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Entropic Resonance Principle: A Unified Informational Framework for Persistence

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Abstract

This paper develops the Entropic Resonance Principle (ERP) as a unified informational framework for understanding how organized systems persist across physical, biological, cognitive, and engineered domains. ERP proposes that stability arises not from resisting entropy but from a regulated co-variation between coherence (R) and entropy (H), expressed by the proportionality $\frac{dR}{dH} \approx \lambda$,where the resonance parameter $\lambda = \ln \varphi \approx 0.4812$ is derived from a minimal self-similar renewal model. This proportionality admits both a flux form and a variational form, $\delta(R - \lambda H) = 0$,which together define persistent trajectories in an informational state space. ERP does not modify microphysical laws; rather, it functions as a meta-theoretical constraint that may emerge under appropriate coarse-graining. The paper clarifies the mathematical structure of ERP, analyzes its conceptual implications, and outlines empirical predictions that render the framework testable and falsifiable. Applications are explored in quantum decoherence, non-equilibrium chemistry, neural dynamics, adaptive computation, and complex engineered systems. A methodological protocol is proposed for estimating effective slopes $\frac{dR}{dH}$ in real data using sliding-window regression, bootstrap uncertainty quantification, and model comparison. ERP is ultimately positioned as the nucleus of a research programme whose validity hinges on whether λ-like proportionalities recur across systems and scales. If supported, ERP may reveal a previously unrecognized informational invariant governing the persistence of structure; if not, it offers a precise template for evaluating 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; cross-scale invariants; complex systems resonance; phenomenal qualia geometry; consciousness as reflexive resonance; metastable neural dynamics; biological oscillations; entropy production

1. Introduction

Many developments in contemporary physics support an informational interpretation 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, a measure of multiplicity, openness, and irreversibility (Boltzmann, 1877; Shannon, 1948; Jaynes, 1957). Coherence thus reflects structured relational alignment, while entropy captures contextual variability and the diversification of accessible states.

Despite their foundational roles, these two concepts have rarely been treated as conjugate informational variables governed by a unified principle. Standard accounts typically emphasize their opposition: coherence is fragile and tends to decay under environmental coupling, whereas 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 arise from entropy flow (Prigogine, 1980; Kondepudi & Prigogine, 1998). Yet no general framework specifies whether coherence and entropy may stand in a systematically quantifiable relationship that underlies persistence across scales.

The Entropic Resonance Principle (ERP) is proposed as a candidate for such a framework. ERP advances the hypothesis that organized systems persist not by resisting entropy, but by sustaining a regulated proportionality between coherence and entropy . Under this view, stability is not a static equilibrium but a resonant equilibrium: coherence is continually renewed at a rate tuned to the entropic variation the system undergoes. Formally, ERP posits that persistent regimes satisfy an approximate proportionality

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

where the resonance parameter is conjectured to take the dimensionless value

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

with φ the golden ratio. ERP further proposes that persistent trajectories extremize a simple informational functional, expressed through the variational condition

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

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: systems endure to the extent that coherence and entropy remain dynamically balanced. Empirically, findings from quantum thermodynamics, dissipative chemical oscillations, biological rhythms, neural dynamics, and cosmology reveal structured co-variation between coherence-like and entropy-like quantities. While these results do not determine a universal numerical slope, they strongly 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, to articulate the ontological motivations for treating coherence and entropy as dual aspects of organized systems. Second, to develop the mathematical formulation of ERP, including its flux relation, variational form, and derivation of the resonance parameter λ. Third, to examine cross-domain empirical findings through the lens of coherence–entropy coupling. Fourth, to propose explicit predictive tests and falsifiability criteria for ERP, framing $\lambda = \ln \varphi$ as an empirically measurable hypothesis rather than an assumed constant.

ERP is not intended to replace established physical theories. Instead, it offers an informational lens through which their portrayals of order, variability, and persistence may be seen as instances of a deeper structural regularity. The following sections 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

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

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.

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 the spatial and temporal strands yields ERP's central ontological thesis: coherence R and entropy H are conjugate informational variables whose regulated proportional co-variation underlies persistence. Coherence indexes structured relational alignment; entropy indexes contextual openness and diversification. Neither extreme suffices—excess coherence leads to rigidity and loss of adaptability, while excess entropy dissolves organization into noise. ERP expresses the equilibrium of persistence 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,

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

governs effective, coarse-grained evolution along that manifold.

2.4. From Ontology to Formal and Empirical Implementation

The ontological claim is intentionally economical: it identifies the variables and the structural form of their coupling while leaving operational instantiation dependent on domain-specific measures. For empirical evaluation, coherence R and entropy H must be given principled, normalized definitions—for example: off-diagonal norms, purity, or Kuramoto-type order parameters for R; von Neumann, spectral, or algorithmic entropy for H.

The transition from ontology to implementation proceeds in two stages. Section 3 develops the mathematical formulation of ERP, deriving its flux and variational relations and showing how a self-similar renewal ansatz yields a candidate value for λ. Section 5 then provides the empirical protocol for estimating effective slopes dR/dH (including sliding-window regression, bootstrap confidence intervals, and model comparison) and articulates explicit falsification criteria for the λ-hypothesis.

Superposition supplies the spatial architecture of coherence; Pulse Ontology supplies its temporal regeneration. ERP unifies them as entropic resonance: a regulated proportionality between coherence and entropy that structures stable trajectories across scales. With these ontological foundations in place, the next section translates them into a precise mathematical framework, derives the resonance parameter within a minimal renewal model, and prepares the ground for the empirical tests of Section 5.

3. Mathematical Formulation of ERP

The ontological framework developed in Section 2 suggests that persistence is not a primitive property of systems, but an emergent consequence of a regulated co-variation between coherence and entropy. The Entropic Resonance Principle (ERP) gives this idea a mathematical expression by treating coherence (R) and entropy (H) as conjugate informational variables whose temporal changes are dynamically coupled.

