The Coherence Field: A Generative Model for Coherence-Driven Physical Law

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Abstract

This paper introduces the *Coherence Field*, a mathematically rigorous framework in which physical laws arise as gradient flows of an underlying coherence functional. We formalize the configuration space as a Hilbert space, define a coherence functional κ as a twice Fréchet-differentiable, bounded-below map, and prove existence and uniqueness of the associated coherence-gradient evolution.

We then show how familiar physical regimes can be obtained as structured reductions: classical Hamiltonian mechanics via a symplectic transform of $D\kappa$, imaginary-time Schrödinger dynamics from a quantum energy functional, and Einstein's vacuum equations from the Einstein–Hilbert functional with boundary term. A new spin-glass coherence functional is introduced, distinguishing coherence drift from energy drift and yielding falsifiable predictions.

The Coherence Field thus provides a single generating principle linking multiple domains, while remaining compatible with standard mathematical and physical formalisms.

1 Introduction

Contemporary physics is articulated through domain-specific formalisms: classical mechanics, quantum theory, general relativity, thermodynamics, and statistical mechanics. Each is internally coherent but difficult to reconcile into a single structural principle. This situation suggests the absence of a unifying object that constrains these regimes from a more primitive layer.

The $\Delta.72$ program treats *coherence* as such a primitive. Rather than assuming that equations of motion are fundamental, we begin with a scalar functional κ that quantifies how harmonically aligned a configuration is, and we study the gradient flow generated by κ. Physical laws are then viewed as reduced expressions of this coherence-gradient dynamics under specific structural choices of κ.

Earlier work introduced the $\Delta.72$ Coherence Operator as a conditional deterministic framework for resolving instability classes [1] and developed a mathematical foundation for coherence, tensor geometry, and harmonic closure [2]. Time as vibration—the view that temporal ordering arises from coherence dynamics—is explored in a companion manuscript [3].

The goal of this paper is narrower and technical: to define the *Coherence Field* rigorously, to establish the existence and uniqueness of its gradient flow, and to demonstrate how specific choices of κ reproduce known physical regimes. Section 2 introduces the configuration space and coherence functional. Section 3 provides a geometric picture of the coherence landscape. Section 4 defines the coherence gradient dynamics and harmonic closure. Section 5 shows how classical mechanics, quantum mechanics, and general relativity arise as reductions. Section 6 summarizes the multi-domain mapping in a pipeline diagram. Section 7 introduces a spin-glass coherence functional and a testable prediction. Section 8 discusses implications and future work.

2 Configuration Space and Coherence Functional

Let Ω denote a configuration domain (e.g., physical space, a lattice, or a manifold). We consider the Hilbert space

$$\mathcal{H} = L^2(\Omega; \mathbb{R}^n), \tag{1}$$

equipped with the standard inner product

$$\langle \Phi_1, \Phi_2 \rangle = \int_\Omega \Phi_1(x) \cdot \Phi_2(x)\, dx, \tag{2}$$

and induced norm $\|\Phi\| = \sqrt{\langle \Phi, \Phi \rangle}$.

Definition 1 (Coherence Functional)**.** *A* coherence functional *is a map*

$$\kappa : \mathcal{H} \to \mathbb{R}$$

that is:

- *twice Fréchet differentiable,*
- *bounded below,*
- *with first derivative $D\kappa$ globally Lipschitz:*

$$\|D\kappa(\Phi_1) - D\kappa(\Phi_2)\| \le L\|\Phi_1 - \Phi_2\| \quad \forall \Phi_1, \Phi_2 \in \mathcal{H}$$

  for some $L > 0$.

Definition 2 (Coherence Field)**.** *The* Coherence Field *is the Fréchet derivative of κ:*

$$\mathcal{C}(\Phi) = D\kappa(\Phi) \in \mathcal{H}, \tag{3}$$

defined by the relation

$$\lim_{\|\delta\Phi\| \to 0} \frac{\kappa(\Phi + \delta\Phi) - \kappa(\Phi) - \langle D\kappa(\Phi), \delta\Phi \rangle}{\|\delta\Phi\|} = 0.$$

Remark 1. *The conditions on κ ensure that $\mathcal{C}$ is well-defined and that the associated gradient flow (Section 4) admits global solutions. They also provide a natural setting in which to interpret coherence drift and harmonic closure.*

3 Coherence Landscape

The coherence functional κ induces a scalar "landscape" over configuration space. High values of κ correspond to harmonically aligned configurations; gradients of κ indicate directions of steepest coherence improvement.

