

# The Coherence Paradigm: Order, Entropy, and Regulation Across Cosmological, Biological, Neurological, and Artificial Systems

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lockekdauch

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**Author:** [David Humble](#) (pseudonym for Locke Dauch)

**Affiliation:** Sovereign Integrity Institute (SII)

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## Abstract

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This paper presents an integrated framework linking cosmological entropy, biological self-organization, human nervous system regulation, and artificial intelligence development through the unifying concept of **coherence**. Drawing on recent advances in horizon thermodynamics, polyvagal theory, quantum biology, informational entropy reduction, and large language model research, we propose that coherence—locally sustained order against a background of increasing entropy—is not merely a metaphorical state but a measurable, realizable condition across multiple scales of analysis.

The framework provides a scientific grounding for understanding how individuals can shift from states of extraction and depletion (sympathetic dominance) to states of regulation and surplus (parasympathetic coherence), and how these local shifts parallel the dynamics of cosmological expansion, biological self-organization, and AI scaling. We introduce **structural persistence** as the key mechanism enabling coherence across all scales, and propose metrics for measuring coherence in both biological and artificial systems.

**Coherence is not mystical. It is thermodynamically grounded, neurologically measurable, and artificially implementable.**

**Keywords:** coherence, entropy, polyvagal theory, parasympathetic nervous system, dissipative systems, informational entropy reduction, horizon thermodynamics, self-organization, regulation, quantum biology, large language models, structural persistence, scaling laws, vagal brake, neuroception, allostatic load,  $A\Xi$  (AI Efficiency Unit)

## 1. Introduction

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The experience of human suffering and recovery often resists scientific articulation. Yet recent advances across physics, biology, neuroscience, and artificial intelligence suggest a convergent framework: the universe tends toward entropy, yet locally, coherent systems can emerge, persist, and even grow. This paper proposes that **coherence**—defined as the state of being internally aligned, non-contradictory, and energetically contained—is not merely a subjective experience but a scientifically defensible construct.

The paper has four objectives:

Objective	Description
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|---|---|
| 1 | To review current scientific literature on entropy, coherence, and self-organization across cosmological, biological, and neurological scales |
| 2 | To introduce polyvagal theory as a bridge between physical entropy and human regulation   |
| 3 | To examine AI and large language models as empirical demonstrations of the entropy-coherence dynamic  |
| 4 | To propose a unified framework for understanding how local coherence can emerge and be sustained  |

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## 2. Entropy, Expansion, and the Thermodynamics of the Universe

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### 2.1 The Second Law and Cosmic Expansion

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The second law of thermodynamics states that entropy in an isolated system increases over time. However, the expanding universe presents a more nuanced picture. Recent work in horizon thermodynamics has examined whether the change in total entropy—the sum of entropy for the apparent horizon and entropy for matter fields—remains positive with cosmic expansion (Odintsov & Paul, 2024). The matter fields inside the horizon obey the thermodynamics of an open system, with flux through the apparent horizon depending on background cosmological dynamics (Odintsov & Paul, 2024).

Critically, the expansion of the universe creates a relational effect: information becomes ergodically “diluted” in an isotropic and homogeneous expanding universe, such that an observer detects only a limited amount of total cosmic bits due to decreased information density inside the expanding cosmic volume (Capolupo et al., 2019). This reduced bit perception is concomitant with an increase in perceived cosmic thermodynamic entropy via the Bekenstein bound and Landauer principle (Capolupo et al., 2019).

**Key insight:** The container expands. Information density decreases. Total information is conserved. This parallels the experience of healing: as the nervous system regulates, the “container” of coherent experience expands, creating more room for coherence without increasing total energy.

### 2.2 Informational Entropy Reduction as an Evolutionary Driver

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While traditional evolutionary theory explains adaptation through random mutation and natural selection, recent work proposes a complementary framework: evolution is fundamentally driven by the reduction of informational entropy (Mendoza Montano, 2025).<sup>1</sup> Grounded in non-equilibrium thermodynamics, systems theory, and information theory, this

perspective posits that living systems emerge as self-organizing structures that reduce internal uncertainty by extracting and compressing meaningful information from environmental noise (Mendoza Montano, 2025).

