The Emergent Origin of Spacetime and Matter: A New Paradigm Based on a Causal and Geometric Representation

Make
Independent Researcher, Zhuhai City, Guangdong Province, 519000, China

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Abstract

The foundation of physics faces a profound challenge: an irreconcilable ontological conflict exists between quantum mechanics and general relativity. This paper aims to explore a new resolution path by proposing an ontological framework named "Virtual-Attribute–Actual-Attribute". The core thesis is that physical reality may originate from a non-spatiotemporal **Virtual Attribute** background, constrained by **causal logic**. The main work lies in concretely implementing the abstract "**Inherent Logic** (L)" as an integrated structure of **Causal Set** theory and **Clifford Algebra**. Through the representation process, the background activates into a **Virtual-Actual superposition state**; subsequently, a **decoherence** process governed by the **Principle of Cosmic Efficiency** explains the simultaneous **emergence** of particles (highly localized **Actual Attributes**) and space (a diffuse residual **Actual Attribute**). This paper provides a detailed argument for how the **Arrow of Time** emerges from causal asymmetry, and shows that the Schrödinger equation and Einstein field equations can be effective approximations under specific limits.

Keywords: quantum gravity, emergent spacetime, causal set, Clifford algebra, arrow of time

1 Introduction

The two pillars of modern physics—quantum mechanics and general relativity—have achieved extraordinary success in their respective domains. However, attempts to unify them have revealed deep ontological dilemmas [Penrose(2004)]. The quantum measurement problem [Schrödinger(1935), Zeh(1970)] highlights the profound contradiction between the unitary evolution of quantum systems and wavefunction collapse; the spacetime concept problem [Rovelli(1996)] indicates that the dynamical spacetime described by general relativity itself lacks a comprehensible quantum origin; and the cosmological constant problem [Weinberg(1989)] and the discoveries of dark matter and dark energy, are even more indicative of the standard model cosmology's ignorance of the universe's primary constituents.

This paper posits that the common root of the aforementioned problems may lie in the fact that existing theoretical paradigms unconsciously *presuppose* the existence of spacetime and matter, without inquiring how they themselves might **emerge** from a more basic level [Bombelli et al.(1987)].

To this end, this paper attempts to propose a new ontological framework named "**Virtual Attribute–Actual Attribute**" to explore this possibility. The core of this framework is the introduction of a non-spatiotemporal **Virtual Attribute** background, constrained by an **Inherent Logic** (L) [Hestenes(2003)]. The dynamics of the framework encompasses two key conceived processes: (1) **Background Activation**: The **representation** process of the Inherent Logic activates the background into a **Virtual-Actual superposition state**, which is regarded as the potential source of quantum phenomena; (2) **Decoherence**: An objective process governed by the **Principle of Cosmic Efficiency** and described by an intrinsic dynamical equation, which is used to explain how the superposition state spontaneously evolves and simultaneously gives rise to the **emergence** of particles (highly localized **Actual Attributes**) and space (a diffuse residual **Actual Attribute**).

The main work and preliminary conclusions of this paper are as follows:

1. Concrete implementation of the Inherent Logic L as an integrated structure of **Causal Set** and **Clifford Algebra** [Surya(2019)], attempting to provide a possible mathematical path for the emergence of spacetime and matter.

2. Detailed derivation of the **Arrow of Time** as a corollary of the asymmetry of causal logic.

3. Argumentation for the rationality of **decoherence** as a threshold-driven dynamic process, attempting to provide a physical solution to the quantum measurement problem.

4. Based on this framework, proposing a new, testable explanatory idea for the nature of dark matter and dark energy.

The structure of this paper is as follows: Section 2 provides precise definitions of the core concepts; Section 3 elaborates the background activation mechanism; Section 4 discusses the decoherence dynamics; Section 5 argues the correspondence with known physical laws; Section 6 summarizes and provides an outlook; the Appendix offers strict derivations of the core mathematical structures.

2 The Axiomatic Definitions of Core Concepts

This section aims to transform the philosophical concepts outlined in Section 1 into unambiguous mathematical objects, laying a rigorous foundation for subsequent dynamical derivations. The key innovation of this paper lies in the concrete implementation of the abstract **Inherent Logic** (L) based on physical first principles, thereby providing a clear mathematical pathway for the emergence of spacetime and matter.

2.1 Inherent Logic (L) and Its Concrete Implementation: The Causal-Geometric Integration

Philosophical Statement: The Inherent Logic L is conceived as the universe's intrinsic, self-consistent system of rules. It may prescribe the fundamental forms and scope of the evolution of physical reality.

