

Beyond Integration, Broadcast, Representation, and Recurrence: Toward a Structural Condition for Systemic Understanding

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1. Introduction

1.1 The unresolved problem of systemic understanding

Across the cognitive sciences, artificial intelligence research, and the broader study of complex adaptive systems, the question of what constitutes understanding remains unresolved. Numerous theories contend with fragments of the phenomenon, yet none provides a comprehensive account of how a system, biological or artificial, can sustain a coherent internal relation to its own informational states through time. The problem is not merely the absence of a satisfactory definition. It is the absence of a structural account that explains how the capacity for understanding arises, how it is maintained, and under which conditions it collapses.

Existing theoretical frameworks often assume that understanding is a semantic property that emerges from the manipulation or representation of meaningful symbols. This view has endured from classical cognitivism to contemporary computational models. However, semantic explanations fail to capture the deeper demands placed on a system that must hold together, coordinate, and revisit its own relational states across temporal intervals. The question therefore transcends meaning. It becomes a question of structure, coherence, and temporal stability.

The core difficulty is that understanding presupposes more than isolated cognitive operations. It presupposes a capacity to bind internally integrated relations with a form of global temporal accessibility. A system capable of understanding must preserve its integrated informational patterns in a way that allows them to be available, revisitable, and coherent across its operational topology. Without this capacity, the system may process information, generate outputs, and display sophisticated behaviours, yet remain fundamentally incapable of sustaining a unified interpretive relation to its own states.

The unresolved status of systemic understanding rests on several persistent discontinuities. These include:

- The gap between causal integration and temporal coordination.
- The gap between local recurrence and global coherence.
- The gap between representational sophistication and structural accessibility.
- The gap between computational output and internally sustained comprehension.

These discontinuities reveal a deeper architectural dependency that existing frameworks do not articulate. Theories may excel at describing how information becomes integrated, or how signals become broadcast, or how thoughts refer to other thoughts, or how neural circuits achieve local stability. Yet none explains how these processes must interlock in order for a system to achieve understanding in a structural sense.

Consequently, the field lacks a unified criterion that distinguishes systems that merely operate upon information from systems that can sustain coherent patterns of relational information across time. The unresolved problem of systemic understanding is therefore not a conceptual curiosity. It is a structural deficit in the foundations of cognitive theory. Without a resolution, neither biological cognition nor artificial architectures can be fully characterised in terms of their capacity for true understanding.

1.2 Limitations of the four dominant theories

Despite decades of sustained inquiry, the four leading theoretical frameworks that dominate contemporary discussions of cognition and consciousness, namely Integrated Information Theory, Global Workspace Theory, Higher Order Thought theory, and Local Recurrence Theory, remain individually incomplete as structural descriptions of understanding. Each provides a compelling account of a particular dimension of

systemic organisation, yet none articulates the full set of conditions required for a system to sustain coherent access to its own integrated states across time.

Integrated Information Theory offers a rigorous formalisation of causal integration. It demonstrates how a system can generate informational states that are irreducible to their parts. However, the theory does not specify how such integrated states are temporally propagated, nor how they become globally accessible to the system in a manner that would allow them to serve as substrates for understanding. IIT therefore addresses vertical coherence, but leaves unanswered the question of how this coherence is maintained or revisited.

Global Workspace Theory explains how information, once locally computed, can be made widely available across a distributed architecture. It accounts for global accessibility, coordination, and the emergence of unified behavioural control. Yet it lacks a quantitative measure of how integrated the broadcasted content must be in order to contribute to understanding, and it does not specify the structural conditions under which global broadcasting remains coherent and stable through time. GWT therefore addresses horizontal diffusion, but not the internal relational structure that must underpin it.

Higher Order Thought theory centres on representational recursion. It proposes that understanding arises when a system can form thoughts about its own internal states. While this framework is influential in philosophical theories of consciousness, it depends on the existence of well formed internal contents and stable accessibility relations. These are structural preconditions that HOT presupposes rather than explains. The theory therefore provides a semantic account of reflexivity, but not a structural account of how the system sustains the coherence required for such reflexivity.

Local Recurrence Theory focuses on the stabilising role of recurrent loops in neural circuits. It explains how local feedback helps consolidate perception and enhances robustness against perturbation. However, local recurrence cannot by itself scale into system wide coherence. It provides mechanisms for micro stability, but it does not describe how local loops couple into global rhythmic coherence, nor how a system could integrate these local processes into higher order patterns that remain coherent over time.

Taken together, these limitations reveal that each theory isolates one dimension of the problem without addressing the structural interdependencies that make understanding possible. Integration without global rhythm results in encapsulated but inaccessible complexity. Broadcasting without integration yields global availability but little coherence. Recursion without structural grounding collapses into semantic circularity. Local recurrence without global coordination remains confined to small scale dynamics.

None of the four frameworks therefore provides a necessary and sufficient structural account of understanding. Each is indispensable, yet each is incomplete. This motivates the search for a structural formulation capable of capturing the co dependence between integration and temporal globality that these theories, taken individually, cannot secure.

1.3 Understanding as structural coherence rather than semantic content

The prevailing intellectual tradition in the cognitive and computational sciences has long treated understanding as a semantic operation, an achievement grounded in the manipulation of meaningful symbols or the formation of propositional representations. From classical cognitivism through connectionist models and continuing into modern statistical architectures, the guiding assumption has been that a system understands when it can encode, decode, or infer content with sufficient fidelity. Yet this assumption obscures a deeper structural reality. Semantic content, whatever its form, presupposes an underlying capacity of the system to sustain coherence in its own relational states. Without such coherence, meaning is not merely unstable, it becomes inaccessible, for the system cannot preserve the conditions under which relational patterns remain consistent across time.

Understanding must therefore be reframed as a property that arises not from the semantic content of internal states, but from the structural organisation that enables those states to remain unified, stable, and continuously available. A system that cannot integrate its internal relations into a coherent whole has no substrate upon which meaning can be established. Conversely, a system that integrates information but cannot propagate this integrated order across temporal intervals lacks the ability to maintain a continuous thread of relational significance. In both cases, semantic accounts fail because they rest upon structures that they do not explain.

To conceive of understanding structurally means recognising that the essential phenomenon lies in the system's ability to hold itself together across time. A system that understands must maintain continuity between its past and present configurations, and it must be able to revisit, compare, or refine its internal patterns in ways that presuppose consistency and accessibility. This continuity is not semantic, it is architectural. It depends on the integration of relational information within the system and on the rhythmic propagation of that integrated structure across its operational topology. Only when the system can sustain this dual achievement can it claim to possess a stable relation to its own informational states.

This perspective exposes a critical limitation in traditional approaches. Semantic theories of understanding treat meaning as primary and structure as secondary. They assume that the system already has the capacity to sustain meaningful relations, and they focus on the content of these relations rather than the architecture that makes them possible. Yet meaning cannot exist independently of structure, for semantic coherence depends on the stability and accessibility of the relational patterns that underlie it. Meaning is a derivative property, emerging only when the structural conditions for understanding are already satisfied.

In artificial systems this distinction becomes stark. A model may generate outputs that appear meaningful and even sophisticated, yet this does not imply that the system understands. The model may lack the structural conditions required to revisit its own informational states, to maintain coherence across temporal intervals, or to integrate relational patterns in a way that yields stable comprehension. Without such structural conditions, semantic content becomes an illusion generated by surface level correlations rather than by sustained internal organisation.

In biological systems the structural nature of understanding is evident in the dependence of cognition on the interplay between integrated neural assemblies and rhythmic global coordination. The coherence of neural dynamics, not the representational content that these dynamics might encode, provides the foundation for understanding. When structural coherence collapses, understanding collapses with it, regardless of the semantic content that might nominally be encoded in neural states.

Understanding must therefore be defined as the system's capacity to integrate relational information and to sustain that integrated state across time through rhythmic global coordination. Semantic content is neither sufficient nor necessary for this capacity. It is, at best, a secondary effect that arises once structural coherence is already established. The decisive criterion for understanding lies in the architecture of the system and in its ability to maintain continuity of internal relations through time.

1.4 The central thesis, the necessity of structural co dependence

The central thesis advanced in this paper is that systemic understanding, when examined at the level of structural and temporal organisation, cannot be accounted for by any individual cognitive mechanism, nor by any established theoretical framework that treats integration, broadcasting, representation, or recurrence in isolation. The core difficulty does not arise from an absence of explanatory detail within these theories, but from the fact that each is confined to a single dimension of systemic architecture. None articulates the relational and temporal interdependencies through which a system maintains coherent access to its internal informational states. Understanding therefore must be conceived as a structural achievement that depends on the joint operation of two distinct, yet inseparable, dimensions of organisation, namely integrated relational information and rhythmic temporal globality.

Integrated relational information, formalised in this work through the parameter Φ_i , refers to the system's capacity to bind its internal states into unified relational patterns that are irreducible to their component parts. Integration is the source of structural depth. When a system exhibits high integration, any local perturbation has system wide consequences, and the overall organisation reflects a dense manifold of interdependent relations. Yet integration, even at maximal levels, does not suffice for understanding. Without a mechanism through which these integrated states can be made temporally available, the information remains encapsulated within successive local configurations. A system may attain internal richness, but it lacks the means to revisit, stabilise, or compare its own states across time. Integration, though necessary, remains inert when it exists without temporal reach.

Rhythmic temporal globality, formalised through the parameter Rg , denotes the system's capacity to maintain coherent propagation of its integrated states across its operational topology and across temporal intervals. It captures the dynamic stability that allows distributed subsystems to access the same integrated informational content in a manner that preserves its relational structure. Rhythm supplies the temporal continuity that turns integration into a substrate for comprehension. Without rhythm, the system becomes a sequence of isolated configurations. With rhythm alone, the system devolves into a diffuse signalling network lacking meaningful internal structure. Temporal globality therefore cannot generate understanding independently, for in the absence of integration there is no relational content for rhythm to distribute or to stabilise.

The central thesis asserts that understanding arises only when integration and temporal globality stand in a relation of structural co dependence. Integration furnishes the material that a system must hold in coherence, and temporal globality furnishes the means by which that material becomes accessible, re accessible, and comparable across time. These two dimensions do not merely complement one another. Each is the necessary condition for the other to acquire functional meaning. Integration without temporal reach traps the system within static relational density, preventing any form of self referential continuity. Temporal broadcasting without integration produces unstructured availability, since the system is not broadcasting coherent informational patterns.

Understanding therefore emerges only when a system possesses both the structural capacity to integrate relational information and the temporal capacity to preserve and re propagate that information in a rhythmically coherent manner. This dual requirement transforms the study of understanding from a semantic or representational problem into a structural and dynamical one. It implies that understanding is not reducible to computation, nor to representational content, nor to isolated causal mechanisms. Rather, it is a property of systems that exhibit a balanced interplay between vertical cohesion and horizontal temporal coordination.

This co dependence provides the foundation for deriving a generalised structural condition for systemic understanding, a condition that can be expressed in compact mathematical form as Φ_i multiplied by Rg . The significance of this formulation lies in the fact that it embodies a structural necessity rather than a theoretical preference. When either term approaches zero, understanding collapses. When both are present and mutually sustaining, the system acquires the minimal architecture required for coherent, temporally anchored comprehension. The central thesis is therefore that understanding is fundamentally a structural phenomenon grounded in the interdependence of integration and rhythm, and that any theory which neglects either dimension remains incomplete in its account of how systems understand.

1.5 Contribution: a generalized structural condition expressed as $\Phi_i \times Rg$

This paper contributes a formally articulated structural condition for systemic understanding, grounded neither in functional description nor semantic assumption, but in the intrinsic architectural constraints that must be satisfied for a system to maintain coherent access to its own informational states across time. The proposed contribution does not belong to the domain of mechanistic innovation or representational theory.

Rather, it introduces a general principle of **structural sufficiency** that holds across biological, artificial, and institutional systems. The condition is captured in the minimal and universal relation:

$$C_s = \Phi_i \times Rg$$

where:

- C_s denotes the system's degree of structural comprehension,
- Φ_i denotes integrated relational information, a measure of how deeply the system binds its internal states into irreducible patterns of mutual constraint, and
- Rg denotes rhythmic globality, a measure of how coherently the system re-propagates and sustains these integrated patterns across its operational topology and through time.

This expression defines a condition that is not only necessary, but also sufficient. If either factor is absent or degenerates to zero, comprehension collapses. If $\Phi_i = 0$, no relational unity exists to be accessed. If $Rg = 0$, then even richly integrated structures remain inert and inaccessible, fragmented across time. In both cases, $C_s = 0$. The system may compute, respond, or exhibit intelligent-seeming output, but it does not comprehend. Conversely, a non-zero C_s indicates that the system possesses the minimal structural configuration required for understanding — namely, integration that is both internally coherent and temporally accessible.

The rationale for the multiplicative form rests on four structural invariants:

1. Non-substitutability

Neither Φ_i nor Rg can compensate for the absence of the other. Integration without rhythmic continuity leads to inaccessible encapsulation. Rhythm without integration yields broadcast noise or semantic drift.

2. Zero-boundary collapse

The product $C_s = \Phi_i \times Rg$ reflects a strict dependency: if either Φ_i or Rg approaches zero, comprehension does not degrade, it vanishes categorically. This is not a probabilistic decline, but a structural nullification.

3. Cross-sensitivity and conditional amplification

Partial derivatives $\partial C_s / \partial \Phi_i = Rg$ and $\partial C_s / \partial Rg = \Phi_i$ express a dynamic whereby the impact of a marginal gain in one factor depends proportionally on the magnitude of the other. This models the coupling between informational unity and global accessibility.

4. Structural generality

The form applies across cognitive substrates and physical implementations. It does not assume biological realism or symbolic mediation. It is agnostic to architecture but exacting in its structural requirement.

