

A Unified Variational Principle for Physical and Informational Equilibrium

A Conceptual Architecture Coupling Classical Action, Quantum-Geometric Corrections, Causal Constraints, and Informational Invariants

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Scope and Intellectual-Property Notice

This preprint communicates the conceptual architecture, motivation, internal consistency, and predictive program of the model. The operational mathematical core — the explicit functional forms of the constituent terms, their kernels, coupling coefficients, the construction of the informational invariant, and the closed-form equilibrium operator — is the subject of an intellectual-property filing (WIPO) and is deliberately withheld. The structural relations shown here are presented only at the level of named placeholders and symbolic roles; they are insufficient, by design, to reconstruct, re-derive, or reverse-engineer the protected expressions by analytical, numerical, or automated (including AI-assisted) means. Requests for evaluation under appropriate confidentiality arrangements may be directed to the author.

Abstract

We present the conceptual architecture of a **Unified Variational Principle (UVP)**, a single formal framework proposed to couple four domains that are conventionally treated in isolation: (i) the classical action of mechanics and gravitation; (ii) discrete quantum-geometric corrections of the type predicted by Loop Quantum Gravity (LQG)^[1]; (iii) relativistic causality constraints that forbid pathological time orderings^[3]; and (iv) a quantum informational invariant aligned with the holographic preservation of information^[5]. The principle is organized as a global equilibrium condition in which a generalized dynamical-geometric contribution and a causal-informational contribution are held in a stationary balance. From this single condition the framework is designed to recover the classical equations of motion in the appropriate limit while admitting quantum, causal, and informational corrections as structured deformations. We further propose a disciplined conceptual extension of the same equilibrium logic to socio-informational systems, where shared values, governance, and cultural memory are modeled as coherence-maintaining fields. This document states the architecture, its consistency requirements, its relationship to established results, and a falsifiable research program. The explicit operational expressions are withheld under intellectual-property protection and are not required to evaluate the conceptual claims.

1. Introduction

Classical mechanics, general relativity, and candidate theories of quantum gravity have historically supplied separate languages for motion, causality, and fundamental interaction. Despite substantial progress in Loop Quantum Gravity and in holographic approaches, there remains no broadly accepted single principle from which classical dynamics, quantum-geometric discreteness, causal protection, and informational conservation all follow as facets of one stationarity condition.

Two observations motivate the present work. First, several of the most robust results in modern gravitational physics are *structural* rather than model-specific: area and volume spectra are discrete in LQG^[1]; the classical singularity is replaced by a bounce in loop quantum cosmology^[2]; closed timelike curves appear to be

dynamically suppressed^[3]; and information appears to be preserved across black-hole evaporation, with the entanglement entropy following a Page curve^[8]. These are exactly the kinds of constraints a unifying principle should encode *simultaneously*.

Second, the same equilibrium logic that governs physical systems recurs, in suggestive form, in the study of complex adaptive systems: stability emerges when competing tendencies are held in a structured balance rather than when any single tendency is maximized. This invites a careful, clearly demarcated extension of the framework beyond physics, which we treat as a conceptual program rather than as a physical claim.

Existing approaches tend to fall into one of two categories: physically rigorous frameworks that are silent on informational and causal bookkeeping, or broad informational narratives that lack predictive structure. The contribution of this work is to specify a single equilibrium architecture in which physical dynamics, quantum-geometric correction, causal protection, and informational invariance are co-constrained, and to do so in a way that is evaluable without disclosing the protected operational core.

2. The Equilibrium Architecture

The Unified Variational Principle is posed as a global **equilibrium condition** on a total functional. At the highest level of description it states that a generalized dynamical-geometric contribution, denoted Φ_1 , and a causal-informational contribution, denoted Φ_2 , are held in exact balance:

$$\Phi_1 \oplus \Phi_2 = 0 \quad (\text{global equilibrium})$$

The symbol $\oplus$ denotes the structured composition that defines the principle; its explicit form is part of the protected core. Equilibrium is not a numerical coincidence but a *stationarity requirement*: admissible histories of the system are those for which the first variation of the total functional vanishes. Imposing stationarity is what, in the appropriate limit, returns the classical equations of motion, and what, away from that limit, organizes the quantum-geometric, causal, and informational corrections.

2.1 The first contribution: dynamics and quantum geometry (Φ_1)

Φ_1 collects the **generalized classical action together with quantum-geometric corrections**. It carries two roles. The first is the Hamiltonian action of mechanics and gravitation, treated as an effective action over admissible configurations and conditioned on the gravitational field and on an entropic contribution in the spirit of emergent/entropic gravity^[6] and black-hole thermodynamics^[7]. The second is a quantum-geometric regulator whose existence and qualitative behavior are fixed by the discreteness of geometric spectra in LQG^[1]. The regulator acts to tame the classical action at short scales; its detailed functional form, scaling kernel, and coefficients are withheld.

$$\Phi_1 \sim [\text{generalized action}] \vdash [\text{quantum-geometric regulator}]$$

Here $\vdash$ marks a protected coupling, not an ordinary sum, and the bracketed objects are *roles*, not expressions. The qualitative consequences are nonetheless concrete and testable: in cosmological regimes the regulator is required to replace the initial singularity with a bounce^[2], and in black-hole regimes it must supply subleading corrections to horizon entropy.

