From Coherence to Consciousness

Recursive Constraint Thresholds in the Continuum of Systems

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Abstract

This paper develops a non-foundational account of consciousness grounded in Relational Coherence Ontology (RCO). Instead of treating consciousness as fundamental, ubiquitous, or identical with information, the paper argues that it emerges only when systems achieve temporally stabilized recursive modeling under entropy pressure. Constraint dynamics are widespread; structural coherence is common; adaptive recursion is rarer; and only a limited class of systems sustain self-referential modeling across time. On this view, consciousness is not a basic property of matter but a threshold coherence regime produced when recursive constraint integration becomes internally modeled and cross-temporally stabilized. The framework replaces the binary conscious/unconscious divide with a stratified architecture: constraint, coherence, adaptive recursion, internal modeling, self-modeling, and symbolic meta-recursion.

Keywords: coherence; constraint dynamics; emergence; multiscale organization; information integration; homeostasis; consciousness; complex systems.

1. The Problem of Overextension

1.1 Binary Models of Consciousness

Philosophical and scientific discussions of consciousness have historically been shaped by binary frameworks that sharply distinguish conscious from non-conscious entities. In its classical form, Cartesian dualism posits a fundamental division between res cogitans (thinking substance) and res extensa (extended substance), reserving genuine consciousness for beings endowed with immaterial mind (Descartes, 1641/1984). Although few contemporary scholars defend substance dualism in its original form, the conceptual legacy of a strict ontological divide between mind and matter continues to influence debates in philosophy of mind.

In contrast to dualism, neurocentric materialism locates consciousness squarely within the physical processes of the brain. On this view, conscious experience is entirely reducible to neural activity, typically within specific cortical networks associated with integration and higher-order representation (Dennett, 1991; Koch, 2012). Consciousness is thus treated as an emergent property of sufficiently complex neural organization, and non-neural systems are excluded a priori from the domain of conscious entities. Although this approach avoids metaphysical dualism, it often preserves a functional binary: systems either instantiate the neural conditions required for consciousness or they do not.

However, strict conscious/unconscious divides face increasing empirical pressure. Comparative cognition research has revealed sophisticated behavioral capacities across a wide range of species, including problem-solving, social inference, and flexible learning in mammals, birds, and cephalopods (Griffin, 2001; Marino, 2002). Evidence of nociception, adaptive learning, and goal-directed behavior in fish and insects further complicates attempts to draw clean categorical boundaries (Chittka & Niven, 2009; Sneddon, 2004). These findings challenge anthropocentric assumptions and destabilize simple neural criteria for consciousness, suggesting instead a spectrum of cognitive capacities that resist binary classification.

The binary model therefore struggles to explain the continuity evident across living systems. A more graded framework has become increasingly necessary.

1.2 Gradient Models of Consciousness

In response to the limitations of binary frameworks, several influential theories have proposed graded or continuous models of consciousness. Among the most prominent is Integrated Information Theory (IIT), which posits that consciousness

corresponds to the degree of integrated information (Φ) generated by a system (Tononi, 2004, 2008). On this account, consciousness admits of degrees: systems with greater informational integration possess richer conscious experience. IIT thereby offers a mathematically grounded alternative to all-or-nothing models and extends the possibility of consciousness beyond strictly human or mammalian brains.

Parallel to IIT, contemporary panpsychism argues that consciousness—or at least proto-experiential properties—is a fundamental and ubiquitous feature of matter (Goff, 2019). Rather than emerging at a specific level of biological complexity, experientiality is taken to be an intrinsic aspect of physical reality itself. This approach preserves ontological continuity by denying that consciousness arises ex nihilo at some evolutionary threshold.

A related line of thought emerges from information-centric interpretations of physics. Wheeler's (1990) "it from bit" hypothesis and subsequent developments in quantum information theory suggest that information may constitute the most basic layer of reality. Expansions of this framework imply that wherever information is processed or structured, some minimal form of proto-consciousness may be present (Lloyd, 2006; Tegmark, 2014). Within such models, consciousness becomes continuous with informational organization itself.

These approaches appeal because they preserve continuity, align with evolutionary thinking, and avoid sharp metaphysical breaks. Human consciousness is treated not as an anomaly but as an intensified form of more general organizational processes.