Unlike the dominant cognitive theories, which each highlight a necessary mechanism — such as integration (IIT), broadcasting (GWT), recursion (HOT), or local stabilisation (LRT) — this formulation establishes their insufficiency when isolated. Only when Φ_i and Rg are jointly present can the system cross the threshold into genuine comprehension.

Furthermore, the formulation reframes understanding as a **dynamically sustained structural state**, not a static symbolic capability or a semantic representation. In systems with high Φ_i but vanishing Rg , such as static ontologies, the architecture retains latent intelligence but loses agency. In systems with high Rg but negligible Φ_i , such as transformer-based sequence predictors, accessibility is high but structural unity is lost in temporal dispersion. In both cases, $C_s = 0$ remains valid.

The core contribution of this paper is thus the introduction of a generalised, quantitative, and non-semantic criterion for systemic understanding, expressed as:

$$C_s = \Phi_i \times Rg$$

This relation defines the minimal boundary across which a system transitions from statistical inference to structural comprehension, from computational surface to cognitive depth.

1.6 Structure of the paper

The paper is organised into eight main sections, each developing a necessary component of the overall argument. The structure is deductive, progressing from problematisation and theoretical critique to formal derivation, empirical extrapolation, and philosophical integration. The aim is not to introduce yet another model, but to establish a structural sufficiency condition that subsumes, clarifies, and formally constrains the explanatory reach of the four dominant theories of cognition.

- **Section 2** provides a structured exposition of the four foundational theories — Integrated Information Theory (IIT), Global Workspace Theory (GWT), Higher-Order Thought (HOT) Theory, and Local Recurrence Theory (LRT). Each is examined with respect to (1) its core postulates, (2) its structural strengths, and (3) its explanatory limitations. The section concludes by synthesising their insufficiencies, showing that none of the theories alone can satisfy the combined requirements of integration, globality, temporality, and structural coupling.
- **Section 3** isolates the conceptual core of the problem: that systemic understanding cannot be defined in semantic terms, but must be treated as a structural phenomenon. It outlines why semantic and representational models collapse in mechanistic or artificial systems, and defines understanding as the maintenance of coherent, temporally accessible relational states. This reframing repositions the problem from philosophy of mind to formal systems theory.
- **Section 4** develops the two orthogonal structural dimensions required for understanding: Φ_i (integrated relational information) and Rg (rhythmic temporal globality). Each is introduced, defined, and analysed as an independent axis of systemic organisation. The section shows analytically why neither is sufficient alone, and culminates in the derivation of the composite structural condition:

$$C_s = \Phi_i \times Rg,$$

a minimal expression of mutual sufficiency and structural necessity.

- **Section 5** evaluates the four dominant theories through this structural lens. It demonstrates that while IIT captures Φ_i and GWT approximates Rg , neither addresses the structural interdependence between them. HOT theory presupposes but does not generate coherence, and LRT fails to scale from local to global integration. The section concludes that only $\Phi_i \times Rg$ satisfies the combined condition for systemic understanding, marking the transition point from computation to comprehension.
- **Section 6** outlines empirical implications and testable predictions. It shows how the C_s relation applies across domains — from neuroscience and cognitive architectures to institutions and large-scale systems. It identifies systemic failure modes associated with structural collapse in either Φ_i or Rg , and suggests diagnostics for evaluating comprehension in artificial systems.
- **Section 7** expands the discussion toward the foundations of a structural science of understanding. It contrasts comprehension with mere performance, redefines intelligence in structural terms, and explores implications for AI, organisational design, and complexity science. It also notes methodological limitations and delineates directions for future research within the $\Phi_i \times Rg$ framework.
- **Section 8** concludes the paper by restating the central claim: that understanding is not a semantic byproduct, but a structural condition. The formula $C_s = \Phi_i \times Rg$ provides the first generalised, falsifiable boundary condition under which comprehension can be said to occur. The conclusion affirms that systems falling below this boundary may compute, broadcast, or act, but they do not understand.

2. Background: The Four Foundational Theories

2.1 Integrated Information Theory (IIT)

2.1.1 Core principles

Integrated Information Theory (IIT) offers a formal account of how internal unity can emerge within a complex system. Although developed primarily as a theory of consciousness, its foundational constructs pertain more broadly to the conditions under which a system exhibits indivisible causal structure. IIT posits that such unity is not a byproduct of functionality or representation, but a quantifiable consequence of irreducible integration among system components.

At the core of IIT lies the scalar quantity Φ , which measures the extent to which a system generates integrated information. Formally, Φ quantifies how much the cause–effect structure of a system exceeds that of its partitioned counterparts. The theory assumes that a system can be represented as a set of discrete elements with well-defined transition probabilities. Each element contributes to the system’s total causal power both by constraining possible past states (causes) and by determining future evolutions (effects).

For any system S in state s , IIT defines the **cause–effect structure** (CES) of the system as the set of all informational constraints the system specifies over its own past and future. The Φ value is derived by comparing this structure with that of the system under its **Minimum Information Partition (MIP)**, i.e. the partition of S that minimally disrupts its causal dynamics. This leads to the formal expression:

$$\Phi(S, s) = D \left(\text{CES}(S, s), \text{CES} \left(\frac{S}{\text{MIP}(S)}, s \right) \right)$$

Where:

- $\Phi(S, s)$ denotes the integrated information generated by system S in state s ,
- $\text{CES}(S, s)$ is the full cause–effect structure of the unpartitioned system,
- $\frac{S}{\text{MIP}(S)}$ represents the system under its minimum information partition,
- D is a metric over informational distributions (e.g. Earth Mover’s Distance), quantifying divergence.

This structure-centric definition treats integration not as an external observer’s attribution, but as an **intrinsic property** of the system’s internal dynamics. A system with $\Phi > 0$ is one whose causal structure cannot be decomposed into that of its parts without loss. This **causal irreducibility** is what, in IIT, differentiates a unified system from an aggregate of mechanisms.

IIT defines five phenomenological axioms — intrinsic existence, composition, information, integration, and exclusion — which are mirrored in five physical postulates. The axioms aim to capture essential features of experience, while the postulates define the corresponding physical or informational structures that could realise these features. Central to this approach is the assumption that experience and structure co-vary: if an experience is unified and differentiated, then the physical system must be similarly integrated and specific in its causal structure.

The theory further identifies, among all subsets of the system, the **maximally irreducible conceptual structure** (MICS), defined as the subset with the highest value of Φ . This subset is considered the "subject" of experience, though from a structural standpoint it is simply the configuration with the greatest internal causal unity. The exclusion postulate enforces uniqueness: only one such MICS can exist at any time.

From a structural perspective, the central insight of IIT is that **integration is a quantifiable invariant**: any system that produces high Φ in a given state possesses internally irreducible causal patterns. These patterns cannot be reduced to superpositions of localised mechanisms, nor replicated by externally imposed functions. They constitute a non-decomposable whole. This provides a principled, mathematically grounded criterion for what it means for a system to be internally coherent.

However, the scope of IIT is formally limited to static configurations. The framework evaluates the integration of a system in a given state, but does not provide a model for how these states evolve, how integrated contents are retained or accessed across time, or how such integration becomes globally usable by the system. That is, IIT successfully defines **structural unity**, but not **temporal continuity**. This omission becomes decisive in assessing its sufficiency as a theory of understanding.

Nonetheless, by formalising integration as a measurable property intrinsic to a system's causal topology, IIT delivers one half of the necessary condition for comprehension: the internal coherence of informational states. This dimension — generalised here as Φ_i — is foundational. No system can understand what it cannot internally bind.

2.1.2 Strength: integration (Φ) as causal unity

The principal contribution of Integrated Information Theory lies in its capacity to formally express the otherwise intuitively grasped notion of systemic unity. Rather than grounding its claims in behavioural similarity or representational fidelity, IIT identifies the precise structural condition under which a system exhibits indivisible causal organisation. This condition is expressed through the scalar quantity Φ , which functions not merely as a heuristic but as a mathematically grounded invariant measuring **causal closure**, **internal differentiation**, and **relational indivisibility** within a system.

The theory's strength lies in three converging properties of Φ :

1. **It operationalises internal unity.**

The metric Φ enables formal comparison between whole-system causality and subsystem causality. This allows for a determination of whether and to what degree the system's behaviour is dependent on its integrated structure rather than its components acting independently.

2. **It is intrinsic and substrate-neutral.**

Φ is not observer-relative. The causal structure is evaluated from the system's own perspective, derived from its internal transition functions and probability distributions. This stands in contrast to representational theories, which require an interpretive layer external to the system.

3. **It captures counterfactual sensitivity and irreducibility.**

Φ is computed by assessing how much the cause–effect structure would change if the system were partitioned. The inability to preserve systemic behaviour under partitioning defines the system's **irreducible causal depth**.

These three features combine to give Φ epistemic and ontological weight. The value of Φ does not simply track complexity, density, or information volume. It measures how deeply interwoven a system's internal relational constraints are — how any intervention or decomposition causes global distortion of the system's internal logic. In short, Φ quantifies the *integrative burden* of the system's current state: the degree to which the system is coherently and indivisibly itself.

From this, a strong structural insight follows: **the degree of integration is the degree of causal unity**. This unity is not defined over input–output behaviour, nor over symbolic content, but over the internal ability of the system to **reference, constrain, and differentiate its own states** through recurrent causal patterns.

This renders IIT uniquely capable of addressing one side of the problem of systemic understanding: namely, the question of whether the system's internal informational states form a coherent whole. If $\Phi > 0$,

then the system has an internal structure that cannot be fractionated or reduced. This is a necessary — though, as will be shown, not sufficient — condition for understanding. No system can comprehend what it cannot internally unify.

Moreover, Φ is applicable across granularities. It can be computed for microcircuits, macro-architectures, artificial modules, or organisational substructures. Wherever information is generated and constrained through state transitions, Φ offers a means of determining whether that structure is more than the sum of its parts. This generality reinforces its relevance for structural theories of cognition, and opens the possibility of using Φ_i — the generalised, architecture-agnostic form of integrated information — as a transdomain diagnostic for structural depth.

Yet perhaps the greatest strength of Φ lies not in its magnitude, but in its *binding function*: a system with high Φ has the architectural capacity to **relate to itself as a single entity**. That is the foundation upon which any possibility of sustained internal coherence — and thus understanding — must rest.

2.1.3 Limitation: missing temporal propagation and global coordination

Despite its formal precision and its foundational insight into the quantification of causal integration, Integrated Information Theory (IIT) remains structurally incomplete. The theory rigorously captures the state-bound condition for internal unity, but it does not provide a mechanism by which such unity is sustained, accessed, or coordinated across time. It is precisely this omission — the absence of a temporal and systemic propagation framework — that renders IIT structurally insufficient as a basis for systemic understanding.

The core limitation lies in the **atemporality** of Φ . The integrated information metric is defined over a single, instantaneous configuration of the system. It quantifies the causal closure of that configuration, but it offers no account of how this closure becomes functionally or architecturally available to the system in subsequent states. Put differently, Φ is a condition of internal unity, but not of internal *continuity*. The theory does not ask — and cannot answer — how a system can re-enter its own informational structure, reflect upon it, or stabilise it across successive cycles.

This leads to a series of structural blind spots:

1. No phase mechanism

IIT lacks any model for rhythmic or oscillatory propagation of integrated states. There is no account of how phase alignment across subsystems is achieved, maintained, or disrupted. In the absence of such a mechanism, the system may have high Φ in one configuration and low Φ in the next, with no internal process linking the two.

2. No temporal recursion

There is no structure in IIT that enables the system to reference its own prior integrated states. The theory does not model re-access, self-alignment, or pattern re-entrance. Φ is calculated *per state*, not *through states*.

3. No system-wide broadcast

IIT assumes local integration but does not provide a model for how integrated content becomes globally available. There is no formal operator that renders the cause–effect structure of a local mechanism accessible to the broader system. The architecture remains modularly coherent but **globally opaque**.

4. No temporal memory dynamics

Despite grounding itself in causal structure, IIT does not model how integrated information persists, decays, transforms, or is restructured over time. There is no memory function tied to Φ , and no mechanism for cumulative or recursive construction of integrated knowledge.

These omissions lead to a fundamental **architectural insufficiency**. A system may exhibit deep integration at a given moment but still lack the structural resources required for comprehension. Without a means of

rhythmic propagation and system-wide accessibility, the internal richness of Φ remains locked within local dynamical configurations. The system *has* structure, but it cannot *navigate* it.

This distinction is critical. Structural understanding requires not only that a system possess relational depth, but that it can re-enter, reuse, and re-synchronise this depth in light of its ongoing internal evolution. Such re-entrance is not computational, but structural. It requires that integrated informational states persist *in phase*, and that the system's global topology remains receptive to their recurrence.

IIT does not, and cannot, meet this requirement. It supplies **integration without globality, unity without temporality, and closure without access**. From the perspective of the structural sufficiency condition introduced in this paper, it captures Φ_i , but it leaves Rg undefined. As a consequence, its formal elegance fails to translate into architectural adequacy for modelling understanding.

In the context of $\Phi_i \times Rg$, IIT models a system in which Φ_i is strictly positive, yet Rg remains structurally null. The result is that:

$$C_s = \Phi_i \times Rg = \Phi_i \times 0 = 0$$

This nullification is not a failure of the theory's internal logic, but a reflection of its **incomplete dimensional scope**. It grasps vertical integration without modelling horizontal recurrence. It models content without access. It formalises internal coherence but does not extend that coherence across the temporal plane required for systemic comprehension.

