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Article

Entropic Resonance Principle: A Unified Informational Framework for Persistence

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Abstract

This paper introduces the Entropic Resonance Principle (ERP) as an informational framework for investigating how organized systems persist across physical, biological, cognitive, and engineered domains. ERP advances the hypothesis that stability is associated not with resistance to entropy, but with a regulated co-variation between coherence (R) and entropy (H), schematically expressed by an approximate proportionality of the form $dR/dH \approx \lambda$. A specific candidate value for the dimensionless resonance parameter λ , motivated within a minimal self-similar renewal model, is examined as a conjectural organizing quantity rather than as an established constant. This proportionality admits both a flux formulation and a variational formulation, $dR - \lambda dH \approx 0$, which together characterize persistent regimes in an informational state space without modifying underlying microphysical laws. The paper develops the conceptual and mathematical structure of ERP, examines its ontological motivations, and situates it within existing work on coherence, entropy, and non-equilibrium organization. It further outlines strategies for empirically engaging the framework, including methods for estimating effective coherence–entropy slopes under coarse-graining and for assessing their stability across systems and scales. ERP is presented as the nucleus of a research programme whose empirical adequacy remains an open question. If future studies reveal constrained coherence–entropy relations recurring across domains, ERP may point toward a previously unrecognized structural regularity underlying persistence; if not, it nevertheless provides a precise framework for analyzing how coherence and entropy jointly shape organized behavior.

Keywords: informational ontology; coherence–entropy coupling; entropic dynamics; non-equilibrium systems; dissipative structures; open quantum systems; neural complexity; metastable neural dynamics; biological oscillations; entropy production; cross-scale regularities; resonance in complex systems; phenomenal structure; reflexive resonance; consciousness dynamics

1. Introduction

Many developments in contemporary physics motivate informational interpretations of physical theories. Quantum mechanics describes systems not as collections of independently existing objects, but as coherent amplitude structures—relational patterns extended across possibilities rather than localized entities (Bohm, 1980; Wallace, 2012; Rovelli, 2021). Thermodynamics, by contrast, characterizes physical processes in terms of entropy, understood as a measure of multiplicity, openness, and irreversibility (Boltzmann, 1877; Shannon, 1948; Jaynes, 1957). Within this broad informational perspective, coherence reflects structured relational alignment, while entropy captures contextual variability and the diversification of accessible states.

Despite their foundational roles, coherence and entropy are typically treated as opposing tendencies rather than as jointly constrained informational quantities. Coherence is commonly regarded as fragile, decaying under environmental coupling, while entropy production is associated with dissipation and loss of structure. Decoherence theory explains the suppression of quantum interference as systems interact with their environments (Zurek, 2003; Schlosshauer, 2007), while non-equilibrium thermodynamics demonstrates how organized dissipative structures can arise through sustained entropy flow (Prigogine, 1980; Kondepudi & Prigogine, 1998). What remains largely

unexplored is whether coherence and entropy may stand in a systematically constrained relationship that underwrites persistence across physical, biological, and cognitive scales.

The Entropic Resonance Principle (ERP) is introduced as a framework for exploring this possibility. ERP advances the hypothesis that organized systems persist not by resisting entropy, but by maintaining a regulated proportionality between coherence and entropy. On this view, stability is not a static equilibrium, but a resonant one: coherence is continually renewed at a rate tuned to the entropic variation the system undergoes. At an effective, coarse-grained level, ERP suggests that persistent regimes may be characterized by an approximate proportionality of the form

$$\frac{dR}{dH} \approx \lambda,$$

$$\delta(R - \lambda H) = 0.$$

The motivation for ERP is both conceptual and empirical. Conceptually, it integrates insights from quantum superposition, non-equilibrium thermodynamics, and complexity science into a unified informational account of persistence, in which systems endure insofar as coherence and entropy remain dynamically balanced. Empirically, findings from quantum thermodynamics, dissipative chemical oscillations, biological rhythms, neural dynamics, and cosmology reveal systematic couplings between coherence-like and entropy-like quantities. While these results do not establish a universal numerical constant, they suggest that persistence is governed by the relation between coherence and entropy rather than by either quantity in isolation.

The purpose of this paper is fourfold. First, it articulates the ontological motivations for treating coherence and entropy as complementary aspects of organized systems. Second, it develops the mathematical formulation of ERP, including its flux relation, variational form, and the structural motivation for a candidate resonance parameter. Third, it examines cross-domain empirical findings through the lens of coherence–entropy coupling. Fourth, it outlines explicit strategies for empirically assessing ERP, framing the proposed resonance parameter as a testable and potentially falsifiable hypothesis rather than as an assumed constant.

ERP is not intended to replace established physical theories. Instead, it offers an informational lens through which their respective accounts of order, variability, and persistence may be understood as manifestations of a deeper structural regularity. The sections that follow develop this perspective in detail.

2. Ontological Foundations of Entropic Resonance

The Entropic Resonance Principle (ERP) is founded on an informational ontology in which persistence arises not from enduring substances or fixed spacetime points but from the ongoing reconstitution of coherent relational patterns under entropic variation. Systems persist because relational alignment (coherence) is periodically restored in proportion to contextual diversification (entropy). Two complementary conceptual strands—Superposition as Structure and Pulse Ontology—supply the spatial and temporal poles of this claim and together form the ontological core upon which ERP's formal framework is constructed (Khorwat, 2025a; Khorwat, 2025b).