2.2 The second contribution: causality and information (Φ_2)

Φ_2 collects a **causal-separation constraint** together with a **quantum informational invariant**. The causal-separation constraint enforces a minimal, irreducible temporal interval and penalizes configurations that

would approach closed timelike curves, in direct correspondence with chronology protection^[3]. The informational invariant is a compact, observer-independent fingerprint of the system's state, conceptually aligned with quantum fingerprinting^[4] and with holographic information preservation^[5]. Its role is to guarantee that information is conserved under the dynamics — in particular across evaporation-like processes, consistent with the Page curve^[8]. The constructive definition of the invariant, including how the holographic projection is realized, is withheld.

$$\Phi_2 \sim [\text{causal-separation constraint}] \vdash [\text{informational invariant}]$$

2.3 What the equilibrium condition is designed to deliver

Imposing stationarity on the total functional is designed to reproduce four properties at once. These are stated here as requirements the operational core must satisfy; they are also the criteria against which the framework can be judged or falsified.

1. **Correct classical limit.** In the regime where quantum-geometric and informational terms are negligible, the variation returns the standard classical equations of motion.
2. **Singularity resolution.** The quantum-geometric regulator must remove the initial cosmological singularity, yielding a bounce rather than a divergence.
3. **Causal protection.** The causal-separation term must dynamically forbid closed timelike curves and enforce a minimal temporal interval.
4. **Informational unitarity.** The informational invariant must be conserved across the dynamics, so that no information is destroyed even in evaporation-like processes.

3. Relationship to Established Results

The framework is intentionally anchored to results that are independently supported in the literature. The table summarizes how each established result enters as a constraint on, or a consequence of, the equilibrium architecture.

Established result	Role in the architecture	Primary source
Discrete area/volume spectra (LQG)	Fixes existence and qualitative behavior of the quantum-geometric regulator in Φ_1	Rovelli & Smolin (1995) [1]
Big-bounce cosmology (LQC)	Required consequence: singularity replaced by a bounce	Ashtekar, Pawłowski & Singh (2006) [2]
Chronology protection	Justifies the causal-separation constraint in Φ_2	Hawking (1992) [3]
Quantum fingerprinting	Conceptual basis for the compact informational invariant	Buhrman et al. (2001) [4]
Holographic correspondence	Frames information preservation on a boundary projection	Maldacena (1998) [5]
Entropic / emergent gravity	Supplies the entropic conditioning of the action	Verlinde (2011) [6]
Black-hole entropy	Subleading corrections constrain Φ_1	Bekenstein (1973) [7]
Page curve / unitarity	Target behavior for the informational invariant	Page (1993) [8]

No claim in this preprint requires the reader to accept any single one of these programs as final; the architecture is compatible with refinements within each. What the UVP asserts is that a single stationarity condition can hold all of these constraints simultaneously, which is a stronger and more falsifiable statement than any of them individually.

4. Predictive Program and Falsifiability

A unifying principle is only useful if it can fail. The framework is constructed so that its protected operational core makes commitments that are, at least in principle, testable. We list qualitative predictions that follow from the architecture without disclosing the underlying expressions.

- **Pre-inflationary signatures.** Because the regulator enforces a bounce, the framework predicts modifications to the primordial power spectrum at the largest angular scales, of the kind discussed in loop quantum cosmology.
- **Entropy corrections.** Horizon entropy must carry specific subleading (e.g., logarithmic-order) corrections; their qualitative sign and structure are a commitment of the model.
- **No-paradox guarantee.** Any regime that the standard theory would allow to develop closed timelike curves must instead be dynamically excluded, with a quantifiable cost as such configurations are approached.
- **Information recovery.** The fine-grained entropy of an evaporating system must follow a unitary (Page-type) curve rather than a monotonically increasing one.

A demonstrated violation of any of these — a non-bouncing cosmology forced by the same regulator, an entropy correction of the wrong structure, a stable closed timelike curve, or genuine information loss — would falsify the corresponding component of the principle.

5. Conceptual Extension to Socio-Informational Systems

Beyond physics, the same equilibrium logic offers a disciplined language for complex human and informational systems. We present this as a conceptual extension, clearly separated from the physical claims above: it borrows the structure of the principle, not its empirical content.

In this extension, Φ_1 is read as the *generative tendency* of a system — its production of action, value, and structure — while Φ_2 is read as the *conserving tendency* — its constraints, memory, and informational integrity. Shared values, governance, and cultural memory then act as coherence-maintaining fields, analogous to the informational invariant: they preserve the identity of the system across time and perturbation.

Under this reading, a resilient civilization is one held near equilibrium between generation and conservation, rather than one that maximizes either growth or preservation alone. The framework thus offers a strategic vocabulary for reasoning about sustainability, institutional memory, and technological ethics. We emphasize that this extension is heuristic: it is intended to guide analysis and modeling, not to assert that social systems obey physical law.

6. Discussion and Outlook

The Unified Variational Principle is, at its core, a claim that four constraints usually addressed separately — classical dynamics, quantum-geometric discreteness, causal protection, and informational conservation — can be co-derived from a single stationarity condition. This preprint establishes the architecture, its anchoring to established results, and its falsifiable commitments, while deliberately withholding the operational expressions that are the subject of intellectual-property protection.

The natural next steps are the controlled disclosure of the operational core under confidentiality, independent checks of the classical limit and the bounce condition, and a quantitative treatment of the entropy corrections and the informational invariant. We welcome engagement from the gravitational, quantum-information, and complex-systems communities, and will make the formal content available for evaluation under appropriate arrangements.

Intellectual-Property Statement

The conceptual architecture described in this document is original to the author. The operational mathematical core — explicit functional forms, kernels, coupling coefficients, the construction of the informational invariant, and the closed-form equilibrium operator — is the subject of an intellectual-property filing (WIPO) and is withheld. Nothing in this preprint should be construed as a public disclosure sufficient to reconstruct, re-derive, or reverse-engineer the protected expressions. The author retains all rights to the operational content.

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