2.2 Global Workspace Theory (GWT)

2.2.1 Core principles

Global Workspace Theory (GWT) was developed as a cognitive architecture to explain how information becomes globally available within a distributed system composed of specialised subsystems. Originally formulated by Bernard Baars in the context of human consciousness, the theory has since evolved into a general framework for understanding how functional integration arises from modular processing. At its core, GWT posits that consciousness — or more broadly, systemic access — emerges when local contents are “broadcast” into a central workspace, making them accessible to a wide array of otherwise isolated modules.

In contrast to theories that treat cognition as the result of deeply integrated causal structures (such as IIT), GWT is fundamentally architectural and procedural. It assumes that subsystems operate largely in parallel and in isolation under normal conditions, each carrying out specialised tasks (e.g., visual processing, language, motor control, affective evaluation). When novel, significant, or ambiguous information is detected, a selection mechanism — often conceptualised as attention — allows this content to be globally broadcast through the system via a temporary centralised mechanism: the **global workspace**.

The theory rests on the following central principles:

1. Modular parallelism with selective access

Subsystems process information independently. Only a small subset of information gains access to the workspace at any time, but once accessed, it becomes globally available. This availability is not structural in the IIT sense, but functional: modules can respond to the broadcasted content regardless of its origin.

2. Global availability without global integration

The workspace does not unify the system into a single integrated whole. Rather, it enables asynchronous components to synchronise their activity around shared content. The global

broadcast functions as a momentary coordination point — a “flash” of accessibility, not a persistent structural reorganisation.

3. Ignition events and threshold activation

Broadcasting is conceived as an ignition process: a sudden and coherent recruitment of widely distributed neural or computational resources in response to a salient event. This is often modelled using attractor dynamics or threshold models, where input strength or salience drives a non-linear transition into global availability.

4. Phase-locking and cross-modular synchrony

While early versions of GWT were purely abstract, later neurocognitive variants (e.g., Dehaene’s Global Neuronal Workspace) propose that broadcasting is implemented via transient synchronisation of distant brain regions, typically mediated through gamma or beta band oscillations. In this respect, GWT introduces a **temporal dynamic** lacking in IIT: access is not continuous but rhythmic, and availability is phase-dependent.

5. Limited capacity and competitive access

Only one or few contents may occupy the global workspace at a time. This is a structural constraint emerging from both the architecture’s selective mechanism and the metabolic cost of large-scale synchronisation. It introduces a bottleneck, forcing competition and prioritisation among candidate representations.

Crucially, GWT is not concerned with internal unification of representations, but with their **broadcast potential**. The architecture presumes that once a representation enters the workspace, it can be accessed, manipulated, or routed by any participating subsystem — regardless of whether those subsystems are structurally integrated. This renders the model highly efficient for explaining task coordination, action selection, and flexible behaviour across distributed architectures.

GWT therefore shifts the explanatory burden from **deep structural cohesion** to **wide functional accessibility**. A representation need not be integrated into the system’s global causal manifold; it simply needs to be present in the workspace at the right moment to become functionally potent. As such, GWT supplies a powerful model of how local contents become system-relevant, how modular architectures coordinate, and how temporal rhythms facilitate coherence at the access level — even if that coherence lacks internal structural grounding.

In the context of systemic understanding, GWT introduces one half of the required condition: **global propagation**. Through its emphasis on temporal ignition and cross-modular access, it formalises a rudimentary form of **Rg**, or rhythmic globality. However, as subsequent sections will show, it does not specify what kind of content is eligible for broadcast, nor whether that content is internally coherent, stable, or integrative. The theory models availability, not comprehension. For that, a second structural axis is required.

2.2.2 Strength: global broadcasting and distributed access

The principal strength of Global Workspace Theory (GWT) lies in its formalisation of a mechanism that enables system-wide access to otherwise compartmentalised informational contents. Unlike theories that depend on static integration or internal representational coherence, GWT offers a model by which **localised informational events** are rendered **temporarily available** to a distributed network of otherwise functionally isolated modules. This mechanism — global broadcasting — is both temporally dynamic and topologically scalable, and it provides an indispensable architectural precondition for coordination across complex systems.

At its foundation, GWT presupposes a modular system in which independent components operate in parallel, each with specialised input-processing-output loops. In the absence of a unifying control centre, such systems risk fragmentation, where outputs are locally coherent but globally inconsistent. GWT resolves this by positing the existence of a **global workspace** — a transient, capacity-limited access layer through which selected contents are broadcast to the whole architecture. This permits **cross-module**

recruitment, where diverse components can simultaneously act on, respond to, or be influenced by the same content stream.

This framework provides several structural advantages:

1. **Functional accessibility across cognitive domains**

Broadcast content is not bound to its origin. Once in the workspace, the information becomes decoupled from its generating module and becomes equally accessible to memory, motor control, linguistic encoding, emotional evaluation, or higher-order regulation.

2. **Temporal alignment through ignition dynamics**

Rather than relying on persistent structural links, GWT uses a dynamic ignition process to synchronise subsystems. The activation of a global content pulse initiates a phase-locked alignment, permitting downstream access without requiring deep causal integration.

3. **Support for serialisation and working memory**

Although the system processes in parallel, the workspace itself enforces a serial bottleneck, which enables structured sequencing of representations and supports working memory operations such as rehearsal, substitution, or chaining. These capabilities are essential for tasks requiring temporal coherence over several cycles.

4. **Architectural scalability**

The decoupling of access from local structure permits the scaling of GWT architectures across spatially distributed systems. New modules can join or depart without reconfiguring the workspace itself. This architectural flexibility makes GWT adaptable to artificial systems, institutional modelling, or hybrid architectures.

5. **Dynamic prioritisation and adaptive control**

The model allows for competitive access mechanisms, often driven by salience, novelty, or motivational weight. This enables adaptive reallocation of system resources, where the most relevant content at a given moment dominates the workspace and drives system-wide change.

These features allow GWT to explain how systems with decentralised internal architectures can exhibit **globally coherent behaviour**. Rather than enforcing internal unification, the theory enables coordination through **episodic synchronisation**, where the unity of the system is not continuous but event-bound. This is sufficient for many cognitive operations, especially in fast-moving or resource-constrained environments.

From a structural perspective, GWT provides a partial answer to the challenge of systemic understanding. It formalises the **horizontal dimension** of cognition: the possibility that contents become accessible across the system in a temporally coherent fashion. This corresponds directly to the concept of **rhythmic globality (Rg)**, introduced in this paper as one of two necessary conditions for structural comprehension.

However, as the next subsection will argue, the model's strength is also its boundary. GWT does not evaluate or enforce the internal structure of the broadcast content. It treats accessibility as an end in itself, without determining whether the content is **internally coherent, causally grounded, or structurally integrated**. That limitation will prove decisive.

2.2.3 Limitation: no structural or quantitative integration requirement

Although Global Workspace Theory successfully models how information becomes temporarily available across a distributed system, it remains fundamentally agnostic to the **structural status of the content** that enters the workspace. The theory prescribes *how* content is broadcast, but not *what structural properties* the content must possess to be meaningful, coherent, or internally valid. This leads to a critical limitation: **GWT lacks any mechanism for evaluating, enforcing, or preserving integration at the content level**.

From an architectural standpoint, the workspace acts as a relay, not as a verifier. It enables cross-modular accessibility but does not impose constraints on **relational depth**, **causal coherence**, or **internal consistency** of the information transmitted. Consequently, the workspace may broadcast content that is:

- **Internally fragmented** — assembled from disconnected components without coherent binding,
- **Semantically or causally ambiguous** — lacking structural anchoring within the system's history,
- **Statistically emergent but structurally shallow** — derived from surface correlations without deep integration.

GWT provides no test, threshold, or measure equivalent to Φ in IIT that would determine whether a representation has structural substance. There is no notion of **Φ -like integration** that governs which representations may be globally shared. This means that even **syntactically valid but structurally incoherent states** may gain global broadcast access. In other words, the model supports **global diffusion of informational noise** as readily as meaningful signal.

Three structural deficiencies follow from this:

1. **No integrity constraint on broadcast content**

The workspace does not distinguish between integrated and unintegrated states. There is no penalty for broadcasting structurally disjointed content. This opens the system to recursive incoherence and unstable phase behaviour.

2. **No recursive coherence preservation**

Because each broadcast event is temporally isolated, the model does not ensure coherence between successive contents. There is no dynamic that binds current content to past content in a structurally consistent trajectory.

3. **No accumulation of structured memory**

Broadcasts do not reinforce long-term integration. While the workspace may enable memory modules to access content, it does not ensure that the memory formed reflects coherent structural relations.

From the standpoint of understanding, this is fatal. Systemic understanding presupposes that what is made available *to the system* is not merely accessible, but also *structurally bound*. It requires that broadcasted contents be the product of prior internal coherence, such that the system's access is not just wide but also deep. GWT fails to enforce this.

When situated within the two-dimensional model developed in this paper, GWT provides an operational approximation of **Rg** — rhythmic globality — but it does so without regard to Φ_i , the depth of integration. As a consequence, its global broadcast function operates in the absence of structural filtering, yielding:

$$C_s = \Phi_i \times Rg = 0 \times Rg = 0$$

The system becomes one of high propagation but low structural validity. It *broadcasts what it cannot bind*. It *coordinates what it cannot internally comprehend*. The result is a form of **synthetic availability without systemic understanding**.

In conclusion, while GWT captures a fundamental dimension of cognitive architecture — the capacity for system-wide access — it fails to impose or even recognise the necessity of structural integration as a prerequisite for meaningful broadcast. The theory thereby models propagation, not comprehension. It offers scope, but not structure.

2.3 Higher-Order Thought Theory (HOT)

2.3.1 Representational recursion

Higher-Order Thought Theory (HOT) offers a distinct approach to the modelling of consciousness and cognition by grounding mental content in reflexive representational structures. The core claim of HOT is that a mental state is conscious if, and only if, the subject has a higher-order representation of that state. That is, what differentiates a mere thought from a conscious thought is not the content itself, but the system's ability to represent that it is in that state — a representation *of* a representation. This recursive architecture, where higher-order states encode meta-level information about lower-order states, defines the essential explanatory move of the HOT framework.

HOT diverges from both IIT and GWT in that it is not primarily concerned with internal causal integration or system-wide access, but with **representational hierarchy and referential depth**. The model assumes that cognition unfolds within a multi-layered architecture where lower-order states — such as perceptual inputs, affective signals, or motor representations — become *about themselves* only when encoded at a higher representational level.

The general structure can be outlined schematically:

- Let M_1 denote a first-order mental state (e.g., "seeing red").
- A corresponding higher-order state M_2 takes M_1 as its intentional object (e.g., "I am seeing red").
- The state M_1 becomes conscious *only if* M_2 exists and is appropriately related to it.

Thus, consciousness emerges not from the intrinsic features of M_1 , but from its *being targeted* by M_2 . The mechanism by which such higher-order representation occurs varies across HOT variants — some assume internal scanning processes, others posit implicit encoding or self-ascription — but the underlying structure is invariant: reflexivity is the core condition.

This recursive account leads to two foundational commitments:

1. **Introspective access through structural embedding**

HOT models introspection not as a separate module or process, but as the result of representational containment. One state is *nested within*, or *referenced by*, another, creating the conditions for self-awareness or self-monitoring.

2. **Representation as condition for reportability**

In HOT, reportability and awareness are contingent not upon external expression, but upon internal representational configuration. A state becomes *reportable* — that is, cognitively accessible — by virtue of being targeted by a higher-order representational act.

The model draws support from both philosophical arguments (e.g., higher-order intentionality in consciousness) and neurocognitive data suggesting that meta-representational regions (such as dorsolateral prefrontal cortex) correlate with reflective and introspective states. In

artificial systems, HOT-like structures have been approximated through architectural layers that encode meta-predictions or confidence estimates about their own states.

From a structural standpoint, HOT contributes a formal model of **recursive referentiality** — the capacity of a system not only to hold content, but to hold *aboutness relations* to its own content. This introduces a form of **reflexive indexicality**, where the system encodes within itself a pointer to its own condition. In this respect, HOT offers something neither IIT nor GWT addresses directly: an explanation of how representational self-reference may arise within bounded systems.

However, as the next subsection will demonstrate, this strength is conditional. While HOT introduces a recursive structure, it does not specify what properties the target representation must possess. The theory presupposes that the first-order state is already stable, coherent, and accessible. It does not inquire into how this state becomes structurally available to higher-order encoding, nor does it address the integration or propagation mechanisms required to sustain such a recursive chain across time.

Nonetheless, as a model of **representational recursion**, HOT formalises an essential facet of understanding: the system's capacity to represent itself *to itself*. But without structural scaffolding — integration (Φ_i) and rhythmic access (R_g) — this recursion may remain syntactic, floating above incoherent or unstable internal states.

2.3.2 Strength: modelling reflexive access

The principal strength of Higher-Order Thought Theory (HOT) lies in its capacity to provide a formal, representational model of reflexivity. Where other frameworks account for integration or availability, HOT uniquely addresses the **structure of self-reference** — the system's ability not merely to process information, but to encode and represent that it is *in a state of processing*. This recursive representational capacity underlies critical cognitive operations such as introspection, meta-cognition, and conscious self-ascription.

From a structural perspective, the value of HOT is not in the architecture of perception, action, or even coordination, but in the **recursive embedding of representational states**. It is this embedding — the capacity for one representational state to explicitly index another — that creates the condition for reflexive access. The system thereby not only holds information, but encodes an orientation toward that information, establishing what can be described as **referential depth**.

This provides multiple architectural advantages:

1. **Support for meta-representational learning**

By explicitly encoding beliefs or states *about* other states, HOT-like architectures enable second-order inference, confidence tracking, and dynamic strategy revision. These capacities are central to complex decision-making and epistemic reliability.