2.1. Superposition as Structure—Spatial Coherence

Quantum theory suggests that the most complete description of a physical system is a structured amplitude field rather than an aggregation of independently existing elements. A quantum state may be written

$$|\psi\rangle = \sum_i c_i |i\rangle,$$

Where the coefficients c_i index modal participation in an extended relational pattern (Bohm, 1980; Wallace, 2012). Interpreted ontologically, superposition encodes genuine structural relations: coherence is the pattern of mutual participation that constitutes a system's organizational identity. Decoherence theory explains how environmental coupling suppresses incompatible phase relations and produces locally robust mixtures (Zurek, 2003; Schlosshauer, 2007). ERP interprets this process

as resonant realignment: system–environment interaction reconfigures the relational geometry of the amplitude field, concentrating coherence on modes attuned to contextual constraints. Apparent “collapse” is thus the stabilization of a context-selected resonant attractor, not an ontological discontinuity (Khorwat, 2025a).

2.2. Pulse Ontology—Temporal Renewal

Spatial coherence alone does not secure persistence through time. Coherent structures drift from alignment under fluctuations and coupling; this drift corresponds to increases in informational entropy (Boltzmann, 1877; Shannon, 1948). Pulse Ontology reframes temporality as the activity of periodic coherence renewal: systems undergo cycles of dephasing and reattunement that restore relational alignment (Khorwat, 2025b). Each renewal—the pulse—constitutes a finite persistence interval during which the system reestablishes resonance with its context. Empirical manifestations of pulse-like dynamics appear across scales: quantum ensembles display dephasing–rephasing and partial revivals (Gorin et al., 2006); biochemical networks sustain limit cycles and circadian oscillations (Goldbeter, 1996; Prigogine, 1980); and neural populations realize metastable coordination via nested oscillations (Kelso, 2012; Breakspear, 2017). In such systems, stability is rhythmic: persistence is achieved not by stasis but by recurrent compensation for entropic variation.

2.3. Coherence and Entropy as Informational Conjugates

Integrating these spatial and temporal perspectives yields ERP’s central ontological proposal: coherence R and entropy H can be treated as informationally conjugate quantities whose regulated co-variation underlies persistent organization. Coherence indexes the degree of structured relational alignment within a system, while entropy indexes contextual openness and diversification. Neither extreme is sufficient for persistence: excessive coherence tends toward rigidity, whereas excessive entropy undermines organized structure.

ERP expresses this balance through the variational constraint

$$\delta[R(S, C) - \lambda H(S, C)] = 0,$$

Where S denotes the system’s informational state, C its contextual configuration, and λ is a dimensionless resonance parameter. This variational form identifies the manifold of persistent trajectories without prescribing microscopic dynamics. Its flux analogue $\frac{dR}{dH} \approx \lambda$, characterizes effective, coarse-grained evolution along that manifold.

2.4. From Ontology to Formal and Empirical Implementation

The ontological commitments of ERP are intentionally economical. They identify the relevant informational variables and the structural form of their coupling, while leaving operational instantiation to domain-specific measures. For empirical application, coherence R and entropy H must be operationalized in ways appropriate to the system under study—for example, through off-diagonal norms, purity measures, or order parameters for R , and through von Neumann, spectral, or algorithmic entropy measures for H .

The transition from ontology to implementation proceeds in two steps. Section 3 develops the mathematical formulation of ERP, introducing its flux and variational relations and motivating a candidate value for λ within a minimal renewal model. Section 5 then outlines an empirical protocol for estimating effective coherence–entropy slopes $\frac{dR}{dH}$, including normalization procedures, sliding-window regression, and explicit falsification criteria for the λ -hypothesis.

Superposition, interpreted structurally, supplies the spatial architecture of coherence; Pulse Ontology supplies an account of its temporal regeneration. ERP unifies these perspectives under the concept of entropic resonance: a regulated proportionality between coherence and entropy that may underwrite persistent organization across scales. With these ontological foundations in place, the subsequent sections translate this perspective into a precise mathematical framework and articulate the conditions under which its empirical adequacy can be assessed.

3. Mathematical Formulation of ERP

The ontological framework developed in Section 2 suggests that persistence should not be treated as a primitive property of systems, but rather as an emergent consequence of a regulated co-variation between coherence and entropy. The Entropic Resonance Principle (ERP) provides a mathematical heuristic formalization of this idea by treating coherence (R) and entropy (H) as conjugate informational variables whose effective temporal variations may be coupled under appropriate coarse-graining.

The formulation proceeds in four stages. First, coherence and entropy are introduced as informational functionals defined on an evolving system and its context. Second, a proportional flux relation is postulated between their effective rates of change. Third, this relation is reformulated as a variational constraint defining candidate persistent trajectories. Fourth, a minimal self-similar renewal model is introduced as a motivational device to explore how a characteristic coupling parameter might arise. Throughout, ERP is not presented as an alternative dynamical theory to quantum mechanics or thermodynamics, but as a meta-theoretical constraint that may hold in regimes where organized systems exhibit long-lived persistence.

3.1. Coherence and Entropy as Informational Functionals

Consider a system characterized at time t by an informational state $S(t)$, embedded in a contextual configuration $C(t)$. ERP assigns to this pair two informational functionals:

$$R = R[S, C], \quad H = H[S, C]$$

The functional R is intended to quantify coherence, understood as the degree to which the system's degrees of freedom participate in a structured and integrated relational pattern. The functional H quantifies entropy, understood as the degree of variability, openness, or informational diversification. The precise operational meaning of R and H is domain-dependent. In quantum systems, R may be instantiated by measures of off-diagonal coherence or purity-related quantities, while in thermodynamic or chemical systems it may correspond to an order parameter or pattern amplitude. In neural or cognitive systems, R may index synchronization or functional integration, whereas H may capture complexity, uncertainty, or dynamical richness.

