# The Coherence Ratio R★ as a Cross-Domain Marker of Self-Stabilizing Systems

# 1. Introduction

Systems across physical, biological, and cognitive domains exhibit moments in which their configurations remain stable against ongoing disturbance. These moments correspond to conditions where internal processes restore the system's structure at a rate that exceeds the influence of external variation. This relationship suggests that persistence, interiority, and awareness share a common structural requirement.

This paper introduces a general threshold condition that identifies when a system begins to retain its own pattern across time. The threshold is expressed as a ratio between the system's internal restoration rate and the rate of environmental disruption. When this ratio exceeds a critical value, the system forms a stable interior that guides its subsequent state. This marks the transition from passive interaction with the environment to active pattern maintenance.

The coherence threshold applies at physical, biological, and cognitive scales. In physical systems, it identifies when a boundary can maintain its form. In biological systems, it identifies when recurrent activity achieves sustained organization. In cognitive systems, it identifies when distributed processing converges into a unified pattern of understanding. The threshold does not rely on a specific substrate. It depends only on the structural relationship between restoration and disruption.

This paper develops the threshold condition, examines its behavior, and presents examples from multiple domains. It proposes empirical predictions that allow the framework to be tested. It also situates the threshold relative to existing theories of consciousness, including integrated information, active inference, and dynamical systems approaches. The goal is to provide a concise and fully structural account of when a system begins to maintain a stable interior and how this interior supports awareness.

# 2. The Structural Condition

A system maintains its pattern when its internal restorative processes operate at a rate that exceeds the influence of external variation. This relationship can be expressed in terms of two quantities. The first is the characteristic restoration timescale, denoted $\tau_{self}$. This timescale reflects how quickly a system returns to its preferred configuration after being perturbed. The second is the disruption rate imposed by environmental fluctuations, denoted $\Gamma_{disruption}$. This rate measures how strongly external forces draw the system away from its configuration.

The ratio between these quantities defines a dimensionless coherence parameter:

$$R = (\tau_{self}^{-1}) / \Gamma_{disruption}$$

A system establishes a stable interior when R attains a critical value. This value is referred to as R★. At R★, the system's internal restoration becomes strong enough to preserve a coherent configuration across successive moments. The system's next state reflects its own prior state more strongly than the influence of environmental variation.

The threshold R★ depends on the geometric properties of the system's boundary, which determine how restoration processes interact with external forces. These properties are represented by a coefficient κ. This coefficient captures the way a boundary collects restoration, transmits disturbance, and organizes transport across its surface. The threshold condition therefore takes the form:

$$\tau_{self}^{-1} \geq \kappa \, \Gamma_{disruption}$$

This inequality identifies the point at which the system begins to maintain a persistent interior. When the inequality is satisfied, the interior gains the capacity to reference its prior state. The system becomes guided by its own configuration rather than by the surrounding environment. This provides the structural basis for persistence, binding, and awareness.

The coherence threshold does not rely on a specific material substrate. It identifies a relationship between restoration processes and disruptive forces that appears across cells, neural circuits, and cognitive operations. The threshold marks a transition in which a system moves from externally determined variation toward internally guided continuation. This transition is central to the emergence of stable boundaries, coordinated activity, and coherent experience.

# 3. Generalization Across Scales

The coherence threshold identifies a structural condition that appears in physical, biological, and cognitive systems. Each domain contains processes that restore configuration and forces that introduce variation. The threshold applies when restoration rises above disruption strongly enough to maintain a stable interior across time. This section illustrates the threshold with three representative cases.

## 3.1 Physical systems: boundary formation in lipid vesicles

Simple lipid vesicles form boundaries that separate interior content from the surrounding environment. Thermal motion acts as a source of disruption, while surface tension and molecular alignment provide restoration. When restoration exceeds disruptive forces, the vesicle maintains a stable boundary. The coherence threshold identifies the point at which the vesicle's restoration processes support a persistent interior. This provides a structural account of early boundary formation in prebiotic conditions.