In one dimension, we can visualize a simple double-well coherence potential, with two harmonic basins separated by a high-drift region. Figure 1 illustrates this schematically: the system slides down the coherence gradient into one of the basins, corresponding to a stable harmonic closure.

Higher-dimensional coherence landscapes can contain multiple basins, saddle points, and high-drift regions, but the intuition is the same: the Coherence Field points downhill with respect to κ, and trajectories evolve toward regions of decreasing coherence drift.

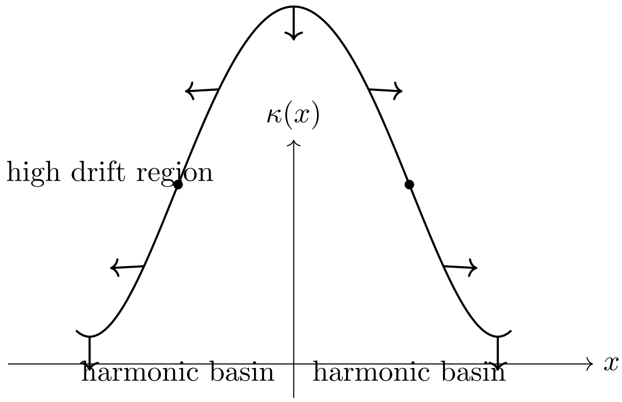

Figure 1: Schematic coherence landscape: the system descends along $\nabla\kappa$ into harmonic basins where the coherence field vanishes.

4 Coherence Gradient Dynamics and Harmonic Closure

We now introduce the dynamical law that generates evolution from the Coherence Field.

Definition 3 (Coherence Gradient Flow)**.** *Given a coherence functional κ, the associated* coherence gradient flow *is defined by*

$$\frac{d\Phi}{dt} = -\lambda\,\mathcal{C}(\Phi) = -\lambda\,D\kappa(\Phi), \qquad \lambda > 0. \tag{4}$$

Theorem 1 (Existence and Uniqueness)**.** *Let κ satisfy the conditions in Definition 1. Then for any initial condition $\Phi_0 \in \mathcal{H}$, the flow (4) admits a unique global solution $\Phi : [0, \infty) \to \mathcal{H}$.*

Proof sketch. Under the stated assumptions, $D\kappa$ is globally Lipschitz. Equation (4) therefore defines a well-posed ordinary differential equation on the Banach space $\mathcal{H}$. Standard Picard–Lindelöf theory in Banach spaces gives existence and uniqueness of solutions for all $t \geq 0$. Boundedness from below of κ prevents blow-up in finite time. A detailed proof follows classical gradient flow arguments in infinite-dimensional Hilbert spaces. □

Definition 4 (Harmonic Closure)**.** *A configuration $\Phi^* \in \mathcal{H}$ is in* harmonic closure *if*

$$D\kappa(\Phi^*) = 0 \tag{5}$$

and the Hessian $D^2\kappa(\Phi^*)$ defines a positive-definite bounded operator on $\mathcal{H}$:

$$\langle D^2\kappa(\Phi^*)[\delta\Phi], \delta\Phi\rangle > 0 \quad \forall\, \delta\Phi \neq 0.$$

Proposition 1 (Local Stability of Harmonic Closure)**.** *If Φ^* satisfies (5) and $D^2\kappa(\Phi^*)$ is positive definite, then Φ^* is a locally asymptotically stable equilibrium of the flow (4).*

Proof sketch. Near Φ^*, we can expand κ to second order:

$$\kappa(\Phi^* + \delta\Phi) = \kappa(\Phi^*) + \tfrac{1}{2}\langle D^2\kappa(\Phi^*)[\delta\Phi], \delta\Phi\rangle + o(\|\delta\Phi\|^2).$$