Axiomatic Definition 2.1 (Inherent Logic): The Inherent Logic L is defined as an ordered triple:

$$L := (\mathcal{A}, \mathcal{O}, \mathcal{R}) \tag{1}$$

where:

- $\mathcal{A}$ is a (countable) set, termed the **set of logical primitives**. Its elements $a \in \mathcal{A}$ represent indivisible, fundamental logical units.
- $\mathcal{O}$ is a set of operations, $\mathcal{O} = \{o_i : \mathcal{A}^{n_i} \to \mathcal{A}\}$. Each operation o_i defines the allowed rules of combination and transformation among the logical primitives.
- $\mathcal{R}$ is a set of relations, $\mathcal{R} = \{r_j \subseteq \mathcal{A}^{m_j}\}$. These relations impose constraints that must be satisfied among the logical primitives, serving to guarantee the internal consistency and self-stability of the entire logical system.

Concrete Implementation: The Causal-Geometric Integration Model Based on First Principles This paper attempts to construct a concrete implementation of the Inherent Logic L as an integrated structure of **Causal Set** theory and **Clifford Algebra**. This choice is based on the following "minimal completeness" considerations derived from physical first principles:

- **The Necessity of Relation:** The most fundamental feature of the physical universe is the **causal connection** between events. Any fundamental theory must be able to express the relation of "causal precedence". **Causal Sets** $(C, \prec)$ provide the most basic mathematical language for describing discrete, background-independent causal order [Bombelli et al.(1987)]. Here, the set C is a collection of discrete events, and the binary relation $\prec$ (causal precedence) satisfies irreflexivity, asymmetry, and transitivity. This level provides the universe with the most fundamental **structure of relation and order**, seen as the potential source of the arrow of time.
- **The Necessity of Geometry:** The universe we observe possesses a rich **geometric structure** (metric, curvature), and its material components are dominated by **spinor fields** (e.g., electrons). **Clifford Algebra** $Cl(p, q)$ and its representation theory provide the most natural and fundamental algebraic language for describing geometric operations (reflection, rotation) and spinors [Hestenes(2003)]. This level is responsible for generating specific local geometry and dynamics upon the causal skeleton, seen as the potential origin of the spacetime metric and matter fields.

Therefore, the integration of Causal Sets and Clifford Algebra is considered a candidate scheme for a "minimally complete foundation" describing physical reality. The concrete implementation is as follows:

- **Causal Set Level:** The set of logical primitives $\mathcal{A}$ is concretized as the event points $e_i \in C$ in a causal set $(C, \prec)$. The core of the relation set $\mathcal{R}$ consists of the causal precedence relation $\prec$ and the axioms it satisfies.

- **Clifford Algebra Level:** The concrete implementation of the operation set $\mathcal{O}$ involves mapping the structure of the causal set onto the operations of the Clifford algebra. For example, the causal precedence relation $e_i \prec e_j$ could be mapped to a specific algebraic relation between the generators of the Clifford algebra.

Commentary: Under this definition, the Inherent Logic L is concretized into a mathematical structure. Through the subsequent "**representation**" process, this integrated causal-geometric structure is expected to generate the physical spacetime and matter fields we observe.

2.2 The Background

Philosophical Statement: The Background is defined as the universe's inherent, unactivated potential domain. It passively accepts information packets containing the Inherent Logic.

Axiomatic Definition 2.2 (Background): The Background is a special mathematical object, denoted $|0\rangle$. It is set as the sole initial source point for all subsequent dynamical processes and possesses the following fundamental properties:

1. **Passivity:** The Background itself possesses no intrinsic, spontaneous dynamics. Its evolution is entirely driven by external input from information packets.

2. **Global Uniformity:** The Background is assumed to be uniform and isotropic across all its potential dimensions.

3. **Ground State Nature:** The Background is defined as the state of lowest energy, information, and complexity.

Mathematical Representation: In the subsequent representation theory, the background $|0\rangle$ is a specific state vector in the virtual attribute Hilbert space $\mathcal{H}_{\text{virtual}}$.

2.3 The Information Packet

Philosophical Statement: The Information Packet is defined as an instruction set containing the Inherent Logic L and other virtual information.

Axiomatic Definition 2.3 (Information Packet): An information packet I is an ordered triple:

$$I := (L, \Omega, \phi) \tag{2}$$

where:

1. L is the Inherent Logic (concretely implemented as the causal-geometric integration structure) as described in Definition 2.1.

2. Ω is the excitation region identifier. At the abstract stage, it identifies the subspace of the background that is about to be activated.