The formulation proceeds In four stages: (i) coherence and entropy are introduced as informational functionals defined on an evolving state and its context; (ii) a proportional flux relation is posited between their temporal derivatives; (iii) this relation is recast as a variational condition defining persistent trajectories; and (iv) a minimal self-similar renewal model is used to motivate a specific value for the resonance parameter λ.

ERP is not advanced as an alternative dynamical theory to quantum mechanics or thermodynamics. Rather, it is proposed as a meta-theoretical constraint: an informational relationship that diverse systems may satisfy when they exhibit stable organization and 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, integrated relational pattern. The functional H quantifies entropy, understood as the degree of variability, openness, or informational diversification. The specific operational meaning of R and H is domain-dependent. In quantum systems, R may be instantiated by measures of off-diagonal coherence or purity deficits, in line with contemporary coherence quantification in quantum information theory (e.g., Baumgratz et al., 2014; Streltsov et al., 2017). In thermodynamic and chemical systems, R may correspond to an order parameter or pattern amplitude, while in neural or cognitive systems, R may index synchronization or integration and H may capture complexity or uncertainty.

ERP thus does not privilege a single measure of coherence or entropy. Instead, it postulates a structural relationship that is expected to hold, for appropriately chosen R and H, in regimes where organized structures persist over time.

3.2. Proportional Flux Relation

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

$$\frac{dR}{dt} = \lambda \cdot \frac{dH}{dt},$$

so that, along a persistent trajectory in (R, H)-space,

$$\frac{dR}{dH} = \lambda$$

holds at an effective mesoscopic scale.

This relation is interpreted as defining a resonant equilibrium: as entropy increases, reflecting contextual diversification and exploration of alternative micro-configurations, coherence is continuously renewed at a rate tuned to that entropic variation. The proportionality is not intended as a microscopic law valid at every instant, but as a coarse-grained constitutive relation characterizing the macrodynamics of organized persistence. Local fluctuations and deviations are expected. 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. Define the informational functional

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

ERP postulates that persistent trajectories are those that render this functional stationary under admissible variations:

$$\delta I = 0.$$

Formally, this condition is analogous to a Lagrangian extremality principle, but its interpretation is informational rather than mechanical. It defines a manifold in the (R, H) space on which coherence and entropy co-adjust in fixed proportion λ.

Three limiting regimes illustrate the structure of this balance:

For $\lambda = 0$, the functional reduces to I = R, so that persistence would require maximizing coherence independently of entropy. This corresponds to unrealistically rigid systems that cannot accommodate variability or openness.

For R = 0, the functional becomes purely entropic, and persistence collapses into unstructured dissipation.

When both R and H are non-zero, the functional expresses a trade-off between order and openness, encoding the idea that persistent structures maintain coherence while remaining responsive to, and partially aligned with, entropic diversification.

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

3.4. Self-Similar Renewal and the Resonance Parameter λ

To motivate a specific value for 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. Consider the discrete recurrence:

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

In each cycle, coherence in the next step incorporates both its prior value and the entropic contribution from the current step, while entropy in the next step inherits the prior coherence. This reciprocal update schematically represents the idea that coherence and entropy regenerate one another across renewal cycles. For generic initial conditions, the ratio of successive coherence terms converges to a constant:

$$\frac{R_{n+1}}{R_n} \to \varphi,$$

where φ is 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).

ERP does not claim that physical systems literally implement this recurrence. The model is a highly idealized ansatz intended to show how a characteristic proportion between coherence-like and entropy-like contributions can arise from self-similar renewal dynamics. Within this minimal schema, φ expresses the asymptotic proportion between coherence and entropy across renewal cycles.

To translate this structural proportion into a continuous coupling parameter, ERP identifies λ with the natural logarithm of φ:

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

The logarithm maps multiplicative self-similarity (encoded by φ) into an additive rate domain, mirroring the role of logarithmic transforms in information theory and statistical mechanics, where multiplicative state weights and probabilities are recast as additive entropies and free energies (Jaynes, 1957; Shannon, 1948). This mapping is consistent with the interpretation of λ as a constant slope governing the co-variation of R and H at the level of infinitesimal changes. It imposes scale invariance: additive increments in entropy correspond to multiplicative adjustments in coherence across hierarchical renewal cycles. It also naturally leads to sublinear scaling, whereby increasing entropy yields progressively smaller increments in coherence, capturing saturation-like behavior in open, self-organizing systems.

3.5. Numerical Convergence and Interpretive Invariance

Beyond its derivation from the renewal model, the resonance parameter λ exhibits a notable numerical convergence that links decay, renewal, and informational balance. The logarithmic golden-ratio constant is numerically close to the square of the ubiquitous half-life constant:

$$(\ln 2)^2 \;\approx\; 0.48045,$$
$$\ln(\varphi) \approx 0.48121,$$

So that

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

To within a relative error on the order of 10^{-3}.

In first-order exponential decay processes, including chemical kinetics and radioactive dissipation, the half-life $t_1/_2$ of a quantity N(t) evolving as

$$N(t) = N^0 \cdot e^{-kt}$$

Is determined by the relation

$$k \cdot t_1/_2 = ln\, 2,$$

So that ln 2 functions as an invariant linking microscopic decay rates to macroscopic halving times (Atkins & de Paula, 2014). By contrast, φ arises as an invariant of self-similar renewal in recursive generative processes (Livio, 2002). The near-equality ln(φ) ≈ $(\ln 2)^2$ therefore numerically connects two structurally opposed informational tendencies: attenuation, governed by ln 2, and regeneration, governed by φ.

