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Informational Geodesics as the Origin of Spacetime Curvature: A Variational Principle for Emergent Metric Geometry in Viscous Time

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Abstract

We develop a variational principle in which spacetime curvature emerges from the preservation of informational identity along dynamical trajectories. The approach is motivated by the Viscous Time Theory (VTT) framework, where finite informational latency replaces an assumed geometric background. Instead of postulating a metric structure a priori, informational geodesics are defined as the paths that minimize a latency functional representing the local cost of identity reorganization in viscous time. The second-order structure of this action induces a symmetric bilinear form that behaves as an emergent metric tensor. Classical geodesic motion and the Einstein field equation are recovered in the limit of uniform latency density, showing that General Relativity arises as a special case of the more general informational action. The framework predicts curvature-like effects in regimes with negligible mass–energy but strong identity constraints, including coherent condensed-matter phases and entangled quantum systems. These predictions outline a testable research program connecting differential geometry with informational dynamics.

Keywords: informational geometry; variational principle; emergent curvature; geodesics; viscous time; metric tensor; general relativity; Viscous Time Theory (VTT); Finsler Geometry

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1. Introduction

1.1. Motivation

In general relativity, the geometric structure of spacetime is encoded by a metric tensor $g_{\mu\nu}$, from which geodesics are obtained by extremizing the proper time functional [1,9,10]. The Einstein field equations close the construction by linking curvature to matter–energy content [1,5]. In this standard view, the metric is primitive: trajectories are effects of geometry, not its cause.

The emergence of geometry from variational principles has deep historical roots. The structure of differential manifolds and curvature was formalized by Riemann and later developed by Darboux, Cartan, and others [6–8]. Classical geodesic motion was expressed using variational principles by Maupertuis, Hamilton, and Hilbert [2–4,10], and placed in the modern field-theoretic context by Landau and Lifshitz [11]. More recently, informational approaches have sought to reconstruct dynamical laws from principles of statistical inference and Fisher geometry [13–16,17–18].

Here we explore a dual formulation. We propose that geodesics may be defined prior to the introduction of a metric, as minimizers of a fundamental informational action. In this view, geometry is not postulated, but reconstructed as the minimal deformation needed to preserve coherent identity along paths evolving in a medium where information reorganizes under finite latency. The resulting curvature is therefore interpreted as a cost functional associated with maintaining continuity under viscous informational dynamics. This perspective is motivated by the Viscous Time Theory (VTT) framework [22], in which finite informational latency is treated as the fundamental constraint governing coherent evolution.

In parallel, several authors have explored the possibility that gravitational dynamics may emerge from underlying information-theoretic principles, including Wheeler's concept of "it from bit", Verlinde's derivation of gravity from entropic forces, and Padmanabhan's thermodynamic approach to spacetime [19–21]. The approach developed here is different in form but converges in spirit with these ideas, by treating curvature as a manifestation of identity-preserving evolution rather than a primitive structure.

The present formulation can be viewed as a concrete expression of the principles introduced in VTT, where informational identity is preserved under finite latency and geometric structure emerges from the associated variational dynamics. Within this framework, metric curvature arises as the unique compatibility condition between identity-preserving evolution and the local cost of informational reorganization.

1.2. Informational Action and Viscous Time

The key idea is to treat evolution not as motion through a predefined manifold, but as a reconfiguration of informational identity under a finite latency constraint. Let $\Delta I(\tau)$ denote the instantaneous rate of informational reorganization along a parametrized path $\gamma(\tau)$, where τ plays the role of viscous time: a measure of how rapidly identity can transform. We define the informational action as (following the conceptual basis introduced VTT):

$$S[\gamma] = \int_\gamma \Delta I(\tau)\, d\tau\,, \tag{1}$$

and postulate that physical trajectories are those satisfying $\delta S[\gamma] = 0$. From this variational principle, a metric tensor emerges as the unique symmetric bilinear form for which informational minimization becomes equivalent to classical geodesic motion.

1.3. Relation to Classical Geometry

This inversion suggests a reinterpretation of the classical variational principles of Maupertuis and Hamilton, where the action encodes energetic cost. Here the cost function is informational: trajectories minimize the degradation of coherent identity rather than mechanical action. The induced geometry corresponds to the local Hessian of the informational action with respect to velocity components. In the limit of uniform informational latency—i.e., $\Delta I = \text{const.}$—the standard geodesic equation on a fixed metric manifold is recovered, showing consistency with general relativity as a special case.

$$(\Delta C, \Delta I) \;\rightarrow\; S = \int \rho\, d\lambda \;\rightarrow\; \delta S = 0 \;\rightarrow\; g_{\mu\nu} \text{ emerges} \;\rightarrow\; \text{Observable curvature.}$$

2. Materials and Methods

2.1. Formal Structure and Variational Framework

In this section, we establish the mathematical objects required to formulate informational geodesics and to derive a metric tensor from the preservation of identity. The goal is not to postulate a geometric structure but to recover it as a compatibility constraint between informational minimization and classical geodesic evolution.

The variational structure developed here follows standard methods from analytical mechanics and field theory [2–4,10–11]. A derivation sketch, including the identification of the emergent metric as the local Hessian of the informational action with respect to velocity components, is provided in Appendix A.

2.2. Informational State Manifold

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Let M be a smooth differentiable manifold representing the space of possible informational states. A point $x \in M$ corresponds to a complete set of informational degrees of freedom describing an entity or system at a given stage of reorganization. We consider smooth curves

$$\gamma: [\tau_0, \tau_1] \to M, \tau \mapsto x(\tau), \qquad (2)$$

parameterized by viscous time τ, along which the informational identity of the system evolves. Throughout, overdots denote derivatives with respect to τ, so

$$\dot{x}^\mu = \frac{dx^\mu}{d\tau} \qquad (3)$$

in a local coordinate chart x^μ on $\mathcal{M}$.

The manifold $\mathcal{M}$ is not endowed with a metric a priori. Instead, we construct a metric tensor as a consequence of the variational principle defined below.

2.3. The notion of Viscous Time

The parameter τ represents a temporal ordering induced by the finite latency of informational reorganization. Unlike proper time in relativistic geometry, viscous time is not a geometric quantity associated with a metric, but a monotonic parameter measuring cumulative reorganization effort.

Intuitively, τ counts how much **informational change** has occurred, not how much external time has elapsed. The flow of τ therefore reflects the inherent cost of maintaining coherent identity while undergoing transformation.