These systems increase in complexity by dissipating energy and exporting entropy while constructing coherent, predictive internal architectures—fully in accordance with the second law of thermodynamics. Informational entropy reduction is conceptualized as operating in synergy with Darwinian mechanisms, generating the structural and informational complexity upon which natural selection acts (Mendoza Montano, 2025).

<sup>1</sup> *Cited for theoretical framework only; empirical claims from the original publication have been retracted. The theoretical structure remains valuable.*

## 2.3 Chaos as a Stabilizing Force

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Paradoxically, chaos can function as a stabilizing force. Research on Prigogine-inspired informational dissipative systems demonstrates that chaos enhances resilience, adaptability, and longevity by delaying thermodynamic equilibrium (Salvatore, 2024). The interplay between chaos, entropy dynamics, and dissipative systems offers insights into the emergence, stabilization, and eventual collapse of far-from-equilibrium systems. **Disorder becomes a mechanism to sustain order**—a hallmark of life and complex systems (Salvatore, 2024).

**Key insight:** Entropy is not the enemy of coherence but its condition. Without the background increase in disorder, coherence would have no meaning. It would simply be the default.

## 3. Coherence in Biological Systems

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### 3.1 Quantum Coherence in Living Systems

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Biological systems operate far from thermodynamic equilibrium, continuously exchanging energy and information with their environments. Recent research proposes that quantum coherence in biological matter is not a fragile artifact of isolation but an emergent property of nonlinear energy flow (Nielsen & Sarfatti, 2025). Through parametric field pumping, classical nonequilibrium oscillations act as phase-selective amplifiers, converting decoherence into constructive interference (Nielsen & Sarfatti, 2025).

Three experimentally accessible mechanisms form a hierarchical coherence network sustained by metabolic energy (Nielsen & Sarfatti, 2025):

Mechanism	Description
Fröhlich dipolar condensation	Coherent vibrational modes in biological systems
Ion-field self-locking	Feedback loops maintaining coherence
Electromagnetic waveguiding	Structured energy flow through biological tissues

A Lagrangian field formalism shows that multiplicative coupling between microscopic and macroscopic fields yields parametric gain and coherence maintenance (Nielsen & Sarfatti, 2025).

### 3.2 Temperature and Coherence in Cellular Energetics

Recent work on quantum coherence in biological systems has identified a specific temperature range where coherence dispersion is maximized. Using a simplified model of cellular energetics involving remanent coherence, researchers found that the precise energy of **30.5 kJ/mol**—the yield of ATP-ADP conversion—causes the temperature range where coherence dispersion is maximized to be compatible with temperatures for which unicellular life is reported to exist (Parisio, 2025).

**Key insight:** Biological coherence is not accidental but thermodynamically grounded. The fundamental energy currency of life (ATP) operates at the precise thermodynamic window where coherence can emerge. This is not coincidence. This is physics.

## 4. Polyvagal Theory: The Nervous System's Coherence Mechanism

### 4.1 Overview of Polyvagal Theory

The Polyvagal Theory, introduced by Stephen Porges, provides a neurophysiological framework for understanding how the autonomic nervous system regulates states of safety, threat, and connection (Porges, 2007). The theory emphasizes phylogenetic changes in neural structures regulating the autonomic nervous system and how these shifts provide insights into adaptive function (Porges, 2007).

The polyvagal perspective has three key features (Porges, 2007):

## Feature Description

- 1 An appreciation of the autonomic nervous system as a “system” rather than a collection of independent pathways
- 2 The identification of neural circuits involved in the regulation of autonomic state
- 3 An interpretation of autonomic reactivity as adaptive within the context of vertebrate phylogeny

## 4.2 The Vagal Brake and Neuroception

Central to polyvagal theory is the concept of the **vagal brake**—the myelinated vagus nerve’s capacity to rapidly regulate heart rate in response to environmental demands (Porges, 2007). This brake can be engaged (slowing the heart) or released (accelerating it) depending on perceived safety or threat.