ERP does not privilege any single operational definition. Instead, it posits that, for appropriately chosen measures of R and H , a structured relationship between them may characterize regimes of persistent organization.

3.2. Proportional Flux Relation

The central hypothesis of ERP is that persistent systems may satisfy an approximate proportionality between the effective rates of change of coherence and entropy :

$$\frac{dR}{dt} \approx \lambda \cdot \frac{dH}{dt}, \quad \frac{dR}{dH} \approx \lambda$$

This relation is introduced as a postulated constitutive constraint, not as a microscopic law valid at all times. It is intended to capture a resonant balance: as entropy increases through contextual diversification and exploration of micro-configurations, coherence is renewed at a rate tuned to that variation. Local fluctuations and deviations are expected, and the proportionality is not assumed to hold instantaneously or universally. In this sense, ERP specifies an informational closure condition rather than a deterministic equation of motion.

3.3. Variational Formulation

The proportional flux relation can be reformulated in variational terms by defining the informational functional

$$I[R, H] = R - \lambda H$$

ERP proposes that candidate persistent trajectories are those for which this functional is stationary under admissible variations,

$$\delta I = 0.$$

This condition should be interpreted as an informational constraint, not as a dynamical principle derived from an underlying action. It defines a manifold in the (R,H)-space on which coherence and entropy co-adjust in fixed proportion λ .

Several limiting regimes illustrate the structure of this balance. For $\lambda = 0$, persistence would require maximizing coherence independently of entropy, corresponding to unrealistically rigid systems. For $R = 0$, the system reduces to purely entropic dissipation with no organized persistence. When both R and H are non-zero, the functional expresses a trade-off between order and openness, consistent with the idea that persistent systems maintain coherence while remaining responsive to entropic diversification.

Taken together, the flux and variational formulations define ERP's notion of a candidate persistent trajectory: an informational path along which coherence and entropy remain in regulated resonance rather than evolving independently.

3.4. Self-Similar Renewal and the Resonance Parameter λ

To motivate a possible value for the coupling parameter λ , ERP introduces a minimal self-similar renewal model that links spatial structure with temporal regeneration. Let R_n and H_n denote the coherence and entropy associated with the n-th renewal cycle, and consider the schematic recurrence:

$$R_{n+1} = R_n + H_n, \quad H_{n+1} = R_n$$

This recurrence is not proposed as a physical model, but as an illustrative ansatz capturing the idea that coherence and entropy may recursively regenerate one another across renewal cycles. For generic initial conditions, the ratio $\frac{R_{n+1}}{R_n}$, converges to a constant φ determined by the fixed-point condition

$$x^2 = x + 1,$$

whose positive solution is the golden ratio

$$\varphi = \frac{(1 + \sqrt{5})}{2} \approx 1.618$$

(see, e.g., Livio, 2002, for a comprehensive treatment of φ in mathematics and the sciences).

Within this minimal schema, φ represents an asymptotic proportion emerging from self-similar renewal, rather than a physical constant. To express this multiplicative proportion in an additive, rate-based informational language, ERP proposes identifying the coupling parameter with

$$\lambda = \ln \varphi \approx 0.4812$$

The logarithmic mapping is introduced heuristically, reflecting the standard role of logarithms in information theory and statistical mechanics, where multiplicative weights are translated into additive measures. This identification is not presented as a derivation of a universal constant, but as a motivated conjecture consistent with scale-invariant renewal dynamics.

3.5. Numerical Convergence and Interpretive Invariance

The numerical proximity

$$\ln(\varphi) \approx (\ln 2)^2$$

Accordingly, within ERP the parameter λ is treated neither as a fitted constant nor as an established invariant, but as a testable conjecture. Its relevance can only be assessed through future empirical and theoretical investigations that estimate effective coherence–entropy relations across systems and scales.

4. Cross-Scale Conceptual and Empirical Motivation for the Entropic Resonance Principle

The mathematical structure of ERP proposes that persistence arises when coherence R and entropy H co-vary in a regulated proportion. While no existing experimental literature directly defines or measures this relation in the form $R \approx \lambda H$ numerous empirical domains independently exhibit systematic couplings between coherence-like and entropy-like quantities. These cross-domain patterns do not establish a numerical value for λ , nor do they confirm ERP as a law. Rather, they provide conceptual and empirical analogies that motivate the plausibility of ERP's central qualitative idea: that persistent organization depends on a balance between structural coherence and entropic openness.

Accordingly, this section does not present empirical validation of ERP. Instead, it surveys representative cases across quantum physics, non-equilibrium chemistry, biological regulation, neural dynamics, and cosmology, illustrating how coherence–entropy trade-offs recur across scales in ways that are structurally compatible with the ERP framework.

4.1. Quantum Coherence, Decoherence, and Entropy Production

Quantum systems provide a clear illustration of the tension between coherence and entropy. Environmental decoherence suppresses phase relations while increasing effective entropy, yielding classical behavior (Zurek, 2003; Schlosshauer, 2007). Experiments in matter-wave interferometry and controlled decoherence (e.g., Hackermüller et al., 2004) show that coherence loss is accompanied by irreversible entropy production due to environmental coupling.