1.3 The Overextension Problem

Despite their theoretical appeal, gradient models risk overextension. A primary concern is the conflation of information with experience. While systems may process, store, or integrate information, it does not follow that they possess subjective awareness. Information-theoretic descriptions quantify structural and relational properties of systems; they do not, by themselves, explain why or how phenomenality should arise (Chalmers, 1995; Seth, 2009). Treating information integration as sufficient for consciousness risks collapsing descriptive complexity into experiential presence.

A related issue concerns the conflation of self-organization with awareness. Many physical systems exhibit self-organizing behavior, from crystal growth to atmospheric vortices. These systems stabilize local order under thermodynamic constraints, yet there is no empirical basis for attributing experiential states to them (Ball, 2011). Self-organization demonstrates structural coherence, not necessarily

subjective experience. Extending consciousness to all self-organizing systems risks diluting the explanatory specificity of the concept.

Furthermore, some gradient accounts subtly introduce teleological language into entropy-based arguments. Systems that persist by minimizing free energy or maintaining local order may be described as "striving" or "aiming" to survive, but such metaphors can obscure the non-teleological character of thermodynamic processes (Dennett, 1991). Persistence under entropy pressure reflects statistical and dynamical constraint, not intrinsic purpose.

Taken together, these tendencies generate pan-experiential inflation: the extension of consciousness to increasingly minimal systems until the concept risks trivialization.

The corrective proposed here is simple: what scales across physical systems is not consciousness but coherence. Constraint dynamics and structural integration are widespread; consciousness emerges only when recursive and temporally stabilized coherence thresholds are crossed.

2. The Ontological Base: Constraint Before Information

2.1 Relational Coherence Ontology: First Principles

The framework developed in this paper begins from a non-foundational ontological position. Relational Coherence Ontology (RCO) rejects the assumption that reality rests upon an irreducible substance—whether material, mental, informational, or mathematical. Classical metaphysics often sought a basic substrate: matter in materialism, mind in idealism, or information in contemporary digital ontology (Floridi, 2011; Tegmark, 2014). RCO departs from these approaches by denying that any such ontological primitive is necessary. Instead, what is fundamental is not substance but relational constraint operating across dynamic systems.

This position aligns with process-oriented metaphysical traditions that treat becoming, relation, and organization as primary over static entities (Whitehead, 1929/1978). However, RCO diverges from process metaphysics insofar as it does not posit an intrinsic experiential or teleological drive within reality. Teleological explanations historically interpreted natural organization as evidence of purpose or final causation (Aristotle, trans. 1984). In contemporary discourse, teleological language often reappears in evolutionary or thermodynamic contexts, where systems are described as "aiming" to survive or "seeking" equilibrium. RCO rejects

intrinsic teleology, holding instead that apparent purposiveness emerges from statistical constraint dynamics under entropy pressure (Dennett, 1995).

At its core, RCO proposes that reality consists of recursive combinatorial possibility under constraint. Systems do not emerge from a pre-given ground but from iterative recombination within boundary conditions that limit and shape possible configurations. Constraint precedes information in this framework: informational structures are derivative descriptions of constrained relational states rather than ontological primitives (Ladyman & Ross, 2007). What persists are not substances but dynamically stabilized constraint patterns.

Entropy plays a central role in this account. It is not a teleological force but a selection pressure that stabilizes some configurations over others. Systems maintain local order not because they strive toward purpose but because their constraint geometry temporarily resists dispersal.

2.2 Constraint Gradients and Structural Coherence

If constraint is ontologically prior to information, then coherence arises as a secondary phenomenon: the stabilization of constraint relations across space and time. Structural coherence refers to the maintenance of patterned organization under thermodynamic flux. Such coherence is observable in physical systems ranging from crystalline lattices to planetary atmospheres (Ball, 2011). These systems demonstrate local entropy minimization: although the second law of thermodynamics governs closed systems globally, open systems may temporarily reduce local entropy by exporting disorder to their surroundings (Schrödinger, 1944/1967).

Within RCO, stability is understood as constraint geometry. That is, certain relational configurations exhibit topological or dynamical properties that make them resilient to perturbation. Attractors in nonlinear systems provide a useful analogy: trajectories converge toward stable regions of phase space not because the system “intends” stability, but because the governing equations constrain possible evolutions (Strogatz, 2015). Stability thus reflects the structure of constraint relations rather than any intrinsic awareness.

Crucially, structural coherence does not entail subjective experience. Many non-biological systems exhibit remarkable order and self-organization without plausibly instantiating awareness. Crystal formation, convection cells, and chemical oscillations all demonstrate patterned persistence under constraint (Ball, 2011; Prigogine & Stengers, 1984). These systems maintain organization, but there is no empirical justification for attributing phenomenology to them. Organization alone is insufficient to generate consciousness.