Within the ERP framework—where coherence renewal is posited to compensate entropy-driven diversification—this convergence is interpreted as suggestive rather than conclusive. It indicates that λ may encode a scale-invariant balance located at the interface between decay and renewal. ERP does not treat this numerical relation as a fundamental physical law, but as a structural hint that the same informational scale may mediate both the dissipation of structure and its self-similar reconstitution.

Accordingly, λ is treated as a resonance invariant rather than a fitted parameter. Its proposed universality is explicitly framed as a testable conjecture. Empirical evaluation would require estimating coherence–entropy relationships in concrete systems across domains and scales—for example, relating measures of neural synchrony to entropy production, or comparing order-parameter coherence to thermodynamic entropy generation in non-equilibrium condensed-matter systems.

4. Cross-Scale 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 $\dot{R} \approx \lambda \dot{H}$ numerous empirical domains independently reveal systematic couplings between coherence-like and entropy-like quantities. These convergences do not establish the numerical value of λ, but they strongly support ERP's central qualitative claim: Persistent organization across scales depends on a balance between structural coherence and entropic openness.

ERP interprets these findings not as confirmation of a universal constant, but as evidence that the coherence–entropy relation is a fundamental structural feature of organized systems. This section surveys these empirical convergences across quantum physics, non-equilibrium chemistry, biological regulation, neural dynamics, and cosmology.

4.1. Quantum Coherence, Decoherence, and Entropy Production

Quantum systems provide the most direct illustration of the interplay between coherence and entropy. Environmental decoherence selectively suppresses phase relations and increases the system's effective entropy, yielding classical behavior (Zurek, 2003; Schlosshauer, 2007). Experiments in matter-wave interferometry and controlled decoherence (e.g., Hackermüller et al., 2004) demonstrate that coherence loss proceeds in tandem with entropic irreversibility induced by photon emission and scattering.

More recently, quantum thermodynamic studies have shown that entropy production can be decomposed into classical and coherence-based contributions (Esposito, Harbola & Mukamel, 2009), and experiments such as Micadei et al. (2019) have directly linked coherence changes to measurable thermodynamic irreversibility. Theoretical analyses in open quantum systems (Landi & Paternostro, 2021; Santos et al., 2017) similarly identify coherence as a quantifiable resource whose degradation correlates with entropy flow.

ERP interprets these results as evidence that quantum persistence requires coherence renewal in proportion to entropic divergence, aligning with the structural form of the ERP flux relation.

4.2. Dissipative and Non-Equilibrium Chemistry

Non-equilibrium chemical systems—such as Belousov–Zhabotinsky (BZ) reactions, reaction–diffusion media, and thermochemical oscillators—exhibit persistent spatiotemporal patterns sustained by continuous entropy flow. Prigogine's theory of dissipative structures (Prigogine, 1980; Kondepudi & Prigogine, 1998) shows that such systems maintain coherence only when driven away from equilibrium and when entropy production lies within specific ranges.

Experimental and modeling studies of BZ systems (e.g., Botré, 1981; Montoya, 2024) demonstrate that oscillatory coherence—phase synchrony, wave stability, and pattern amplitude—depends sensitively on thermodynamic dissipation rates. Too little entropy flow leads to damping; too much leads to chaotic degradation. Coherence is thus sustained by regulated compensation against entropic drift, echoing the ERP picture.

ERP interprets dissipative structures as macroscopic manifestations of the same informational principle underlying quantum coherence: organization persists through balanced entropic throughput.

1.1. Biological Oscillations and Physiological Regulation

Biological systems illustrate coherence–entropy coupling with exceptional clarity. From glycolytic oscillations and circadian rhythms to calcium waves and gene-expression cycles, living systems rely on continual energy dissipation to preserve coherent temporal structure (Goldbeter, 1996). These oscillations represent organized coherence sustained through metabolic entropy export.

Similarly, physiological regulation—cardiorespiratory coupling, autonomic balance, neural integration—depends on maintaining coherence within a functional window of variability. Studies of heart-rate variability (Thayer & Lane, 2000) and metabolic homeodynamics show that biological stability requires both order and variability: coherence must renew at a rate commensurate with entropic challenges.

ERP views biological autonomy as a paradigmatic case of resonant equilibrium: coherence and entropy evolve proportionally to preserve functional identity.

4.3. Neural Dynamics, Criticality, and Conscious State Transitions

Neural systems exhibit intricate relationships between integration (coherence) and complexity (entropy). Large-scale brain dynamics often operate near criticality—between excessive synchrony

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and excessive disorder (Tagliazucchi et al., 2016; Lee et al., 2019). Conscious states, in particular, appear to occupy a regime in which coherence and entropy are jointly optimized.

The "entropic brain" hypothesis (Carhart-Harris, 2018) and its subsequent refinement (Carhart-Harris & Friston, 2019) propose that conscious experience corresponds to a balance between neural integration and entropic richness. Empirical work shows that transitions between wakefulness, anesthesia, sleep, and psychedelic states involve systematic, often monotonic, trade-offs between coherence-like and entropy-like measures (Deco et al., 2021; Mediano et al., 2021).

ERP interprets these findings as further evidence that persistent cognitive organization depends on a regulated proportion between coherence and entropic variation, consistent with the ERP principle, though not establishing a precise .

4.4. Cosmological Structure, Entropy, and Horizon Constraints

At cosmological scales, informational and thermodynamic ideas also play central roles. The de Sitter–like fate of the ΛCDM universe entails a cosmological event horizon with enormous Bekenstein–Hawking entropy (Gibbons & Hawking, 1977; Egan & Lineweaver, 2010). This entropy dwarfs the internal entropy of matter and radiation by many orders of magnitude, implying that large-scale structure evolves within a background dominated by horizon entropy.

Holographic bounds (Bekenstein, 1973; 't Hooft, 1993; Susskind, 1995) further suggest that the information content of any cosmological region is limited by its boundary surface, not its volume. Entropic-gravity approaches (Verlinde, 2011) treat gravitational dynamics at large scales as emergent responses to entropy gradients.