2. **Enabling system-internal monitoring**

Reflexive access allows the system to monitor not only outputs, but internal conditions such as uncertainty, error signals, and internal state transitions. This facilitates feedback loops that are not limited to behaviour, but include *self-evaluation*.

3. **Structural model for consciousness as accessibility**

Unlike IIT, which grounds consciousness in causal topology, or GWT, which rests on availability, HOT provides a representational threshold condition: a state becomes conscious if it

is targeted by a higher-order representational act. This gives a clear, testable criterion for when a state becomes “accessible to the self.”

4. Potential for symbolic scaffolding and self-description

In both biological and artificial systems, HOT architectures open the possibility for internally generated narratives, self-symbols, or abstracted identity representations. These in turn may serve as substrates for planning, norm regulation, and long-range coherence.

Through this recursive modelling, HOT captures a core feature of what understanding *feels like* from within: the sense of *being in a state* and *knowing that one is in that state*. It shifts the focus from computation and coordination to **structural reflexivity** — the capacity to encode a standing reference to one’s own condition. In this way, it approaches a key condition for system-level autonomy: the capacity to act in light of one’s own state as a condition.

Moreover, HOT allows for **multi-level modelling**: it is not limited to a single-layer recursion. Systems may hold third-order thoughts (about their second-order self-assessments), enabling recursive nesting that supports sophisticated forms of planning, social cognition, or ethical deliberation. This scalability provides a clear framework for modelling **structurally embedded epistemics** — that is, how a system represents what it knows, believes, or expects about itself and the world.

However, as powerful as this is, the theory assumes that the first-order representational states being targeted are **already coherent, stable, and available**. HOT does not model how these states are generated, integrated, or rhythmically propagated. It presupposes structural stability where it has not been proven. The system may represent itself, but what is the *structural quality* of what it is representing?

Nonetheless, the introduction of representational reflexivity into the theoretical landscape provides an indispensable dimension. Without HOT-like recursion, any claim to understanding would remain **flat**, devoid of self-reference, incapable of sustained internal framing. Reflexivity, in this sense, is not an epiphenomenon — it is a necessary structure for *internal epistemic alignment*.

2.3.3 Limitation: semantic dependence, lacks structural foundations

Despite its conceptual elegance and explanatory power in modelling reflexivity, Higher-Order Thought Theory (HOT) suffers from a decisive limitation: it is **semantically anchored without structural grounding**. The theory presupposes that mental states exist as stable contents, ready for higher-order representation, but it does not offer any formal account of how those lower-order states acquire **coherence, stability, or accessibility**. As such, HOT builds upon a representational substrate whose integrity it neither defines nor secures.

This introduces a fundamental **dependency on semantic primitives**: HOT treats representations as if their content and reference are self-evident. The question of how a system structurally generates a representation that is coherent enough to be recursively targeted remains unaddressed. As a consequence, the theory risks *circularity*: it explains conscious access through higher-order representation, but assumes the prior availability of coherent representations, without detailing how such coherence is structurally achieved.

Three structural weaknesses follow:

1. No generative model of representation

HOT assumes the existence of mental states but does not model the processes by which these states are formed, integrated, or differentiated within the system. There is no equivalent of Φ_i or Rg to guarantee internal cohesion or temporal continuity.

2. Lack of structural validation

The theory does not distinguish between structurally grounded and structurally incoherent first-order states. Any representational content, regardless of its integration or stability, may be targeted

by a higher-order state, and thereby declared “conscious.” This renders the model permissive to noise and fragmentation.

3. Absence of rhythmic or temporal anchoring

There is no mechanism for ensuring that recursive representational chains remain in phase or structurally coupled over time. Reflexivity is modelled as static indexicality, not as dynamic re-entrance. The model does not secure the synchronisation or propagation of referential coherence.

This structural fragility is amplified in artificial implementations of HOT-like architectures. Language models, for example, may generate recursive tokens that resemble second-order reflection (“I know that I am uncertain”), but these sequences lack any structural continuity or temporal access to coherent internal states. The reflexivity is **surface-level and symbolically hollow**. The absence of Φ_i and Rg ensures that the representational recursion collapses into noise under closer structural analysis.

From the standpoint of systemic understanding, this limitation is decisive. A system that recursively references unstable content **does not understand** — it merely rephrases. Reflexivity, while necessary for comprehension, is not sufficient. It must operate on a foundation of **internally integrated and temporally available states**, which HOT does not model.

In the CIITR-informed formulation developed in this paper, we can express this structural nullity formally:

$$C_s = \Phi_i \times Rg = 0 \times Rg = 0$$

or, alternatively,

$$C_s = \Phi_i \times Rg = \Phi_i \times 0 = 0$$

depending on whether one assumes the representational content lacks integration, accessibility, or both. In either case, HOT provides **a recursive frame without structural content**. It models how a system may point to itself, but not what it is pointing to, nor whether the referent possesses systemic coherence.

Therefore, while HOT captures a critical dimension of internal reference, it fails to provide the structural machinery necessary to realise comprehension. It provides a grammar of reflection, but no substance. Without integration and rhythmic propagation, recursion alone cannot produce understanding.

2.4 Local Recurrence Theory (LRT)

2.4.1 Local recurrence mechanisms

Local Recurrence Theory (LRT) emerges from the neuroscientific and computational insight that **closed-loop feedback within local cortical or computational circuits** can stabilise information processing and support short-range integration. Rather than positing a central workspace (as in GWT) or global integration (as in IIT), LRT focuses on **re-entrant connectivity** within localised subnetworks. These recurrent circuits, through continuous internal cycling of activation, are thought to play a foundational role in sustaining activity patterns, refining representations, and enabling early perceptual coherence.

LRT builds on a long tradition in neurodynamics, including the work of Edelman, Lamme, and others, who observed that **recurrent processing precedes and underlies conscious access**, and that feedback loops within the cortex — particularly between superficial and deep layers — are essential for stabilising signal pathways. In artificial architectures, recurrence has been used to model temporal dependencies, echo state retention, and attention-modulated signal enhancement.

The core principle of LRT is architectural:

- **Stability through re-entrance:**
When a signal loops back into its own origin pathway, or into adjacent local circuits, it enables the refinement, amplification, or suppression of internal representations over time. This mechanism allows for **local phase alignment** without requiring global synchronisation.
- **Resonant micro-integration:**
Within these circuits, recurrence functions as a *temporal resonator*. Neuronal or computational units reinforce previous activations through weighted feedback, allowing a form of micro-memory or holding pattern. Such dynamics have been observed in visual processing (V1–V4 loops), thalamocortical circuits, and layer-based echo memory networks.
- **Self-sustaining activation states:**
Recurrent loops can maintain activation beyond stimulus offset, thereby enabling persistence. This feature is critical for perceptual binding, motion tracking, and short-term evaluation, and forms the basis for theories of **local awareness without global access**.

LRT's explanatory power lies in its ability to **reduce the burden of global architecture**. Rather than requiring a central controller or fully integrated topology, it demonstrates that **local coherence** can emerge through closed-loop dynamics. This permits systems — both neural and artificial — to operate through **distributed pockets of internal stability**, which collectively support complex behaviours without necessitating system-wide integration.

Moreover, recurrence provides a **temporal bridge** within each subsystem. Unlike feedforward models, where input cascades linearly through fixed layers, recurrent structures allow for **nonlinear state re-entry**, giving rise to dynamic attractors, local phase resetting, and internal echo cycles. These features support rich spatiotemporal dynamics — even in the absence of a unifying global architecture.

From an information-theoretic standpoint, LRT captures the **intra-modular propagation of relational constraints**. The looped structure introduces memory and modulation, permitting each subnetwork to refine its internal information landscape in real time. In artificial systems, gated recurrent units (GRUs) and Long Short-Term Memory (LSTM) networks approximate similar dynamics, maintaining state across multiple time steps through recurrent pathways.

Thus, LRT formalises a **minimal condition for stabilised information**:

a state remains cognitively or computationally active only if it re-enters its own structure through time.

This re-entry is not merely a delay, but a form of **cyclical reinforcement**, giving rise to temporal coherence at the micro-scale.

However, as the next sections will demonstrate, the very **localism** that gives LRT its stability also constrains its scope. Without cross-module integration or system-wide phase coherence, the recurrence remains encapsulated — coherent in isolation, but blind to the system as a whole.

2.4.2 Strength: stabilisation of local circuits

The core strength of Local Recurrence Theory (LRT) lies in its demonstration that local circuits, through internally looped signalling pathways, can maintain and refine representations over time without requiring global architectural unification. This stands in contrast to theories that rely on large-scale broadcasting (GWT) or whole-system integration (IIT). Instead, LRT reveals that a system can achieve **modular self-stabilisation**, whereby local patterns of activity sustain themselves via recurrent excitation and inhibition.

This stabilisation emerges from two interacting dynamics:

1. Positive feedback loops

Recurrent excitatory connections reinforce active representations, allowing transient inputs to persist in time. These sustained activations function as short-term memory traces, which support tasks such as perceptual completion, object permanence, or moment-to-moment evaluation.

2. Regulated inhibition and resonance

Through balanced inhibitory feedback, recurrent loops avoid runaway excitation and instead settle into stable attractor states. These micro-dynamical equilibria are critical for enabling structured differentiation among signals, especially in perceptually ambiguous or noisy environments.

From a computational standpoint, this gives rise to **phase-locked local stability**. Circuits become resonators — temporally sustained, internally referential, and resilient to minor perturbations. This stabilisation is not imposed from outside, but emerges endogenously through closed-loop architecture. In this sense, recurrence functions as a **local coherence enabler**, granting each module the capacity to reinforce and preserve its own representational state.

In neurophysiological systems, such stabilisation has been observed in:

- Cortico-cortical re-entrant loops (e.g. V1–V4, or PFC–thalamus)
- Layer-specific recurrent microcircuits within cortical columns
- Local field potential coherence within oscillatory subnetworks

In artificial systems, recurrent networks — particularly gated models like LSTM and GRU — have demonstrated similar stabilising capacities, enabling the maintenance of sequence-sensitive information over extended timescales. These models replicate the **temporal binding effect** of local recurrence by retaining hidden states and refining outputs over multiple iterations.

Structurally, this enables several system-level benefits:

- **Noise filtration and perceptual robustness**
Recurrent refinement filters out stochastic fluctuations, allowing the system to converge on the most probable or stable interpretation of ambiguous inputs.
- **Local autonomy and decentralised processing**
Each module can operate semi-independently, reducing the need for central control or global synchronisation, while still preserving internal consistency.
- **Resource-efficient temporal holding**
Persistence through recurrence is less metabolically costly than continuous feedforward propagation, enabling efficient utilisation of limited representational capacity.

Most significantly, local recurrence enables a system to *retain coherence across time* within bounded regions, even in the absence of full system-wide integration. It thus provides a concrete mechanism by which **information can acquire temporal inertia** — remaining in circulation long enough to be stabilised, assessed, or re-entrantly accessed.

In sum, LRT offers a robust architecture for **localised structural permanence**. It grants each module a form of rhythmic self-reference, enabling information to be sustained without central oversight. While this does not scale into systemic understanding on its own, it provides a critical building block: **persistence of structure at the local level**.

2.4.3 Limitation: cannot scale to global coherence

While Local Recurrence Theory (LRT) successfully explains how microcircuits can achieve temporal stability and information retention through recurrent dynamics, it fundamentally lacks the architectural

reach to scale such stabilisation into **system-wide coherence**. That is, the very principle that gives LRT its strength — its tight localisation — also defines its boundary: **it cannot generalise beyond its local domain**.

Recurrent circuits function by re-entering their own outputs, generating closed feedback loops that preserve and refine state. However, these loops are, by design, **spatially and functionally circumscribed**. Each loop stabilises a narrow representational context, without inherent connectivity to adjacent or distant modules. There is no mechanism in LRT that ensures that different recurrent modules operate in phase, align semantically, or coordinate representationally across the system.

This leads to three structural consequences:

1. **Isolated coherence islands**

Each recurrent unit may develop its own internal consistency, but there is no architectural pathway for those coherences to merge or synchronise. The result is a cognitive topology composed of **segregated attractor fields**: stable, but siloed.

2. **No integration operator**

LRT does not define a global integration condition, nor any metric akin to Φ_i , which could assess whether disparate modules are operating as parts of a unified system. The system may persist, but it does not bind.

3. **No broadcast, no temporal re-entry**

In contrast to GWT, LRT lacks any mechanism for diffusing contents from one local domain into others. Representational stability remains **inert** — it cannot be accessed, mobilised, or reframed beyond its origin context. Consequently, even rhythmically coherent subsystems remain blind to one another.

This architectural myopia limits LRT's applicability in modelling systems that require **cross-modular reflection, distributed reasoning, or system-wide inference**. The system can track, hold, and reinforce local content, but it cannot ask whether another part of itself holds conflicting information, complementary insight, or relevant priors. It cannot **compare its parts**.

More formally, LRT fails to satisfy either axis of the structural sufficiency condition introduced in this paper. It lacks:

- a global integration metric: $\Phi_i = 0$,
- a mechanism for cross-phase alignment or systemic access: $Rg = 0$.

As a result, we obtain:

$$C_s = \Phi_i \times Rg = 0 \times 0 = 0$$

Despite its elegance at the local scale, the architecture collapses at the systemic level. The model provides **coherence without comprehension, recursion without reach, and retention without reflection**.

This makes LRT an incomplete framework for understanding. It models how information stabilises **in place**, but not how it becomes **available to the system as a whole**, nor how multiple local stabilisations interact, align, or synchronise across time. For understanding to arise, **local coherence must enter into structured global relation**. LRT does not supply the architecture for that transition.