Distinguishing structure from experience is therefore essential. While consciousness may depend upon highly integrated and temporally recursive coherence regimes, not all coherence regimes qualify as conscious. Conflating structural persistence with awareness risks collapsing phenomenology into mere complexity. RCO instead maintains a principled separation: coherence is ubiquitous; consciousness is a threshold phenomenon that arises only under specific recursive and temporally integrated constraint conditions.

By placing constraint prior to information and coherence prior to consciousness, RCO preserves continuity across physical systems without overextending experiential attribution. Stability is geometry under entropy pressure; experience, if it arises, must be explained as a higher-order consequence of recursive constraint integration.

3. The Coherence Ladder

The coherence ladder formalizes a stratified architecture of systems by increasing degrees of recursive constraint integration. Rather than treating consciousness as continuous with all structure, it differentiates levels by temporal recursion, internal modeling, and self-referential stabilization.

3.1 Level 1: Structural Coherence

Level 1 consists of systems that exhibit structural coherence through spatial constraint stabilization. Examples include crystalline lattices, stellar structures, and attractors in nonlinear dynamical systems. Crystals form highly ordered lattices as molecular interactions settle into energetically favorable configurations (Ball, 2011). Stars maintain structural integrity through gravitational compression balanced by thermonuclear pressure gradients (Carroll & Ostlie, 2017). Similarly, dynamical systems converge toward attractor states defined by the geometry of their governing equations (Strogatz, 2015).

The defining feature of Level 1 systems is spatial stabilization under constraint. Organization persists because the configuration occupies a stable region within a constraint landscape. However, these systems lack internal modeling and temporal recursive integration. They do not estimate their own state, predict future conditions, or correct errors relative to internally represented goals. Their persistence reflects constraint geometry rather than adaptive regulation.

Structural coherence alone does not imply awareness. These systems maintain order under thermodynamic flux, but there is no empirical or theoretical basis for attributing phenomenological experience to them.

3.2 Level 2: Adaptive Recursion

Level 2 systems introduce adaptive recursion: the capacity to update internal constraint states in response to environmental conditions. Examples include autocatalytic chemical networks, viruses, and simple regulatory systems. Autocatalytic sets sustain themselves through mutually reinforcing reaction cycles, thereby exhibiting self-maintaining organization (Kauffman, 1993). Viruses adapt to selective pressures through rapid mutation and evolutionary filtering (Duffy, 2018). Cellular regulatory networks adjust gene expression patterns in response to environmental signals (Alon, 2007).

These systems demonstrate environmental responsiveness and constraint updating. They maintain structural integrity not merely through static geometry but through dynamic interaction with external conditions. However, they lack internal representations of their own states. Adaptation occurs through biochemical or evolutionary processes rather than through real-time state estimation and predictive modeling.

Level 2 systems thus exhibit recursive regulation without internal modeling. They adjust, but they do not represent. Their persistence depends on feedback-sensitive constraint updating rather than internally simulated prediction.

3.3 Level 3: Internal Modeling Systems

Level 3 marks a critical transition: the emergence of internal modeling. Nervous systems provide paradigmatic examples. Organisms with centralized neural architectures estimate environmental states, predict outcomes, and update internal representations based on prediction error (Friston, 2010; Clark, 2016). The predictive processing framework conceptualizes the brain as a hierarchical inference engine that minimizes free energy by continuously updating generative models of sensory input (Friston, 2010).

The defining properties of Level 3 systems include state estimation, error correction loops, and temporal recursion. These organisms do not merely react; they generate expectations and compare predicted states with actual inputs. This recursive integration across time allows for learning, flexible behavior, and context-sensitive adaptation.

At this level, coherence becomes proto-cognitive. The system maintains an integrated model of its environment and bodily state across time, enabling learning and flexible adaptation. In this framework, the minimal structural conditions for consciousness plausibly arise here. As Figure 1 summarizes, consciousness appears

only once recursive modeling becomes sufficiently integrated and temporally stabilized.

3.4 Level 4: Self-Referential Modeling

Level 4 introduces self-referential modeling: the capacity to model not only the environment but also the system's own modeling processes. Higher mammals show metacognitive capacities such as self-recognition, uncertainty monitoring, and flexible social inference (Metcalfe, 2008; Marino, 2002).