More recent developments in quantum thermodynamics indicate that entropy production can be decomposed into classical and coherence-related contributions (Esposito, Harbola & Mukamel, 2009), and experiments such as Micadei et al. (2019) have demonstrated links between coherence changes and thermodynamic irreversibility. Theoretical analyses of open quantum systems (Landi & Paternostro, 2021; Santos et al., 2017) similarly treat coherence as a quantifiable resource whose degradation correlates with entropy flow.

From the ERP perspective, these results illustrate—rather than confirm—the idea that quantum persistence involves the continual negotiation between coherence maintenance and entropic divergence.

4.2. Dissipative and Non-Equilibrium Chemistry

Non-equilibrium chemical systems, including Belousov–Zhabotinsky reactions and reaction–diffusion media, exhibit long-lived spatiotemporal patterns sustained by continuous entropy production. Prigogine's theory of dissipative structures (Prigogine, 1980; Kondepudi & Prigogine, 1998) emphasizes that such coherence emerges only within restricted thermodynamic regimes: insufficient dissipation leads to decay, while excessive dissipation destroys ordered patterns.

Experimental and modeling studies of oscillatory chemical systems (e.g., Botré, 1981; Montoya, 2024) show that pattern stability depends sensitively on entropy throughput. These systems therefore provide a macroscopic analogy for ERP's claim that persistence arises not from minimizing entropy production, but from maintaining it within an appropriate range.

4.3. Biological Oscillations and Physiological Regulation

Biological systems offer particularly transparent examples of coherence–entropy interplay. Oscillatory processes—such as circadian rhythms, metabolic cycles, and calcium signaling—depend on continuous energy dissipation to preserve temporal coherence (Goldbeter, 1996). Physiological regulation likewise requires maintaining coherence within a window of variability rather than at a rigid optimum.

Empirical studies of heart-rate variability and autonomic regulation (Thayer & Lane, 2000) indicate that biological stability depends on the coexistence of structured order and stochastic

variability. From the ERP standpoint, these observations can be interpreted as qualitative analogues of a resonant balance between coherence renewal and entropic challenge.

4.4. Neural Dynamics, Criticality, and Conscious State Transitions

Large-scale neural dynamics are often described as operating near criticality, intermediate between excessive synchrony and excessive disorder (Tagliazucchi et al., 2016; Lee et al., 2019). Conscious states appear to occupy regimes in which measures of integration and complexity are jointly optimized.

The entropic brain hypothesis (Carhart-Harris, 2018; Carhart-Harris & Friston, 2019) and subsequent empirical work (Deco et al., 2021; Mediano et al., 2021) suggest that transitions between cognitive states involve systematic trade-offs between coherence-like and entropy-like measures. These findings do not determine a specific proportionality constant, but they reinforce the idea that persistent cognitive organization depends on regulated coherence–entropy relations.

4.5. Cosmological Structure, Entropy, and Horizon Constraints

At cosmological scales, entropy and information also impose fundamental constraints. The de Sitter-like future of the Λ CDM universe entails an event horizon with enormous Bekenstein–Hawking entropy (Gibbons & Hawking, 1977; Egan & Lineweaver, 2010), while holographic bounds limit the information content of spatial regions by their boundaries (Bekenstein, 1973; 't Hooft, 1993; Susskind, 1995).

Although ERP does not claim that cosmological observations measure any ERP parameter, these considerations highlight a structural coupling between large-scale coherence and entropic bounds. In this limited sense, cosmology provides a conceptual backdrop consistent with ERP's informational grammar.

4.6. Synthesis

Across quantum systems, dissipative chemistry, biological regulation, neural dynamics, and cosmological thermodynamics, a recurring structural theme emerges: persistent organization depends on the continual negotiation between coherence and entropy. None of these domains currently yields a direct measurement of an ERP ratio, nor do they establish

$$\lambda = \ln \varphi$$

Instead, these cross-scale regularities motivate treating ERP as a testable conjectural framework rather than a confirmed law. Persistence, on this view, is not resistance to entropy, but a form of informational resonance through which systems sustain coherence amid ongoing entropic flux.

5. Predictions, Tests, and the Scientific Status of ERP

The Entropic Resonance Principle (ERP) aims to articulate more than a unifying conceptual picture. It advances a structural and testable hypothesis about organized persistence: namely, that long-lived systems may be characterized by a regulated relationship between coherence R and entropy H . This proposal is not introduced as a metaphysical doctrine, but as a conjecture concerning the informational architecture of persistence across physical, biological, and cognitive domains (Popper, 1959; Lakatos, 1970).

For ERP to possess scientific content, it must entail empirical commitments in a conditional sense. If the principle captures a genuine structural regularity, then certain patterns of coherence–entropy co-variation should be more likely than others, while some patterns should be difficult to reconcile with the framework. The purpose of this section is therefore not to claim empirical confirmation, but to clarify how ERP could be constrained, tested, or falsified in practice.

5.1. Operationalizing Coherence and Entropy

ERP treats coherence and entropy as abstract informational functionals whose concrete realization depends on the domain under investigation. This intentional generality is consistent with structural and informational approaches in contemporary physics and complexity science (Jaynes, 1957; Haken, 1983; Gell-Mann & Lloyd, 1996). The framework requires only that coherence R quantify the degree of structured relational alignment within a system, while entropy H capture the degree of contextual openness, variability, or diversification.

