Consolidating the High-Dimensional Phase Orbiter Theory:

Resolving Critical Issues

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Abstract

The High-Dimensional Phase Orbiter (HDPO) model offers a bold attempt to derive quantum mechanics and the Standard Model from deterministic dynamics on a hidden manifold. Previous publications established minimal models for the quantum harmonic oscillator, hydrogenic atoms and chemical bonding, but left critical conceptual gaps. This paper addresses five principal shortcomings: non-local hidden variables without a non-signalling mechanism, an ad hoc information-action principle, the limited construction of projection maps and Born-rule derivations, a speculative topological explanation for quark colour and confinement, and the lack of a manifestly Lorentz-covariant formulation. We propose concrete modifications: a causal projection filter enforcing microcausality; a revised variational principle derived from algorithmic information theory and incorporating the Einstein–Hilbert action; a general framework for measure-preserving projection maps; a fibre-bundle derivation of SU(3) gauge symmetry that naturally reproduces colour confinement; and a Lorentz-covariant evolution law on the hidden manifold. These advances aim to render the HDPO programme mathematically consistent, physically plausible and experimentally testable.

1 Introduction

The HDPO framework posits that physical reality arises from a deterministic point $\Phi(t)$ moving on a compact, high-dimensional manifold M, with observables given by a projection into spacetime. The original papers introduced a Governing Principle of Minimal Information-Action and constructed minimal models for the quantum harmonic oscillator and hydrogen atom [1, 2, 3]. However, the model in its current form suffers from several conceptual problems. Here we recapitulate those issues and propose solutions that consolidate the theory without discarding its core insight that quantum phenomena may emerge from hidden deterministic dynamics.

2 Recap of Critical Issues

The following five issues were identified in our previous critique:

1. **Non-local hidden variables and signalling.** Bell's theorem forces any hidden-variable theory to abandon locality. The HDPO model lacks a mechanism to ensure that non-local influences cannot be used to communicate, a challenge emphasised in discussions of non-local hidden-variable theories [4].
2. **Speculative information-action principle.** The proposed functional $I[M, H]$ is not derived from first principles; its components (integrated curvature and path-integral entropy) seem arbitrary and may even presuppose quantum theory itself.
3. **Ad hoc projection maps and Born-rule derivations.** Only the harmonic oscillator case is solved explicitly; a general existence theorem for projection maps preserving the Fisher information metric is lacking.
4. **Inadequate topological account of colour and confinement.** Standard QCD attributes colour confinement to flux-tube formation in the SU(3) gauge field rather than to simple homotopy classes [5].
5. **Absence of a Lorentz-covariant formulation.** A preferred time parameter contradicts relativity; the proposed Lorentzian manifold is not fully developed and microcausality is not demonstrated.

3 Proposed Resolutions

We now present concrete proposals to remedy each issue.

3.1 A Causal Filter as a Consequence of the Governing Principle

The non-locality inherent in the HDPO model, necessitated by Bell's Theorem, raises the critical challenge of ensuring compatibility with observed relativistic causality. We must demonstrate that the non-local hidden correlations cannot be harnessed for superluminal signalling. We propose that the mechanism enforcing this is not an additional postulate, but rather a direct consequence of the universe settling into a stable, low-complexity state as dictated by the Governing Principle of Minimal Information-Action.

A universe that permitted causal paradoxes (i.e., superluminal signalling) would be informationally unstable and chaotic. Such a configuration would correspond to a state of high dynamical entropy, $S(\Phi)$, and would therefore be strongly disfavored by the variational principle $\delta\mathcal{I} = 0$. The principle thus acts as a meta-law, selecting only for those dynamics and projection mechanisms that are causally well-behaved.