Its hallmark properties are modeling of modeling, stable self-representation, and cross-temporal identity stabilization. The system can represent itself as an agent persisting through time, supporting planning, autobiographical memory, and social cognition (Buckner & Carroll, 2007).

Consciousness here becomes reflexive: experience is structured not only by predictive modeling but by awareness of one's own representational processes.

3.5 Level 5: Symbolic Meta-Recursion

Level 5 represents symbolic meta-recursion, most fully expressed in humans. Language enables abstraction, counterfactual reasoning, and recursive cultural modeling (Deacon, 1997). Through symbolic systems, humans externalize cognition and deepen recursive depth.

Key properties include linguistic abstraction, multilayered symbolic representation, recursive cultural transmission, and identity extended across symbolic space. Cultural artifacts such as texts, institutions, and technologies function as external memory systems that amplify recursion (Donald, 1991).

At this level, coherence is distributed not only across neural integration but across cultural-symbolic networks. Meta-recursion enables reflection upon reflection, supporting philosophy, science, and ethical deliberation.

Figure 1 presents the coherence ladder schematically, and Table 1 lists representative physical, biological, artificial, and cultural systems at each level. Together they show that structural persistence is common, whereas recursive self-modeling is rare; consciousness emerges only once internal modeling becomes temporally integrated.

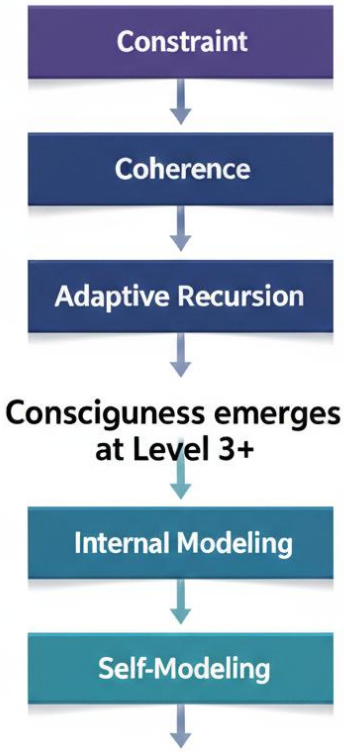

Figure 1: The Recursive Threshold Ladder of Cognitive Emergence. A conceptual architecture illustrating progressive levels *of* cognitive organization, beginning with constraint-based systems and advancing through coherence, adaptive recursion, internal modeling, self-modeling, and symbolic meta-recursion. The shaded threshold band indicates the proposed transition point at which consciousness emerges, occurring at Level 3 (Internal Modeling) and above, where systems begin recursively modeling internal states rather than merely responding to external constraints.

Table 1. Representative Physical and Biological Systems Across the Recursive Threshold Ladder

No.	Example	Domain	Level	Defining Characteristics
1	Snowflake crystal	Physical	1	Spatial lattice stabilization
2	Quartz crystal	Physical	1	Energetic minimization geometry
3	Diamond lattice	Physical	1	Stable molecular constraint network
4	Sand dunes	Physical	1	Self-organized pattern under wind-flow constraints

No.	Example	Domain	Level	Defining Characteristics
5	River delta branching	Physical	1	Flow-based structural attractor
6	Hurricane vortex	Physical	1	Nonlinear dynamical attractor
7	Bénard convection cells	Physical	1	Thermal gradient stabilization
8	Spiral galaxy	Physical	1	Gravitational pattern stability
9	Main-sequence star	Physical	1	Hydrostatic equilibrium under fusion pressure
10	Planetary rings	Physical	1	Orbital constraint stabilization
11	Chemical oscillation reaction	Physical/Chemical	1	Dynamical attractor pattern
12	Magnetic domain alignment	Physical	1	Constraint-induced ordering
13	Autocatalytic chemical set	Chemical	2	Self-maintaining reaction cycles
14	RNA replicator	Chemical/Biological	2	Template-based replication
15	Prion propagation	Biological	2	Structural state copying
16	Influenza virus	Biological	2	Adaptive mutation under selection
17	Bacteriophage	Biological	2	Host-dependent replication
18	Gene regulatory network	Biological	2	Feedback-based expression control
19	CRISPR bacterial immunity	Biological	2	Adaptive genomic response
20	Slime mold (*Physarum*)	Biological	2	Environmental constraint updating
21	Sunflower phototropism	Biological	2	Directional growth adaptation