ERP does not claim that cosmology measures . Rather, it interprets cosmology as reinforcing the structural idea that coherence (cosmic structure) and entropy (horizon bounds) co-determine the universe's long-term organization, consistent with the conceptual grammar of ERP.

4.5. Synthesis

Taken together, quantum decoherence, dissipative chemistry, biological oscillations, neural dynamics, and cosmological thermodynamics exhibit a common structural theme: The stability of organized systems depends on a continuous negotiation between coherence and entropy.

None of these domains currently provides a direct measurement of the ERP ratio

$$\lambda = ln\varphi$$

Across scales, persistence thus appears not as resistance to disorder but as informational resonance—a dynamic equilibrium through which systems sustain coherence amid flux. These cross-scale regularities provide a powerful empirical motivation for treating ERP not as a metaphysical hypothesis but as a testable informational law governing persistence across physical, biological, and cognitive domains.

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

The Entropic Resonance Principle (ERP) aspires to more than conceptual elegance: it aims to articulate a structural feature of organized systems that can, in principle, be tested, constrained, and potentially falsified (Popper, 1959; Lakatos, 1970). Its central proposal—that coherence R and entropy H co-vary in a regulated proportion characterized by a dimensionless resonance parameter $\lambda = ln\varphi$ —is not offered as metaphysical doctrine, but as a hypothesis about the architecture of persistence across physical, biological, and cognitive domains. For ERP to bear scientific weight, it must generate empirical commitments: it must render some patterns in nature expected, others improbable, and some incompatible with its framework. The aim of this section is to make those commitments explicit and to clarify how ERP may be evaluated in light of empirical data.

5.1. Operationalizing Coherence and Entropy

ERP treats coherence and entropy as abstract informational functionals whose precise instantiation depends on the domain under study. This intentional generality is in line with structural and informational approaches in contemporary physics and complexity science (Jaynes, 1957; Haken, 1983; Gell-Mann & Lloyd, 1996). What the framework requires is that coherence R capture the degree of structured relational alignment in the system, while entropy H measure the degree of contextual openness or variability.

In quantum systems, coherence may be operationalized through off-diagonal elements of the density matrix, purity measures, or the relative entropy of coherence (Baumgratz, Cramer, & Plenio, 2014), while entropy may be quantified using von Neumann entropy or entropy production defined via fluctuation theorems (Esposito, Harbola, & Mukamel, 2009; Micadei et al., 2019; Landi & Paternostro, 2021). In oscillatory and networked systems, R may be instantiated through order parameters such as the Kuramoto synchrony index or related phase-synchrony statistics (Kuramoto, 1984; Pikovsky, Rosenblum, & Kurths, 2001), while H 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 measures of dynamical richness (Tononi, 2004; Carhart-Harris, 2018; Mediano et al., 2021).

ERP does not privilege any single operational form; rather, it asserts that once such measures are chosen in a principled way, their temporal profiles should not be independent but exhibit a constrained relationship.

5.2. The Core Predictive Claim: The λ-Hypothesis

ERP's central scientific claim is that organized systems evolve along trajectories in which coherence and entropy satisfy an approximate proportionality:

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

This relation is not proposed as a strict microphysical law, but as a structural regularity observable under appropriate coarse-graining, analogous to how critical exponents characterize universality classes rather than single microscopic models (Stanley, 1971; Goldenfeld, 1992). The prediction has two intertwined components.

First, ERP anticipates that in systems exhibiting robust, long-lived organization, coherence and entropy will not fluctuate independently. Variations in R(t) and H(t) should display an approximately linear or at least monotonic relationship, indicating that gains or losses in coherence correspond systematically to changes in entropy.

Second, ERP proposes that the slope of this relationship, when expressed in suitable dimensionless units, will tend to cluster around the resonance value $\lambda = \ln\varphi$. This does not entail exact equality in every system or regime. Rather, it predicts a pattern of convergence: persistent regimes in diverse systems, once described at an appropriate informational scale, should exhibit effective slopes $\frac{dR}{dH}$ that lie within a band centered on λ.

5.3. Falsifiability and Constraints on ERP

For a principle as abstract as ERP, falsifiability must be understood in practice rather than as a slogan (Popper, 1959; Lakatos, 1970). Several types of empirical findings would count as serious challenges to the framework.

1. Absence of systematic coupling.

If systems that clearly display robust organized persistence show no identifiable relationship between changes in coherence and changes in entropy—if R(t) and H(t) appear to drift independently over relevant timescales—then ERP's central structural assumption would be undermined.

2. Systematic divergence from λ.

If, across carefully normalized domains and operationalizations, effective slopes $\frac{dR}{dH}$ in stable regimes consistently cluster far from $ln\varphi$ with no tendency to approach λ, the λ-hypothesis would lose credibility.

3. Indifference of persistence to the slope.

If systems remain equally stable across a wide range of effective slopes, and conversely become unstable even when the slope approaches λ, ERP's claim that λ captures a resonance condition for persistence would be weakened.

4. Superior alternative invariants.

If alternative dimensionless constants or functional relations systematically outperform λ in predicting when coherence is sustained or lost, ERP, in its present form, would require revision or abandonment.

Under such conditions, λ would be best regarded as an attractive but empirically unsuccessful conjecture, joining many other constants and principles in the history of physics that proved not to describe the actual world.

5.4. Domains of Empirical Inquiry

The empirical content of ERP becomes concrete when applied to specific systems in which coherence and entropy can be measured side by side.

In engineered quantum systems, interferometric setups, trapped ions, or superconducting qubits allow decoherence and entropy production to be controlled and monitored jointly (Esposito et al., 2009; Micadei et al., 2019; Landi & Paternostro, 2021). ERP predicts that regimes exhibiting stable revivals or long-lived coherence will show effective slopes $\frac{dR}{dH}$ closer to λ than regimes leading rapidly to classicality.