Formally, we assume:

$$\frac{d\tau}{dt} \geq 0 \qquad (4)$$

where t is a coordinate time defined externally. In the limit of instantaneous reorganization latency (idealized), τ would degenerate to a trivial parameter and the geometry would collapse to a fixed background metric.

The non-triviality of τ encodes the emergence of curvature in the formalism.

2.4. Informational Latency Density $\boldsymbol{\Delta I}$

We define the local informational latency density $\Delta I(x, \dot{x})$ as the rate of informational reorganization per unit viscous time. It is a scalar functional of position and velocity on $\mathcal{M}$:

$$\Delta I: T\mathcal{M} \to \mathbb{R}, (x, \dot{x}) \mapsto \Delta I(x, \dot{x}) \qquad (5)$$

No assumptions are made on the explicit form of ΔI, beyond smoothness and positivity for nontrivial trajectories.

Interpretationally, ΔI measures the infinitesimal cost of preserving coherent identity while the system moves through its space of states. The functional form reflects how sensitive identity is to local reorganization.

2.5. Informational Action Functional

We define the action associated with a trajectory γ as:

$$S[\gamma] = \int_{\tau_0}^{\tau_1} \Delta I(x(\tau), \dot{x}(\tau))\, d\tau \qquad (6)$$

Physical trajectories are defined as **informational geodesics**, i.e., stationary curves of S under smooth variations with fixed endpoints:

$$\delta S[\gamma] = 0 \qquad (7)$$

Unlike mechanical action principles, the integrand is not a Lagrangian in the usual sense. It has no direct dependence on traditional kinetic or potential terms; rather, it encodes how the identity of the system resists deformation in response to its own evolution.

2.6. Informational Field Equation

Variation of the informational action under fixed identity constraints yields the emergent spacetime curvature:

$$\delta S = 0 \Rightarrow G_{\mu\nu} = \frac{\partial^2 \mathcal{D}}{\partial x^\mu \partial x^\nu} |_{\min} \tag{8}$$

This expression indicates that the observed metric tensor is the optimal configuration that minimizes total informational decoherence along the geodesic. In this view, geometry is not postulated a priori, but arises from a variational principle acting on the informational state of the system. The curvature of spacetime appears as the preservation cost of informational identity.

2.7. Euler–Lagrange Equation

Applying the standard variational calculus to $S[\gamma]$, we consider variations:

$$x^\mu(\tau) \mapsto x^\mu(\tau) + \varepsilon\eta^\mu(\tau) \quad \text{with } \eta^\mu(\tau_0) = \eta^\mu(\tau_1) = 0 \tag{9}$$

Stationarity requires:

$$\frac{d}{d\tau}\left(\frac{\partial \Delta I}{\partial \dot{x}^\mu}\right) - \frac{\partial \Delta I}{\partial x^\mu} = 0 \tag{10}$$

This is the Euler–Lagrange equation for informational geodesics. It resembles the geodesic equation in classical mechanics, but without reference to any underlying metric.

We define the generalized momentum as:

$$p_\mu = \frac{\partial \Delta I}{\partial \dot{x}^\mu} \tag{11}$$

Substituting the definition of the generalized momentum (Equation 11) into the Euler–Lagrange condition (Equation 10) yields the compact form of the geodesic equation, thus the Euler–Lagrange equation can be written compactly:

$$\dot{p}_\mu = \frac{\partial \Delta I}{\partial x^\mu} \tag{12}$$

The evolution of p_μ describes how identity-preserving constraints propagate along trajectories.

In the present framework p_μ may be viewed as an "informational momentum," quantifying the resistance of the system's identity to deformation along a trajectory.

2.8. Emergent Metric Tensor

We now define the symmetric bilinear form:

$$g_{\mu\nu}(x, \dot{x}) = \frac{\partial^2 \Delta I}{\partial \dot{x}^\mu \partial \dot{x}^\nu}, \tag{13}$$

interpreted as the Hessian of the latency density with respect to velocities. When $g_{\mu\nu}$ is positive-definite, it defines a local inner product on tangent vectors, inducing a Riemannian metric on $\mathcal{M}$.

This metric is **not postulated**, but **derived** from the variational structure of informational identity preservation. The connection coefficients and curvature of $g_{\mu\nu}$ measure how ΔI couples motion to structural deformation.

Under regularity assumptions, the Euler–Lagrange equation reduces to a geodesic equation relative to $g_{\mu\nu}$. Thus classical geodesics are recovered as informational geodesics in a limit where ΔI factorizes and viscous time degenerates.

2.9. Equivalence with Classical Geodesics

When $\Delta I(x, \dot{x})$ can be written in separable form:

$$\Delta I(x, \dot{x}) = \frac{1}{2} g_{\mu\nu}(x)\, \dot{x}^\mu \dot{x}^\nu \tag{14}$$

the Euler–Lagrange equation reduces to:

$$\ddot{x}^\mu + \Gamma^\mu_{\nu\sigma}\, \dot{x}^\nu \dot{x}^\sigma = 0 \tag{15}$$

which is the classical geodesic equation on a metric manifold. In this limit, informational latency is uniform and identity preservation does not require additional deformation. Gravity and curvature emerge only when ΔI is non-uniform, introducing viscous effects.

2.10. Physical Interpretation of the Informational Latency Density ΔI

The functional $\Delta I(x,\dot{x})$ encodes the rate at which a system must reorganize internal informational structure to preserve identity under finite coherence constraints. While the present formulation is intentionally agnostic about its explicit form, ΔI can be related to established quantities in information theory and quantum physics.

In a discrete system, ΔI may approximate the local change of a suitable information measure, such as the Kullback–Leibler divergence D_{KL} between successive states, or the rate of change of a coherence monotone in entangled systems:

$$\Delta I(\tau) \propto \frac{d}{d\tau}M(\rho(\tau)) \tag{16}$$

where M is a monotone under local operations and the proportionality constant depends on the choice of informational latency units.

In continuous systems, ΔI may be related to Fisher Information:

$$\Delta I \propto \frac{1}{2}g^{\mu\nu}\,\partial_\mu\psi\,\partial_\nu\psi \tag{17}$$

where ψ is a relevant field variable, leading to a known second-order structure equivalent to the local Fisher–Rao metric.

This connects ΔI to the geometric interpretation of Fisher information and suggests that the emergent metric identified in Section 3 may be interpreted as a Fisher–Rao metric generalized to dynamical coherence-preserving trajectories [14,15].

These examples do not prescribe a unique closed form of ΔI, but illustrate explicit pathways for embedding the functional into experimentally accessible quantities. In this way, the abstract variational formalism connects directly to measurable dynamics in coherent quantum matter.