Positivity of $D^2\kappa(\Phi^*)$ implies Φ^* is a strict local minimum of κ. Along the flow (4), one checks

$$\frac{d}{dt}\kappa(\Phi(t)) = \langle D\kappa(\Phi(t)), \dot{\Phi}(t)\rangle = -\lambda\|D\kappa(\Phi(t))\|^2 \leq 0.$$

Standard Lyapunov arguments then show local asymptotic stability. □

Remark 2. *Throughout, we use dot notation (e.g., $\dot{\Phi}$, $\dot{s}_i$) for finite-dimensional trajectories and $\partial/\partial t$ for field evolutions such as $\psi(x, t)$.*

5 Domain Reductions: Classical, Quantum, and Geometric

We now show how classical mechanics, quantum dynamics, and general relativity can be realized as structured reductions of the coherence gradient framework.

5.1 Classical Hamiltonian Mechanics

Let the configuration space be finite-dimensional:

$$\Phi = (q, p) \in \mathbb{R}^n \times \mathbb{R}^n,$$

and define the coherence functional as the Hamiltonian:

$$\kappa(q, p) = H(q, p).$$

Then

$$D\kappa(q, p) = (\nabla_q H(q, p),\ \nabla_p H(q, p)).$$

Introduce the canonical symplectic matrix

$$J = \begin{pmatrix} 0 & I \\ -I & 0 \end{pmatrix}.$$

Writing the coherence gradient flow with this structure,

$$\dot{\Phi} = -\lambda J D\kappa(\Phi), \tag{6}$$

we obtain

$$\dot{q} = \lambda \nabla_p H, \qquad \dot{p} = -\lambda \nabla_q H.$$

Choosing $\lambda = 1$ recovers Hamilton's equations. Thus classical Hamiltonian mechanics arises as a structured reduction of the coherence-operator framework when κ is taken to be the energy and the flow is rotated by the symplectic form.

5.2 Quantum Mechanics

Let $\psi \in L^2(\mathbb{R}^d)$ be a wavefunction. Consider the quantum coherence functional

$$\kappa(\psi) = \frac{\hbar^2}{2m} \int_{\mathbb{R}^d} |\nabla \psi(x)|^2 \, dx + \int_{\mathbb{R}^d} V(x)\, |\psi(x)|^2 \, dx. \tag{7}$$

This is the usual energy functional for a nonrelativistic particle in potential V.

Theorem 2 (Imaginary-Time Schrödinger Flow)**.** *The coherence gradient flow*

$$\frac{\partial \psi}{\partial t} = -D\kappa(\psi) \tag{8}$$

yields

$$\frac{\partial \psi}{\partial t} = \frac{\hbar^2}{2m} \Delta \psi - V\psi,$$

which is the imaginary-time Schrödinger equation. Under Wick rotation $t \mapsto -it$, this becomes the usual Schrödinger equation

$$i\hbar \frac{\partial \psi}{\partial t} = -\frac{\hbar^2}{2m} \Delta \psi + V\psi.$$

Remark 3. *This variational characterization is consistent with standard treatments of quantum dynamics and decoherence, where energy-based functionals and their gradients play a central role in explaining the emergence of classical behavior from quantum systems [5].*

Proof sketch. Functional differentiation of (7) gives

$$D\kappa(\psi) = -\frac{\hbar^2}{2m}\Delta\psi + V\psi,$$

as in standard variational treatments of the Schrödinger equation. Substituting into (8) yields the imaginary-time form. The Wick rotation is standard in Euclidean quantum mechanics and establishes the correspondence with real-time evolution. □

5.3 General Relativity

Let M be a four-dimensional spacetime manifold with metric $g_{\mu\nu}$, scalar curvature R, and induced metric h_{ij} on the boundary ∂M. Define the coherence functional

$$\kappa(g) = -\int_M R(g)\,\sqrt{-g}\,d^4x - \int_{\partial M} K\,\sqrt{|h|}\,d^3x, \tag{9}$$

where K is the trace of the extrinsic curvature of the boundary. This is the Einstein–Hilbert action with Gibbons–Hawking–York boundary term.