In non-equilibrium chemical systems, such as Belousov–Zhabotinsky oscillators and reaction–diffusion media, oscillatory coherence (pattern amplitude, phase synchrony) and entropy production can be tracked as control parameters are varied (Prigogine, 1980; Kondepudi & Prigogine, 1998). ERP suggests that persistent oscillatory regimes may occupy narrow bands in the (H,R) plane whose effective slopes approximate λ, while regimes far from this band correspond to damping or chaotic breakdown.

In neural dynamics, datasets from EEG, MEG, and fMRI already reveal systematic relationships between measures of neural integration and measures of dynamical entropy or complexity (Tononi, 2004; Carhart-Harris, 2018; Carhart-Harris & Friston, 2019; Mediano et al., 2021). ERP proposes that transitions between conscious states—sleep, anesthesia, psychedelic states, and recovery—may be reinterpreted as movements away from and back toward a λ-like resonance band.

In computational models of coupled oscillators, adaptive networks, or self-organizing systems, it is possible to compute R and H directly across parameter sweeps (Pikovsky et al., 2001; Breakspear, 2017). Such simulations offer a clean setting in which to ask whether persistent regimes tend to cluster around λ and whether deviations correlate with fragmentation or rigidity.

Even in cosmological contexts, where descriptions are necessarily coarse-grained, the interplay between large-scale structure formation and horizon entropy suggests a deep informational coupling between coherence and entropy (Bekenstein, 1973; Susskind, 1995; Egan & Lineweaver, 2010). ERP does not claim that λ can be straightforwardly extracted from cosmological data, but it does regard cosmology as an arena where the idea of entropic resonance may have nontrivial implications.

In all these domains, ERP does not dictate new micro-dynamics; it supplies a lens through which existing phenomena can be re-examined: not only "Do coherence and entropy change?", but "Do they change together in a way that reveals a characteristic slope, and does that slope approximate λ?"

5.5. A Practical Protocol for Estimating the Coherence–Entropy Slope

To make ERP empirically testable, studies must be able to estimate the effective coherence–entropy slope from real data. Given time series of coherence $R(t_i)$ and entropy $H(t_i)$, defined through domain-appropriate operational measures, an empirical approximation to dR/dH can be obtained through the following general procedure:

1. Normalization.

Transform R and H into dimensionless units (e.g., z-scoring or scaling by empirical range) to avoid unit-dependent slopes.

2. Temporal alignment and smoothing.

Align $R(t_i)$ and $H(t_i)$ in time and optionally smooth them to reduce high-frequency noise.

3. Sliding-window regression.

Apply a moving window of fixed duration. Within each window, fit the linear model:

$$R \approx a + bH$$

where b serves as a local estimate of the effective slope dR/dH.

4. Resonance-band identification.

ERP predicts that persistent regimes will exhibit slopes b(t) within a tolerance band centered on $\lambda = \ln \varphi$, while instabilities and transitions will correspond to sustained deviations from this band.

This protocol does not assume linear micro-dynamics; it provides a coarse-grained empirical method for testing ERP's central hypothesis: whether coherence and entropy co-vary with the characteristic slope posited by the λ-hypothesis.

5.6. ERP as a Research Programme

In light of contemporary philosophy of science, ERP is best understood as the nucleus of a research programme rather than as a single, isolated hypothesis (Lakatos, 1970). Its hard core is the claim that organized persistence is governed by an informational resonance between coherence and entropy. The identification $\lambda = ln\varphi$ is a bold but revisable conjecture residing within this hard core. It may be confirmed, refined, or replaced, while leaving intact the deeper idea that persistence is a matter of informational balance between structure and openness.

The role of the present paper Is not to present ERP as already empirically secured, but to make its empirical commitments sufficiently precise that further work—experimental, computational, and theoretical—can meaningfully engage with it. If the world does indeed exhibit a cross-scale resonance between coherence and entropy, λ will eventually leave a discernible trace in the data. If not, ERP will have served a different purpose: it will have clarified what it would mean for persistence to be governed by an informational principle, and it 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 empirical framework outlined in Section 5, the Entropic Resonance Principle (ERP) offers a broader scientific lens for interpreting persistence across domains. ERP proposes that organized systems remain stable by maintaining a regulated proportionality between coherence and entropy. Even as an approximate relation, this proportionality supplies a unifying informational grammar for understanding how quantum, biological, cognitive, and engineered systems preserve structure amid continual fluctuation.

1. Physics and Cosmology

ERP provides a structural vocabulary for describing how ordered physical patterns emerge and endure. In quantum systems, coherence reflects the degree of phase alignment or entanglement, while entropy quantifies environmental openness. ERP frames decoherence not simply as loss of quantum order, but as a deviation from a resonance relation,

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

With the corresponding variational condition written as

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

This is not an alternative dynamical law but a mesoscopic constraint compatible with decoherence theory and non-equilibrium thermodynamics (Zurek, 2003; Schlosshauer, 2007; Esposito, Harbola, & Mukamel, 2009). At cosmological scales, ERP offers a formal analogy between informational and physical ratios: one can compare R/H heuristically with cosmological density ratios such as

At cosmological scales, ERP offers a heuristic mapping between informational and physical quantities. Coherence (R) may be associated with the structured matter component of the universe, and entropy (H) with its more diffuse dark-energy component. The empirical density ratio

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

lies numerically close to λ, not as evidence for ERP, but as a formal analogy suggesting that similar coherence–entropy proportions may appear across vastly different regimes.