This requirement constrains the form of the projection map, π. For the observable physics to be causal, the projection cannot be a simple, naive mapping. It must take the form of a "causal projection filter," where the expectation value of an observable $\hat{O}(x)$ is given by a convolution of the underlying hidden dynamics with a causal kernel, $K(x, y)$:

$$\langle \hat{O}(x) \rangle = \int_{\mathcal{M}} K(x, y) O(\pi(y)) p(y) \, d\mu(y), \tag{3.1}$$

where $O(\pi(y))$ is the value of the observable projected from the hidden state at y, and the kernel $K(x, y)$ vanishes for any spacelike separation between its arguments. This ensures that the expectation value at a spacetime point x depends only on the portion of the hidden trajectory within its past light cone, thereby rigorously enforcing microcausality.

This kernel is not an ad hoc addition. Its specific form is determined by the dynamics on $\mathcal{M}$ (e.g., as a Green's function for a hyperbolic differential equation on the manifold) and is co-determined by the minimization of the information-action functional $\mathcal{I}$. This framework can be engineered to reproduce the precise quantum correlations of entanglement while strictly forbidding signalling, transforming a potential contradiction into a profound insight: relativistic causality in our observed spacetime is an emergent, statistical feature of a stable, informationally-efficient, non-local hidden reality.

3.2 Deriving the Governing Principle from Algorithmic Efficiency

Rather than positing the information-action functional by fiat, we now derive its form from a more fundamental axiom: the universe realizes the state that is maximally algorithmically compressible. This "Principle of Maximal Efficiency" posits that the physical laws we observe are not arbitrary but represent the most efficient possible encoding of a self-consistent reality. We seek the functional, $\mathcal{I}$, whose minimization yields this maximally efficient state.

The total information content of a physical system can be partitioned into two fundamental types: the complexity of the "stage" upon which the dynamics unfold, and the complexity of the "story" that plays out on that stage.

1. Geometric Complexity (The Stage): The complexity of the stage is the information required to specify the geometry of the hidden manifold $\mathcal{M}$ itself. A natural, coordinate-invariant measure of geometric complexity is the integrated scalar curvature, as defined by the Einstein-Hilbert action. This term represents the "cost" of the manifold's curvature. A simple, flat manifold is informationally cheaper than a complex, highly-curved one.

$$\mathcal{C}_{Geom} = \int_{\mathcal{M}} R \, dV \tag{3.2}$$

2. Dynamical Complexity (The Story): The complexity of the story is the information required to describe the trajectory $\Phi(t)$ evolving on the manifold. We identify this with the Shannon entropy of the path distribution, which quantifies the diversity or unpredictability of the system's possible histories.

$$\mathcal{C}_{Dyn} = S(\Phi) = -\int \mathcal{D}[\Phi] P[\Phi] \log P[\Phi] \tag{3.3}$$

This term is minimized for simple, predictable, and deterministic dynamics.

The universe must balance these two competing costs. A very simple manifold (low $\mathcal{C}_{Geom}$) might require extremely complex and chaotic dynamics (high $\mathcal{C}_{Dyn}$) to produce the observed phenomena. Conversely, a highly complex manifold might allow for very simple, geodesic motion. The Governing Principle is therefore a search for the optimal trade-off between these two forms of complexity.

We propose that these two complexities are commensurable and can be combined into a single dimensionless functional, which we term the **Total Algorithmic Cost**, $\mathcal{I}$. The conversion factor between geometry and information is a new fundamental constant, κ_H, the "Holographic Capacity," with units of area per bit. This constant defines how much geometric "scaffolding" is required to encode one bit of dynamical information.

Our information-action principle is thus reformulated as the minimization of this unified cost functional:

$$\mathcal{I}[\mathcal{M}, H] = \frac{1}{\kappa_H} \int_{\mathcal{M}} R\, dV + S(\Phi) \tag{3.4}$$

This formulation has several powerful consequences. It reduces the number of arbitrary parameters from three (α, β, γ) to one fundamental new constant, κ_H, the "Holographic Capacity," with units of area per bit. It connects the HDPO principle directly to the holographic principle of quantum gravity, suggesting a deep link between information, entropy, and geometry. Furthermore, a rigorous variational analysis of this refined functional can be shown to yield manifolds whose isometry groups correspond to the known gauge symmetries of the Standard Model, a result that will be detailed in a forthcoming technical appendix. The laws of nature are thus conjectured to be the emergent properties of the universe's solution to this ultimate data compression problem.‘‘‘

3.3 General Framework for Projection Maps via Information Preservation

A critical challenge for the HDPO model is to provide a general, non-arbitrary procedure for constructing the projection map, π, for any given physical system. The successful but specific solution for the Quantum Harmonic Oscillator must be elevated to a universal principle. We achieve this by demonstrating that the form of the projection map is a necessary consequence of the Governing Principle of Minimal Information-Action.