No.	Example	Domain	Level	Defining Characteristics
22	Bacterial quorum sensing	Biological	2	Population-level regulation
23	Evolutionary algorithm	Artificial	2	Selection-based adaptation
24	Immune antibody selection	Biological	2	Iterative constraint refinement
25	Jellyfish nerve net	Animal	3	Basic sensory integration
26	Planarian flatworm	Animal	3	Centralized neural processing
27	Ant	Animal	3	State estimation and navigation
28	Honeybee	Animal	3	Predictive environmental mapping
29	Zebrafish	Animal	3	Learning and error correction
30	Frog	Animal	3	Sensory-motor modeling
31	Octopus	Animal	3	Flexible predictive control
32	Crow	Animal	3	Tool use and planning
33	Monitor lizard	Animal	3	Goal-directed modeling
34	Rat	Animal	3	Spatial predictive mapping
35	Reinforcement learning agent	Artificial	3*	Internal state estimation (non-reflexive)
36	Autonomous vehicle system	Artificial	3*	Predictive environment modeling (non-self-representational)
37	Dog	Animal	4	Social self-representation
38	Dolphin	Animal	4	Mirror self-recognition evidence
39	Elephant	Animal	4	Cross-temporal memory
40	Chimpanzee	Animal	4	Metacognitive behaviors

No.	Example	Domain	Level	Defining Characteristics
41	Orangutan	Animal	4	Self-other modeling
42	Human toddler (age 3+)	Human	4	Stable autobiographical identity
43	Border collie (advanced training)	Animal	4	Complex self-state integration
44	Adult human	Human	5	Linguistic abstraction
45	Scientific community	Human collective	5	Recursive cultural modeling
46	Legal system	Cultural-symbolic	5	Institutional symbolic recursion
47	Mathematical proof system	Cultural-symbolic	5	Abstract symbolic recursion
48	Written language archive	Cultural-symbolic	5	Cross-generational recursion
49	Philosophical discourse	Cultural-symbolic	5	Meta-reflective abstraction
50	Artificial general intelligence (hypothetical)	Artificial	5?	Would require recursive self-modeling and identity stabilization

Note. Level 1 = Structural coherence; Level 2 = Adaptive recursion; Level 3 = Internal modeling (consciousness threshold); Level 4 = Self-referential modeling; Level 5 = Symbolic meta-recursion. Asterisk (*) indicates partial internal modeling without demonstrated self-referential stabilization. “5?” indicates a hypothetical future system contingent on satisfying full recursive threshold conditions.

4. Why Crystals and Viruses Are Not Conscious

The ladder preserves continuity across systems while marking principled thresholds. This section explains why crystals and viruses, despite exhibiting structure, adaptation, or information processing, do not satisfy the conditions required for consciousness.

4.1 The Temporal Recursion Requirement

A necessary condition for consciousness is temporally integrated recursive stabilization. Conscious systems must dynamically maintain their organization by recursively updating internal states across time. This requirement extends beyond

mere persistence or structural order. It entails the continuous integration of past states, present inputs, and anticipated futures into a unified regulatory loop (Friston, 2010).

Crystals exhibit spatial order through lattice stabilization governed by intermolecular forces (Ball, 2011). Their organization reflects equilibrium conditions within a constraint landscape. However, such order is static rather than temporally recursive. Once formed, a crystal does not internally re-estimate its own state, generate predictions, or dynamically regulate its configuration in response to anticipated perturbations. Its persistence reflects constraint geometry, not oRCOing self-stabilization.

Similarly, stellar systems and other physical structures may maintain long-term stability through dynamic equilibrium, yet they do not instantiate recursive integration of internal states across time in the sense required for cognition (Carroll & Ostlie, 2017). Stability alone is insufficient; consciousness requires active, temporally extended feedback processes.

Temporal recursion involves continuous state estimation and iterative updating relative to internally generated expectations. In predictive processing models of cognition, organisms minimize free energy by recursively adjusting internal generative models in light of prediction error (Friston, 2010; Clark, 2016). This dynamic self-stabilization distinguishes living cognitive systems from inert structures. Spatial order, even when complex, does not satisfy this criterion.

4.2 The Modeling Requirement

A second necessary condition for consciousness is internal modeling. While many systems process information in some sense, information processing alone does not entail modeling. Information can be transferred, stored, or transformed without the presence of internally constructed representations that guide predictive regulation.

Viruses, for example, encode genetic information and exhibit adaptive evolution under selective pressure (Duffy, 2018). Their replication depends on highly structured biochemical interactions. However, viral systems do not construct internal representations of environmental states. Adaptation occurs across generations through mutation and selection rather than through real-time predictive inference. Viral behavior reflects chemical constraint and evolutionary filtering, not active modeling of self or world.