Informational readings of quantum geometry also align with ERP: geometric coherence corresponds to long-range entanglement or mutual information, and entropy corresponds to boundary measures such as the Bekenstein–Hawking relation $S = \frac{A}{4}$, (Bekenstein, 1973; Hawking, 1975; Susskind, 1995). ERP proposes that stable spacetime configurations may approximate the resonance condition $\delta(R - \lambda H) = 0$, offering a conceptual interface with approaches in quantum gravity and holography.

2. Neuroscience and Psychopathology

ERP provides a principled framework for characterizing neural dynamics across states of consciousness. Neural activity involves a balance between integration (coherence) and variability (entropy). Many global brain states—wakefulness, sleep, anesthesia, and altered states—can be schematically captured by relations of the form:

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

Where K reflects anatomical and structural constraints. Excessive coherence corresponds to rigidity and reduced cognitive flexibility, whereas excessive entropy corresponds to fragmentation and network instability. Empirical work on neural criticality (e.g., Deco et al., 2021; Tagliazucchi et al., 2013) often identifies intermediate zones between order and disorder that resemble ERP's resonance regime, though such findings remain preliminary.

In psychopathology, depressive or obsessive states may reflect hyper-coherent, low-entropy regimes; manic or psychotic states may reflect entropy-dominant regimes; anxiety and trauma may reflect dysregulated coupling between integration and variability. (Breakspear, 2017; Carhart-Harris & Friston, 2019). These descriptions are not diagnostic claims but hypotheses about systematic departures from the proportionality:

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

Therapeutic interventions—pharmacological modulation, neurostimulation (TMS, tACS, DBS), neurofeedback, and contemplative practices—can then be viewed as operations that modulate coherence, entropy, or their coupling.

3. Artificial Intelligence and Adaptive Computation

In artificial systems, ERP operates as a design principle for balancing stability and plasticity. Learning can be interpreted as the ongoing adjustment of internal coherence—model structure, parameter organization—relative to external informational load. Standard optimization seeks to reduce a scalar loss; an ERP-guided approach would instead minimize deviations from resonance, aiming to satisfy:

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

Where $\dot{R}$ and $\dot{H}$ denote rates of change in coherence and entropy. Architectures governed by this constraint may avoid hyper-coherent overfitting and entropy-driven catastrophic forgetting. ERP itself is neutral regarding which specific metrics instantiate R and H; its contribution is the claim that these measures should co-vary proportionally in resilient systems.

4. Engineering and Complex Systems

ERP reframes engineered systems—communication networks, power grids, swarm robotics, biochemical circuits—as entities that maintain stability through informational homeostasis. The design constraint:

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

Suggests that resilient systems preserve a characteristic proportionality between order and variability. Monitoring proxies for coherence (e.g., synchrony, structural coupling) and entropy (e.g., load variability, uncertainty) may support the early detection of critical transitions, such as cascading failures or loss of synchronization (Motter & Lai, 2002; Barabási, 2016). Synthetic systems where R and H can be experimentally manipulated provide promising platforms for testing whether persistent regimes cluster near slopes close to λ.

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

The Entropic Resonance Principle (ERP) provides a unified informational framework for understanding experience as a dynamic equilibrium between coherence and entropy. From perception to consciousness and boundary phenomena such as near-death experiences (NDEs), ERP interprets experience as the stabilization of structured variability through proportional reorganization. Across these levels, stability arises when systems preserve the invariant proportionality

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

7.1. Perception as Resonant Attunement

Perception emerges when an organism's internal coherence field dynamically reattunes to the structured variability of its environment. Within the ERP formalism, perceptual stabilization corresponds to a flux equilibrium between internal coherence and external entropy,

$$\dot{R}_{internal} \approx \lambda \cdot \dot{H}_{external}$$
$$\dot{R}_{internal} < \lambda \cdot \dot{H}_{external}$$
$$\dot{R}_{internal} > \lambda \cdot \dot{H}_{external}$$

Empirical findings are consistent with this resonant 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, in turn, modulates the bandwidth of resonance, regulating the amplitude and selectivity of coherence fields. Fluctuations in α- and γ-band synchrony track attentional engagement (Jensen & Mazaheri, 2010), in a manner consistent with ERP's variational constraint

$$\delta[R_{internal} - \lambda\, H_{external}] = 0$$

7.2. Consciousness as Reflexive Resonance

Whereas perception involves resonance with external structure, consciousness corresponds to reflexive resonance—a system's attunement to its own coherence field. Let $R_{self(t)}$ denote internally generated coherence, and le $H_{self(t)}$ denote endogenous entropy, reflecting stochastic neural fluctuations and ongoing predictive updating. In this setting, conscious awareness corresponds to an equilibrium condition of the form

$$\delta\left[R_{self(t)} - \lambda\, H_{self(t)}\right] = 0 \qquad \frac{dR_{self}}{dH_{self}} \approx \lambda$$

Neuroscientific evidence supports this account. Wakeful consciousness is associated with metastable synchronization among thalamocortical and frontoparietal networks (Engel & Singer, 2001; Deco et al., 2021; Buzsáki, 2019), whereas unconsciousness reflects a breakdown of this balance, with coherence either fragmenting,

$$\frac{dR_{self}}{dH_{self}} \ll \lambda$$

$$\frac{dR_{self}}{dH_{self}} \gg \lambda$$

Nested oscillations, such as γ-bursts nested within θ–α cycles (Lisman & Jensen, 2013; van Vugt et al., 2018), implement recurrent coherence renewal and thereby sustain reflexivity over time. The temporal dimension of awareness follows naturally from this picture: each coherence cycle defines a finite persistence interval—the "specious present"—lasting on the order of 100–300 ms (Varela et al., 1999). On this view, the subjective flow of time is the lived rhythm of self-resonant renewal implied by ERP's temporal ontology. Feedback between successive coherence states yields self-referential attractors of the form

$$R_{self}(t + \Delta t) = F(R_{self(t)}, H_{self(t)})$$

7.3. Qualia as Resonance Geometry

ERP treats phenomenal qualities not as primitive, irreducible mental properties (as suggested by Chalmers, 1996) nor as mysterious additions to a physical substrate (Nagel, 1974), but as the intrinsic form taken by reflexive resonance within an organized system. On this account, a conscious agent is one that not only sustains an internal coherence field against endogenous variability—consistent with contemporary models of metastable neural integration (Buzsáki, 2019; Deco et al., 2021)—but also generates a self-model capable of tracking how coherence adjusts to entropy over time. When this coupling approaches the resonance invariant

$$\frac{dR_{self}}{dH_{self}} \approx \lambda$$

The system enters a regime in which its own informational dynamics become experientially manifest. In this sense, qualia are the first-person signature of a specific informational geometry: the subjective appearance of a stable proportional adjustment between coherence and entropy within the self-organizing loop.