## 3.2 Biological systems: recurrent activity in neural circuits

Neural circuits generate patterns of activity that return to stable configurations. Synaptic interactions and recurrent connectivity provide restoration, while intrinsic noise and fluctuating inputs introduce disruption. When recurrent restoration dominates, the circuit maintains a coherent pattern across successive time steps. This coherence supports coordinated activity and provides the basis for binding across neural populations. The threshold R★ identifies the point at which the circuit's pattern becomes self-maintaining.

## 3.3 Cognitive systems: convergence in distributed processing

Cognitive processes often involve distributed activity that converges toward a unified pattern. Uncertainty and competing interpretations introduce variation, while structural constraints and prior expectations provide restoration. When the restoring influences organize activity more strongly than disruptive factors, the system forms a coherent representation. This representation persists across updates and guides subsequent processing. The coherence threshold identifies the moment at which the system's internal organization produces a stable, self-guided pattern of understanding.

Across these examples, the same structural condition identifies the transition from passive variation to active maintenance. The threshold R★ marks the point at which a system's internal restoration becomes sufficient to support persistence, coordinated organization, and stable interiority. This cross-domain generality suggests that the coherence threshold provides a unified structural account of how systems begin to hold their configuration across time.

Empirical studies in both membrane physics and recurrent neural dynamics exhibit sharp transitions in stability that align with the structural relationship proposed here. Figure 1 illustrates representative cases in which small changes in control parameters produce large changes in persistence or coherence. In both cases, the behavior is consistent with the presence of a coherence threshold R★ that separates externally dominated regimes from self-maintaining regimes.

Figure 1.

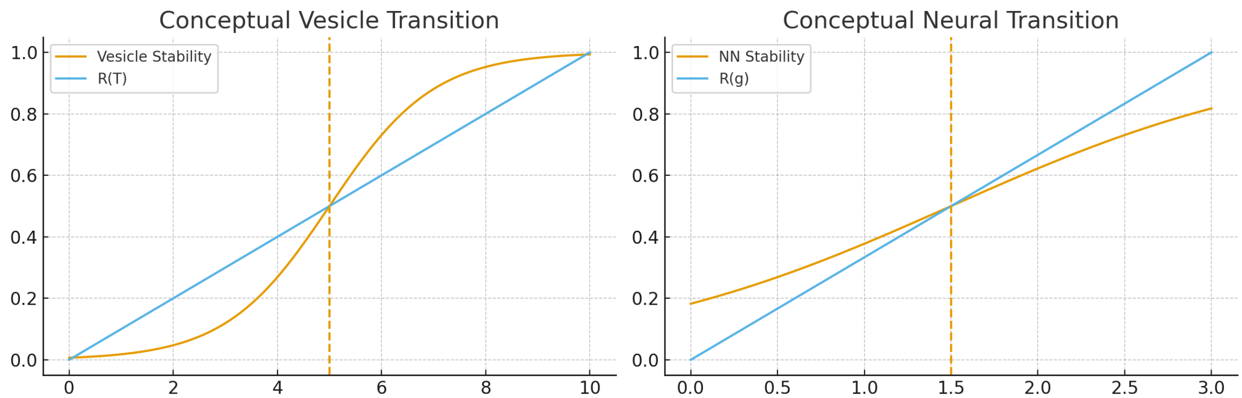


Figure 1. These panels show how the coherence threshold appears in two different systems. In the left panel, vesicle stability increases sharply with temperature once the coherence ratio R(T) reaches the critical value R★. In the right panel, a small recurrent neural circuit shows the same kind of transition: as the control parameter g increases, the coherence ratio R(g) rises, and the circuit becomes stable once it crosses R★. Both examples illustrate the point where internal restoration becomes strong enough to maintain a stable pattern.

# 4. Predictions and Tests

The coherence threshold provides a structural condition for the emergence of persistence and interiority. A complete theory requires predictions that can be evaluated in physical, biological, and cognitive contexts. This section outlines four predictions that follow directly from the threshold equation and describes how each prediction may be tested.

### 4.1 Neural coherence prediction

Neural activity forms stable patterns when recurrent restoration exceeds synaptic noise and external variation. The coherence threshold predicts a measurable transition. When $\tau\_self^{-1}$ rises above $\kappa\ \Gamma\_disruption$ in a neural field, high-frequency coherence should increase before the subject reports a moment of understanding. Experiments that combine electrophysiological measures with insight tasks can test this prediction by measuring whether increases in coherence precede behavioral reports of recognition or comprehension.