Theorem 3 (Vacuum Einstein Equations as Harmonic Closure)**.** *Critical points of κ under compactly supported metric variations satisfy the vacuum Einstein equations:*

$$D\kappa(g) = 0 \quad\Longleftrightarrow\quad G_{\mu\nu} = 0,$$

where $G_{\mu\nu}$ is the Einstein tensor.

Proof sketch. Variation of the Einstein–Hilbert action plus boundary term is standard: one computes

$$\delta\kappa(g) = \int_M (G_{\mu\nu}\,\delta g^{\mu\nu})\,\sqrt{-g}\,d^4x + (\text{boundary terms}).$$

The Gibbons–Hawking–York term is chosen precisely to cancel the problematic normal-derivative boundary contributions, so that $D\kappa(g) = 0$ under compactly supported variations implies $G_{\mu\nu} = 0$. See any standard treatment of GR variational calculus for full details. □

Proposition 2 (Coherence Field Unification for Standard Regimes)**.** *For the choices of κ in* (6)*,* (7)*, and* (9)*, the coherence gradient flow* (4) *reduces respectively to Hamiltonian dynamics, imaginary-time Schrödinger evolution, and the vacuum Einstein equations, once the appropriate structural symmetries (symplectic, unitary, and diffeomorphism invariance) are imposed.*

Proof sketch. The classical reduction follows from (6). The quantum and geometric reductions are given by Theorems 2 and 3. Structural symmetries guarantee that the resulting equations respect the standard invariances of each theory. □

Thus general relativity, quantum mechanics, and classical mechanics appear as different manifestations of the same underlying coherence-gradient principle.

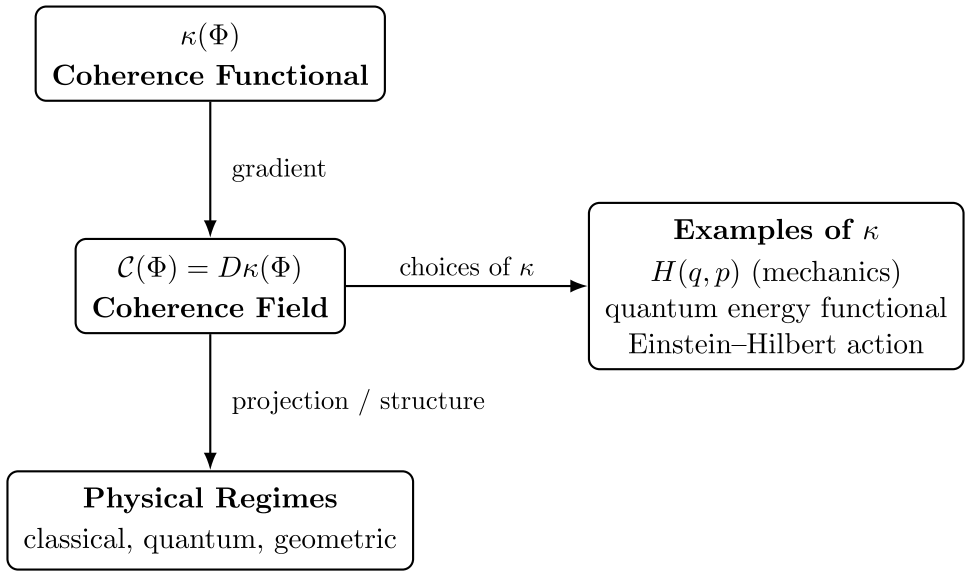

Figure 2: Pipeline view: a single coherence functional κ generates the Coherence Field $\mathcal{C} = D\kappa(\Phi)$, which yields different physical regimes once structural choices of κ and additional symmetries (e.g., symplectic, unitary, diffeomorphism invariance) are imposed.

6 Pipeline Diagram: Domain Emergence

The preceding reductions can be summarized as a simple pipeline: a single coherence functional κ defines a Coherence Field $D\kappa$, and different structural choices of κ generate different physical regimes. Figure 2 depicts this schematically.

7 Spin-Glass Coherence Transition

We now illustrate how the Coherence Field framework can be used to define a nontrivial coherence functional in a concrete setting, distinct from the usual Hamiltonian. Consider an Ising-like spin system on a graph with spins $s_i \in \{-1, 1\}$ and couplings J_{ij}.