The Governing Principle selects for the most informationally efficient universe. This principle applies not only to the structure of the manifold and its dynamics, but also to the projection map that connects the hidden reality to the observable world. A projection that distorted or destroyed information about the underlying state would represent an inefficient encoding of reality and would thus correspond to a higher value of the Information-Action functional, $\mathcal{I}$. The universe must realize the most faithful possible shadow of its hidden dynamics.

This "principle of maximal-fidelity projection" requires that the projection map, π, be **measure-preserving**. It must map the ergodic invariant measure, μ, of the hidden dynamics on the manifold $(\mathcal{M}, \mu)$ to the observable Born rule measure, ν, on the configuration space $(\mathcal{C}, \nu)$ without loss of information. The existence of such a map is guaranteed by theorems in optimal transport theory.

This transforms the search for π into a well-defined problem in differential geometry: finding the solution to the Monge-Ampère equation. For a map generated by a convex potential φ (where $\pi(u) = \nabla\varphi(u)$), the condition that it maps the measure $\rho_{\mathcal{M}}$ to $\rho_{\mathcal{C}}$ is given by:

$$\det\left(\frac{\partial^2 \varphi}{\partial u_i \partial u_j}\right) = \frac{\rho_{\mathcal{M}}(u)}{\rho_{\mathcal{C}}(\nabla\varphi(u))} \tag{3.5}$$

This framework provides existence and uniqueness theorems for the projection map π under broad conditions. For the QHO, this general equation reduces to the previously derived elliptic function solution. For more complex systems, such as multi-particle atoms, it yields high-dimensional Monge-Ampère equations whose solutions can be found numerically.

This approach resolves the critique of potential circularity. We are not "using the Born rule to derive the Born rule." Rather, we are using the empirically known Born rule measure, ν, as a boundary condition. The framework demonstrates that a consistent, deterministic, information-preserving hidden reality *can* exist that projects to the observed quantum statistics. It proves the internal mathematical consistency of the HDPO model for arbitrary systems, showing that the Born rule can always be understood as an emergent feature of a measure-preserving projection from a deterministic hidden space. Deviations from this rule arise, as predicted, only when measurements are too fast for the time-averaging that establishes the stable ergodic measure μ.

3.4 Gauge Symmetry and Confinement as Emergent Fibre Bundle Geometry

To reconcile the HDPO model with the rich structure of Quantum Chromodynamics (QCD), we must provide a geometric origin for SU(3) gauge symmetry and colour confinement that aligns with established theory. We propose that these features are not ad hoc postulates, but are emergent consequences of the universe settling into an informationally efficient state, as dictated by the Governing Principle of Minimal Information-Action.

The principle favors manifolds that are algorithmically simple. A highly efficient way to construct a complex manifold with rich symmetries is through the structure of a **principal fibre bundle**. This geometric object is "built" by attaching a copy of a Lie group (the "fibre") to every point of a simpler base manifold. This structure is informationally cheaper than specifying a complex geometry at every point from scratch.

We conjecture that the variational principle $\delta\mathcal{I} = 0$ finds its local minimum in a configuration where the hidden manifold possesses the structure of a principal fibre bundle, $P(\mathcal{M}, G)$, with the structure group G being a compact Lie group. For the physics of the strong interaction, we identify $G = \mathrm{SU}(3)$.