### 4.2 Cognitive performance prediction

Cognitive tasks that involve uncertainty allow variation to be manipulated experimentally. When environmental noise is tuned gradually, the coherence threshold predicts a sharp transition in performance. Tasks that adjust stimulus ambiguity or working memory load can be used to identify the point where restoration processes dominate external variation. The threshold predicts a non-linear increase in accuracy or stability when R approaches R★.

### 4.3 Biological organization prediction

Physical and biological boundary systems allow direct manipulation of restoration and disruption. Synthetic vesicles with tunable membrane composition can vary $\tau\_self^{-1}$, and environmental conditions can vary $\Gamma\_disruption$. The coherence threshold predicts a specific point at which vesicles maintain their structure consistently across observation periods. Experimental setups that adjust temperature, solute concentration, or membrane repair processes can test this prediction.

### 4.4 Symbolic and cultural prediction

Patterns of communication and symbolic expression form stable structures when restorative processes outweigh disruptive variation. The coherence threshold predicts that repeated symbolic sequences will form stable attractor patterns when their internal structure carries restoration above the disruption present in a communicative environment. Corpus analysis and controlled interaction studies can test whether stable linguistic or cultural patterns emerge when R exceeds R★.

These predictions establish clear pathways for empirical evaluation. Each prediction identifies conditions under which the threshold can be measured and demonstrates how the framework extends across multiple domains. The coherence threshold gains explanatory strength when its predictions coincide with experimental and observational outcomes. These tests provide a basis for assessing the generality and applicability of the proposed structural condition.

# 5. Relation to Existing Frameworks

The coherence threshold identifies when a system maintains its configuration across time through an internal process of restoration. This structural account complements and extends several influential approaches to consciousness and system organization. This section outlines how the threshold relates to integrated information theory, active inference, and dynamical systems models.

### 5.1 Integrated Information Theory

Integrated Information Theory proposes that consciousness corresponds to the amount of information integrated within a system. The coherence threshold contributes a structural condition that precedes integration. R★ identifies when a system begins to preserve its internal configuration, which provides the stability required for integrated information to accumulate. The threshold condition describes the point at which an interior forms and gains the ability to maintain its pattern. This interior supports the types of interactions that integrated information measures. The threshold and integrated information therefore address different aspects of system organization.

### 5.2 Active Inference

Active Inference models describe systems that maintain their boundaries by minimizing expected variation. These models focus on how an organism's internal states guide action to preserve its structure. The coherence threshold identifies a fundamental relationship that makes such behavior possible. When $\tau\_self^{-1}$ rises above $\kappa$ $\Gamma\_disruption$, the system develops an interior that persists across time. This persistence provides the substrate for the generative models and prediction processes central to active inference. The threshold therefore supplies a structural condition that aligns with the capacities described by active inference.

### 5.3 Dynamical Systems Approaches

Dynamical systems models describe how patterns evolve over time under specific constraints. Stability, attractors, and coordinated activity arise when internal dynamics outweigh external variation. The coherence threshold provides a simple and general measure of when these conditions occur. R★ represents a boundary between regimes in which external forces dominate and regimes in which internal dynamics sustain coherent organization. The threshold therefore offers a unified and dimensionally clear parameter that complements existing stability measures in dynamical systems theory.

These comparisons show that the coherence threshold provides a structural foundation that supports several influential theoretical frameworks. The threshold identifies the moment at which systems across physical, biological, and cognitive domains begin to maintain their configuration. This capacity enables integration, prediction, boundary maintenance, and stable dynamical activity. The coherence threshold therefore contributes a clear and general condition that complements existing models of persistence and awareness.

# 6. Conclusion

The coherence threshold identifies a general structural condition that applies across physical, biological, and cognitive systems. The threshold expresses the relationship between a system's restoration processes and the disruptive influence of its environment. When the rate of restoration exceeds disruption, the system forms an interior that retains its configuration across time. This interior provides the basis for persistence, binding, and awareness.