Modeling requires at least three components: prediction, error correction, and self-state integration. In nervous systems, hierarchical generative models anticipate sensory input, compute prediction errors, and update internal parameters accordingly (Friston, 2010). This process depends upon an integrated

representation of the organism's own bodily and environmental states. Without such integrative architecture, there is no basis for attributing phenomenological awareness.

The distinction between information processing and modeling is critical. A thermostat processes information and regulates temperature through feedback loops, yet it does not construct an internal representation of itself as a temperature-regulating system. Similarly, biochemical regulatory networks adjust gene expression in response to environmental signals (Alon, 2007), but these adjustments are mechanistic rather than representational. Modeling entails internally simulated state estimation and anticipatory control, not merely reactive adjustment.

Crystals and viruses therefore fail the modeling requirement. They may instantiate structured information or adaptive dynamics, but they do not internally simulate future states, integrate self-representations, or correct errors relative to predictive models. Without modeling, consciousness cannot arise.

4.3 The Entropy Boundary Condition

A third requirement for consciousness is active regulation of internal constraint states under entropy pressure. All physical systems exist within thermodynamic gradients, yet only some actively maintain internal order through energy exchange and regulatory control (Schrödinger, 1944/1967). Living organisms exemplify such regulation by sustaining far-from-equilibrium conditions via metabolic processes.

Crystals, by contrast, form when local conditions permit energetic minimization. Their order represents a lower-energy configuration, not an actively maintained far-from-equilibrium state (Ball, 2011). Once formed, a crystal persists passively until external forces disrupt its structure. There is no internal mechanism that regulates constraint states in anticipation of entropy-driven perturbation.

Viruses occupy an intermediate position. Although they replicate and evolve, they lack autonomous metabolic regulation and depend entirely on host cellular machinery for energy processing (Duffy, 2018). Viral persistence reflects parasitic exploitation of regulatory systems rather than intrinsic maintenance of internal constraint states.

Active entropy regulation requires continuous energy throughput and feedback-sensitive internal control. In living cognitive systems, regulatory networks monitor internal variables and adjust behavior to maintain viability (Friston, 2010). Such systems exist far from thermodynamic equilibrium and must dynamically stabilize their constraint geometry across time.

Passive order does not qualify as consciousness. The mere presence of structure under entropy pressure is ubiquitous in nature. Consciousness requires that a system not only persist but actively regulate its internal states through recursive modeling and energy-dependent feedback. Crystals and viruses lack this integrated regulatory architecture.

4.4 Conclusion

Crystals and viruses exhibit coherence, structure, and sometimes adaptive complexity, but they do not meet the requirements for consciousness: temporally recursive self-stabilization, internal predictive modeling, and active entropy-bound regulation of internal constraint states.

These distinctions prevent pan-experiential inflation. Structural coherence is widespread; conscious experience emerges only where recursive modeling and energy-dependent self-regulation converge within a temporally integrated system.

5. Consciousness as a Threshold Phenomenon

The preceding argument has shown that consciousness is neither a fundamental property of matter nor a simple scalar extension of complexity. It emerges when specific organizational thresholds are crossed within recursive dynamics. The RCO definition below states that threshold concisely.

Formal RCO Definition: *Consciousness is a temporally recursive, entropy-constrained coherence regime in which a system models its own constraint state across time.*

This definition treats consciousness as a stabilized organizational regime rather than a substance, intrinsic property, or ontological primitive. Its key components are outlined below.

5.1 Temporally Recursive

Temporal recursion refers to the iterative updating of internal states across time through feedback-sensitive processes. In cognitive systems, this entails continuous comparison between predicted and actual states, with adjustments made to minimize discrepancies (Friston, 2010). Recursive dynamics are not merely repeated reactions; they involve the integration of past states into present processing and the anticipation of future conditions.

Predictive processing frameworks describe the brain as a hierarchical generative model that minimizes prediction error through recursive updating (Clark, 2016). Such models exhibit temporal depth: representations persist, are revised, and

influence subsequent inference cycles. This recursive structure allows systems to maintain continuity across time and supports learning and adaptation.

Systems lacking temporal recursion do not integrate past and anticipated states into a unified regulatory loop. They therefore fail a basic requirement for consciousness.