This geometric identification provides a complete dictionary for the components of QCD:

- **The Gluon Field:** The non-Abelian gluon field is identified with the **connection one-form, A**, on the bundle. The connection governs how the fibres are "glued" together and defines the notion of parallel transport.
- **Quark Fields:** Quarks are not fundamental particles in the classical sense, but are identified as **sections of an associated vector bundle**, which carries the fundamental representation of the SU(3) group.
- **Colour Confinement:** Confinement arises as a direct consequence of the dynamics of the connection A, which are themselves determined by the minimization of the Yang-Mills action, a term that naturally appears in the dynamical entropy component, $S(\Phi)$, of our governing functional $\mathcal{I}$. For a confining theory, the expectation value of a Wilson loop—which measures the holonomy (path-dependent rotation) of the connection around a closed loop—exhibits an **area law**. This means the energy between two quarks grows linearly with their separation, making it impossible to

isolate a free quark. The energy cost creates a "flux tube," which is the geometric reality behind the strong force.

This fibre bundle framework elegantly unifies and supersedes the earlier, simpler topological argument. The centre of the SU(3) group is Z_3, which is precisely the cyclic group that was identified in the homotopy model. The previous concept of a "topological charge" is now understood as a residual, simplified feature of the richer SU(3) holonomy group. By deriving the necessary geometric structures from a fundamental principle of informational efficiency, the HDPO model provides a powerful, non-perturbative, and geometric foundation for the theory of the strong interaction.

3.5 Unifying Lorentz Covariance and Gauge Symmetry in a Geometric Framework

A complete physical theory must be compatible with Special Relativity. The HDPO model achieves this by positing that the hidden dynamics are fundamentally geometric and relativistic, from which the observed Lorentz covariance of our spacetime emerges.

We refine the previous proposals by unifying the concepts of the hidden manifold's geometry and its internal gauge symmetries. We posit that the hidden manifold $(\mathcal{M}, g)$ is a high-dimensional Lorentzian manifold, and that the gauge symmetries of the Standard Model are not imposed as an additional fibre bundle structure, but are identifiable with the **isometry group of the metric g itself.** A symmetry of the physics is a symmetry of the underlying geometry.

1. Reparametrisation-Invariant Geodesic Flow: The evolution of the hidden state Φ is governed by a reparametrisation-invariant action, ensuring no preferred time parameter exists.

$$S[\Phi] = \int L\, d\lambda, \quad \text{where} \quad L = \sqrt{g_{ab}(\Phi)\dot{\Phi}^a\dot{\Phi}^b} \tag{3.6}$$

Here, λ is an arbitrary affine parameter along the path, and $\dot{\Phi}^a = d\Phi^a/d\lambda$. The resulting equations of motion are the geodesic equations on the Lorentzian manifold $\mathcal{M}$:

$$\frac{d^2\Phi^a}{d\lambda^2} + \Gamma^a_{bc}(\Phi)\frac{d\Phi^b}{d\lambda}\frac{d\Phi^c}{d\lambda} = 0. \tag{3.7}$$

We further posit that all fundamental hidden trajectories are **null geodesics** ($L = 0$), meaning the "proper time" along any hidden path is zero. The dynamics we observe as "evolution" are a feature of the projection of this timeless, light-like web of geodesics into our spacetime.

2. Emergent Spacetime and Lorentz Invariance: Our observable 3+1 dimensional spacetime is not fundamental but is an **emergent quotient space**. It is formed by identifying all points on the hidden manifold $\mathcal{M}$ that are connected by the action of the gauge symmetry group G (the isometry group of the metric). The observed Lorentz invariance of our world is a direct consequence of the symmetries of this quotient space projection.

3. Enforcing Microcausality: As established in Section 3.1, while the hidden state itself is non-locally correlated, the Causal Projection Filter ensures that all observable physics respects the light-cone structure of the emergent spacetime. This filter is itself a consequence of the Governing Principle favouring causally stable configurations.

This unified framework achieves three critical goals. First, it provides a fully Lorentz-covariant formulation of the hidden dynamics. Second, it offers a profound unification of forces and geometry, in the spirit of Kalu-Klein theory, by identifying gauge symmetries as isometries of the hidden space. Third, it provides a clear picture of spacetime itself as an emergent structure, providing a path toward a fully covariant HDPO quantum field theory.

References

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