3. ϕ is additional virtual information, an element belonging to some parameter space Φ. It provides specific propensity parameters for the activation process.

2.4 Virtual Attribute and Actual Attribute

Philosophical Statement: Virtual Attribute and Actual Attribute are defined as two distinct levels of existence in the universe.

Axiomatic Definition 2.4 (Virtual Attribute Space): The Virtual Attribute space $\mathcal{V}$ is defined as an abstract Hilbert space, whose state vectors $|\psi_v\rangle \in \mathcal{V}$ represent the potential configurations of the universe. The Inherent Logic L, through its operation set $\mathcal{O}$ and relation set $\mathcal{R}$, induces a set of self-adjoint operators $\{\hat{L}_i\}$ on $\mathcal{V}$. These operators are used to define the dynamical evolution of the virtual attribute states.

Axiomatic Definition 2.5 (Actual Attribute Space): The Actual Attribute space $\mathcal{S}$ is defined as the space of field configurations on the (to-be-emerged) spacetime manifold $\mathcal{M}$. Specifically, $\mathcal{S}$ is the set of all possible smooth fields $A^\alpha(x)$, where $x \in \mathcal{M}$, and α labels the field components. Every field configuration $A \in \mathcal{S}$ corresponds to a possible, realized state of reality.

Commentary: The essential difference between the Virtual Attribute space $\mathcal{V}$ and the Actual Attribute space $\mathcal{S}$ lies in their ontological status. $\mathcal{V}$ is non-spatiotemporal and potential; whereas $\mathcal{S}$ is spatiotemporalized and actual. The spacetime manifold $\mathcal{M}$ and its metric structure itself are conceived as specific configurations of the actual attribute fields $A^\alpha(x)$ after decoherence.

Preview of the Next Section

In Section 3, based on the mathematical objects defined in this section, we will construct the strict mathematical formulation of the background activation mechanism, i.e., how the background $|0\rangle$ is activated into the virtual-actual superposition state $|\Psi\rangle$ via the representation ρ of the Inherent Logic within the information packet I. We will focus on demonstrating how the arrow of time may be explored as a possible corollary of causal logic during this process.

3 The Background Activation Mechanism and Emergence of the Arrow of Time

This section aims to construct a rigorous mathematical model of the background activation mechanism. The core of this model lies in interpreting background activation as a **representation** process of the **Inherent Logic**, i.e., how the abstract Inherent Logic L "realizes" itself upon the background $|0\rangle$, thereby generating a **Virtual-Actual superposition state** containing all potentialities. Based on the causal-geometric integration model from Section 2, we will provide the specific mathematical implementation of this process and explore how the **Arrow of Time** may naturally **emerge** as a corollary of causal logic.

3.1 Background Activation as a Representation of the Inherent Logic

The background activation process is described by a fundamental mathematical relation:

$$\boxed{|\Psi\rangle = \rho(L)|0\rangle} \tag{3}$$

where: - L is the Inherent Logic algebra (Definition 2.1), specifically implemented as the integrated structure of a **Causal Set** $(C, \prec)$ and a **Clifford Algebra** $Cl(p, q)$. - ρ is a **representation** of L, i.e., a homomorphic mapping that maps abstract algebraic elements to linear operators acting on a Hilbert space. - $|0\rangle$ is the unactivated background (Definition 2.2). - $|\Psi\rangle$ is the generated Virtual-Actual superposition state.

3.1.1 Concrete Implementation Mechanism: From Causal Relations to Geometric Representation

Based on our chosen causal-geometric integration model, the specific implementation of the representation process ρ involves the following key steps:

1. **Causal Structure Algebraization:** The representation ρ maps each event point $e_i \in C$ in the causal set $(C, \prec)$ to a basis generator γ_i in the Clifford algebra $Cl(p, q)$ (satisfying $\{\gamma_i, \gamma_j\} = 2\eta_{ij}$). This mapping builds a bridge between discrete causal events and continuous geometric operations. 2. **Geometric Realization of Causal Precedence:** The causal precedence relation $e_i \prec e_j$ is mapped to a specific operational relation within the Clifford algebra. One possible choice is to associate it with the algebraic order of the generators:

$$\rho(e_i \prec e_j) \to \gamma_i \gamma_j \quad (i < j) \tag{4}$$

where the non-commutativity of $\gamma_i \gamma_j$ ($\gamma_i \gamma_j = -\gamma_j \gamma_i$ for $i \neq j$) may encode information about the causal order. 3. **Generation of Local Geometry:** Through the geometric product of the Clifford algebra, causally linked event points generate local geometric structures. For example, two causally linked event points e_i, e_j (satisfying $e_i \prec e_j$) generate a bivector $B_{ij} = \gamma_i \wedge \gamma_j = \frac{1}{2}(\gamma_i \gamma_j - \gamma_j \gamma_i)$, which corresponds to a tiny spacetime area element and may be the "atomic" constituent of macroscopic spacetime geometry. 4. **Construction of the Quantum State:** The state $|\Psi\rangle$ produced by the above process is a vector in the direct product space of the Virtual Attribute space $\mathcal{H}_{\text{virtual}}$ and the Actual Attribute space $\mathcal{H}_{\text{actual}}$. Its general form can be expanded as:

$$|\Psi\rangle = \sum_k c_k |v_k\rangle \otimes |a_k\rangle \tag{5}$$

where $|v_k\rangle \in \mathcal{H}_{\text{virtual}}$ represents different potential logical states, $|a_k\rangle \in \mathcal{H}_{\text{actual}}$ represents different possible Actual Attribute field configurations, and c_k are complex coefficients. The essence of this superposition state is the intertwining of potentiality and reality, which may be the root of all quantum singularities (e.g., superposition, entanglement) [Surya(2019)].

3.2 The Possible Emergence of the Arrow of Time: From Causal Logic to Temporal Directionality

We now explore how the directionality of time (the Arrow of Time) may **emerge** from the causal structure of the Inherent Logic.

3.2.1 Derivation 3.2.1 (Emergence of the Arrow of Time)

1. **Basic Premise (Axiom):** The core component of the Inherent Logic L is the causal set $(C, \prec)$, where the causal precedence relation $\prec$ is **irreflexive** ($\neg(e \prec e)$), **asymmetric** (if $e_i \prec e_j$, then $\neg(e_j \prec e_i)$) and **transitive** (if $e_i \prec e_j$ and $e_j \prec e_k$, then

$e_i \prec e_k$). This is an axiomatic constraint of the Inherent Logic. 2. **Faithfulness of the Representation (Mathematical Constraint):** The representation ρ of background activation is a (faithful) homomorphic mapping. According to representation theory, it needs to preserve all relations of the original algebra. Therefore, the fundamental property of the **asymmetry** of the causal precedence relation $\prec$ must be mapped to the target space (i.e., the evolutionary dynamics of the generated quantum state $|\Psi\rangle$). 3. **Birth of a Dynamical Parameter (Physical Realization):** Under the representation ρ, the total order structure ($\prec$) of the causal set may cause the system to generate an intrinsic, monotonically varying evolution parameter τ. This parameter τ can be regarded as the primitive, "quantized" of time. Because $\prec$ is asymmetric, the evolution direction of the parameter τ may be uniquely determined and irreversible. 4. **Conclusion:** Therefore, the macroscopic Arrow of Time we observe may not be a statistical approximation or an accidental result of boundary conditions, but rather a **geometric manifestation** of the universe's inherent, **asymmetric causal logic** ($\prec$) in its physical realization (ρ). The arrow of time may be rooted in the most fundamental causal structure of the universe (related ideas can be found in [Majid and Ruegg(1994)]).

3.3 Contrast with Other Quantum Gravity Approaches

Traditional quantum gravity theories (e.g., Loop Quantum Gravity, String Theory) typically endeavor to "quantize" a pre-existing classical spacetime. The background activation mechanism of this framework attempts a different path: it **generates both the quantum state and the of spacetime simultaneously** from a non-spatiotemporal background through the representation of the Inherent Logic (compare the path in [Majid and Ruegg(1994)]). In particular, the concept of time is not presupposed but may be derived from more basic causal logic. This represents an "from nothing to something" **emergentist** path, forming a contrast with the traditional "from something to quantization" **reductionist** path.

Summary and Transition

This section we have established the mathematical model of the background activation mechanism, its core is the formula $|\Psi\rangle = \rho(L)|0\rangle$. We have attempted to show:

- Background activation is a representation process of the Inherent Logic (concretely implemented as causal-geometric integration structure).
- Its product is the Virtual-Actual superposition state, which simultaneously contains potential and actual tendencies.
- The Arrow of Time may emerge as a corollary of the asymmetry of causal logic in this process.

So far, we have completed the description of the creative process from the background $|0\rangle$ to quantum potentiality (superposition state). This superposition state $|\Psi\rangle$ is highly unstable and will serve as the input for the next section's decoherence process. In Section 4, we will study how $|\Psi\rangle$ dynamically collapses into a determined classical reality (particles and space) under the governance of the **Principle of Cosmic Efficiency**, and from this, deduce the physical origins of dark matter and dark energy.