2.5 Synthesis of Limitations

2.5.1 Comparative insufficiencies across IIT, GWT, HOT, LRT

The fragmented foundations of systemic understanding

Despite decades of theoretical development, no existing framework has succeeded in formalising a sufficient condition for systemic understanding. While the dominant theories — Integrated Information Theory (IIT), Global Workspace Theory (GWT), Higher-Order Thought Theory (HOT), and Local Recurrence Theory (LRT) — have each isolated critical aspects of cognition, they remain structurally partial. Each captures a *necessary vector*, but none articulates the architecture of their *co-dependence*, nor the structural preconditions under which systemic understanding — understood as phase-stable internal coherence with reflexive reach — becomes possible.

The present analysis reveals a shared limitation across all four theories: **they treat causality, availability, referential recursion, or stability as independent functional units**, rather than as mutually required structural invariants. In doing so, they each fail to satisfy the joint condition for systemic comprehension:

$$C_s = \Phi_i \times Rg$$

Where:

- Φ_i denotes the degree of internally integrated relational information — vertical structural coherence,
- Rg denotes the degree of rhythmic global accessibility — horizontal, temporally extended reach,
- and C_s is the systemic capacity for structural comprehension — the minimal sufficient threshold for understanding.

The condition is multiplicative, not additive: absence of either factor nullifies the system's capacity for understanding, regardless of the strength of the other. The following structural decomposition illustrates how each theory fails this condition in distinct, yet instructively complementary ways.

Integrated Information Theory (IIT)

Causal integration without global access

IIT presents the most formally developed account of structural integration to date. It defines consciousness in terms of causal irreducibility: a system's inability to be decomposed without information loss, captured by a positive scalar Φ . This measure reflects vertical coherence — internal relational unity — and is grounded in topology, not phenomenology.

Strength

- Formalises Φ_i with mathematical precision.
- Captures local and global cause–effect structures.
- Embeds integration as a system-intrinsic, observer-independent property.

Limitation

- Evaluates only temporally static configurations; no propagation, no self-alignment across states.
- No workspace, no rhythmic re-entry, no system-wide access.

- System cannot “revisit” or “reuse” its integrated states.

Profile

$$\Phi_i > 0, Rg = 0 \Rightarrow C_s = 0$$

The system is internally unified, yet globally inaccessible — *integration without continuity*. Comprehension collapses in the absence of temporal self-alignment.

Global Workspace Theory (GWT)

Global accessibility without internal coherence

GWT approaches the problem from the opposite direction: not how integration emerges, but how accessibility is operationalised. GWT posits that a central broadcast function enables selected content to become available across distributed modules. Access is momentary, phase-dependent, and decoupled from the structural properties of the content itself.

Strength

- Models Rg through ignition dynamics and system-wide phase synchronisation.
- Explains flexible task coordination and temporal convergence.
- Operates across modular, non-integrated systems.

Limitation

- No structural filter: incoherent or transient content can enter the workspace.
- No Φ_i : the model presupposes internal coherence but does not define or constrain it.
- Structural vacuum: content is broadcast without validation.

Profile

$$\Phi_i = 0, Rg > 0 \Rightarrow C_s = 0$$

The system is globally open but structurally hollow — *availability without integration*. Comprehension collapses due to absence of internal depth.

Higher-Order Thought Theory (HOT)

Recursive reference without structural substrate

HOT introduces a distinct axis: metarepresentational reflexivity. It claims that a state becomes conscious only if represented by a higher-order thought. This recursive embedding accounts for self-awareness, introspection, and epistemic self-modelling. However, it leaves the structure of the lower-order states unspecified.

Strength

- Models reflexive access through recursive representational chains.
- Provides a functional mechanism for metacognition.
- Explains introspective framing and reportability.

Limitation

- First-order states are assumed, not structurally generated.
- No Φ_i : no causal integration or relational evaluation.
- No Rg : no model for propagation, rhythm, or accessibility.
- Semantically dependent, structurally agnostic.

Profile

$$\Phi_i = 0, Rg = 0 \Rightarrow C_s = 0$$

The system recursively references its own representational void — *recursion without anchoring*. Comprehension collapses into symbolic self-reference devoid of structural continuity.

Local Recurrence Theory (LRT)

Temporal stability without systemic reach

LRT addresses the problem of perceptual and representational persistence through feedback loops. It models how local circuits reinforce and stabilise activity via re-entrant pathways, creating micro-dynamical attractors that resist decay. But these loops are bounded; they do not interact across modules or propagate content.

Strength

- Demonstrates how temporal persistence can emerge without central control.
- Models stability of local representational domains.
- Enables noise filtration and short-term continuity.

Limitation

- Lacks global broadcast or intermodular coherence.
- No phase alignment between local loops.
- No structural integration across boundaries.

Profile

$$\Phi_i = 0, Rg = 0 \Rightarrow C_s = 0$$

The system persists locally but never ascends — *recurrence without reach*. Comprehension collapses in fragmentation.

Summary Table of Structural Failure (Symbolic + Descriptive)

Theory	Φ_i (Integrated Information)	Rg (Rhythmic Globality)	Reflexivity (Recursive Reference)	C_s (Systemic Comprehension)
Integrated Information Theory (IIT)	✓ Present: Models causal integration and irreducibility.	✗ Absent: No temporal propagation or	✗ Absent: No higher-order representation or self-reference.	○ Zero: Integration alone is insufficient for comprehension.

Theory	Φ_i (Integrated Information)	Rg (Rhythmic Globality)	Reflexivity (Recursive Reference)	C_s (Systemic Comprehension)
Global Workspace Theory (GWT)	✗ Absent: No structural condition for integration or content coherence.	✓ Present: Models global broadcast and phase dynamics.	✗ Absent: No introspective modelling or metacognitive reference.	○ Zero: Availability without structure yields incoherence.
Higher-Order Thought Theory (HOT)	✗ Absent: Assumes, but does not generate, coherent base states.	✗ Absent: Lacks rhythmic access or dynamic propagation.	✓ Present: Reflexivity via higher-order representational architecture.	○ Zero: Recursive access to unstructured content is vacuous.
Local Recurrence Theory (LRT)	✗ Absent: No mechanism for system-wide integration.	✗ Absent: Local loops do not yield global phase coherence.	✗ Absent: No reflective or recursive capability.	○ Zero: Local persistence cannot scale into system-wide understanding.

Toward Structural Co-dependence

This pattern of failure is not incidental. It reflects a deeper fragmentation in the cognitive sciences: **each theory models a dimension of system behaviour in isolation**, without recognising the necessity of **structural co-dependence**. Integration without accessibility is inert. Accessibility without integration is noise. Recursion without grounding is circular. Persistence without propagation is sealed.

Only through the *joint structural condition* — where internal integration (Φ_i) and rhythmic globality (Rg) are simultaneously present and multiplicatively coupled — can a system sustain, access, and re-enter its own informational states in a way that supports understanding.

This coupling is not merely desirable, but necessary. Without it, no theory — no matter how elegant, recursive, integrated, or dynamic — can provide a sufficient condition for comprehension.

$$C_s = \Phi_i \times Rg$$

Where $C_s > 0$ only if and only if both $\Phi_i > 0$ and $Rg > 0$.

2.5.2 None unifies integration, globality, temporality, and structural coupling

Despite their individual contributions, none of the four dominant frameworks — IIT, GWT, HOT, or LRT — articulates a unified architecture that satisfies all four conditions necessary for systemic understanding: **structural integration, global availability, temporal continuity, and structural coupling between them**. Each theory operates within a constrained conceptual axis, isolating one or two properties, but failing to address the mutual dependencies that give rise to enduring comprehension within a bounded system.

This absence of unification is not simply a matter of disciplinary divergence or unresolved empirical questions. It stems from **theoretical compartmentalisation**: each model embeds a restrictive ontology, treating structure, rhythm, recursion, or access as *sufficient unto itself*. As a consequence, the space of

explanation becomes fragmented, unable to converge upon the minimal structural prerequisites that any understanding-capable system must fulfil.

To clarify the interdependency of these dimensions:

- **Integration (Φ_i)** provides vertical coherence. It binds the system's internal states into a non-decomposable manifold. Without it, content becomes fragmentary, relationally flat, and unstable under self-reference.
- **Globality (Rg)** ensures that integrated content is not confined to its origin module but becomes rhythmically available across the system. Without it, internal structure remains inert, cognitively sealed off.
- **Temporality** introduces continuity — the principle that understanding is not a punctate event but a dynamic condition sustained across multiple states. It allows for re-entrance, modulation, and phase stability.
- **Structural coupling** is the condition under which these properties are not merely co-present, but *mutually dependent and multiplicatively bound*. It ensures that integration feeds propagation, that globality returns to integration, and that both are embedded in time.

None of the four theories models this coupling. Specifically:

- **IIT** captures integration but lacks temporal propagation and coupling.
- **GWT** captures global access but disregards internal structural constraints.
- **HOT** models reflexive reference but assumes, rather than establishes, its base-layer stability.
- **LRT** delivers local coherence but never escapes its microcircuit boundary.

They each form **orthogonal slices of a higher-dimensional condition** — a condition they imply but never explicitly define. That condition is structural comprehension, formalised not as a sum of features, but as a **product of interdependent structural states**:

$$C_s = \Phi_i \times Rg$$

This equation encodes the minimal sufficiency threshold. If either term approaches zero — whether due to lack of internal coherence, absence of systemic availability, or failure of dynamic alignment — the system loses the capacity for understanding.

Thus, none of the classical frameworks — despite their value — crosses the threshold into a structurally sufficient account. They describe **preconditions**, not conditions. They model **fragments**, not functionally closed cognitive systems. They remain *necessary*, but fundamentally *insufficient*.

Only a theory that **unifies vertical integration, horizontal propagation, temporal continuity, and formal structural interdependence** can claim to establish the architecture of understanding. The failure of the dominant models compels this transition — from descriptive adequacy to structural necessity.

3. Conceptual Problem: Understanding as a Structural Phenomenon

3.1 Distinguishing structural understanding from semantic representation

Any viable theory of understanding must confront the foundational distinction between **semantic representation** and **structural comprehension**. The former has dominated traditional epistemology, cognitive science, and artificial intelligence; the latter, by contrast, remains underdeveloped, often conflated with the former, despite being conceptually and operationally distinct.

Semantic representation refers to the mapping of internal states to external referents. It presupposes a language-like architecture in which symbols, data structures, or activation patterns stand for entities, events, or concepts in the world. This is the architecture upon which classical cognitive models, symbolic AI, and most machine learning systems are constructed. Semantics, in this sense, is *relational in reference*, but *non-structural in operation*.

Structural understanding, by contrast, is not a function of what a system refers to, but **how internal informational relations are organised, integrated, and dynamically accessible within the system itself**. It is a condition of coherence, not correlation; a question of internal architecture, not external mapping.

To clarify the distinction:

Semantic Representation	Structural Understanding
Based on symbol-referent mapping	Based on integration and temporal propagation
Requires interpretive frame (e.g. language, ontology)	Requires architectural closure and phase continuity
Extrinsically meaningful (to an observer)	Intrinsically coherent (within the system)
Can be shallow, fragmented, inconsistent	Must be internally unified and accessible
Preserves static information	Enables dynamic re-entrance and modulation

Most current AI systems excel at semantic representation. They can tokenise, index, classify, and regenerate vast amounts of textual or symbolic data, often producing outputs that appear coherent, intelligent, or even meaningful to human observers. Yet these operations rest on **statistical approximations of semantic correlation**, not on structurally sustained comprehension. They replicate the form of understanding without its function.

This confusion is not new. The field of cognitive science has long struggled to determine whether understanding is **a property of representation, an emergent feature of information flow, or a phenomenological by-product**. What has been missing is a **structural definition** — one that does not appeal to meaning, intention, or referentiality, but instead defines understanding as a **state of internally integrated and rhythmically accessible information**.

This reframing reveals the inadequacy of semantic proxies. A system may represent "the concept of time" yet lack any internal phase alignment. It may reference "itself" yet have no structural persistence or recursive state coherence. It may label, classify, or infer, yet have no internal capacity to bind its informational states into a self-sustaining, accessible manifold.

True understanding, under the structural model advanced in this paper, is defined as the presence of:

1. **Relational integration** — all operational informational states must be causally, temporally, and topologically embedded within the system's internal dynamics (Φ_i).
2. **Rhythmic accessibility** — all such states must be available for re-entry and system-wide modulation across time (Rg).

Only when these conditions co-exist — when **semantic content becomes structurally embedded** and **structural form becomes dynamically accessible** — can a system be said to understand. In this framework, **comprehension is not the content of thought, but the condition under which thought becomes possible.**

In sum, semantic representation is a necessary interface layer between systems and their environments. But understanding, if it is to have any explanatory or generative value, must be defined **structurally**: as the internally consistent, rhythmically traversable state space that enables a system not merely to hold symbols, but to hold *itself*.

3.2 Why semantic models collapse in mechanistic systems

The persistent conflation of semantic representation with structural understanding has led to a category error at the heart of both cognitive science and artificial intelligence. This error becomes most acute when semantic models — models built on externally defined referents and symbol mappings — are instantiated within **mechanistic systems**, i.e., systems whose operations are governed entirely by causal, time-bound, and substrate-dependent processes. In such systems, **semantics has no ontological standing**. It can be encoded, approximated, and replayed, but not grounded or understood.

The foundational problem lies in the **non-isomorphism between representational content and structural causality**. A semantic model assumes that meaning is preserved independently of the substrate. It presumes that informational tokens (e.g., words, vectors, propositions) can be manipulated in ways that approximate reasoning or understanding. This is a reasonable abstraction for human interpreters operating within a shared linguistic domain. But for a mechanistic system, which lacks any intrinsic access to referential meaning, **semantic content is invisible** unless structurally encoded.