In quantum systems, coherence may be operationalized using off-diagonal elements of the density matrix, purity measures, or the relative entropy of coherence (Baumgratz, Cramer, & Plenio, 2014), while entropy may be quantified via von Neumann entropy or entropy production defined through fluctuation relations (Esposito, Harbola, & Mukamel, 2009; Micadei et al., 2019; Landi & Paternostro, 2021). In oscillatory or networked systems, coherence can be represented by order parameters such as the Kuramoto synchrony index (Kuramoto, 1984; Pikovsky, Rosenblum, & Kurths, 2001), whereas entropy may be expressed through thermodynamic entropy flow or Shannon entropy over microstates (Shannon, 1948). In neural systems, coherence may be captured by measures of functional integration or metastability (Friston, 2010; Breakspear, 2017), and entropy by spectral entropy, Lempel–Ziv complexity, or related indices of dynamical richness (Tononi, 2004; Carhart-Harris, 2018; Mediano et al., 2021).

ERP does not privilege any single operational definition. Rather, it asserts that once coherence-like and entropy-like measures are chosen in a principled manner, their temporal evolution in persistent regimes should not be independent but structurally constrained.

5.2. The Core Predictive Claim: The λ -Hypothesis

At the heart of ERP lies the conjecture that organized systems exhibiting sustained persistence may evolve along trajectories in which changes in coherence and entropy are approximately related,

$$\dot{R} \approx \lambda \dot{H}, \quad \lambda = \ln \varphi$$

This relation is not advanced as a strict microphysical law, nor as an exact equality valid at all times. Instead, it is intended as a conditional structural regularity observable under appropriate coarse-graining, analogous to how critical exponents characterize universality classes rather than specific microscopic models (Stanley, 1971; Goldenfeld, 1992). If ERP is approximately correct, coherence and entropy in persistent regimes would be expected to co-vary in a constrained manner rather than fluctuate independently.

Importantly, the conjecture does not require exact numerical agreement across systems. It instead suggests a pattern of convergence: effective slopes $\frac{dR}{dH}$ when defined in suitable dimensionless units, may tend to occupy a restricted band rather than span arbitrary values.

5.3. Falsifiability and Constraints on ERP

Given its abstract character, the falsifiability of ERP must be understood pragmatically rather than as a simple logical criterion (Popper, 1959; Lakatos, 1970). Several classes of empirical findings would constitute serious challenges to the framework:

1. Absence of systematic coupling.

If systems that clearly exhibit robust organized persistence show no discernible relationship between coherence-like and entropy-like measures—such that $R(t)$ and $H(t)$ drift independently over relevant timescales—then ERP's central structural assumption would be undermined.

2. Persistent divergence from the conjectured scale.

If, across carefully normalized studies, effective slopes $\frac{dR}{dH}$ in stable regimes consistently cluster far from any narrow range without any tendency toward convergence, the conjectured role of λ would lose plausibility.

3. Insensitivity of persistence to the slope.

If systems remain equally stable across a wide range of coherence–entropy slopes, or become unstable even when slopes approach the conjectured range, ERP’s claim that persistence reflects a resonant balance would be weakened.

4. Superior alternative relations.

If other dimensionless constants or functional relations consistently outperform the ERP conjecture in organizing empirical data, the framework would require revision or abandonment. Under such outcomes, λ would be best regarded as an attractive but empirically unsuccessful conjecture, joining many other proposed invariants that failed to describe the actual world.

5.4. Illustrative Strategies for Empirical Examination

To render ERP empirically accessible, one may consider illustrative testing strategies rather than a fixed protocol. Given time series $R(t_i)$ and $H(t_i)$, defined through domain-appropriate measures, researchers can examine whether coarse-grained changes in these quantities exhibit constrained relationships during persistent regimes.

One possible approach involves normalization to dimensionless units, temporal alignment, and local slope estimation using sliding windows, for example through linear fits of the form

$$R \approx a + bH,$$

ERP itself does not mandate any specific statistical technique. Its contribution lies in specifying what to look for, not how it must be calculated.

5.5. ERP as a Research Programme

From the perspective of the philosophy of science, ERP is best understood as the nucleus of a research programme rather than as a single, self-contained hypothesis (Lakatos, 1970). Its core commitment is the idea that organized persistence reflects an informational balance between coherence and entropy. The identification $\lambda = \ln \phi$ is a tentative conjecture within this programme, offered for scrutiny rather than insulation.

The role of the present paper is not to claim that ERP has already been empirically secured. Rather, it seeks to render the framework sufficiently explicit that further experimental, computational, and theoretical work can meaningfully engage with it. If future studies reveal a cross-scale resonance between coherence and entropy, the conjectured parameter λ may leave a discernible trace in the data. If not, ERP will nevertheless have clarified what it would mean for persistence to be governed by an informational principle, and will have invited empirical inquiry to decide whether nature, in fact, answers to such a principle.

6. The Scientific and Technological Significance of ERP

Building on the conjectural and empirical considerations outlined in Section 5, the Entropic Resonance Principle (ERP) offers a conceptual lens for interpreting persistence across a range of scientific and technological domains. Rather than introducing new dynamical laws, ERP proposes that organized systems may be fruitfully described in terms of a regulated relationship between coherence and entropy. Even as an approximate and conditional relation, this perspective supplies a unifying informational grammar for thinking about how physical, biological, cognitive, and engineered systems preserve structure amid continual fluctuation.