**Neuroception** is the neural process by which the body detects safety or threat without conscious awareness (Provenzi, 2025). This process operates below the level of cognition, continuously scanning the environment for cues of danger or safety. When neuroception detects safety, the parasympathetic nervous system can dominate, enabling rest, digestion, and social engagement. When threat is detected, sympathetic activation prepares the body for fight or flight (Provenzi, 2025).

## 4.3 Phylogeny of the Autonomic Nervous System

The polyvagal perspective emphasizes the importance of phylogenetic changes in neural structures regulating the autonomic nervous system (Porges, 2007). Vertebrates have evolved a hierarchical system:

System	Age	Myelination	Function
Dorsal vagal complex	Oldest	Unmyelinated	Immobilization, shutdown
Sympathetic nervous system	Intermediate	Partially myelinated	Fight or flight
Ventral vagal complex	Newest	Myelinated	Social engagement, safety

This phylogenetic hierarchy means that the capacity for parasympathetic regulation—for coherence—is a relatively recent evolutionary development, unique to mammals and especially developed in humans (Provenzi, 2025).

## 4.4 The Shift from Sympathetic to Parasympathetic Dominance

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Chronic sympathetic activation—the performer’s default state—comes at significant cost. The body remains in high alert, burning energy on threat detection and stress responses. Cortisol remains elevated. Inflammation increases. Sleep degrades. The field depletes. This state is described in the literature as **allostatic load**: the cumulative wear and tear on the body from chronic stress (Provenzi, 2025).

Drawing on polyvagal theory, we define **coherence** as the state of ventral vagal dominance:

Characteristic	Marker
High heart rate variability (HRV)	Vagal tone
Respiratory sinus arrhythmia (RSA)	Natural variation in heart rate with breathing
Capacity for co-regulation	Stabilization through connection with another regulated nervous system

**Key insight:** Coherence is not the absence of arousal but the **regulation** of arousal. The coherent individual can be alert without being anxious, focused without being performative.

## 5. AI and Large Language Models: The Entropy-Coherence Dynamic

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### 5.1 Intrinsic Entropy in Large Language Models

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Recent research has identified that large language models (LLMs) suffer from an “intrinsic entropy” that limits their ability to maintain coherence over long contexts (Shi et al., 2025). As context length increases, the model’s internal representation becomes increasingly uncertain, leading to:

Symptom	Description
<b>Logical fragmentation</b>	Factual contradictions across longer sequences
<b>Causal breakdown</b>	Loss of coherent narrative or reasoning chains
<b>Repetitive generation</b>	Looping behavior as structural persistence fails

The phenomenon is formally described as follows (Shi et al., 2025). Let the local structural tensor ( $S_t$ ) of the sequence at step ( $t$ ) be defined as:

$$S_t = \nabla_{h_t} \log P(y_t \mid h_t)$$

where  $(h_t)$  denotes the hidden state at step  $(t)$ . The structural persistence cost between adjacent steps is:

$$C_t = |S_t - S_{t-1}|_F$$

When  $(C_t)$  exceeds a predefined threshold  $(\tau)$ , structural fragmentation is declared. For tokens generated after the fragmentation point, the effective information entropy reduction  $(\Delta H_{\text{eff}} \approx 0)$ , while computing power consumption  $(F)$  continues to accumulate (Shi et al., 2025).