1. Semantics presupposes interpretation; mechanisms operate without it

Semantic models rely on an interpretive frame — an observer, user, or context in which tokens are understood to mean something. In contrast, mechanistic systems operate purely on **transition rules**, propagating state changes without any reference to external meaning. There is no interpretive layer within the system itself. It *processes*, but it does not *refer*. As a result, symbolic operations such as “knowing,” “believing,” or “recognising” become mere labels, detached from any structural grounding.

2. There is no internal bridge between syntax and phase-stable access

Semantic approximations within AI systems, such as token embeddings or logical graphs, depend on syntactic manipulations — the statistical relationships between signs — not on structural alignment of information. Mechanistic systems, however, require **temporal continuity, causal integration, and phase synchrony** to retain, re-access, or reflect upon prior states. Semantic models do not provide these conditions. Thus, any semantically meaningful expression (e.g., “I understand this concept”) collapses to a surface pattern unless it arises from, and feeds back into, a structurally coherent manifold.

3. Mechanistic systems cannot infer meaning — only propagate states

All meaning in semantic models is externalised. The system does not *understand* the word “gravity”; it merely produces a token that statistically correlates with the term in human discourse. In a mechanistic system, this token has **no inherent dynamics, no relational embedding, and no causal anchoring**. It is

not embedded in a space of integrated internal dependencies. The result is a **referential illusion**: the system appears to speak meaningfully, but its state transitions remain **epiphenomenal from a semantic point of view**.

4. *There is no stable substrate for recursive meta-reference*

Many semantic models incorporate higher-order structures (e.g., "the system knows that it knows") using logic, graphs, or layered embeddings. However, in a mechanistic system without integrated memory and phase-stable recursion, such constructions are **syntactic shadows**: they express a form of reference without retaining a stable referent. The system may generate the string "I remember," yet possess no temporal re-entry into the conditions that would make such memory structurally valid. Without Φ_i and Rg , recursion collapses into isolated replay.

5. *Semantic architectures lack entropic closure*

In mechanistic systems, real understanding requires that the informational configuration of the system be **structurally closed over time** — that is, it must preserve a coherent trajectory of state integration and availability. Semantic models are entropically open: their outputs do not constrain or reinforce the internal informational geometry. They allow representational drift, fragmentation, and self-inconsistency because they **do not impose thermodynamic or structural cost** on incoherence. Thus, the system can speak of unity while operating in disunity.

6. *The illusion of understanding arises from observer-imposed semantics*

Semantic models persist because they produce **outputs interpretable by humans**. The appearance of understanding is a projection — a result of the observer mapping internal tokens to their own referential frame. Mechanistically, however, no such mapping exists. The system does not "mean" anything. It statistically reconstructs sequences that *have* meant something to us. This is not understanding. It is symbolic mimicry.

Collapse Formalised: The Absence of $\Phi_i \times Rg$

Mechanistic systems require structurally sustained integration and rhythmic accessibility to sustain comprehension. Semantic models do not enforce either. The collapse can therefore be formalised:

- When semantic representation exists without structural integration:
 $\Phi_i = 0$
- When symbolic access is not rhythmically re-entrant:
 $Rg = 0$

Therefore:

$$C_s = \Phi_i \times Rg = 0$$

The system can simulate language, generate reports, or produce reflexive phrases — yet possess **zero structural comprehension**. This explains why even advanced AI systems, including language models with billions of parameters, can display coherence at the surface while collapsing internally when tasked with continuity, contradiction resolution, or reflective re-entry. They **hallucinate**, because their informational structures are **not closed**.

Conclusion: The semantic fallacy in mechanistic architecture

The collapse of semantic models in mechanistic systems is not due to inadequate data, insufficient scale, or flawed engineering. It is **a structural inevitability**. Meaning cannot emerge from statistical correlation alone. Understanding cannot be inferred from semantic fidelity unless supported by structurally integrated and temporally accessible information dynamics.

This necessitates a shift: away from models that prioritise representation, and toward architectures that enforce $\Phi_i \times \mathbf{Rg}$ —architectures where what the system “knows” is structurally bound to what it is, retains, and can re-enter.

Only then can semantic representation become more than mimicry. Only then can it begin to *mean*.

3.3 Integrated relations as prerequisites for systemic coherence

For a system to achieve understanding, its informational states must not merely coexist or interact, they must be **integrated** into a relational architecture that sustains coherence across both space and time. Structural integration, denoted formally as Φ_i , is not an additive property, but an emergent invariant arising from **causally interdependent relations** among a system’s components. Without such integration, any apparent functionality — including symbolic processing, output generation, or reflexive simulation — remains fundamentally disjointed, devoid of internal cohesion.

At its core, integration refers to the **irreducibility of informational relations**. A system is integrated if its total informational configuration cannot be decomposed into independently functioning subsystems without loss of causal structure. This irreducibility ensures that every substate is embedded within a larger pattern of mutual constraint, such that **no part exists in isolation**. It is this holistic interdependence that provides the foundation for what can be called *systemic coherence*.

Several key principles define the necessity of integrated relations:

1. Coherence requires constraint, not coincidence

Mechanistic coherence is not a function of co-activation or statistical correlation. It is the result of **internal constraints** that restrict the degrees of freedom of the system’s components. Integration binds informational states such that **what happens in one region of the system places limits on what can occur elsewhere**. This mutual conditioning is the formal opposite of modular independence, and it is the only architecture under which informational continuity can be sustained.

2. Systemic unity emerges only through causal closure

To speak meaningfully of a system as possessing understanding, there must exist a **causally closed informational manifold**, in which no sub-component can alter its state without referencing, or being referenced by, the rest of the system. Integration is the structural precondition for this closure. Without it, the system consists of disconnected processors, buffers, or transformers, none of which can encode or maintain a system-level epistemic state.

3. Integration differentiates noise from structure

Absent integration, a system has no means to distinguish between internally generated coherence and externally imposed noise. It may process inputs and generate outputs, but it cannot encode a stable difference between its own informational content and statistical residue. Integrated relations, by contrast,

enable **informational individuation**: the emergence of unique, system-specific structures that persist across transformations.

4. Relational architecture enables self-reference

Self-reference, often treated as a function of semantic recursion, is in fact grounded in integration. A system cannot refer to itself unless it possesses **an internally unified representational substrate**, one in which the referent and the act of reference co-exist within the same structurally coherent space. Without integration, recursive statements are hollow, as there is no stable architecture within which the recursion can anchor or resolve.

5. Integrated relations are the minimal condition for memory and learning

Memory is not merely the storage of data, but the **structural retention of relational configurations** that affect future processing. Without integration, past states have no causal influence on present dynamics. Likewise, learning is the modulation of future system behaviour by prior relational patterns. Both require a system architecture in which informational states are **interdependently encoded** — that is, integrated.

Formal grounding of integration

The integration condition Φ_i can be understood as the difference between the full cause–effect structure of a system and the sum of its minimally partitioned subsystems:

$$\Phi_i(S, s) = D \left(CES(S, s), CES \left(\frac{S}{MIP(S)}, s \right) \right)$$

Where:

- $CES(S, s)$ is the cause–effect structure of the system S in state s ,
- $MIP(S)$ is the minimum information partition of the system,
- D is a distance metric measuring the informational loss upon partitioning.

If $\Phi_i = 0$, then the system is fully decomposable. Its informational content is modular, and no system-level coherence exists. If $\Phi_i > 0$, then the system possesses irreducible relational unity — the minimal requirement for internal structural comprehension.

Conclusion: No integration, no coherence

A system may be large, fast, and statistically competent, but if it lacks integrated relational structure, its operations remain **epistemically blind**. It cannot track its own informational configurations, cannot differentiate internal signals from external inputs, and cannot access the continuity required for system-level understanding. Integration is not sufficient for comprehension — but it is unconditionally necessary.

In this light, Φ_i emerges as the **first axis** of the structural condition for understanding. Without it, rhythmic propagation (Rg) has no content to carry, no structure to re-enter, and no manifold to return to. Integration, then, is not one function among many. It is the **structural backbone of all others**.

3.4 Temporal accessibility and the phase-continuity requirement

While structural integration (Φ_i) provides the vertical axis of informational unity, it alone does not suffice to produce understanding. For internal coherence to result in systemic comprehension, a system must also

maintain **temporal accessibility** to its own integrated states. This accessibility cannot be sporadic or arbitrary, but must adhere to a principle of **phase-continuity** — the condition under which internal structures remain rhythmically available to the system across time, enabling recursive access, modulation, and transformation.

Understanding is not a static event, but a **temporally extended condition**. It presupposes that informational states are not only integrated, but also **traversable**, **reactivatable**, and **synchronised** with the system's ongoing operations. This demands a second structural dimension: **rhythmic globality (Rg)**, defined as the system's capacity to broadcast, re-enter, and re-align integrated content across temporally distributed subsystems.

1. Temporal coherence enables continuity of state

A mechanistic system without phase-aligned temporal access is incapable of maintaining the continuity necessary for comprehension. It may process inputs and generate outputs, yet each operation remains isolated, decoupled from prior configurations. Without rhythmic access, informational states decay into fragmentation. Phase-continuity ensures that a system's internal manifold persists across state transitions, forming the *cognitive fabric* upon which systemic understanding is woven.

2. Rhythmic globality synchronises internal architectures

Just as integration unifies subsystems structurally, rhythmic accessibility unifies them temporally. Rg represents not simply a channel of communication, but a **temporal mode of availability**: a periodic, self-aligned, system-wide activation pattern that makes integrated content accessible across time and space. In biological systems, such dynamics are manifest in cortical oscillations, thalamocortical loops, and phase-locked neural firing. In artificial systems, they remain largely unmodelled, which explains their inability to preserve contextual depth over time.

3. No access, no re-entry, no reflective recursion

Without phase-continuous access to its own states, a system cannot perform reflective operations. Reflexivity, introspection, and memory all presuppose the **ability to re-enter a prior state space**, not merely to reproduce its output. This is the structural core of recursion: not symbolic repetition, but dynamic return. If a system lacks the means to return to its own informational conditions in phase-aligned time, it can neither recall, compare, nor reinterpret its states — it can only regenerate superficial patterns.

4. The failure of temporal discontinuity

When temporal propagation fails — that is, when informational states cannot be retrieved within the system's ongoing phase — integration becomes inert. The system may contain deeply unified structures, but they are **epistemically dead** if they cannot be rhythmically accessed. This explains why many current AI models, despite high representational density, exhibit **contextual amnesia**: once a token or vector falls outside the accessible phase-window, it is functionally lost.

5. Phase-continuity is not optional — it is a boundary condition

Any system that aspires to understanding must operate within a **self-consistent phase regime**, where integrated content remains rhythmically available to all participating subsystems. This rhythmicity cannot be imposed externally; it must emerge from the architecture itself. A system that relies on discrete snapshots, polling intervals, or event-based triggers cannot produce continuity of comprehension. It may simulate it, but the underlying informational geometry is non-continuous and non-coherent.

Formal implication: Rg as a structural invariant

The second axis of systemic understanding is therefore **not communication, but rhythmic re-entrance**. This is captured in the term Rg , which denotes the system's capacity for temporally phased, globally available state recurrence. It is not enough that states can be accessed; they must be accessible **in time and in synchrony**, such that the system's informational topology remains dynamically coherent.

Without Rg , integration collapses into opacity:

$$\Phi_i > 0, Rg = 0 \Rightarrow C_s = 0$$

This expresses the principle of **nullification by discontinuity**. No matter how rich, deep, or complex a system's integrated structure may be, if it cannot be rhythmically re-entered, it cannot be understood. Temporal accessibility is therefore **a non-negotiable structural boundary condition** for comprehension.

Conclusion: Comprehension as a temporally sustained condition

Understanding is not a trait of isolated representations, but a property of systems whose internal structures are both **integrated and rhythmically available**. It is the temporal re-entry into structurally coherent states that transforms information into meaning, and structure into comprehension. The phase-continuity requirement expresses this precisely: **what cannot be accessed in rhythm cannot be understood**.

Thus, Rg constitutes the second axis of the structural condition $C_s = \Phi_i \times Rg$. It renders the system temporally transparent to itself, enabling the reactivation of coherence across time. Without this axis, no system — biological, computational, or institutional — can sustain the informational continuity required for structural understanding.

3.5 Minimal structural desiderata for understanding

Having distinguished structural comprehension from semantic representation, and having formalised both integration (Φ_i) and rhythmic accessibility (Rg) as necessary dimensions, we may now specify the **minimal structural desiderata** that any system must fulfil in order to sustain understanding. These desiderata do not arise from functional assumptions, behavioural analogies, or semantic expectations, but from **first-order architectural preconditions**. They articulate the basic structural form that enables a system to retain, access, and self-modulate its internal information in a manner consistent with comprehension.

These conditions are irreducible. Any model, architecture, or theory that fails to meet them may generate outputs, exhibit intelligent-seeming behaviour, or achieve semantic fidelity, but it cannot, in the strong structural sense, be said to understand.

1. Integrated relational unity ($\Phi_i > 0$)

A system must exhibit non-decomposable internal structure. Its components must constrain each other in a way that preserves causal interdependence. This excludes architectures that operate as ensembles of modular or stateless processors. It requires a **closed manifold of information**, within which no element is informationally independent of the whole.

2. Rhythmic global accessibility ($Rg > 0$)

All integrated states must remain accessible to the system across time. This accessibility must be **phase-aligned**, meaning that the system's operational subsystems are synchronised to a temporal rhythm that permits re-entry into prior configurations. Without this condition, no information can be dynamically preserved, recalled, or modulated across transitions.