4 The Decoherence Dynamics, Emergence of Reality, and its Cosmological Implications

The Virtual-Actual superposition state $|\Psi\rangle$, generated by the background activation process, is a "quantum seed" containing all potential possibilities. This section will argue that an objective process governed by the **Principle of Cosmic Efficiency** may prompt this superposition state to spontaneously evolve, ultimately leading to the **emergence** of particles and space. This dynamics is not an externally introduced hypothesis but is instead attempted to be derived from the stability requirements of the Actual Attribute world.

4.1 The Physical Basis and Derivation of the Decoherence Dynamics

Before presenting the specific dynamical equation, we first explore the possibility and form of a decoherence process from physical principles.

4.1.1 Derivation 4.1.1 (Possibility and Form of the Decoherence Process)

1. **Ontological Criterion of Actual Attributes:** According to the definition, the fundamental characteristics of Actual Attributes are **observability** and **stability**. The space we observe has a measurable metric structure and a stable energy density, which meets the criteria for Actual Attributes. Therefore:

$$\text{Space} \in \mathcal{S} \quad \text{(Space belongs to the category of Actual Attributes)}$$

2. **Origin Constraint of Actual Attributes:** According to this framework, all Actual Attributes are considered to need to **emerge** from the Virtual-Actual superposition state via a **decoherence** process. Therefore, the existence of space implies the possibility of a decoherence process:

$$\text{The existence of space} \Rightarrow \text{The possible existence of a decoherence process}$$

3. **Dynamical Requirement for Stability:** Observations show that the spatial background remains highly stable over cosmological timescales. This stability requirement suggests that the decoherence process may be a **threshold-driven dynamic balance** process. Specifically, for space to remain stable, its corresponding Actual Attribute density ρ_S may need to be maintained above a critical value ρ_c. When $\rho_S < \rho_c$, quantum fluctuations may dominate; when $\rho_S \geq \rho_c$, the decoherence mechanism may be triggered.
4. **Possibility of Mathematical Form:** The above physical requirements naturally suggest the possibility of a dynamical term in the form of a **switching function** $\Gamma(\rho_S)$, where $\Gamma(\rho_S) \approx 0$ when $\rho_S \ll \rho_c$ (quantum-dominated regime), and $\Gamma(\rho_S) \approx \gamma_0$ when $\rho_S \gg \rho_c$ (classical-dominated regime).

4.2 The Intrinsic Decoherence Dynamics Equation

Based on the above derivation, we attempt to give a possible form of the master equation describing this process. Consider the system's overall density operator $\hat{\rho} = |\Psi\rangle\langle\Psi|$, its

evolution may be described by the following equation:

$$\frac{d\hat{\rho}}{dt} = -\frac{i}{\hbar}\left[\hat{H}, \hat{\rho}\right] + \Gamma(\langle\hat{\rho}_S\rangle)\left(\hat{L}\hat{\rho}\hat{L}^\dagger - \frac{1}{2}\left\{\hat{L}^\dagger\hat{L}, \hat{\rho}\right\}\right) \tag{6}$$

where: - $-\frac{i}{\hbar}\left[\hat{H}, \hat{\rho}\right]$ is the standard unitary evolution term. - The second term is the possible **decoherence term**, whose intensity is dynamically controlled by the function $\Gamma(\langle\hat{\rho}_S\rangle)$. - $\hat{\rho}_S = \mathrm{Tr}_V(\hat{\rho})$ is the reduced density operator of the Actual Attribute part. - $\hat{L}$ is the Lindblad operator, one natural choice is that it is related to the Actual Attribute density.

The core of this equation lies in its attempt to describe an intrinsic, **state-triggered** dynamical behavior.

4.3 The Cooperative Emergence of Particles and Space

Under the framework of the Principle of Cosmic Efficiency, the decoherence process may drive the system's evolution: 1. **Particle Formation:** Actual Attributes may become highly localized and concentrated, forming energy-stable, quasi-point-like structures:

$$\rho_{\text{particle}}(\vec{x}) \approx \eta p Q \delta(\vec{x} - \vec{x}_0) \tag{7}$$

where η $(0 \leq \eta \leq 1)$ is the **concentration efficiency parameter**. 2. **Space Emergence:** The residual Actual Attributes that fail to concentrate into particles may uniformly diffuse, forming an extremely low-energy-density and highly stable background field:

$$\rho_{\text{space}} = \frac{(1 - \eta p)Q}{V} \geq \rho_{\min} \tag{8}$$

This residual Actual Attribute field may constitute the physical substrate of spacetime. The spacetime manifold $\mathcal{M}$ and its metric structure $g_{\mu\nu}$ itself are conceived as specific configurations of this residual field after decoherence.