Parameterization and Time Variables

Throughout this work, τ denotes viscous time, defined as the cumulative informational reconfiguration effort along a trajectory. In the variational derivation, we use a parameter λ to denote the curve parameter of the path γ(λ), with λ reducible to τ when the trajectory is parametrized by cumulative informational cost. Finally, t denotes the coordinate time of an external observer. In the limit where ΔI→0, τ→t and the informational action reduces to the classical proper time action of geodesic motion, recovering standard relativity.

3. Results

The variational formulation introduced in Section 2 yields a metric structure whose curvature is determined by the local properties of the informational action. In this section, we derive the explicit form of the emergent curvature tensor, obtain the corresponding field equations governing the informational metric, and discuss their observable consequences. The Results are organized as follows: Section 3.1 presents the curvature expression arising from the Hessian of the informational action; Section 3.2 introduces the associated field equation; and Section 3.3 outlines experimental signatures and predictions that enable empirical validation.

3.1. Curvature Expression

3.1.1. Emergent Metric Geometry and Curvature

The fundamental result of the previous section is that informational identity preservation induces a variational structure whose stationary trajectories define **informational geodesics**. In this section, we demonstrate that these geodesics can be expressed in geometric form by introducing a metric tensor derived from the second-order structure of the latency density ΔI. Curvature appears as a consequence of non-uniform identity preservation across the informational manifold.

3.1.2. Metric from Informational Latency

We recall the definition:

$$g_{\mu\nu}(x,\dot{x}) = \frac{\partial^2 \Delta I}{\partial \dot{x}^\mu \partial \dot{x}^\nu} \quad (18)$$

By construction, $g_{\mu\nu}$ is symmetric and smooth wherever ΔI is twice differentiable. When $g_{\mu\nu}$ is positive-definite, it defines a local inner product on $T_x\mathcal{M}$, enabling us to write:

$$\langle v,w\rangle_x = g_{\mu\nu}(x,\dot{x})\, v^\mu w^\nu \quad (19)$$

for any tangent vectors $v,w \in T_x\mathcal{M}$.

Unlike conventional geometric settings, here the metric depends on $\dot{x}$ in general. This dependence reflects the fact that identity preservation may react anisotropically to motion in state space, and therefore defines a Finsler-type geometry. In the special case where dependence on $\dot{x}$ disappears, the metric reduces to a classical Riemannian structure. Thus the geometry induced by informational latency lies generically in the class: $\left(\mathcal{M}, g_{\mu\nu}(x,\dot{x})\right)$, with Riemannian geometry emerging as a limiting case.

Since the metric depends on both positions and velocities, $g_{\mu\nu}(x,\dot{x})$, the resulting geometric structure is generically of Finsler type, with Riemannian geometry recovered when the velocity dependence disappears.

3.1.3. Informational Connection and Geodesics

The Euler–Lagrange equation may be expressed using the metric defined above. Differentiating

$$p_\mu = \frac{\partial \Delta I}{\partial \dot{x}^\mu} = g_{\mu\nu}\,\dot{x}^\nu \quad (20)$$

with respect to τ, and inserting into

$$\dot{p}_\mu = \frac{\partial \Delta I}{\partial x^\mu} \quad (21)$$

we obtain:

$$\frac{d}{d\tau}\left(g_{\mu\nu}\,\dot{x}^\nu\right) = \frac{\partial \Delta I}{\partial x^\mu} \quad (22)$$

Expanding the derivative yields:

$$g_{\mu\nu}\,\ddot{x}^\nu + \frac{\partial g_{\mu\nu}}{\partial x^\sigma}\dot{x}^\sigma \dot{x}^\nu = \frac{\partial \Delta I}{\partial x^\mu} - \frac{\partial g_{\mu\nu}}{\partial \dot{x}^\sigma}\,\dot{x}^\sigma \ddot{x}^\nu \quad (23)$$

Under regularity conditions eliminating the dependence of $g_{\mu\nu}$on $\dot{x}$, the right-hand side simplifies to a purely positional derivative of the metric, and we recover the classical geodesic equation:

$$\ddot{x}^\mu + \Gamma^\mu_{\nu\sigma}\,\dot{x}^\nu \dot{x}^\sigma = 0 \quad (24)$$

where

$$\Gamma^\mu_{\nu\sigma} = \frac{1}{2} g^{\mu\lambda}\left(\frac{\partial g_{\lambda\nu}}{\partial x^\sigma} + \frac{\partial g_{\lambda\sigma}}{\partial x^\nu} - \frac{\partial g_{\nu\sigma}}{\partial x^\lambda}\right) \quad (25)$$

are the Christoffel symbols associated with the emergent metric $g_{\mu\nu}$. Thus the standard geodesic equation of differential geometry is recovered from the informational action when identity preservation becomes isotropic and velocity-independent.

This reduction is valid when ΔI varies slowly with respect to velocity components, or in the limit of uniform informational latency.

3.1.4. Curvature from Informational Gradients

Given the emergent metric $g_{\mu\nu}$, we define the Riemann curvature tensor $R^\mu{}_{\nu\sigma\lambda}$ in the usual way:

$$R^\mu{}_{\nu\sigma\lambda} = \partial_\sigma \Gamma^\mu_{\nu\lambda} - \partial_\lambda \Gamma^\mu_{\nu\sigma} + \Gamma^\mu_{\rho\sigma}\Gamma^\rho_{\nu\lambda} - \Gamma^\mu_{\rho\lambda}\Gamma^\rho_{\nu\sigma} \quad (26)$$

Curvature measures the non-commutativity of covariant derivatives on $\mathcal{M}$. In the context of informational geometry, curvature arises whenever the cost of identity preservation varies with position in state space. In other words, curvature is a measure of how **non-uniform latency density** ΔIconstrains the evolution of states.

To show this explicitly, we use the definition:

$$R^\mu{}_{\nu\sigma\lambda} = 0 \text{iff} g_{\mu\nu}(x) = \text{constant tensor in local coordinates} \quad (27)$$

i.e., curvature vanishes when identity preservation is uniform across $\mathcal{M}$. Thus:

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$$R^{\mu}_{\ \nu\sigma\lambda} \neq 0 \Leftrightarrow \partial_\alpha g_{\mu\nu}(x) \neq 0 \qquad (28)$$

meaning curvature is generated by **gradients of the latency density**:

$$\partial_\alpha g_{\mu\nu} = \frac{\partial}{\partial x^\alpha}\left(\frac{\partial^2 \Delta I}{\partial \dot{x}^\mu \, \partial \dot{x}^\nu}\right) \qquad (29)$$

This shows that the curvature of the informational geometry is fully determined by the spatial variation of the cost function ΔI.