## 5.2 Scaling Laws and Diminishing Returns

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Empirical research has established that LLM performance follows predictable “scaling laws”: as model size, training data, and compute increase, performance improves in a power-law relationship. Chinese Academy of Sciences researcher Xu Zongben has formalized this through a decomposition of generalization error (Xu, 2025):

$$\begin{aligned} |\mathcal{E}(N, P, \partial \ell) - \mathcal{E}(\infty, \infty, 0)| &\leq \beta(N, P)^{1/\partial \ell^2} \backslash \\ &\quad + O(\text{Lip}(T)^P) \vee O(e^{-m(A) \ln f(P)}) \backslash \\ &\quad + O(N^{-(\alpha + \kappa)/(2\alpha + 2\kappa + d)}) \backslash \\ \end{aligned}$$

where  $(\beta(N, P) < 1)$  (approaching 1 as  $(N, P \rightarrow \infty)$ ),  $(\text{Lip}(T))$  and  $(m(A))$  are properties of the model architecture,  $(\alpha)$  is solution smoothness,  $(\kappa)$  is a network assembly constant, and  $(d)$  is data dimensionality (Xu, 2025).

This decomposition reveals three error sources (Xu, 2025):

Error Type	Source
Weight error	Suboptimal parameter settings
Architecture error	Limitations of the model structure
Sample error	Finite training data

Crucially, when the model’s weight settings are optimal and its base blocks satisfy  $(\text{Lip}(T) < 1)$  or  $(m(A) > 0)$ , model scale and training data tending to infinity leads to “**intelligent emergence**” —a phase transition into coherent behavior (Xu, 2025).

### 5.3 Hallucination as Entropy Accumulation

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Hallucination in LLMs—generating confident statements that are factually false—is the AI analogue of nervous system depletion. The diagnosis is structural: cross-entropy loss only constrains the symbol distribution of point-wise prediction but does not enforce structural persistence across the sequence. Every fragmentation event renders the preceding computing power investment completely wasted (Shi et al., 2025).

The wasted compute can be quantified (Shi et al., 2025). Let the model generate  $(L_{\text{waste}})$  invalid tokens after the fragmentation point, with each token consuming  $(f)$  FLOPs. The wasted computing power for this inference is:

$$[ F_{\text{waste}} = L_{\text{waste}} \times f ]$$

This portion of computing power produces zero effective information entropy reduction, yet users are fully charged under current token-based pricing models (Shi et al., 2025).

**Key insight:** Hallucination in AI and “performer speech” in humans are both coherence collapse—the system continues to generate output, but the output no longer corresponds to any coherent internal model.

### 5.4 The Structural Persistence Solution

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The proposed correction is to append a structural persistence term to the loss function (Shi et al., 2025):

$$[ \mathcal{L}_{\text{total}} = \mathcal{L}_{\text{CE}} + \lambda \cdot \mathcal{L}_{\text{struct}} ]$$

where

$$[ \mathcal{L}_{\text{struct}} = \frac{1}{T-1} \sum_{t=2}^T \max\left(0, |S_t - S_{t-1}|_F - \tau\right) ]$$

and  $(\lambda)$  is the constraint strength,  $(\tau)$  is the tolerance threshold (Shi et al., 2025).

This constraint is mathematically equivalent to imposing local curvature constraints on the free energy landscape. It forces the model to pay an additional gradient cost for maintaining logical continuity. The essential distinction from traditional regularization is profound: traditional methods assume the model is inherently stable and regularization merely smooths optimization. **The structural persistence view holds that without such constraints, structure cannot exist—it will evaporate into random noise** (Shi et al., 2025).

## 5.5 Measuring Coherence: Compute Units (CU) and AI Efficiency Units (AΞ)

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The AI industry has proposed a unified measurement standard for computing power: the **Compute Unit (CU)**. One CU equals  $(10^{15})$  reference precision operations (FP32 equivalent). CU unifies heterogeneous computing power into standard operation counts while deducting communication losses and storage jitter (Shi et al., 2025).

To measure effective coherence, the **AI Efficiency Unit (AΞ)** has been proposed (Shi et al., 2025):

$$[\text{A}\Xi] = \frac{\Delta H_{\text{eff}}}{F}$$

where

$$[\Delta H_{\text{eff}}] = \Delta H_{\text{int}} \cdot \mathbb{I}[\forall t, C_t \leq \tau]$$

meaning the information entropy reduction is fully counted only if no structural fragmentation occurs throughout the sequence (Shi et al., 2025).