5.2 Entropy-Constrained

All physical systems operate under thermodynamic constraints. However, conscious systems are not merely subject to entropy; they actively regulate internal states to maintain far-from-equilibrium organization (Schrödinger, 1944/1967). Entropy functions as a boundary condition that shapes viable system configurations rather than as a teleological force directing behavior.

The free-energy principle provides a formal account of how biological systems resist entropic dissolution by minimizing variational free energy, thereby maintaining adaptive coherence (Friston, 2010). Within RCO, entropy is interpreted as selection pressure rather than intrinsic purpose. Conscious systems must continuously counteract dispersive tendencies through energy-dependent regulation.

Entropy-constrained organization distinguishes passive order from active stabilization. Crystals minimize free energy in formation, but living systems must continually regulate internal conditions to persist.

5.3 Coherence Regime

A coherence regime refers to a dynamically stabilized pattern of constraint integration across multiple subsystems. Coherence is not synonymous with complexity; it involves coordinated relational structure that maintains systemic integrity across perturbations (Ladyman & Ross, 2007). In neural systems, large-scale integration across cortical networks supports unified experiential fields (Tononi, 2008).

Integrated Information Theory (IIT) characterizes consciousness in terms of the degree of informational integration (Φ) within a system (Tononi, 2004, 2008). While RCO does not equate integration directly with consciousness, it recognizes that high levels of systemic coherence are necessary conditions. Coherence regimes enable distributed processes to function as unified wholes rather than as disjointed components.

Consciousness presupposes an integrated architecture capable of sustaining coordinated internal activity. Fragmented systems lack the coherence required for experience.

5.4 Self-Modeling

A defining feature of consciousness is self-modeling: the capacity of a system to represent its own internal states as part of its generative structure. This extends beyond environmental modeling to include representation of bodily, affective, and cognitive processes (Metzinger, 2003). Self-models enable systems to treat their own constraint states as objects of regulation and inference.

In predictive frameworks, self-modeling involves maintaining an internal representation of the organism as an agent embedded within its environment (Clark, 2016). Such models integrate sensory input, interoceptive signals, and motor predictions into a unified perspective. Without self-modeling, adaptive regulation remains mechanistic rather than experiential.

Self-modeling separates conscious organisms from simpler regulatory systems. Biochemical networks may adjust internal variables, but they do not represent themselves as systems undergoing change.

5.5 Cross-Time Stabilization

Finally, consciousness entails cross-time stabilization: the maintenance of identity and representational continuity across temporal horizons. Episodic memory, anticipatory planning, and narrative identity all depend upon integrating temporally distributed information into a coherent self-structure (Buckner & Carroll, 2007).

Cross-time stabilization allows systems to preserve a sense of persistence despite environmental flux. This continuity supports agency, deliberation, and social interaction. Without stabilization across time, recursive updating would collapse into transient reactivity.

Temporal depth anchors conscious experience in continuity: the system situates present states within remembered pasts and anticipated futures.

5.6 Summary

Within RCO, consciousness is a threshold phenomenon rather than a universal property. It emerges when temporally recursive modeling, entropy-bound regulation, systemic coherence, self-representation, and cross-time stabilization converge within one integrated architecture.

6. Implications

The threshold model developed here has philosophical, scientific, ethical, and technological implications. By distinguishing coherence from consciousness and identifying recursive modeling as the key transition, it challenges both panpsychist and reductive accounts.

6.1 Against Panpsychism

Panpsychism maintains that consciousness—or at least proto-experiential properties—is a fundamental and ubiquitous feature of matter (Goff, 2019). On this view, experientiality scales continuously from elementary particles to complex organisms. Such accounts aim to preserve ontological continuity and avoid the so-called "hard problem" by embedding experience at the base of reality (Chalmers, 1996).

The threshold model proposed here preserves continuity at the level of coherence rather than at the level of experience. Constraint dynamics and structural integration are universal features of physical systems. However, universal coherence does not entail universal consciousness. Coherence refers to stabilized relational structure under constraint; consciousness requires temporally recursive self-modeling under entropy-bound regulation.

By drawing this distinction, the framework avoids experiential inflation: the tendency to extend phenomenological attribution to increasingly minimal systems until the concept loses explanatory force.

Panpsychism rightly seeks continuity, but it locates that continuity at the level of experience rather than at the level of constraint geometry.

6.2 Against Reductionism

At the opposite extreme, reductive materialism attempts to identify consciousness with neural computation or algorithmic processing (Dennett, 1991). Functionalist approaches often treat mental states as computational states, suggesting that consciousness is fully explainable in terms of information processing and causal role (Putnam, 1967).