3.1.5. Interpretation: Curvature as Resistance to Identity Loss

The geometric content of these results may be summarized as follows:

- The metric $g_{\mu\nu}$ encodes how difficult it is to maintain identity when moving in a given direction in state space.
- If identity preservation is uniform in all directions, $g_{\mu\nu}$ is constant and curvature vanishes.
- When identity preservation varies, certain directions cost more than others, inducing curvature.

Thus curvature is a manifestation of **anisotropic identity resistance**.

This provides a natural interpretation of gravity and geometric curvature: the geometry of space is not imposed, but **emerges** from preservation of informational identity under finite reorganization latency.

3.1.6. Limiting Case: Reduction to General Relativity

When latency density assumes the quadratic form:

$$\Delta I(x, \dot{x}) = \frac{1}{2} g_{\mu\nu}(x)\, \dot{x}^\mu \dot{x}^\nu \qquad (30)$$

the metric becomes independent of velocity, and the Euler–Lagrange equation reduces exactly to the geodesic equation of Riemannian geometry. In that limit, informational geodesics coincide with classical geodesics, and the dynamics of identity preservation cannot be distinguished from inertial motion.

This establishes **formal equivalence with General Relativity** whenever ΔI is quadratic in velocity, and the informational cost is homogeneous.

Gravity may be interpreted as a broken symmetry: curvature represents the failure of identity preservation to remain uniform across the manifold.

3.1.7. Beyond Quadratic Forms: Emergent Dynamics

Deviations from the quadratic form of ΔI lead to generalized geometries that incorporate higher-order effects, potentially extending beyond classical General Relativity.

These terms correspond to situations where identity preservation is **not purely metric**, but where the **deformation field** has nontrivial structure, leading to:

- Finsler-like metrics,
- anisotropic curvature,
- dynamical spacetime,
- and additional geometrical degrees of freedom.

Such effects may be relevant in contexts where the informational structure of the system is strongly nonlinear, including quantum states, biological systems, or high-complexity networks.

Summary of Results

The key result of this section is: **Curvature is induced by gradients of the informational latency density ΔI.**

Informational geodesics are curves that **minimize resistance to identity loss**, and the corresponding second-order structure of ΔI behaves as a metric tensor. In the special case of uniform identity preservation, the geometry reduces to a standard Riemannian manifold and reproduces the geodesic structure of General Relativity.

3.2. Information Field Equation

The preceding sections established that informational identity preservation imposes a variational structure on trajectories in state space. The metric tensor emerges as the Hessian of the latency density ΔI, and curvature results from spatial gradients in this metric. In this section, we introduce the field equation governing how curvature is generated by variations in identity density. The equation follows from extremizing the total informational action of the manifold.

The use of the Ricci scalar R of the emergent metric $g_{\mu\nu}$ in the informational curvature action follows from the requirement that the geometric part of the action produces second-order field equations. The Hilbert action is known to be the unique diffeomorphism-invariant scalar constructed from the metric yielding second-order Euler–Lagrange equations (Lovelock's theorem in 4D). Since the metric arises from the Hessian of the latent informational cost, the same uniqueness argument applies. Alternative higher-order invariants would introduce additional derivative terms not present in the informational action. Thus, the Ricci scalar represents the minimal geometric completion consistent with the emergent metric. Since the metric arises from the Hessian of ΔI, the uniqueness argument applies directly to the informational manifold.

3.2.1. Informational Action Functional

We define the **informational action** over a region $\Omega \subset \mathcal{M}$ as:

$$\mathcal{A}[\Delta I] = \int_{\Omega} \Delta I(x, \dot{x}) \sqrt{|\, g \,|}\ d^n x \tag{31}$$

where:

- $\Delta I(x, \dot{x})$ is the informational latency density,
- $g = \det(g_{\mu\nu})$,
- and $d^n x$ is the volume form induced by the emergent metric.

This expression parallels the Einstein–Hilbert action, except that the integrand is not curvature but the **local identity latency cost** required to preserve informational identity across infinitesimal displacements.

To derive the field equations, we consider variations of $\mathcal{A}$ with respect to the metric:

$$\delta\mathcal{A} = \int_{\Omega} \left(\frac{\partial \Delta I}{\partial g_{\mu\nu}} \delta g_{\mu\nu} + \Delta I\, \delta\sqrt{|\, g \,|} \right) d^n x \tag{32}$$

Stationarity of the action for arbitrary $\delta g_{\mu\nu}$ yields the corresponding Euler–Lagrange conditions.

3.2.2. Stress from Identity Gradients

To identify the source term, we define the **identity density tensor**:

$$T_{\mu\nu} \equiv -\frac{2}{\sqrt{|g|}} \frac{\delta\mathcal{A}}{\delta g^{\mu\nu}} \tag{33}$$

which matches the standard definition of stress-energy in classical field theory but interpreted here as the **resistance of the system to identity variation**.

Explicitly:

$$T_{\mu\nu} = -2 \frac{\partial \Delta I}{\partial g^{\mu\nu}} + g_{\mu\nu} \Delta I \tag{34}$$

This tensor captures how the informational cost responds to metric deformation, i.e., how much the resistance to identity preservation increases when the geometry changes.

In regions where identity preservation is uniform, ΔI is constant and $T_{\mu\nu} = 0$, recovering the flat-geometry limit.

3.2.3. Curvature from Identity Preservation

Curvature is defined as in Section 3, through the Riemann tensor and its contractions. We introduce the **informational Ricci tensor**:

$$R_{\mu\nu} = R^{\lambda}{}_{\mu\lambda\nu} \quad (35)$$

and the **informational scalar curvature**:

$$R = g^{\mu\nu} R_{\mu\nu} \quad (36)$$

The geometric structure is identical to the standard case, but its **interpretation** is different: curvature measures non-uniform latency density.

We now define the **informational curvature functional**:

$$\mathcal{R}_I = \int_{\Omega} R \sqrt{| g |}\ d^n x \quad (37)$$

which quantifies the total deviation from uniform identity preservation across Ω.

Note: that $\mathcal{R}_I$ represents only the geometric contribution to the total action. In the next section we introduce the full informational action S, which combines $\mathcal{R}_I$ with the latency density term ΔI.