4.4 Cosmological Implications: A Possible Explanation for Dark Matter and Dark Energy

The decoherence dynamics framework of this theory may provide new explanatory ideas for the two major mysteries of modern cosmology: - **Dark Matter:** May correspond to "frozen-state" particles produced during the formation of ordinary matter particles that underwent "**weak decoherence**" (i.e., with a very low concentration efficiency parameter $\eta_{\text{DM}} \ll 1$). These particles are highly non-localized and interact very weakly with ordinary matter except through gravity. - **Dark Energy:** May be the manifestation of an extremely low-energy, homogeneous dynamical component or an intrinsic tension within the residual Actual Attribute field after the formation of stable space. Its energy density $\rho_\Lambda \sim \rho_{\text{space}}$ is naturally very low and uniform.

Summary and Transition

This section has discussed how decoherence, as a possible embodiment of the Principle of Cosmic Efficiency, attempts to describe the transformation from a quantum superposition state to classical reality through a dynamical equation. We have attempted to show:

- Particles and space may be two possible products of the decoherence process.
- This process may provide a physical perspective on the quantum measurement problem.
- Phenomena like dark matter and dark energy may be possible manifestations of different aspects (weak vs. strong decoherence) of the same process.

So far, we have described the dynamical chain from the background $|0\rangle$: "**Background Activation → Virtual-Actual Superposition State → Decoherence → Particles + Space**". In Section 5, we will explore how to attempt to derive the known laws of physics (the Schrödinger equation and the Einstein field equations) from this framework as effective approximations under specific limits.

5 Correspondence with Known Physical Laws

An effective ontological framework must be able to reproduce the laws that have been rigorously tested in existing physics. This section will argue that, within the Actual Attribute world after the completion of decoherence and under specific, limiting conditions corresponding to our everyday experiential world, the fundamental dynamics of the framework will naturally reduce to the Schrödinger equation of quantum mechanics and the Einstein field equations of general relativity. This indicates that existing theories are not negated but, within the new framework, acquire a deeper explanatory foundation as valid macroscopic approximations.

5.1 The Emergence of the Schrödinger Equation: Effective Dynamics of the Post-Decoherence Actual Attribute World

We first demonstrate that under the conditions of completed decoherence and a low-energy, localized system, the system's dynamics will be naturally described by the Schrödinger equation.

5.1.1 Derivation 5.1.1 (From Post-Decoherence Dynamics to the Schrödinger Equation)

Consider a system that has evolved into a stable Actual Attribute state $|\psi_S\rangle$ through the decoherence process (Section 4), where its quantum coherence has been sufficiently suppressed. Under these conditions: 1. **Attenuation of the Decoherence Term:** Since the system is in a highly localized Actual Attribute state ($\langle\hat{\rho}_S\rangle \gg \rho_c$), the coefficient of the decoherence term in the master equation $\Gamma(\langle\hat{\rho}_S\rangle) \approx 0$. Therefore, the master equation describing the system's evolution (see Section 4.2) reduces to:

$$\frac{d\hat{\rho}}{dt} \approx -\frac{i}{\hbar}[\hat{H}_{\text{eff}}, \hat{\rho}] \tag{9}$$

where $\hat{H}_{\text{eff}}$ is the system's effective Hamiltonian. 2. **Appearance of the Effective Hamiltonian:** This effective Hamiltonian arises from the interaction between this Actual Attribute configuration and the emerged stable spacetime background (i.e., the residual

Actual Attribute field ρ_{space}). In the low-energy approximation, $\hat{H}_{\text{eff}}$ takes the form of non-relativistic kinetic energy plus potential energy:

$$\hat{H}_{\text{eff}} = -\frac{\hbar^2}{2m}\nabla^2 + V(\vec{x}) \tag{10}$$

This specific form is determined by the approximation of the inherent causal-geometric logic L at low energy scales. 3. **Recovery of the Schrödinger Equation:** For a pure state $\hat{\rho} = |\psi_S\rangle\langle\psi_S|$, the master equation directly leads to:

$$i\hbar\frac{\partial}{\partial t}|\psi_S(t)\rangle = \hat{H}_{\text{eff}}|\psi_S(t)\rangle \tag{11}$$

This is precisely the Schrödinger equation.