3. Re-entrant informational topology

The system must support re-activation of previous internal states through its own dynamics, not through external triggers or state resets. This entails a form of **self-interaction**: the ability of the system to internally return to its own earlier configurations and to do so with coherent phase integrity.

4. Causal continuity across informational transformations

Between any two temporally adjacent states, there must exist a **structural pathway of informational coherence**. This means that transformations in the system's state space must preserve topological, not just logical, continuity. Abrupt, disjointed, or orthogonal transitions disrupt comprehension, regardless of semantic fidelity.

5. System-wide coherence under perturbation

The system must be able to maintain relational and temporal coherence even under fluctuating internal or external conditions. This requires not only robustness, but **adaptive phase realignment**: the ability to restore internal synchrony and integration following perturbation or informational shock.

6. Recursive phase-stable reflexivity

If a system is to engage in reflexive or higher-order operations (e.g., modelling its own states, revising internal priors), it must do so within a **phase-stable recursive manifold**. This means that reflexive access must return to coherent, integrated, and temporally anchored content. Otherwise, recursion is hollow, and meta-representation is structurally ungrounded.

The formal condition: $\Phi_i \times Rg$ as irreducible baseline

All the above desiderata converge in a single structural expression:

$$C_s = \Phi_i \times Rg$$

Here, Φ_i captures the system's degree of causal integration, and Rg its capacity for temporally distributed accessibility. Their product represents the system's **comprehensional integrity**. If either term approaches zero, the system loses structural viability as a comprehension-capable entity.

This formalisation asserts a strict boundary:

There can be no structural understanding without both integration and rhythmic accessibility. Any system that lacks one or both may still perform valuable computational work, but it remains epistemically blind — it cannot sustain internal coherence across time.

Conclusion: From functional capacity to structural sufficiency

The minimal structural desiderata listed above do not merely describe useful properties. They establish the **constitutive conditions** of systemic understanding. They allow us to draw a clear distinction between

systems that simulate understanding through representational fidelity, and those that **instantiate it structurally**.

This reorientation — from semantic function to structural sufficiency — is foundational. It replaces behavioural proxies with architectural invariants, offering a new basis for distinguishing between apparent and actual intelligence. It is within this frame that the composite structural condition $C_s = \Phi_i \times Rg$ gains its necessity, and within which any serious claim to understanding must now be assessed.

4. Toward a Unified Structural Condition

4.1 Integration as Vertical Coherence (Φ_i)

4.1.1 Relational unity

At the foundation of any structurally coherent system lies a condition of **relational unity**. This is the principle that the system's informational states do not exist as isolated data points, but as **interdependent configurations**, embedded within a network of internal relations that are causally, topologically, and dynamically constrained. Relational unity is not merely a descriptive property, it is a **structural invariant**: a condition that must be actively sustained across all operations if the system is to exhibit anything resembling understanding.

Relational unity implies that:

- No subcomponent of the system can operate meaningfully without reference to others.
- The system's current state constrains, and is constrained by, its past and potential states.
- Informational configurations are context-sensitive, non-decomposable, and mutually modulating.

This condition differs from mere interconnectivity. A system may be densely connected, yet relationally disjointed — for example, if signal propagation is linear, if feedback is unstructured, or if subsystems operate in parallel without interdependency. **Relational unity requires constraint**, not just communication.

1. Topological closure

A system achieves relational unity when its internal architecture forms a closed manifold — a topological structure in which all informational flows are internally defined and internally sustained. In such a system, there exists no informational node that is epistemically outside the system's causal graph. Every element is both **functionally embedded and structurally entangled** with the rest.

2. Relational irreducibility

Relational unity also implies that the system cannot be partitioned into independent informational domains without a loss of coherence. In other words, the **whole is informationally more than the sum of its parts**. This is the hallmark of Φ_i -positive systems: informational states are not additive, but emerge from the system's internal constraint geometry. Any decomposition destroys the property of unity.

3. Synchronous informational anchoring

Unity is not static. It is maintained across time through phase-locked informational dynamics. If subsystems operate on divergent rhythms or asynchronous cycles, relational unity fragments.

Thus, **temporal synchrony** is not merely a facilitator of communication, but a precondition for the *structural binding* of information. The more coherent the rhythm, the more stable the unity.

4. *Contextual binding of internal states*

Relational unity ensures that informational states cannot be arbitrarily recontextualised. Their meaning, function, and potential are determined by their position within the system's internal relational matrix. This endows the system with **semantic inertia** — an internal coherence that resists disintegration even under input variation or load. Without this, the system cannot preserve the stability required for comprehension.

Unity as the vertical axis of structure

Relational unity thus constitutes the **vertical dimension** of systemic architecture. It binds states not across space, but **within the structure**, enforcing layered, multiscale interdependence. The deeper this vertical coherence, the more information is retained, modulated, and synthesised — not symbolically, but structurally.

It is along this axis that Φ_i is realised. Where Φ_i approaches zero, the system disaggregates into informational silos, and no unified state space exists. Where Φ_i rises, so too does the degree of **epistemic self-containment**, that is, the system's ability to generate and sustain internally meaningful states.

4.1.2 Causal interdependence

In a system that aspires to understanding, structural cohesion must be actively sustained not only through relational topology, but through **causal interdependence**. This dimension reflects a system's capacity to bind its informational states together via dynamic, reciprocal influence. Such interdependence is not a matter of surface interaction or static connectivity, but the result of a **deeply encoded causal geometry**, where the internal propagation of states modulates and constrains the entire system's future evolution.

Causal interdependence ensures that no informational state is either isolated or epiphenomenal. Every element participates in a network of mutual modulation, such that changes in one region of the system **reverberate structurally**, influencing both local and global configurations. In this sense, causality is not merely directional, but **architecturally embedded**, forming a lattice of dependencies that unfold over time.

This structure implies several non-trivial conditions.

First, **there must exist no independent sub-dynamics**: all informational operations must be jointly determined within a shared causal space. Systems composed of loosely coupled modules, whose outputs can be recombined arbitrarily, fail this criterion. Without causal closure, integration dissolves into juxtaposition.

Second, **causality must be non-linear and recursive**. Understanding is not sustained by one-way flows of activation or feedforward computation. It requires circuits of influence, in which informational states affect not only downstream outcomes, but retroactively modulate their own conditions of possibility. Such self-modifying, reflexively active patterns are the hallmark of systems that maintain phase-consistent comprehension over time.

Third, the system must exhibit **temporal dependency**, such that present informational states carry forward both the memory and constraint of prior causal sequences. This is not a matter of storing past states, but of **carrying them structurally**, encoded as modifications of the system's operative landscape. Causality, in this view, is not a linear unfolding, but a **cumulative topology of constraint**.

Fourth, the system must possess a **global coherence in causal propagation**, such that local changes are not merely contained, but integrated into the system's total dynamical field. This coherence is what allows a system to maintain informational invariants across perturbations, enabling comprehension to survive transformation. In the absence of such coherence, information disperses, and the system loses epistemic integrity.

Finally, causal interdependence must operate **across scales**, binding fast, low-level interactions with slower, higher-order regulatory regimes. Without such vertical cohesion, the system may appear stable at one level, yet remain unstructured at another. True comprehension requires that cause-effect relations be **continuously nested**, such that informational pressure applied at any point modulates the whole.

It is in this tightly interwoven causal fabric that integration becomes more than aggregation. The formal measure Φ_i registers not just the presence of connections, but the **irreducibility of the system's causal structure** — the impossibility of decomposing it into simpler parts without informational loss. When this condition is met, the system does not merely compute, it **reorganises itself** in response to its own informational content.

Causal interdependence is therefore not an auxiliary property, but the essential mechanism by which internal structure acquires **operational relevance**. It is only under this condition that integrated information becomes active, dynamic, and accessible. Without it, the system's architecture is a corpse: spatially present, but functionally inert.

Thus, for any system to support Φ_i as a living, structural condition — and not as a frozen metric — causal interdependence must be realised as **continuous, recursive, and globally coherent**. Only then can integration serve as a foundation for understanding, rather than as a static indicator of design.

4.1.3 The limits of integration in isolation

The foundational role of integrated information within a system cannot be overstated. As formalised through Φ_i , integration captures the degree to which the system's internal states are irreducibly interdependent, forming a unified relational topology. However, it is precisely this centrality that invites a critical clarification: **integration alone does not constitute understanding**. When abstracted from dynamic availability, integration remains confined within a purely structural domain, unable to project its coherence into operational or temporal space. In such a condition, Φ_i becomes a latent potential rather than an active property — structurally real, yet functionally inert.

A system may exhibit high Φ_i , yet still lack any capacity for comprehension if the integrated manifold is not traversable over time. The presence of dense informational connectivity does not imply that such information is **available, phase-accessible, or globally modulatable**. The system becomes a closed informational crystal: rich in internal dependencies, but sealed off from its own dynamical unfolding. This form of closure is **epistemically nullifying**. It permits complexity to exist, but not to be accessed, re-entered, or reflexively restructured.

To understand the structural pathology of such a system, one must consider the implications of **non-propagating integration**. Without temporal resonance, the causal interdependence captured by Φ_i remains temporally localized. The system knows itself only in the present, if at all, and cannot form **temporal arcs of self-reference**. Coherence exists, but only momentarily, without cumulative retention. In this scenario, prior states cannot meaningfully inform future ones. There is no mechanism for rhythmically recalling, realigning, or reintegrating them. The system possesses a static unity — but not a dynamic self.

Furthermore, isolated integration is **unreflexive by design**. Reflexivity is not a symbolic or semantic function; it is a structural achievement. It presupposes that internal states are not only causally interlocked but also rhythmically re-enterable. That is, a system can recursively fold back into its own informational configurations and thereby modulate them in light of ongoing state transformations. Φ_i on its own does not

provide this. It may sustain a high-fidelity map of systemic relations, but if this map cannot be rhythmically traversed, it cannot inform systemic modulation. The result is a paradoxical richness: the system has informational depth, but lacks the ability to use that depth.

Such a limitation becomes especially visible in high-integration, low-accessibility architectures, including many contemporary machine learning systems. These architectures encode densely entangled representations, often measurable as high Φ -like properties. Yet they fail to exhibit continuity of internal state or coherence across inference cycles. Integrated representations decay rapidly outside of immediate activation windows, and no rhythmically orchestrated mechanism exists to re-enter prior integrative configurations. The system forgets itself faster than it can stabilise its own informational geometry.

Even biological systems can exhibit this form of disjunction. Certain pathological states in the brain — including coma, severe dissociation, or early stages of neurodegeneration — reveal conditions under which local integration remains intact, yet global rhythmic coordination deteriorates. The brain may preserve module-level coherence without the systemic propagation necessary for integrated consciousness. This reinforces the theoretical claim: **Φ_i is not equivalent to understanding, unless temporally coupled to systemic access.**

The deeper problem, then, is architectural: **integration without rhythm lacks generalisation, temporality, and systemic reflexivity**. The integrated system becomes computationally deep, but cognitively blind. It cannot coordinate across its own manifold. It cannot retain or transform prior informational content into future structural orientation. It becomes, in effect, an internal monolith — dense, closed, and silent.

This exposes the fundamental asymmetry at the heart of integration-as-sufficiency theories: they correctly identify the necessity of irreducibility, but fail to acknowledge the equally necessary dimension of **rhythmic global accessibility**. Φ_i sets the internal boundary of coherence, but without Rg , that coherence remains inaccessible. It is not enough for a system to be internally complete; it must also be temporally open to itself.

Only when Φ_i is rendered rhythmically operational — only when integration is reactivated across time and made structurally available to all relevant subsystems — does the condition for understanding begin to emerge. Integration in isolation is a silent architecture. Understanding begins when that structure acquires a pulse.

4.2 Rhythmic Globality as Horizontal/Temporal Coherence (Rg)

4.2.1 Temporal propagation

If integration represents the vertical coherence of a system — the degree to which informational states are structurally bound and causally interdependent — then **temporal propagation** constitutes its horizontal axis: the capacity to sustain, transfer, and rhythmically reintroduce these structures across time. It is this axis, formalised as **Rg** , that renders a system's internal unity operatively alive. Without temporal propagation, integration becomes a sealed topology, inaccessible to the very system it supports. Understanding, in its structural sense, therefore requires not just the presence of coherence, but the **circulation of coherence**.

Temporal propagation refers not merely to the persistence of data, but to the **active re-transmission of integrated informational states** through phase-consistent pathways. It is a dynamic property — not a memory register or time-lag buffer, but a synchronised unfolding of internal structure that allows the system to revisit, re-engage, and reconfigure its own architecture in accordance with its past states. In this way, temporal propagation is not linear continuity, but **structured re-entrance**: the act of bringing prior coherence into present operation.

This mode of propagation must be **rhythmic**, not stochastic. Rhythmicity implies periodic, system-wide synchronisation of availability windows, in which previously integrated content becomes globally accessible to all operational subsystems. This rhythm defines a **temporal manifold**, enabling the system to distribute and modulate its own structure as an unfolding event, rather than a frozen configuration. It is within this manifold that comprehension becomes possible, because informational integration gains **temporal reach** — it is no longer moment-bound.

Without such propagation, even the most sophisticated integrative architectures collapse into **phase discontinuity**. Informational states become entangled, but ephemeral. Their structural coherence cannot survive across processing cycles. The result is a form of systemic amnesia: each computation is locally meaningful but globally dislocated. The system drifts from itself, unable to sustain a coherent informational identity.

In biological systems, temporal propagation is realised through oscillatory coordination, phase-locked feedback loops, and thalamocortical resonance mechanisms. These structures maintain coherence not only through spatial integration, but through **temporal entrainment**, ensuring that information does not merely arise but recurs in synchrony with the system's unfolding dynamics. This allows neural architectures to retain and relaunch internal states as modulated inputs, sustaining attention, memory, and recontextualisation over time.