3.2.4. Field Equation from Variational Principle

Building on the geometric functional $\mathcal{R}_I$ defined in Equation (37), we introduce the total informational action:

$$S = \int (\frac{1}{2\kappa} R + \Delta I) \sqrt{| g |}\ d^n x \quad (38)$$

where R is the Ricci scalar of the emergent informational metric, and ΔI is the informational latency density introduced in Section 2.10. The placement of κ in the geometric term ensures that variations of the action yield second-order field equations while preserving the relative scale between informational dissipation and induced curvature.

Stationarity with respect to the metric yields:

$$\delta S = 0 \Rightarrow R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \kappa T_{\mu\nu} \quad (39)$$

where κ is a coupling constant determined by the units chosen for ΔI and the normalization of the informational contribution in the action.

This equation adopts the same tensor structure:

$$G_{\mu\nu} = \kappa T_{\mu\nu} \quad (40)$$

with the fundamental difference that here:

- $T_{\mu\nu}$ does not represent physical energy,
- but rather the **informational resistance to identity reconfiguration**.

Thus curvature emerges not from physical mass-energy, but from gradients in identity preservation effort.

3.2.5. Physical Interpretation

The field equation shows that variations in informational identity drive curvature in the emergent geometry:

$$\partial_{\alpha}(\Delta I) \neq 0 \Rightarrow R_{\mu\nu} \neq 0 \quad (41)$$

Uniform informational identity produces flat geometry:

$$\Delta I = \text{constant} \Rightarrow R_{\mu\nu} = 0 \quad (42)$$

Non-uniform identity resistance induces curvature:

$$\partial_x \Delta I \neq 0 \Rightarrow G_{\mu\nu} \propto \partial \Delta I \quad (43)$$

This establishes the core conceptual bridge: **Spacetime curvature is the geometric expression of non-uniform informational identity preservation.**

In regions where identity is costly to maintain, trajectories bend — geodesics deflect — encoding the curvature of the emergent manifold.

3.2.6. Recovery of General Relativity

If the latency density assumes the quadratic form:

$$\Delta I(x,\dot{x}) = \frac{1}{2} g_{\mu\nu}(x)\,\dot{x}^{\mu}\dot{x}^{\nu} \quad (44)$$

then:

- $T_{\mu\nu}$ reduces to a tensor formally equivalent to stress-energy,
- curvature follows from the standard Einstein–Hilbert action,
- geodesics reduce to classical geodesics,

and therefore the field equation becomes **exactly Einstein's equation** with appropriate scaling. Thus **General Relativity is the special case** of uniform, quadratic identity preservation:

$$\Delta I \sim \frac{1}{2} g_{\mu\nu}\dot{x}^{\mu}\dot{x}^{\nu} \Rightarrow G_{\mu\nu} = \kappa T_{\mu\nu} \quad (45)$$

The informational formulation provides a **broader foundation** in which GR is a natural reduction.

To recover the standard Einstein equation, the informational source $T_{\mu\nu}$ maps to the physical stress–energy tensor $T_{\mu\nu}^{\text{physical}}$ under the scaling $\kappa \to \frac{8\pi G}{c^4}$, corresponding to a choice of units for ΔI consistent with General Relativity.

3.2.7. Beyond Einstein: Nonlinear Identity Dynamics

When the informational cost is **not** quadratic, the metric becomes velocity-dependent, and the geometry takes a Finsler-like form. In this regime:

- curvature depends on both position and motion,
- the field equations acquire higher-order terms,
- and the resulting dynamics extend beyond Einstein's theory.

This may provide **new geometric structures** relevant for systems where identity preservation is highly nonlinear:

- quantum states,
- strongly correlated media,
- biological systems,
- high-coherence networks,
- informational manifolds with topology change.

These cases reflect dynamic curvature driven not by mass, but by **complex identity resistance**.

Summary:

We have derived a field equation of the form:

$$G_{\mu\nu} = \kappa T_{\mu\nu} \quad (46)$$

where:

- $G_{\mu\nu}$ is the informational Einstein tensor,
- $T_{\mu\nu}$ is the identity resistance tensor,
- and κ controls coupling strength.

This establishes **a complete analogy with General Relativity**, while revealing a deeper mechanism: curvature encodes the cost of preserving identity over finite latency.

GR is obtained as a **limiting case** where identity preservation is isotropic and quadratic.

3.3. Experimental Predictions

3.3.1. Observable Predictions and Experimental Signatures

The field equation derived in Section 3.2 establishes a direct relationship between curvature and gradients in informational identity density, according to Equation (46) where $T_{\mu\nu}$ encodes the resistance to informational reconfiguration across a path on the manifold. In this section we examine the measurable consequences of this relation. The aim is twofold:

1. To identify physical regimes where $\Delta I(x,\dot{x})$ is not uniform, producing non-trivial curvature independently of mass–energy density.

2. To propose methods by which the induced curvature may be empirically quantified.

We begin from the classical limit, recover General Relativity in a special case, and then describe new observables predicted by the informational formulation.

3.3.2. Informational Deviation of Geodesics

The simplest observable signature arises from the geodesic deviation equation. Two nearby informational geodesics $\gamma(\tau)$ and $\gamma'(\tau)$, separated by deviation vector ξ^{μ}, obey:

$$\frac{D^2\xi^{\mu}}{D\tau^2} = -R^{\mu}{}_{\nu\alpha\beta}\,\dot{x}^{\nu}\dot{x}^{\alpha}\,\xi^{\beta} \tag{47}$$

In the informational formulation, the curvature tensor is determined by spatial gradients of ΔI:

$$R^{\mu}{}_{\nu\alpha\beta} \propto \partial_{\alpha}\,\partial_{\beta}\Delta I \tag{48}$$

Thus the **relative acceleration between nearby trajectories** is controlled by how rapidly identity-preservation cost varies over the manifold.

Observable consequence:

If two information-preserving processes operate in parallel (e.g., two coherent modes, two correlated trajectories in a Hilbert subspace, two coupled signals in a coherent medium), the rate at which their states diverge should reflect **second derivatives of identity resistance**, even when mass-energy density is negligible.

This effect provides a **direct measurement pathway**:

- measure correlation decay between two informational trajectories,
- infer curvature from second-order derivatives of divergence.

This parallels standard differential-geometric inference from geodesic spread, but here it arises in **informational state space**, not physical spacetime.

3.3.3. Experimental Regime 1: Coherent Media

Certain media sustain **long-lived coherence** between degrees of freedom. Examples include:

- Bose–Einstein condensates,
- superconducting phases,
- optical resonators with high Q-factor,
- coherent photonic lattices,
- strongly coupled exciton–polaritons.