This perspective reframes several classical objections. The zombie argument (Chalmers, 1996) presupposes the logical possibility of two systems identical in structure yet differing in phenomenality. Under ERP, such identity would require not only matching structural organization but also matching resonance geometry—including local slopes, stability bands, and embodied modulation—making the zombie hypothesis incoherent unless phenomenality is tacitly excluded from the causal description. Similarly, inverted qualia objections (Block, 1990; Shoemaker, 1982) become empirical rather than metaphysical: distinct qualitative characters require distinct resonance profiles. If two agents differ in their experience, ERP predicts measurable divergence in their resonance fingerprints; if such divergence is absent, the inverted-qualia scenario loses its epistemic footing.

The explanatory gap (Levine, 1983) Is likewise reframed. Rather than asking how physical processes "produce" experience, ERP identifies phenomenal character with the intrinsic signature of reflexive informational dynamics—what resonance feels like from within a system capable of modeling its own coherence–entropy balance. This parallels contemporary accounts that locate phenomenality in intrinsic or self-modeling structures (Metzinger, 2009; Seth, 2021), but provides a more explicit informational geometry for such reflexivity.

A qualitative state may therefore be represented by a compact informational fingerprint,

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

Where $s(t)$ denotes the locally estimated coherence–entropy ratio and $\Delta s(t)$ its short-term stability. Conscious qualia correspond to regimes in which s(t) remains close to λ with low variability.

Finally, ERP emphasizes that resonance geometry is fundamentally embodied. Internally sustained coherence–entropy dynamics measurably influence autonomic tone and interoceptive regulation (Craig, 2009), and shape global neural integration associated with conscious feeling (Damasio, 1999; Seth & Friston, 2016). The felt aspect of emotion and perception is thus not an epiphenomenal surplus but the lived expression of how the system's intrinsic resonance geometry perturbs and stabilizes its physiological substrate. Qualia, in this framework, become scientifically characterizable features of an informational topology rather than metaphysical anomalies.

7.4. Boundary Phenomena and Near-Death States

Near-death experiences (NDEs) provide an instructive context in which coherence–entropy coupling undergoes extreme perturbation. Empirically documented NDE motifs—including tunnel vision, out-of-body perception, luminous encounters, and panoramic life review (Greyson, 2003; van Lommel, 2001; Parnia et al., 2014)—coincide with transient surges of high-frequency neural activity following loss of cardiac function (Borjigin et al., 2013). ERP interprets these events as reorganizations of the coherence field as the system attempts to preserve the resonance equilibrium:

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

Tunnel vision reflects peripheral entropic collapse with compensatory hyper-coherence in visual cortices (Blackmore, 1996). Out-of-body experiences align with shifts from egocentric to allocentric mapping as multisensory integration deteriorates (Blanke & Arzy, 2005). Life-review episodes correspond to synchronization bursts across autobiographical memory networks (Rabey et al., 2018). ERP remains metaphysically neutral regarding the ontological status of these phenomena, treating them as lawful informational reorganizations near systemic boundaries.

7.5. Limitations and Empirical Outlook

The empirical basis for ERP remains preliminary. While recent work demonstrates systematic interactions between neural coherence and entropy (Mediano et al., 2021; Luppi et al., 2023), the claim that persistent experiential states cluster around the invariant λ awaits rigorous validation. Testing this claim would require estimating effective coherence–entropy ratios across diverse states—wakefulness, various sleep stages, anesthesia, and psychedelic conditions—and evaluating their convergence toward λ. Perturbational approaches, such as targeted neural stimulation or controlled entropy injection, could probe predicted deviations and recoveries. The resonance fingerprint framework likewise offers a method for operationalizing qualitative differences across individuals, modalities, and conditions. ERP thus provides a structured research program rather than a closed theory, inviting empirical refinement and potential falsification.

7.6. Synthesis

Across perceptual, conscious, and qualitative domains, ERP presents experience as an informational phenomenon governed by a single structural principle: a persistent proportionality between coherence and entropy. Perception expresses outward resonance with environmental structure; consciousness expresses inward resonance with endogenous dynamics; and qualia express the intrinsic geometry of reflexive resonance. ERP does not replace existing neuroscientific or physical theories; rather, it specifies a higher-order constraint identifying the conditions under which experiential organization can arise, maintain stability, and undergo transformation. It thus reframes experience not as a metaphysical anomaly but as a lawful manifestation of informational symmetry.

8. Discussion

The Entropic Resonance Principle (ERP) proposes that persistent organization across physical, biological, and cognitive systems arises from a regulated balance between coherence and entropy. Rather than introducing a new dynamical law, ERP suggests that stability is achieved when these two informational quantities co-vary in a characteristic proportion described at the level of effective trajectories by the relation $dR/dH \approx \lambda$, with $\lambda = \ln \varphi \approx 0.4812$. 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 structural constraint that may be observed when systems exhibit long-lived organization.

The present discussion clarifies the conceptual significance of this claim, evaluates its strengths and limitations, and outlines how it may be tested empirically.