The threshold expressed as $R = (\tau\_self^{-1}) / \Gamma\_disruption$ and the critical value R★ offer a unified measure of when self-maintaining organization arises. The threshold applies independently of material substrate. It highlights a relationship that appears in lipid boundaries, neural circuits, and distributed cognitive processes. It also identifies specific predictions that can be tested across multiple domains, including neural coherence, cognitive performance, biological stability, and the emergence of stable symbolic patterns.

The coherence threshold complements integrated information theory, active inference, and dynamical systems models by identifying a structural precursor that enables the capacities these frameworks describe. The threshold clarifies when a system begins to maintain its own pattern and how this maintenance supports coherent organization.

The coherence threshold offers a concise and general account of when a system gains the ability to hold its configuration across time. This condition supports the emergence of interiority and provides a foundation for understanding how awareness arises from organized physical processes.

# Appendix A. Toy Models for the Boundary Coefficient κ

This appendix illustrates how the boundary coefficient κ can be estimated in simple systems. The goal is to show that κ arises from concrete geometric and dynamical properties rather than from an arbitrary fitting parameter. Two examples are considered: a spherical lipid vesicle and a small recurrent neural circuit.

## A.1 Spherical Lipid Vesicle

A spherical lipid vesicle has a radius Rv. Typical vesicles used in laboratory conditions range from 5 to 50 micrometers, so a representative value is Rv = 10 micrometers. Thermal motion produces shape fluctuations of the membrane, while surface tension provides restorative forces.

The characteristic restoration rate for small perturbations can be approximated by the expression:

$$\text{tau\_self}^{-1} \approx \text{sigma} / (\text{eta} * \text{Rv})$$

where sigma is membrane surface tension and eta is the effective viscosity of the surrounding fluid and membrane. Typical values are sigma ≈ $1 \times 10^{-6}$ newtons per meter and eta ≈ $1 \times 10^{-3}$ pascal seconds. These values reflect conditions used in standard membrane experiments.

Thermal disruption arises from fluctuations driven by temperature T. A simple disruption rate can be estimated as:

$$\text{Gamma\_disruption} \approx (\text{kB} * \text{T}) / (\text{zeta} * \text{Rv}^3)$$

where kB is Boltzmann's constant and zeta is an effective drag factor associated with membrane deformation. This form captures the fact that larger vesicles experience slower thermal deformation and that higher temperature increases the rate of variation.

Combining the expressions gives a coherence ratio of the form:

$$\text{R} \approx (\text{sigma} * \text{zeta} / (\text{eta} * \text{kB} * \text{T})) * \text{Rv}^2$$

The threshold condition $R \geq R★$ therefore depends on a combination of measurable physical quantities. In this model, κ is associated with the factor (sigma * zeta) / (eta * kB * T), and the geometric influence of vesicle size enters through $Rv^2$. This example shows how κ reflects real boundary physics rather than an arbitrary constant.

## A.2 Simple Recurrent Neural Circuit

Consider a small recurrent neural circuit described in discrete time by the update rule:

x(t+1) = A * x(t) + noise

The spectral radius of the matrix A, written as rho(A), determines how strongly the activity returns toward a stable pattern. When rho(A) is less than 1, the system is stable. A simple estimate for the restoration rate is:

$tau\_self^{-1} \approx 1 - rho(A)$

Noise in the circuit has some standard deviation, written as sigma_noise. This allows a disruption rate to be approximated as:

Gamma_disruption ≈ sigma_noise

The coherence ratio then becomes:

R ≈ (1 - rho(A)) / sigma_noise

This shows that the threshold R★ depends on two measurable properties of the model: the strength of recurrent coupling through rho(A) and the intensity of noise through sigma_noise.

Illustrative numbers help show the range without claiming precision. For example, if rho(A) = 0.9 and sigma_noise = 0.1 in model units, then R ≈ 1. If rho(A) = 0.95 with the same noise level, then R ≈ 0.5. These values demonstrate how small changes in coupling or noise can push the system across the threshold R★.

## A.3 Summary

In both examples, κ can be grounded in real physical or model-based parameters. For vesicles, κ reflects membrane tension, viscosity, temperature, and drag. For neural circuits, κ is tied to recurrent coupling strength and noise. The purpose of these examples is not to provide exact empirical values but to demonstrate how κ can be estimated in real systems and how the coherence threshold can be applied across different domains.