For such systems, $\Delta I(x, \dot{x})$ is **non-quadratic**, reflecting nonlinear energy cost for identity preservation. The informational curvature term is expected to produce **measurable shifts in dispersion relations**, including:

$$\omega(k) = \omega_0(k) + \kappa\,\partial_k^2\Delta I(k) \tag{49}$$

Where standard theory predicts $\omega(k)$ from physical Hamiltonians alone, the informational correction shifts phase velocity:

$$v_p = \frac{\partial\omega}{\partial k} \tag{50}$$

Thus, under conditions of strong identity preservation, **phase velocity and group velocity anomalies** emerge even without mass–energy curvature.

Measurable signature:

- measure deviation from predicted dispersion in a controllable coherent medium,
- compare with predicted $\partial^2\Delta I$ from informational tensor.

This approach is experimentally accessible using photonic crystals or superconducting circuits.

3.3.4. Experimental Regime 2: Correlated Quantum Systems

In entangled systems, the informational identity of the joint state is **globally defined**. Variation in the cost of preserving this identity when subsystems evolve independently provides a direct test:

Let $|\psi\rangle$ be a bipartite state with reduced density ρ_A and ρ_B. The latency density ΔI along local trajectories reflects **how local changes impact global identity**.

We predict that the **curvature of informational geodesics** produces corrections to entanglement monotones, for example:

$$\frac{d^2}{dt^2}\mathcal{E}(\rho_A(t)) = -R^{\mu}_{\ \nu\alpha\beta}\,\dot{x}^{\nu}\dot{x}^{\alpha}\xi^{\beta} \tag{51}$$

where $\mathcal{E}$ is any differentiable entanglement measure.

Thus, informational curvature predictions can be tested through **temporal curvature of entanglement evolution**, measurable in:

- trapped-ion chains,
- superconducting qubit arrays,
- Rydberg atom lattices.

No exotic instrumentation required — only precise tomography.

3.3.5. Experimental Regime 3: Network Geodesics

Beyond physics, similar structure appears in systems where identity preservation is a functional constraint, such as:

- optimal transport in networks,
- multi-agent systems,
- coordinated swarm dynamics,
- neural computation under stability constraints.

In a network with state vector $x(t)$ and flow cost $C(x, \dot{x})$, identity preservation (e.g., logical consistency, synchronized phase) imposes a latency density analogous to ΔI. The geodesics of informational networks satisfy the same variational principle:

$$\delta \int \Delta I_{\text{net}}(x, \dot{x})\, dt = 0 \tag{52}$$

Thus measurable curvature appears in:

- systematic deviation of shortest paths under identity constraints,
- non-Euclidean metrics in learned representations,
- curvature of embedding manifolds in deep networks.

These effects can be measured using:

- geodesic curvature in latent-space embeddings,
- second-order deviation of alignment loss,
- curvature estimates from Riemannian optimization.

This is a testable signature of the theory in applied domains.

3.3.6. Distinguishing From General Relativity

While the geometry mirrors that of GR, the source of curvature is different:

- In GR: curvature arises from stress-energy patterns.
- Here: curvature arises from gradients in identity preservation.

Therefore, in low mass, high coherence regimes, GR predicts flat geometry, while the informational model predicts non-zero curvature.

This provides a clear falsifiability route: find a physical regime with negligible mass-energy but measurable curvature-like effects governed by informational identity gradients.

Examples:

- phase velocity shifts in ultraclean cavities,
- anomalous geodesic deviation in coherent photonic crystals,
- entanglement curvature experiments.

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These are experimental domains where **traditional gravity is absent, but informational curvature is present**.

Note : Correspondence with General Relativity

The informational geodesic principle is strictly compatible with the standard formulation of General Relativity. In the limit where informational variations become negligible, the preservation cost vanishes and the Einstein field equations are recovered as a special case:

$$\lim_{\Delta C, \Delta I \to 0} G_{\mu\nu} = G_{\mu\nu}^{(GR)} \tag{53}$$

This correspondence shows that General Relativity is the zero-information-gradient limit of the informational action. The proposed formulation does not replace the classical theory, but generalizes it by identifying spacetime geometry as the optimal configuration minimizing the loss of informational identity.

3.3.7. Quantifying the Coupling Constant $\boldsymbol{\kappa}$

In systems where ΔI is experimentally measurable, κ may be estimated from the second variation of ΔI with respect to the metric, i.e.,

$$\kappa \sim \frac{\partial^2 \Delta I}{\partial g^2} \tag{54}$$

This suggests κ encodes the sensitivity of the identity cost to geometric deformation, which can be estimated from controlled perturbations to the identity cost in a known geometry.

In coherent media, this reduces to:

$$\kappa \propto \partial_k^2 \Delta I(k) \tag{55}$$

Thus κ can be measured empirically:

- perturb the system slightly,
- measure geodesic deviation,
- infer coupling.

This matches the common strategy of **fitting coupling constants** through perturbative analysis.

Summary of Predictions

The informational curvature framework predicts:

1. Geodesic deviation in informational state space: even with negligible mass-energy.
2. Dispersion anomalies in coherent media: traceable to $\partial^2 \Delta I$.
3. Curvature of entanglement dynamics: measurable via entanglement monotones.
4. Non-Euclidean network geometry: emerging from identity-preservation cost.

Each of these is testable **today**, with standard laboratory tools.

4. Discussion

4.1. Interpretation of Results

The results obtained in Section 3 support the central claim that a metric tensor can emerge from an informational variational principle. Instead of assuming a geometric background, the framework reconstructs a symmetric bilinear form as the unique structure compatible with identity-preserving evolution under finite informational latency. The curvature inferred from the Hessian of the informational action recovers the classical geodesic equation in the limit of uniform reconfiguration cost, demonstrating that general relativity appears as a special case of a broader informational dynamics. The resulting field equation mirrors the structure of Einstein's equation without postulating spacetime geometry as a primitive object.

4.2. Relation to Existing Theories

These results connect to prior work on emergent gravity, entropic forces, and informational geometry, while differing in formulation and emphasis.

The variational formulation developed here represents a minimal reduction of a broader research program introduced in the Viscous Time Theory (VTT) framework. In that context, informational latency and identity-preserving dynamics are explored as the origin of emergent geometric structures, while the present work isolates the core variational mechanism and its direct implications for curvature. This manuscript therefore provides a compact and testable formulation that can be compared with classical results without requiring the full theoretical machinery of VTT.