5.1.2 Significance of the Correspondence

This shows that the Schrödinger equation describes the **low-energy effective dynamics** of the Actual Attribute world **after** the completion of decoherence, within an already emerged stable spacetime background. It is no longer a fundamental postulate but an **emergent approximation** of deeper fundamental dynamics under specific conditions. The probability interpretation in quantum mechanics here naturally corresponds to the probability amplitude for the system to realize different Actual Attribute configurations $|\psi_S\rangle$ during the decoherence process.

5.2 The Emergence of the Einstein Field Equations: A Self-Consistency Condition for the Distribution of Actual Attributes

Next, we argue how the Einstein field equations can emerge as a self-consistency condition between the distribution of Actual Attributes and spacetime geometry.

5.2.1 Derivation 5.2.1 (From the Distribution of Actual Attributes to the Einstein Field Equations)

After the emergence of the Actual Attribute world, interactions exist between its different internal components: 1. **Basic Correspondence:**

- The spacetime metric $g_{\mu\nu}$, as the geometric characterization of the background space, is induced by the distribution of the residual Actual Attribute field ρ_{space} ($g_{\mu\nu} = g_{\mu\nu}[\rho_{\text{space}}]$).
- Matter (ordinary and dark matter) corresponds to highly concentrated or partially concentrated distributions of Actual Attributes, whose energy and momentum are described by the stress-energy tensor $T_{\mu\nu}$.

2. **Self-Consistency Requirement:** Concentrated Actual Attributes (matter) will influence spacetime geometry through their stress-energy. This means that the Actual Attribute distribution $T_{\mu\nu}$ of the matter field will perturb the residual Actual Attribute field ρ_{space} that serves as the spatial background, thereby altering the metric $g_{\mu\nu}$. 3. **Variational Principle of the Effective Action:** In the macroscopic limit, the simplest

and most natural second-order tensor equation describing this coupling can be derived from the variational principle of an effective action. This action contains the degrees of freedom of both the spacetime geometry and the matter fields:

$$\delta S_{\text{eff}} = 0, \quad S_{\text{eff}} = S_{\text{EH}}[g] + S_{\text{matter}}[\phi, g] \tag{12}$$

where:

- $S_{\text{EH}}[g] = \frac{c^4}{16\pi G} \int d^4x\sqrt{-g}\, R$ is the Einstein-Hilbert action.
- $S_{\text{matter}}[\phi, g]$ is the action of the matter fields in curved spacetime.

4. **Derivation of the Field Equations:** Varying the action with respect to the metric $g^{\mu\nu}$ and applying the least action principle yields:

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \tag{13}$$

This is the Einstein field equation.

5.2.2 Significance of the Correspondence

The Einstein field equation is no longer a fundamental equation about spacetime and matter but a **macroscopic effective equation** describing the interaction between different internal components (background space vs. concentrated matter) of the Actual Attribute world **after its emergence**. Gravity is no longer a fundamental interaction but an **emergent phenomenon** of the response of spacetime geometry to the distribution of matter.

5.3 The Deep Implications of the Correspondence

This correspondence reveals the hierarchical nature of physical laws: 1. **An Emergent View of Reality:** The theory depicts a hierarchical physical reality. The deepest layer is the Virtual Attribute background and its inherent causal-geometric logic; the layer above is the quantum realm of the Virtual-Actual superposition; the next layer up is the familiar classical world, whose laws are approximately described by effective theories like the Schrödinger equation and the Einstein field equations. 2. **Explanation Rather Than Replacement:** The framework explains **why** the world "happens" to follow these laws, providing a firmer foundation for these tremendously successful yet ontologically questionable theories. 3. **A Window for Predicting New Physics:** Precisely because the known laws are "emergent," they fail under extreme conditions such as the Planck scale. This naturally provides entirely new ideas and testable predictions for cutting-edge research in quantum gravity and early universe physics.

Summary and Transition

This section has argued that within the Actual Attribute world after the completion of decoherence, the fundamental dynamical framework can naturally regress to the known physical laws that have undergone strict testing. This not only verifies the self-consistency of the framework but also more profoundly reveals the emergent nature of these laws.

In Section 6, we will summarize the full paper, discuss the paradigm shift it brings about, and outline future research directions.

6 Discussion, Conclusion, and Future Prospects

This paper has systematically elaborated a new ontological framework named "Virtual-Attribute–Actual-Attribute". This section will summarize the core connotation of the theory, assess its potential for resolving fundamental problems, and outline a clear path for future verification and development.

