkin, "Causal sets: Discrete gravity," in *Lectures on Quantum Gravity*, edited by A. Gomberoff and D. Marolf (Springer, New York, 2005), pp. 305–327.