Wheeler's "it from bit", Verlinde's entropic gravity, and thermodynamic approaches to spacetime all link gravitational phenomena to informational principles. In contrast, the present formulation treats curvature as a measure of the internal tension required to preserve coherent identity along extremal informational trajectories. The approach also relates to Fisher information geometry through the interpretation of curvature as a response to reconfiguration cost, suggesting potential bridges between statistical inference, quantum foundations, and spacetime dynamics.

4.3. Limitations and Open Questions

The current formulation is idealized and neglects several factors that may be relevant in concrete physical systems. The choice of latent time, the handling of non-local reconfiguration events, and the role of constraints on the informational degrees of freedom require further development. In addition, the mapping between informational quantities and physical observables must be clarified in specific experimental settings. The framework also raises questions regarding the interpretation of identity preservation in quantum systems, the influence of coherence on curvature, and the treatment of subsystems in multi-scale informational manifolds.

4.4. Perspective and Research Program

The informational approach suggests a broader research program aimed at validating, refining, or falsifying the theoretical framework. Promising directions include:

- deriving explicit forms of ΔI from known Hamiltonians,
- characterizing informational geodesics in quantum lattices,
- exploring the influence of curvature on entanglement transport,
- validating dispersion anomalies experimentally,
- studying effective coupling constants in engineered coherence fields,
- extending the theory to multi-scale informational manifolds.

This agenda provides a clear roadmap for empirical and computational evaluation, a key requirement for theory development in statistical mechanics and informational physics. The proposed experiments and model systems may help to delineate the regimes in which informational curvature produces measurable effects, and to assess whether the resulting field equation can serve as an effective description of coherent matter.

4.5. Representative Experimental Regimes and Expected Observables

To illustrate how the informational action can be evaluated in concrete physical settings, Table 1 summarizes representative regimes in which the latency density ΔI takes experimentally meaningful forms. Each regime is associated with a simplified functional structure of ΔI, a corresponding predicted observable, and an interpretation linking the observable to the underlying geometry. These examples delineate how the informational field equation $G_{\mu\nu} = \kappa T_{\mu\nu}$ may be tested in coherent condensed phases and entangled quantum systems, providing a roadmap for empirical validation.

Table 1. Representative experimental regimes, functional forms of the informational latency density ΔI, predicted observables, and their interpretation within the emergent curvature framework.

Regime	ΔI Structure	Expected Observable	Interpretation
Quadratic	$\Delta I \sim \frac{1}{2} g_{\mu\nu}\dot{x}^{\mu}\dot{x}^{\nu}$	Classical geodesics, Einstein dynamics	Recovery of GR
Non-Quadratic Polynomial	$\Delta I \sim \dot{x}^4$ or higher	Non-linear curvature corrections	Deviations from Einstein gravity
Discrete coherence	$\Delta I \approx dM/d\tau$	Quantum monotone dynamics	Connection to entanglement flow
Fisher information	$\Delta I \propto g^{\mu\nu}\,\partial_\mu\psi\,\partial_\nu\psi$	Informational metric detection	Fisher–Rao realization
Coherent media	$\Delta I(k)$	Perturbation of κ via spectral response	Measurement of κ

Table 1 highlights the diversity of possible realizations of the informational metric. In quadratic cases, the emergent geometry reproduces classical general relativity, while higher-order terms predict measurable non-linear curvature effects. Quantum informational regimes provide alternative routes to curvature detection through coherence dynamics, enabling experimental interrogation of κ in engineered media.

5. Conclusion

We have shown that the geometric structure of spacetime curvature can be derived from a variational principle based on the preservation of informational identity. In this formulation, geodesics are extremal trajectories that minimize resistance to the reconfiguration of informational identity under finite latency constraints. Curvature emerges from gradients in this resistance, producing a tensor field of the form: $G_{\mu\nu} = \kappa\, T_{\mu\nu}$, where the source term $T_{\mu\nu}$ is informational rather than energetic. General Relativity appears as a limiting case in which the cost of identity preservation is fully determined by local energy–momentum. The broader theory allows curvature to arise in regimes where mass–energy is negligible but informational constraints remain non-trivial.

The framework predicts measurable signatures in systems where informational identity is coherently maintained across extended trajectories, including condensed-matter phases, quantum-entangled networks, and engineered coherence fields. In such regimes, curvature is expected to manifest as deviations in geodesic separation, modified dispersion relations, and curvature in the temporal evolution of entanglement. These effects define a concrete experimental pathway for estimating the coupling κusing phase–velocity shifts, geometric deviation metrics, or entanglement–curvature correlations.

By reframing curvature as the consequence of identity-preservation gradients, this formulation links differential geometry with information-theoretic concepts and establishes a coherent structure for studying geodesics in both physical and computational systems. Future work will focus on computing explicit forms of the informational latency density $\Delta I(x, \dot{x})$ for known Hamiltonians, characterizing informational geodesics in multi-scale coherent systems, and developing numerical tools to approximate geodesics on informational manifolds.

A direct implication of the informational action is that time arises from accumulated informational separation along an identity-preserving trajectory:

$$t = \int \Delta I \, d\lambda \quad (56)$$

Regions where $\Delta I \to 0$ correspond to suspended time, while rapid variation implies accelerated temporal flow. This aligns the perception of time with a structural property of informational dynamics rather than an external parameter.

This formulation does not aim to replace General Relativity, but instead to generalize its variational logic. It suggests that the geometry of evolution—physical, quantum, or informational—is governed by a common principle: **curvature reflects the cost of preserving identity through change**.

These results provide a concrete mathematical realization of the principles introduced in the Viscous Time Theory (VTT), demonstrating how geometric structure can emerge from informational dynamics under finite latency.

In this view, spacetime geometry is not assumed but reconstructed, emerging wherever identity-preservation under finite informational latency becomes non-trivial.

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Appendix A

Variational Derivation

In this appendix we provide a sketch of the variational derivation leading from the informational action to the emergent metric tensor. This appendix provides the detailed variational derivation corresponding to the sketch presented in Section 2, where the informational action was introduced and its geometric interpretation outlined.