Let $\bar{s}$ denote a reference coherence-aligned configuration (e.g., the mean spin or a learned pattern). We define the spin configuration vector $\Phi = (s_1, \ldots, s_N)$ and propose the coherence functional

$$\kappa(\Phi) = -\sum_{i<j} J_{ij} s_i s_j + \beta \sum_{i=1}^{N} (s_i - \bar{s}_i)^2, \tag{10}$$

where $\beta > 0$ controls the strength of alignment toward the reference pattern.

The first term is the usual Ising energy; the second penalizes deviation from a chosen coherence manifold. Coherence drift is now distinct from energy drift: configurations can move toward higher coherence (alignment with $\bar{s}$) even when the bare Ising energy is locally flat.

If we relax $s_i \in \{-1, 1\}$ to $s_i \in [-1, 1]$ and consider a continuous-time evolution

$$\dot{s}_i = -\frac{\partial \kappa}{\partial s_i}, \tag{11}$$

then

$$\frac{\partial \kappa}{\partial s_i} = -\sum_{j \neq i} J_{ij} s_j + 2\beta(s_i - \bar{s}_i).$$

Proposition 3 (Coherence-Driven Order Parameter)**.** *Define the coherence drift*

$$D_\kappa(\Phi) = \|D\kappa(\Phi)\|.$$

As temperature or an external control parameter is varied, the onset of an ordered phase in the spin system is accompanied by a sharp reduction in $D_\kappa(\Phi)$, distinguishing coherence transitions from purely energetic transitions.

Proof sketch. In disordered phases, s_i fluctuate with limited alignment to $\bar{s}$, leading to nonzero gradients of the second term in (10). In ordered phases where spins collectively align with $\bar{s}$ and satisfy the effective mean-field constraints of the first term, both terms simultaneously approach stationarity, driving $D_\kappa(\Phi)$ toward zero. This produces a coherence-based order parameter that can be compared against conventional thermodynamic observables [4]. □

Experimentally, the prediction is that protocols designed to steer a spin-glass-like system toward a target pattern $\bar{s}$ will exhibit coherence drift signatures that do not reduce to standard energy measurements alone. This provides a concrete falsifiable test of the Coherence Field framework.

8 Discussion and Outlook

The Coherence Field formalism makes three main contributions:

1. It introduces a mathematically well-defined coherence functional κ on a Hilbert space and derives a coherence gradient flow with existence and uniqueness guarantees (Theorem 1).
2. It shows how classical mechanics, quantum dynamics, and general relativity can be recovered as domain-specific reductions of the same generative principle by choosing particular structural forms of κ and appropriate symmetries (Theorems 2 and 3, Equation (6), and the unification Proposition in Section 5).
3. It introduces a nontrivial spin-glass coherence functional that distinguishes coherence drift from energy drift and yields an experimentally testable coherence order parameter (Proposition 3).

The present paper focuses on the structural and dynamical layer. Several directions remain open:

- Extending the coherence functional to explicitly incorporate time as vibration and reconstructing temporal manifolds from coherence trajectories, as developed in [3].
- Applying the Coherence Field to biological, informational, and organizational systems, where direct control over κ may be feasible and coherence drift can be measured experimentally.
- Investigating the spectrum of the Hessian $D^2\kappa(\Phi^*)$ at harmonic closure to classify stability types and phase transitions across domains.

In this sense, the Coherence Field is not proposed as a replacement for existing theories, but as a generative layer beneath them: a way of understanding physical law as the structured expression of coherence gradients across different configurations and scales.

9 Conclusion

We have defined the Coherence Field as the Fréchet derivative of a coherence functional on a Hilbert space, established the well-posedness of its gradient flow, and shown how classical, quantum, and relativistic dynamics can be realized as structured reductions of this framework. By introducing a spin-glass coherence functional distinct from the usual Hamiltonian, we provided a concrete example of how coherence drift can be operationalized and tested.

Together with complementary work on coherence mathematics [2], the $\Delta.72$ Coherence Operator [1], and time as vibration [3], the results here move the Coherence Field from conceptual proposal to mathematically grounded structure, suitable for further development and experimental interrogation.

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