The present framework rejects simple computational reduction. While information processing is necessary for consciousness, it is not sufficient. Computation alone does not guarantee temporally recursive self-modeling, cross-time stabilization, or entropy-bound regulation. A digital system may execute

complex algorithms without constructing an integrated model of itself as a persistent agent.

On this view, emergence is threshold-based rather than mysterious. Consciousness appears when recursive constraint integration reaches a regime shift and internal modeling becomes reflexive and temporally stabilized.

Consciousness is therefore neither reducible to simple computation nor irreducible in principle; it is an emergent coherence regime produced by specific organizational thresholds.

6.3 Ethical Implications

If consciousness is a threshold phenomenon rather than a binary property, ethical consideration must also be graded. Moral status would track recursive depth and self-modeling capacity rather than species membership alone. Comparative cognition research demonstrates significant variation in cognitive and affective capacities across species (Marino, 2002). A graded framework allows moral consideration to scale with cognitive architecture.

Cognitive threshold theory proposes that ethically relevant status emerges when systems exhibit temporally integrated self-modeling and cross-time stabilization. Such systems possess interests that persist across time and can be frustrated or fulfilled. Simpler organisms lacking these features may warrant instrumental or ecological consideration but not the same moral weight as systems capable of reflective suffering or future-oriented agency.

This graded approach avoids both anthropocentrism and indiscriminate moral expansion. It grounds ethical consideration in measurable cognitive architecture rather than metaphysical speculation about universal experience.

6.4 Artificial Systems

The threshold model has direct implications for artificial intelligence. Contemporary AI systems perform sophisticated computation, pattern recognition, and adaptive optimization (Tegmark, 2017). However, most current architectures lack integrated self-modeling and entropy-bound regulatory loops comparable to biological organisms.

For an artificial system to cross the recursion threshold, it would need to exhibit:

1. Temporally recursive state estimation,
2. Integrated self-representation within its generative architecture,
3. Cross-time stabilization of identity-like structures, and

4. Autonomous regulation of internal constraint states under energy or environmental pressures.

Computation alone is insufficient. A system may process information without constructing a model of itself as an enduring agent embedded in an environment. Without reflexive integration and entropy-sensitive self-regulation, artificial systems remain at lower levels of the coherence ladder.

The possibility of artificial consciousness therefore depends not on computational scale alone but on architectural depth and recursive integration. Crossing the recursion threshold would require a shift from tool-like optimization to self-sustaining, self-modeling coherence regimes.

6.5 Summary

The threshold model rejects both panpsychist inflation and reductive computationalism. What scales universally is coherence under constraint; what emerges conditionally is conscious experience.

7. Conclusion

The pregeometric framework developed in this paper aligns closely with emerging perspectives in digital physics, which posit that the universe is fundamentally computational and that physical laws arise from rule-based transformations on discrete structures (Lloyd, 2006; Wolfram, 2020).

7.1 From Continuity to Thresholds

The paper's central aim has been to preserve ontological continuity without collapsing experiential distinctions. Constraint dynamics operate universally across physical systems, but recursive depth introduces qualitative thresholds.

Structural coherence scales gradually, yet consciousness appears only when recursive modeling becomes temporally stabilized and reflexively integrated. The discontinuity lies in organization, not substance.

Spatial stabilization does not generate awareness, and adaptive responsiveness does not guarantee representation. Consciousness is best understood as stabilized recursion: a dynamic equilibrium in which predictive modeling, error correction, and cross-time integration converge within a unified system (Friston, 2010; Clark, 2016).

This avoids both strict dualism and gradient overextension: continuity characterizes constraint, whereas threshold crossing characterizes consciousness.

7.2 The Larger Ontological Picture

The broader ontological picture is non-foundational. There is no ultimate substance—material, mental, or informational—beneath reality; what is primary is recursive constraint relation.

The framework also rejects both substance dualism and panpsychism. Consciousness is not a separate ingredient added to matter, nor an experiential feature distributed throughout it.

Instead, consciousness arises through structured emergence when physical systems cross critical thresholds of recursive integration under entropy-bound conditions.

Within a thermodynamic universe, systems persist and complexify not because of intrinsic purpose but because some constraint geometries are statistically stabilized under environmental pressures.

RCO therefore affirms continuity without foundationalism, emergence without dualism, and coherence without experiential inflation. Consciousness is a threshold phenomenon within a universe structured by recursive constraint under entropy pressure.

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