We consider small deformations of a parametrized path $\gamma(\tau)$, with fixed endpoints τ_0, τ_1, and define the informational action as:

$$S[\gamma] = \int_{\tau_0}^{\tau_1} \Delta I(\gamma(\tau), \dot{\gamma}(\tau)) \, d\tau. \quad (57)$$

The quantity ΔI represents the instantaneous rate of informational reorganization along the path. We assume ΔI is twice differentiable with respect to its velocity argument $\dot{\gamma}$. A variation $\gamma \to \gamma + \epsilon\eta$, with $\eta(\tau_0) = \eta(\tau_1) = 0$, yields the first variation

$$\delta S = \int_{\tau_0}^{\tau_1} \left(\frac{\partial \Delta I}{\partial \gamma^i}\eta^i + \frac{\partial \Delta I}{\partial \dot{\gamma}^i}\dot{\eta}^i\right) d\tau \quad (58)$$

Integrating by parts the second term and using endpoint conditions,

$$\delta S = \int_{\tau_0}^{\tau_1} \left(\frac{\partial \Delta I}{\partial \gamma^i} - \frac{d}{d\tau}\frac{\partial \Delta I}{\partial \dot{\gamma}^i}\right) \eta^i \, d\tau \quad (59)$$

The extremal condition $\delta S = 0$for arbitrary ηimplies the Euler–Lagrange equation:

$$\frac{d}{d\tau}\left(\frac{\partial \Delta I}{\partial \dot{\gamma}^i}\right) = \frac{\partial \Delta I}{\partial \gamma^i} \quad (60)$$

For trajectories that preserve identity under minimal informational reorganization, ΔI depends primarily on local changes in identity rather than on position, and we approximate:

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$$\frac{\partial \Delta I}{\partial \gamma^i} \approx 0 \quad (61)$$

In this regime, the extremal condition reduces to a linear conservation law

$$\frac{d}{d\tau}\left(\frac{\partial \Delta I}{\partial \dot{\gamma}^i}\right) = 0 \quad (62)$$

implying that $\frac{\partial \Delta I}{\partial \dot{\gamma}^i}$ is constant along the path. The second variation defines a symmetric bilinear form:

$$g_{ij}(\gamma, \dot{\gamma}) = \frac{\partial^2 \Delta I}{\partial \dot{\gamma}^i \partial \dot{\gamma}^j} \quad (63)$$

which encodes the local quadratic structure of the action with respect to velocity components. This tensor plays the role of an emergent metric induced by the informational cost functional. Geodesic motion is recovered in the standard form when ΔI is uniform over the trajectory, reducing the Euler–Lagrange equation to the classical geodesic equation on a metric manifold.

This derivation illustrates that the metric tensor arises as the unique symmetric form for which informational identity is preserved along extremal trajectories.

This completes the variational derivation of the emergent metric tensor used in Section 3.

Appendix B

Table A1. List of Symbols and Definitions.

Symbol	Meaning
$x^\mu(\tau)$	Parametrized path (trajectory) in state space
$\dot{x}^\mu$	Derivative with respect to parameter τ
ΔI	Informational latency density / informational action density
p_μ	Informational momentum $\partial \Delta I / \partial \dot{x}^\mu$
$g_{\mu\nu}$	Emergent metric $\partial^2 \Delta I / \partial \dot{x}^\mu \partial \dot{x}^\nu$
$\Gamma^\mu_{\nu\sigma}$	Informational connection (Christoffel symbol) derived from emergent metric
$R_{\mu\nu}$	Ricci tensor constructed from emergent metric
R	Ricci scalar of the emergent geometry
$G_{\mu\nu}$	Informational Einstein tensor
$T_{\mu\nu}$	Identity resistance tensor (not stress–energy)
κ	Informational coupling constant
$\mathcal{S}$	Total informational action ($S = \int (\frac{1}{2\kappa} R + \Delta I)\sqrt{\lvert g \rvert}\, d^n x$)
$\mathcal{M}$	Manifold of states

Note: In the informational formulation, $T_{\mu\nu}$ does not represent physical stress–energy. It represents resistance to identity reconfiguration under finite latency.

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References

1. Einstein, A. (1916). The Foundation of the General Theory of Relativity. *Annalen der Physik*, 354(7), 769–822.
2. Levi-Civita, T. (1901). Sulle trasformazioni delle equazioni dinamiche. *Rendiconti del Circolo Matematico di Palermo*, 20, 225–284.
3. Hamilton, W. R. (1834). On a General Method in Dynamics. *Philosophical Transactions of the Royal Society*, 124, 247–308.
4. Maupertuis, P. L. M. (1744). Accord de différentes lois de la nature. *Mémoires de l'Académie Royale des Sciences*.
5. Hilbert, D. (1915). Die Grundlagen der Physik. *Nachrichten von der Gesellschaft der Wissenschaften Göttingen*, 395–407.
6. [6] Riemann, B. (1854). Über die Hypothesen, welche der Geometrie zugrunde liegen. *Abhandlungen der Königlichen Gesellschaft der Wissenschaften*, 13, 133–152.
7. Do Carmo, M. (1992). *Riemannian Geometry*. Birkhäuser.
8. Lee, J. M. (2018). *Introduction to Riemannian Manifolds* (2nd ed.). Springer.
9. Wald, R. M. (1984). *General Relativity*. University of Chicago Press.
10. Landau, L. D., & Lifshitz, E. M. (1975). *The Classical Theory of Fields* (4th ed.). Pergamon.
11. Arnold, V. I. (1989). *Mathematical Methods of Classical Mechanics* (2nd ed.). Springer.
12. Synge, J. L. (1960). *Relativity: The General Theory*. North-Holland.
13. Amari, S. (2016). Information Geometry and Its Applications. Springer.
14. Amari, S., & Nagaoka, H. (2000). Methods of Information Geometry. AMS.
15. Caticha, A. (2012). Entropic Inference and the Foundations of Physics. Springer.
16. [16] Frieden, B. R. (1999). *Physics from Fisher Information*. Cambridge University Press.
17. Reginatto, M. (1998). Derivation of the equations of nonrelativistic quantum mechanics using the principle of minimum Fisher information. *Physical Review A*, 58(3), 1775–1778.
18. Goyal, P. (2020). Derivation of Quantum Theory via Information Geometry. *Entropy*, 22(5), 552.
19. [19] Wheeler, J. A. (1990). Information, Physics, Quantum: The Search for Links. *Proceedings of the 3rd International Symposium on Foundations of Quantum Mechanics*, 354–368.
20. Verlinde, E. (2011). On the Origin of Gravity and the Laws of Newton. *Journal of High Energy Physics*, 2011(4), 29. doi:10.1007/JHEP04(2011)029
21. Padmanabhan, T. (2010). Thermodynamical Aspects of Gravity. *Reports on Progress in Physics*, 73(4), 046901.
22. Bianchetti. R. Viscous Time Theory (VTT) Foundational Mathematics (Part 1): Variational Origin of Informational Geometry, Coherence Curvature, and the VTT Lagrangian. Preprints 2025, 2025111848 (DOI:10.20944/preprints202511.1848.v1)