1. Physics and Cosmology

In physics, ERP provides a structural vocabulary for interpreting how ordered patterns emerge and endure under non-equilibrium conditions. In quantum systems, coherence characterizes phase alignment or entanglement, while entropy reflects environmental openness and irreversibility. Within the ERP framework, decoherence can be interpreted not merely as the loss of quantum order, but as a departure from a conjectured resonance condition between coherence and entropy,

$$\frac{dR}{dH} \approx \lambda \text{ where } \lambda = \ln \varphi \approx 0.4812.$$

With the corresponding variational condition written as

$$\delta[[R - \lambda H] = 0.$$

At cosmological scales, ERP suggests only formal analogies, not empirical claims. One may heuristically associate coherence with the structured matter content of the universe and entropy with horizon-dominated degrees of freedom. The numerical proximity between the cosmological density ratio

$$\frac{\Omega_m}{\Omega_\Lambda} \approx 0.46$$

Relatedly, informational approaches to quantum geometry and holography associate coherence with long-range entanglement or mutual information, and entropy with boundary measures such as the Bekenstein–Hawking relation $S = \frac{A}{4}$ (Bekenstein, 1973; Hawking, 1975; Susskind, 1995). In this limited interpretive sense, ERP offers a possible interface with informational readings of spacetime structure, without committing to specific models of quantum gravity.

2. Neuroscience and Psychopathology

In neuroscience, ERP provides a high-level framework for describing neural dynamics across different brain states. Neural activity involves a balance between integration (coherence) and variability (entropy). Global states such as wakefulness, sleep, anesthesia, and altered states of consciousness can be schematically represented by relations of the form

$$R \approx \lambda H + K$$

Where K denotes system-specific background constraints fixing the baseline level of coherence, without independent dynamical significance. Empirical studies of neural criticality and large-scale brain dynamics frequently identify intermediate regimes between order and disorder (Tagliazucchi et al., 2013; Deco et al., 2021). ERP interprets these regimes as qualitatively consistent with a resonance-like balance between integration and variability, without claiming quantitative confirmation. In psychopathology, conditions such as depression, obsessive states, mania, psychosis, anxiety, or trauma may be interpreted—hypothetically—as reflecting systematic departures from such balance (Breakspear, 2017; Carhart-Harris & Friston, 2019). These interpretations are not diagnostic claims, but conceptual hypotheses intended to guide future empirical investigation.

From this perspective, therapeutic interventions—including pharmacological modulation, neurostimulation, neurofeedback, and contemplative practices—may be viewed as operations that modulate coherence, entropy, or their coupling, rather than as direct implementations of ERP.

3. Artificial Intelligence and Adaptive Computation

In artificial and computational systems, ERP can be interpreted as a design heuristic for balancing stability and plasticity. Learning processes involve continual adjustments of internal coherence—model structure and parameter organization—relative to external informational variability. While standard optimization focuses on minimizing a scalar loss, an ERP-inspired perspective highlights the importance of maintaining a balance between coherence growth and entropy exposure.

Schematically, this balance may be expressed as a tendency toward

$$\dot{R} - \lambda \dot{H} \rightarrow 0$$

4. Engineering and Complex Systems

In engineering and complex systems science, ERP reframes resilience as a problem of informational homeostasis. Communication networks, power grids, swarm robotics, and biochemical circuits can be described as systems that preserve function by maintaining a characteristic balance between order and variability. The variational expression

$$\delta(R - \lambda H) = 0$$

Monitoring proxies for coherence (e.g., synchrony, coupling strength) and entropy (e.g., load variability, uncertainty) may help identify proximity to critical transitions such as cascading failures or loss of synchronization (Motter & Lai, 2002; Barabási, 2016). Synthetic systems, where coherence and entropy can be experimentally manipulated, offer promising platforms for exploring whether persistent regimes exhibit constrained coherence–entropy relations consistent with the ERP framework.

7. ERP and the Structure of Experience: Perception, Consciousness, and Boundary Phenomena

The Entropic Resonance Principle (ERP) offers a conceptual and informational framework for interpreting experience as a dynamic balance between coherence and entropy. Rather than proposing a theory of consciousness in the strong sense, ERP advances a structural hypothesis: experiential organization may arise when coherence and entropy co-vary within constrained regimes. From perception to conscious awareness and boundary phenomena, ERP treats experience as the stabilization of structured variability under conditions of regulated informational exchange.

Across these levels, ERP does not assert the existence of a fixed experiential invariant. Instead, it proposes that persistent experiential organization may be associated with regimes in which coherence–entropy relations remain approximately constrained,

$$\frac{dR}{dH} \approx \lambda = \ln \varphi \approx 0.4812$$

7.1. Perception as Resonant Attunement

Perception can be interpreted as a process in which an organism’s internal coherence dynamically adjusts to structured variability in the environment. Within the ERP framework, perceptual stabilization corresponds to a regulated coupling between internal coherence and external entropy, not as a strict law but as a heuristic schema. Schematic regimes may be distinguished depending on whether internal coherence renewal undercompensates, overcompensates, or approximately matches environmental variability.

A wide range of empirical findings can be viewed as qualitatively consistent with this picture. In audition, neuronal populations entrain to the temporal envelopes of sound (Schroeder & Lakatos, 2009), while in vision, γ -band synchrony tracks luminance and chromatic modulation (Fries, 2015). Olfactory receptors exhibit frequency-specific sensitivity to molecular vibrations rather than merely static molecular geometry (Turin, 2002; Brookes et al., 2007), in line with resonance-based detection mechanisms. Phenomena such as the missing fundamental illusion (Pantev et al., 1996), chronostasis (Yarrow et al., 2001), and the integration of spectral variability in white-light perception exemplify the dynamic restoration of coherence following entropic discontinuities in sensory input. Attention, within this framework, modulates the bandwidth and selectivity of perceptual coherence. Empirical associations between attentional engagement and oscillatory synchrony (Jensen & Mazaheri, 2010) are therefore interpreted as illustrative of regulated coherence–entropy adjustment, rather than as direct confirmation of ERP.