Conceptually, ERP reframes persistence not as static equilibrium but as continuous resonant adjustment, whereby coherence is actively renewed in proportion to entropic variation. This view moves away from traditional oppositions between order and disorder by treating coherence as a measure of relational alignment and entropy as a measure of contextual diversification. Their balance, rather than the maximization of either, becomes the mark of systemic stability. ERP's ontology thus supports a structural-realist interpretation of physical and biological systems in which identity and openness co-define one another. Because R and H are defined abstractly, ERP can in principle apply across domains, connecting quantum decoherence, chemical oscillations, neural dynamics, and even large-scale cosmological organization within a single informational grammar.

ERP's principal contribution lies in its capacity to coordinate diverse phenomena under a single mathematical relation. Its formal economy—expressed in the flux relation $dR/dt \approx \lambda\, dH/dt$ and the variational condition $\delta[R - \lambda H] = 0$—allows the dynamics of persistence to be expressed without specifying the underlying microscopic mechanisms. Importantly, the theory advances a numerically sharp prediction: if ERP captures a genuine cross-scale invariant, then empirical estimates of the effective slope dR/dH in persistent regimes should tend to cluster near λ. This transformable, dimensionless structure distinguishes ERP from many qualitative frameworks in complexity science and places it closer to theories that live or die by the precision of the values they propose.

Nonetheless, the framework faces significant methodological challenges. Because ERP is meant to span heterogeneous domains, coherence R and entropy H admit multiple operational definitions. Without principled criteria for selecting these definitions—such as dimensionless normalization, interpretive alignment with the theoretical constructs, and robustness to smoothing and coarse-graining—tests of ERP risk being undermined by measurement choices. A further challenge concerns scale: λ is posited as a mesoscopic invariant, yet it is unclear whether the resonance relation should be expected to hold across all levels of aggregation. Establishing the domain of emergence for the proportionality is therefore a central empirical task. Finally, the current literature does not yet contain systematic estimates of dR/dH that would allow direct evaluation of the λ-hypothesis. Existing findings across physics, neuroscience, and complex systems show qualitative coupling between coherence-like and entropy-like quantities, but they do not yet quantify the slope in the manner ERP prescribes.

To transform ERP into a testable research programme, future work should adopt explicit statistical and methodological procedures. A minimal protocol would involve selecting operational measures of R and H that satisfy normalization criteria; estimating local slopes via sliding-window regression $R \approx a + b\,H$ to obtain time-resolved values of $b(t)$; computing bootstrap confidence intervals for slope estimates; and comparing models centered on λ against alternative linear and nonlinear models using information-theoretic criteria. Scale-sensitivity analysis across window sizes and degrees of coarse-graining is essential for determining whether observed proportionalities reflect genuine resonance or methodological artifacts. Applying this protocol across engineered quantum systems, non-equilibrium chemical media, neural recordings, and computational models will either corroborate or refute the universality claim at the heart of ERP.

In its current form, ERP should be regarded not as a completed theory but as the nucleus of a research programme. Its hard core is the assertion that persistence is governed by informational resonance between coherence and entropy; the specific numerical identification $\lambda = \ln \varphi$ is a bold but revisable conjecture within that programme. Whether nature ultimately conforms to this proportionality remains an open question. If empirical studies show systematic convergence toward λ across domains and scales, ERP may reveal a new informational invariant underlying organized behavior. If not, the failure will nevertheless clarify the structure of coherence–entropy interactions and illuminate the conditions under which persistence emerges. In either case, ERP advances the conceptual and methodological conversation by specifying precisely what it would mean for stability to be governed by an informational principle.

9. Conclusion

This work has developed the Entropic Resonance Principle (ERP) as a unified informational framework for understanding persistence across physical, biological, and cognitive systems. By treating coherence and entropy as conjugate informational variables, ERP proposes that organized behavior emerges when their temporal co-variation satisfies an approximate proportionality encoded by the resonance parameter $\lambda = \ln \varphi \approx 0.4812$. The mathematical formulations presented—both the flux relation $dR/dH \approx \lambda$ and the variational condition $\delta[R - \lambda H] = 0$—show how this proportionality can be expressed at a coarse-grained, system-level scale without modifying the underlying microscopic laws that govern each domain.

The analysis suggests that ERP's significance does not lie In replacing existing theories, but in coordinating them under a shared structural constraint. Whether in quantum decoherence, dissipative chemical dynamics, neural state transitions, or adaptive computation, persistence can be interpreted as the continual renewal of coherence in proportion to entropic variation. This perspective yields a conceptual economy that connects phenomena traditionally studied in isolation and provides a precise numerical conjecture against which empirical evidence can be evaluated.

At the same time, ERP remains a provisional framework. Its claims depend on operationalizing coherence and entropy in domain-appropriate, normalized ways, and on verifying whether the proposed resonance parameter captures an actual cross-domain invariant rather than a theoretically appealing coincidence. The absence of systematic empirical estimates of dR/dH means that the status of λ is not yet established, and the theory must remain open to refinement or revision should alternative invariants prove more predictive.

The next stage Is therefore empirical and methodological. The protocols outlined in this paper—combining sliding-window slope estimation, bootstrap uncertainty quantification, model comparison, and scale-sensitivity analysis—provide a concrete roadmap for assessing ERP across quantum platforms, chemical oscillators, neural recordings, and computational systems. Through such investigations, ERP will either converge with observed regularities or reveal the limits of its applicability.

If future research confirms a recurring resonance between coherence and entropy, ERP may identify a previously unrecognized informational invariant underlying stability across scales. If not, its value will lie in having clarified what it would mean for persistence to be governed by an informational principle and in having articulated testable criteria for evaluating such claims. In either outcome, ERP contributes to the broader project of understanding how structure and openness co-produce the enduring patterns that constitute the physical and living world.

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