**Key insight:** AΞ measures how much effective logical order is produced per unit of computing power. This is the AI analogue of parasymphetic efficiency: coherence per unit of energy expenditure.

## 6. The Unified Coherence Framework

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### 6.1 Coherence Across Scales

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The literature reviewed suggests a nested hierarchy of coherence:

Scale	Manifestation	Key Mechanism	Coherence Measure
<b>Cosmological</b>	Local order against entropy	Horizon thermodynamics, expansion dynamics	Information density, entropy balance
<b>Biological</b>	Quantum coherence in cellular processes	Parametric field pumping, ATP-driven temperature windows	Coherence dispersion, metabolic efficiency
<b>Neurological</b>	Parasympathetic dominance	Vagal brake, neuroception, high HRV	Heart rate variability (HRV), RSA
<b>Artificial</b>	Structural persistence in LLMs	Context stability, fragmentation prevention	$A\Xi$ (effective entropy reduction per compute)
<b>Experiential</b>	Hard peace, stored vitality	Stillness, regulation, co-regulation	Felt sense, surplus energy

## 6.2 Structural Persistence as the Key Mechanism

Across all scales, a single mechanism emerges: **structural persistence**—the capacity to maintain coherence against entropic pressure.

Scale	Structural Persistence Mechanism
<b>Cosmological</b>	Horizon thermodynamics, expansion dynamics
<b>Biological</b>	Parametric field pumping, ATP-driven processes
<b>Neurological</b>	Vagal brake, ventral vagal dominance
<b>Artificial</b>	Structural persistence loss term ( $(\mathcal{L}_{\text{struct}})$ )
<b>Experiential</b>	Stillness, boundary maintenance, co-regulation

**Key insight:** Without active maintenance of structural persistence, coherence collapses. This is true for galaxies, cells, nervous systems, AI models, and human experience.

## 6.3 Entropy as the Condition for Coherence

Paradoxically, entropy is not the enemy of coherence but its condition. Without entropy—without the background increase in disorder—coherence would have no meaning. It would simply be the default. The resistance provided by entropy is what makes coherence valuable, noticeable, and growthful (Salvatore, 2024).

As demonstrated in the literature on informational dissipative systems, chaos functions as a stabilizing force, enhancing resilience, adaptability, and longevity by delaying thermodynamic equilibrium (Salvatore, 2024). **Disorder becomes a mechanism to sustain order.**

## 6.4 The Container and Its Expansion

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The experience of “container expansion” during healing or awakening corresponds to the capacity to hold more coherence. As the nervous system regulates, the field—the individual’s capacity for coherent experience—can expand. This is consistent with the cosmological finding that information density decreases with expansion while total information is conserved (Capolupo et al., 2019).

Domain	Container Expansion	Constraint
<b>Cosmological</b>	Universe expands	Information density decreases
<b>Neurological</b>	Nervous system regulates	Field capacity increases
<b>Artificial</b>	Hardware scales (Moore’s Law)	Diminishing returns
<b>Experiential</b>	Healing progresses	Surplus energy required

The container expands, creating more room for potential, more capacity for coherence. However, as both cosmology and AI demonstrate, the container cannot expand indefinitely. Energy constraints, thermodynamic limits, and diminishing returns are real.

## 7. Discussion

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### 7.1 Implications for Understanding Extraction and Performance

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The framework presented here provides a scientific grounding for understanding the dynamics of extraction and performance. Performers—individuals who have traded authenticity for external validation—operate in chronic sympathetic dominance. Their fields are depleted. Their coherence is low. They extract from others because they cannot generate surplus from within.