7.2. Consciousness as Reflexive Resonance

Whereas perception involves attunement to external structure, consciousness may be interpreted as a reflexive process in which a system dynamically regulates its own coherence in the face of endogenous variability. Let $R_{self}(t)$ denote internally generated coherence, and $H_{self}(t)$ endogenous entropy arising from stochastic neural activity and ongoing predictive updating. Within ERP, conscious awareness is associated with regimes in which this internal coupling remains stable over time.

Neuroscientific evidence indicates that wakeful consciousness correlates with metastable synchronization across large-scale networks (Engel & Singer, 2001; Deco et al., 2021; Buzsáki, 2019),

while unconscious states correspond to breakdowns of such coordination. Nested oscillatory patterns, such as gamma activity embedded within slower rhythms (Lisman & Jensen, 2013; van Vugt et al., 2018), can be interpreted as mechanisms for recurrent coherence renewal. From this perspective, the temporal continuity of awareness reflects the repeated stabilization of internal coherence over finite persistence intervals, often associated with the phenomenological “specious present” (Varela et al., 1999).

7.3. Qualia as Resonance Geometry

ERP approaches phenomenal qualities not as irreducible primitives, nor as mysterious additions to physical structure, but as the intrinsic informational form taken by reflexive coherence–entropy dynamics within a self-organizing system. On this view, a conscious system is one that not only maintains internal coherence against variability, but also generates a self-model sensitive to how this balance evolves over time.

When internal coherence–entropy relations remain within stable regimes, the system’s informational dynamics may become experientially salient. In this sense, qualia can be interpreted as the first-person signature of a particular resonance geometry, rather than as entities separable from physical organization. This perspective reframes classical debates concerning zombies, inverted qualia, and the explanatory gap by shifting the focus from metaphysical possibility to empirically characterizable organizational differences (Chalmers, 1996; Block, 1990; Levine, 1983).

A qualitative state may therefore be schematically characterized by an informational fingerprint,

$$Q = (R_{self}, H_{self}, s(t), \Delta s(t))$$

Where $s(t)$ denotes the locally estimated coherence–entropy ratio and $\Delta s(t)$ its short-term stability.

ERP further emphasizes the embodied nature of resonance geometry. Interoceptive regulation, autonomic dynamics, and global neural integration contribute to the lived character of experience (Damasio, 1999; Craig, 2009; Seth & Friston, 2016). Phenomenality, on this account, is not epiphenomenal, but reflects how informational organization is instantiated in a living body.

7.4. Boundary Phenomena and Near-Death States

Boundary phenomena, including near-death experiences (NDEs), provide contexts in which coherence–entropy coupling may be subject to extreme perturbation. Empirical reports of NDE motifs—such as tunnel vision, altered self-location, and vivid memory recall (Greyson, 2003; van Lommel, 2001; Parnia et al., 2014)—have been associated with transient neural activity patterns following severe physiological disruption (Borjigin et al., 2013).

ERP interprets such phenomena not as evidence for metaphysical claims, but as informational reorganizations occurring near systemic limits. Tunnel vision, out-of-body experiences, and life-review phenomena can be interpreted as consequences of compensatory coherence redistribution under conditions of entropic collapse or overload (Blackmore, 1996; Blanke & Arzy, 2005). ERP remains explicitly neutral regarding the ontological status of these experiences, treating them as lawful but extreme reorganizations of informational dynamics.

7.5. Limitations and Empirical Outlook

The empirical grounding of ERP in experiential domains remains preliminary. While recent work demonstrates systematic relationships between neural coherence and entropy (Mediano et al., 2021; Luppi et al., 2023), the conjecture that persistent experiential regimes cluster around specific coherence–entropy relations awaits rigorous testing. Future work would require careful operationalization, cross-state comparisons, and perturbational approaches capable of probing stability and recovery.

Accordingly, ERP is best understood here as a research programme rather than a closed theory. Its value lies in articulating testable organizational questions about experience, not in claiming definitive answers.

7.7. Synthesis

Across perception, consciousness, and qualitative experience, ERP frames experience as an informational phenomenon shaped by the regulated interplay between coherence and entropy. Perception reflects attunement to environmental structure; consciousness reflects reflexive stabilization of endogenous dynamics; and qualia reflect the intrinsic geometry of such stabilization. ERP does not displace existing neuroscientific or physical theories. Instead, it offers a higher-order structural perspective specifying the conditions under which experiential organization may arise, persist, and transform.

8. Discussion

The Entropic Resonance Principle (ERP) proposes that persistent organization across physical, biological, and cognitive systems may be understood in terms of a regulated balance between coherence and entropy. Rather than introducing a new dynamical law, ERP advances the idea that stability can be characterized at an effective level by constrained co-variation between these informational quantities, schematically expressed by the relation $dR/dH \approx \lambda$, with $\lambda \approx \ln \varphi$. This proportionality, together with its variational analogue $\delta[R - \lambda H] = 0$, is intended not as a replacement for established physical theories, but as a higher-order constraint that may become apparent in regimes of long-lived organization. The present discussion clarifies the conceptual significance of this proposal, highlights its limitations, and situates it within a broader empirical and methodological context.