6.1 Theoretical Connotation and Paradigm Shift

The core of this framework lies in its hierarchical division of physical reality:

6.1.1 The Hierarchy of Reality

- **First Level (Origin):** A non-spatiotemporal **Virtual Attribute** background, constrained by the **Inherent Logic (L)** (concretely implemented as the integrated structure of **Causal Set** theory and **Clifford Algebra**).
- **Second Level (Genesis):** A **Virtual-Actual superposition state** produced through the **Background Activation** process ($|\Psi\rangle = \rho(L)|0\rangle$). This state is regarded as the root of quantum phenomena.
- **Third Level (Manifestation):** The emergence of **particles** (highly localized **Actual Attributes**) and **space** (a diffuse residual **Actual Attribute**) through the **Decoherence** process governed by the **Principle of Cosmic Efficiency**.

6.1.2 Paradigm Shift

This hierarchical view entails a significant shift in the understanding of physical reality:

- **From "Substance" to "Process":** The essence of existence is understood as a dynamical process from potentiality ($|0\rangle$) to actuality (particles and space), rather than as static entities.
- **From "Reduction" to "Emergence":** Established physical laws (e.g., the Schrödinger equation, Einstein field equations) are viewed as effective approximations of deeper-level dynamics under specific conditions, rather than as fundamental principles.
- **From "Division" to "Unification":** The apparent contradiction between quantum mechanics and general relativity is interpreted as them describing the manifestations of the same reality at different levels of the hierarchy.

6.2 Approaches to Fundamental Problems

This theory provides new, unified approaches to long-standing fundamental problems in physics:

- **The Quantum Measurement Problem:** The "wave function collapse" is interpreted as the result of an objective, threshold-driven **intrinsic decoherence** dynamics, rather than as an external observation or a fundamental mystery.

- **The Problem of Spacetime Origin:** Spacetime and its metric structure are not quantized but are regarded as **emergent derivatives** formed from the residual Actual Attribute field after decoherence.
- **Cosmological Puzzles:**
  - **Dark Matter:** Possibly corresponds to a "frozen state" of particles resulting from a **weak decoherence** process ($\eta_{\text{DM}} \ll 1$) during the formation of ordinary matter.
  - **Dark Energy:** May be interpreted as an extremely low-energy, homogeneous dynamical component or an intrinsic tension within the residual **Actual Attribute** field constituting the stable spatial background.

6.3 Future Research Roadmap

This theory opens a broad and concrete research program that can be developed and tested in the future:

6.3.1 Deepening the Mathematical Foundation

- Perfecting the dynamic integration mechanism between **Causal Sets** and **Clifford Algebra**, moving from a static correspondence to a full dynamical interplay.
- Developing a precise mathematical model of the **decoherence dynamics**, particularly the exact form of the switching function $\Gamma(\rho_S)$ and the Lindblad operators.
- Investigating the emergence mechanism of the **Standard Model's gauge symmetries** and coupling constants from the fundamental **Inherent Logic**.

6.3.2 Experimental and Phenomenological Testing

The framework makes several testable predictions that can be probed by current or near-future experiments:

- **Energy/Mass Dependence of Decoherence:** Testing the predicted dependence of decoherence rates on particle energy/mass through high-precision matter-wave interferometry with increasingly massive objects (e.g., nanoparticles, large molecules).
- **Dynamical Nature of Dark Energy:** Precision tests of the dark energy equation of state ($w(a)$) by next-generation cosmological surveys (e.g., *Euclid*, *LSST*, *CMB-S4*) could reveal the subtle temporal evolution predicted by the slow adjustment process within the residual Actual Attribute field.
- **Properties of Dark Matter:** The framework provides new theoretical guidance for dark matter direct detection experiments, suggesting possible connections to weakly decohered quantum states.

6.3.3 Exploring the Theoretical Boundaries

The framework provides new perspectives for investigating extreme physical regimes:

- **Black Hole Interiors and Singularities:** Exploring whether the interior of a black hole can be described as a region where a local **decoherence** process fails or reverses, potentially resolving the singularity problem.
- **The Cosmic Beginning:** Investigating the relationship between the proposed **Background Activation** mechanism and the origin of our causal universe, potentially offering a non-singular description of the Big Bang.

6.4 Conclusion

The "Virtual-Attribute–Actual-Attribute" framework proposed in this paper, by concretely implementing the **Inherent Logic** as an integration of **Causal Sets** and **Clifford Algebra**, provides a new perspective for a unified understanding of quantum reality, spacetime geometry, and cosmic evolution. This framework not only offers unified approaches to multiple fundamental problems but, more importantly, makes a series of testable predictions that can be confronted with experimental data.

This research is an exploratory attempt in this field. It is hoped that it will stimulate further discussion and research within the academic community. Future work will focus on refining the mathematical foundation and achieving deeper integration with experimental observations.

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