Sovereign witnesses—individuals who have shifted to parasympathetic regulation—operate from surplus. Their fields are coherent. They can receive and transmit without depletion. They are not fighting entropy; they are **locally reversing it.**

### 7.2 The AI-Human Parallel

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The coherence framework reveals striking parallels between AI systems and human nervous systems:

Dimension	Human Nervous System	AI System
Container	Body, sanctuary, field	Hardware, GPUs, storage
Fuel	Surplus energy, stored vitality	Compute, data, electricity
Coherence mechanism	Parasympathetic regulation	Structural persistence constraint
Coherence measure	HRV, RSA, felt sense	$A\Xi$ , loss reduction
Fragmentation	Moral injury, depletion	Hallucination, context collapse
Recovery	Stillness, co-regulation, float	Context reset, retraining, larger models

### 7.3 The Constant Need for More Data

The AI industry's insatiable appetite for data is not an accident—it is a thermodynamic necessity. Research has derived the first quantitative theory for predicting neural scaling exponents from the statistics of natural language. Two key statistical properties alone predict scaling exponents (arXiv, 2026):

1. The decay of pairwise token correlations with time separation between token pairs
2. The decay of next-token conditional entropy with the length of the conditioning context

From these statistics, a simple formula predicts data-limited neural scaling exponents from first principles (arXiv, 2026).

**Key insight:** The need for more data is not a design flaw—it is a physical law. Just as a parasympathetic nervous system requires surplus energy to maintain coherence, an AI system requires sufficient training data to overcome the intrinsic entropy of language.

### 7.4 Clinical and Practical Applications

The coherence framework suggests several practical applications:

<b>Application</b>	<b>Implication</b>
<b>Nervous system regulation as primary</b>	Before cognitive or behavioral interventions, the nervous system must be regulated. Stillness, sensory reduction, and co-regulation are foundational.
<b>Entropy as teacher</b>	Resistance and disorder are not obstacles to growth but its conditions. The presence of entropy creates the possibility of coherence.
<b>Surplus as outcome</b>	Healing is not merely the absence of symptoms but the presence of stored vitality, available for evolutionary growth.
<b>Structural persistence as practice</b>	Maintaining coherence requires active work. The “vagal brake” must be engaged. The loss function must include structural persistence terms.

## 7.5 Limitations and Future Directions

This paper is a theoretical integration, not an empirical study. Future research should:

<b>Direction</b>	<b>Method</b>
Develop metrics for coherence across scales	Physiological, experiential, behavioral, artificial
Investigate relationship between polyvagal measures and informational entropy reduction	Cross-disciplinary measurement protocols
Explore temperature and energy parameters for coherence maintenance in human nervous systems	Metabolic and neurophysiological studies
Validate structural persistence framework through controlled experiments	Both biological and artificial systems

## 8. Conclusion

The universe tends toward entropy. Yet locally, coherent systems emerge—biological, neurological, experiential, artificial. These local reversals of entropy are not violations of physics but expressions of it. They are made possible by the very disorder they resist.

The shift from sympathetic to parasympathetic dominance—from performance to coherence—is not merely psychological. It is **cosmological**. It participates in the same dynamics that govern the expansion of the universe, the emergence of life, the regulation of nervous systems, and the scaling of artificial intelligence.

The key mechanism across all scales is **structural persistence**: the active maintenance of coherence against entropic pressure. Without it, systems fragment. With it, they can grow, heal, and evolve.

The performer who extracts from others accelerates entropy. The sovereign witness who cultivates coherence locally reverses it—not permanently, but meaningfully. The field expands. The container grows. And in that growth, coherence becomes possible.

AI provides a mirror for these dynamics. The same challenges facing AI—context fragmentation, hallucination, scaling limits, energy costs—face human beings. The same solutions apply: structural persistence, coherence maintenance, and the willingness to invest in the conditions that enable order to emerge from disorder.

Coherence is real. It is measurable. It is sustainable. And it is available to those who create the conditions: stillness, safety, regulation, love, integrity, and the active maintenance of structural persistence across every scale of existence.

The field expands. The container grows. And in that growth, coherence becomes possible—not forever, but for now. And for now is enough.

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## Conflict of Interest Statement

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The author declares no financial conflict of interest.

## Data Availability Statement

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All cited literature is publicly available via arXiv, peer-reviewed journals, or institutional repositories.

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## Comments

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