Conceptually, ERP reframes persistence not as static equilibrium, but as a process of continuous resonant adjustment, in which coherence is actively renewed in proportion to entropic variation. This perspective moves beyond simple oppositions between order and disorder by treating coherence as relational alignment and entropy as contextual openness. Stability, on this view, is associated with their regulated interplay rather than with the maximization or minimization of either quantity alone. ERP thereby supports a structural-realist interpretation in which identity and variability are co-defining features of organized systems. Because coherence R and entropy H are defined abstractly, the framework is intentionally cross-domain, offering a common informational grammar for interpreting phenomena ranging from quantum decoherence and chemical oscillations to neural dynamics and large-scale organization.

A central appeal of ERP lies in its formal economy. By expressing persistence through a simple flux relation and a corresponding variational constraint, the framework captures a wide range of organizational phenomena without specifying underlying microscopic mechanisms. The proposed parameter λ plays an organizing role within this structure: if ERP captures a genuine regularity, then effective estimates of coherence–entropy co-variation in persistent regimes might be expected to occupy restricted ranges rather than being arbitrarily distributed. This expectation is offered not as a definitive prediction, but as a conditional guide for empirical inquiry, distinguishing ERP from purely qualitative accounts of complexity.

At the same time, ERP faces substantial methodological challenges. Because the framework spans heterogeneous domains, coherence and entropy admit multiple operational definitions. Without principled criteria for selecting and normalizing these measures—such as dimensional consistency, interpretive alignment with the theoretical constructs, and robustness under coarse-graining—empirical assessments risk reflecting measurement conventions rather than underlying structure. Scale poses a further challenge: ERP is formulated at an effective, mesoscopic level, and it remains an open question whether the proposed proportionality should be expected to emerge universally or only within restricted regimes. Clarifying the domains and scales at which coherence–entropy resonance might arise is therefore a central task for future work.

Moreover, existing empirical literature does not yet provide systematic estimates of dR/dH suitable for evaluating the conjectured role of λ . While studies across physics, neuroscience, and complex systems document qualitative couplings between coherence-like and entropy-like quantities, they rarely quantify these relations in a way directly comparable to the ERP schema. As a result, ERP should presently be regarded as a framework that poses a precise empirical question, rather than one that already answers it.

From a methodological standpoint, future investigations could explore ERP by adopting explicit but flexible analytical strategies. These may include selecting normalized operational measures of R and H , estimating local coherence–entropy slopes over coarse-grained trajectories, examining their stability across timescales, and comparing observed patterns with alternative functional relations. Such procedures are not mandated by ERP itself, but serve to illustrate how the framework might be engaged empirically without presupposing its validity.

In its current form, ERP is best understood as the nucleus of a research programme rather than as a completed theory. Its hard core is the conjecture that persistence reflects an informational resonance between coherence and entropy, while the specific identification $\lambda \approx \ln \varphi$ remains a bold but revisable hypothesis. Whether nature ultimately exhibits convergence toward this proportionality is an open empirical question. If future studies reveal consistent coherence–entropy constraints across domains and scales, ERP may point toward a previously unrecognized informational regularity underlying organized behavior. If not, its failure will nevertheless sharpen our understanding of how coherence and entropy interact, and clarify the conditions under which persistence can and cannot be sustained. In either case, ERP contributes by making explicit what it would mean for stability to be governed by an informational principle, thereby advancing both conceptual clarity and empirical focus.

9. Conclusions

This work has developed the Entropic Resonance Principle (ERP) as an informational framework for investigating persistence across physical, biological, and cognitive systems. By treating coherence and entropy as conjugate informational quantities, ERP advances the hypothesis that organized behavior may be associated with regulated co-variation between these variables. At an effective, coarse-grained level, this relationship is schematically expressed through an approximate proportionality of the form $dR/dH \approx \lambda$, with a candidate value for the dimensionless parameter λ motivated within the framework. The accompanying flux and variational formulations illustrate how such proportionality can be articulated without modifying the microscopic laws governing individual domains.

The significance of ERP lies not in replacing existing theories, but in coordinating them under a shared structural perspective. Across quantum decoherence, dissipative chemical dynamics, neural state transitions, and adaptive computation, persistence can be interpreted as the continual renewal of coherence in relation to entropic variation. This perspective offers a degree of conceptual economy by linking phenomena typically studied in isolation and by clarifying the conditions under which organized structure can be maintained.

At the same time, ERP remains a provisional and open framework. Its empirical adequacy depends on the principled operationalization of coherence and entropy and on determining whether the proposed resonance parameter captures a genuine regularity rather than a theoretically appealing coincidence. The current absence of systematic estimates of effective coherence–entropy slopes means that the status of λ remains unresolved, and the framework must remain open to refinement or revision should alternative relations prove more empirically informative.

The next stage of work is therefore empirical and methodological. The analytical strategies outlined in this paper—such as coarse-grained slope estimation, uncertainty quantification, model comparison, and scale-sensitivity analysis—provide a roadmap for engaging ERP across quantum platforms, non-equilibrium chemical systems, neural recordings, and computational models.

Through such investigations, ERP may either converge with observed patterns or delineate the limits of its applicability.

If future research reveals recurring constraints linking coherence and entropy across domains and scales, ERP may point toward a previously unrecognized structural regularity underlying persistence. If not, its contribution will lie in having clarified what it would mean for stability to be governed by an informational principle and in having articulated explicit criteria by which such claims can be assessed. In either case, ERP advances the broader effort to understand how structure and variability jointly shape the enduring patterns observed in physical and living systems.

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