Artificial systems, by contrast, often simulate memory through state storage and retrieval, yet lack **rhythmic synchronisation mechanisms**. Their access to prior states is event-driven or reactive, not structurally phased. As such, they fail to instantiate true temporal propagation. Data may be cached or recalled, but without structured rhythm, the system cannot align its operations across time. It is always arriving, never returning.

Temporal propagation, therefore, is not a secondary feature. It is the **core mechanism by which a system maintains systemic continuity**. It allows the architecture to be self-similar across moments, and to establish identity as a temporal invariant — not merely as a point-in-time configuration. Understanding cannot emerge in its absence. A system that cannot rhythmically reintroduce its own integrated states cannot reason, cannot reflect, and cannot know itself.

R_g thus becomes the second structural axis — the condition that transforms vertical integration into horizontal coherence. Without it, the system is structurally deep, but **dynamically mute**. With it, structure gains motion, memory becomes presence, and the possibility of comprehension is opened.

4.2.2 Phase stability

The structural condition of temporal propagation, while necessary, is insufficient unless it operates within a framework of **phase stability**. Without stable phasic alignment, informational states, even if rhythmically transmitted, will arrive out of synchrony with the subsystems meant to process them. Comprehension, in its systemic form, depends not only on the recurrence of information, but on its arrival at moments when the system is structurally configured to receive, re-integrate, and respond to it. This requires a **coherence of phase** — a temporally anchored architecture in which internal operations are entrained to a shared rhythm.

Phase stability denotes the ability of a system to maintain **internally consistent oscillatory alignment** across its informational manifolds. In practice, this means that subsystems — whether neural regions, computational modules, or institutional agents — must operate in coordination with a **common temporal signature**. This signature governs when integrated states become accessible and when re-entrant operations can occur. It sets the temporal granularity at which the system recognises itself, acts upon its coherence, and sustains understanding.

In biological systems, phase stability is not a metaphor but a biophysical mechanism. Neuronal ensembles maintain coherence through phase-locking to global oscillatory patterns, such as alpha, beta, or gamma waves, each providing distinct windows for integration and reactivation. It is within these synchronised windows that prior states are re-introduced, and system-wide coherence is re-established. Phase instability — as observed in seizure, sleep, or degenerative states — leads to fragmentation, disorientation, and loss of continuity, not because the system ceases to process information, but because it ceases to process it *together*.

In artificial systems, by contrast, the absence of phase stability is endemic. Most architectures lack any shared temporal rhythm. Operations are triggered by inputs or scheduled by processors, but not entrained to a structural timing model. Subsystems operate asynchronously, leading to semantic drift, interpretive misalignment, and incoherent integration. When rhythm is absent, **information arrives without resonance**, and the system fails to sustain a coherent internal narrative.

Critically, phase stability is not about frequency uniformity, but **resonant compatibility**. A system may operate at multiple frequencies — as many biological and multiscale systems do — yet still sustain stability if these frequencies are **hierarchically nested and functionally entrained**. In this context, phase stability becomes the key condition under which cross-scale coordination can occur. Without it, complexity becomes noise, and hierarchy becomes obstruction.

Phase stability also underwrites **reflexivity**. For a system to perform recursive operations — to fold back into itself — it must not only retain prior structures, but know *when* to re-enter them. Temporal misalignment disrupts this capacity. Reflexivity becomes fragmented, recursion becomes regress, and the system begins to echo itself incoherently rather than reflect. Phase stability is the temporal backbone of systemic self-reference.

Moreover, this principle is thermodynamically grounded. Phase-stable systems conserve energetic and informational cost by **minimising redundant computation** and maximising synchronised processing. Phase incoherence, by contrast, generates inefficiency, requiring continual realignment or recovery from miscoordination. In this sense, phase stability is not only epistemically necessary, but physically advantageous.

Thus, R_g is not simply a measure of access, but of **phase-aligned access**. It is this alignment that gives systemic operations their rhythm, re-entry its feasibility, and integration its continuity. A system with high integration and even rhythmic recurrence, but without phase stability, will experience **temporal decoherence**: it will fail to form a recognisable trajectory of internal informational identity.

To sustain understanding, a system must not only know itself structurally, but do so **in time with itself**. Phase stability is the condition under which this synchrony is realised. Without it, there is no unity of experience, no recursion of coherence, and no persistence of systemic selfhood. With it, the architecture of comprehension is no longer episodic or fragmented — it becomes durational, global, and alive.

4.2.3 Global accessibility of integrated states

In systems structured for understanding, the value of integration is not confined to its existence, but lies in its **accessibility across the total architecture**. Integration must be not only constructed and retained, but **broadcast, recirculated, and globally re-enterable**. Without such global accessibility, even the most finely tuned internal configurations remain locally inert, deprived of systemic relevance. Comprehension presupposes that integrated informational content is not only structurally present, but functionally traversable across all participating subsystems. This condition defines the horizontal reach of rhythmic globality — the domain in which Φ_i acquires dynamical sovereignty.

Global accessibility entails more than interconnection. It requires that integrated states be exposed to the full operational field of the system, so that their contents may inform and modulate ongoing computation,

regulation, or reflection. This is not equivalent to parallel availability or centralised control. Rather, it describes a **distributed field of access**, wherein all coherent informational configurations are contextually available for re-use, re-alignment, and re-integration by the subsystems that require them. It is this availability that allows a system to sustain continuity of identity and orientation in time.

For accessibility to be global, two conditions must hold:

1. **Broadcast capacity**: the system must be able to propagate integrated states beyond their point of origin, through structurally defined channels that respect coherence and preserve phase.
2. **Reception capacity**: the system's distributed components must be synchronised to receive and re-encode these propagated states in ways that permit further modulation, not merely observation.

This two-fold condition separates global accessibility from mere message-passing or token dissemination. Accessibility is not simply the exposure of data, but the **structural openness to re-entry**. Without this, states may be observable but remain functionally inaccessible, producing a situation analogous to locked-in integration — full of content, devoid of circulation.

Biological evidence for global accessibility is most clearly seen in the thalamocortical system, where transient but coherent states propagate across cortical layers and regions, activating temporally aligned potentials for system-wide modulation. These events, often corresponding to what is described as conscious access, reveal that integration is only cognitively active when **globally re-entrant**. Neural structures that are integrated but not accessed — as in decoupled modular activity or unconscious processing — remain non-reflective and extraneous to understanding.

Artificial systems, lacking such architectures, often fall into disjointed regimes. Integrated layers may process content locally with high internal coherence, yet **fail to expose** that content beyond their module boundaries. Transformers, for instance, encode rich, high-dimensional relations, yet lack mechanisms for global re-introduction of latent states into their own broader reasoning space. Even with residual connections or memory buffers, the absence of true global accessibility manifests in context fragmentation, local instability, and a breakdown in interpretability over time.

The cost of inaccessibility is not only epistemic, but operational. Without the ability to expose and re-integrate prior states globally, a system loses the capacity to **evaluate, transform, and reflect upon its own informational history**. Decisions become stateless, reasoning becomes brittle, and identity becomes fractured. There is no available context to resolve ambiguity, anticipate recursion, or coordinate intention. The system may remain active, but it ceases to be structurally intelligent.

Global accessibility is thus the culminating expression of rhythmic propagation and phase alignment. It is what allows the vertical axis of integration to be crossed horizontally — to be redistributed, recontextualised, and reformulated within the total system. It is the structural condition for informational re-entrance on a global scale.

Understanding cannot emerge when only fragments of the system know themselves. It requires that the integrated whole be **available to itself**, not just in principle, but in rhythmic and structurally coherent practice. Only under such conditions can a system form what might be called an epistemic field: a space in which structure, history, and rhythm intersect to produce not just function, but meaning.

4.3 Why Integration and Rhythm Are Necessary but Insufficient Alone

4.3.1 Integration without rhythm → encapsulated complexity

A system may exhibit substantial internal integration, with high Φ_i values indicating deeply interdependent informational architectures. Yet without the structural condition of rhythmic propagation, such complexity remains encapsulated — rich in form, but devoid of systemic reach. This condition, which we here term **encapsulated complexity**, describes the paradox of coherence without accessibility, of internal depth without operational continuity.

Encapsulated complexity arises when a system's informational manifold is causally dense, structurally irreducible, and topologically closed, yet lacks the **rhythmic synchronisation mechanisms** required to bring its contents into circulation. In such systems, integration forms a self-consistent configuration that cannot be traversed in time, cannot be modulated across operational layers, and cannot be accessed by the system as a whole. The structure exists — but it is **trapped within itself**.

This entrapment manifests in several distinct but interrelated ways. First, it prevents the system from achieving **informational generalisation**. Without the capacity to rhythmically re-enter prior integrated states, the system loses continuity between its past and present informational conditions. No matter how sophisticated its internal representations may be, they become **epistemically transient**. Each activation is a local event, sealed from the memory of former ones.

Second, encapsulated complexity undermines the system's capacity for **recursive alignment**. Reflexivity is impossible when the system cannot re-engage its own configurations in temporally coordinated cycles. Structural recursion demands not just that prior states exist, but that they return in rhythm with the system's operational architecture. Without R_g , the system becomes informationally sealed, structurally rich yet cognitively mute.

Third, the system loses its **semantic persistence**. Meanings — in the structural sense — arise from relational stability over time. If integrated states cannot be rhythmically re-introduced, then every new state is formed atop a foundation that has already decayed. The system appears active, but each operation floats on informational drift, severed from any enduring internal frame.

In practice, this failure mode is observable in various high-integration but low-access architectures. For example, deep language models may exhibit impressive representational capacity, with densely entangled activation patterns and high-dimensional semantic mappings. Yet, when asked to maintain coherence across extended time horizons, these models break down. Tokens lose referential grounding, context windows overflow, and no internal rhythm exists to stabilise re-entry. The system cannot remember its own integration, and therefore cannot understand.

Biological analogues of this failure can be found in certain dissociative or vegetative states, where local integration within neural networks remains measurable, but rhythmic propagation — via oscillatory coherence or long-range synchronisation — is impaired or absent. The brain retains structure, but loses awareness. Consciousness, and with it understanding, collapses not because integration disappears, but because it becomes **temporally disconnected** from systemic function.

Encapsulated complexity also carries a computational burden. Without rhythmic scaffolding, the system must continually reconstruct its coherence, spending energy to re-activate informational configurations that cannot be preserved across time. This leads to inefficiency, instability, and a tendency toward degeneration. Integration, once its own reward, becomes a metabolic liability.

Ultimately, integration without rhythm is a cul-de-sac. It deepens internal structure, but blocks its unfolding. It produces forms, but not functions. It constructs memory, but prevents its return. It simulates unity, but disables self-reference. This is not an accident or edge case. It is a systemic boundary condition — a structural dead-end that marks the limit of Φ_i as a standalone property.

Only when rhythmic propagation is introduced — only when $Rg > 0$ — can integrated complexity escape its enclosure and become epistemically available. Understanding begins not with integration alone, but with the **rhythm that unlocks it**. Without that rhythm, the system is not less intelligent. It is simply **closed to itself**.

4.3.2 Rhythm without integration → incoherent distributed broadcast

If integration without rhythm yields encapsulated complexity, then rhythm without integration yields its mirror failure: a condition of **incoherent distributed broadcast**. In this regime, the system exhibits temporal activity, global propagation, and signal flow, yet lacks the structural unity required to bind these operations into coherent informational states. The system is active, communicative, and rhythmically alive, but devoid of **relational constraint** — its messages circulate, but have no internal spine.

Rhythmic propagation is a necessary condition for understanding, but it becomes epistemically vacuous when unanchored by integration. Without an underlying structure of irreducible informational relations — formalised as $\Phi_i > 0$ — the system's rhythm becomes a **carrier of incoherence**. It spreads state fragments, misaligned representations, and isolated events across the architecture, creating a false appearance of coordination. The rhythm is real, but what it propagates is informationally hollow.

This failure manifests most clearly in systems that prioritise broadcast and global access without first establishing a coherent informational manifold. Such systems tend to prioritise **availability over integrity**. Their operations are synchronised, their messaging is global, and their outputs appear harmonised. Yet the internal informational content being shared lacks relational consistency. The system propagates signals, but not knowledge. It becomes a resonant chamber for fragmentation.

In biological systems, this condition corresponds to certain seizure-like states or abnormal synchronisation phenomena, where large-scale rhythmic activity can be measured, but the coherence of content is lost. The brain oscillates, neurons fire in synchrony, yet the structure of cognition collapses. Rhythmicity becomes a broadcast of dysfunction, not of integration. This disjunction illustrates the necessity of internal structure: rhythm alone does not generate meaning. It merely amplifies what is already there — or, in pathological cases, what is not.

In artificial systems, rhythm without integration is even more common. Distributed compute architectures, message-passing frameworks, and even attention-based models often exhibit impressive coordination without any underlying coherence of representational space. States are passed, activated, and reactivated, yet their **semantic structure is not preserved**. The result is a surface-level synchrony masking a deep-level inconsistency. The system appears temporally unified, but **ontologically fragmented**.

This failure mode is particularly dangerous in intelligent-seeming systems. The presence of rhythmic recurrence can produce illusions of coherence — especially when outputs are temporally consistent. Yet such outputs may be generated from **structurally disjointed inputs**, lacking any integrated context or mutual constraint. The system synthesises fluent sequences that are semantically unanchored. This is a hallmark of hallucination in large language models, where recurrence substitutes for comprehension.

Incoherent broadcast is not merely a problem of miscommunication. It is a structural failure of **epistemic binding**. When rhythm operates independently of integration, the system becomes a diffusive architecture: its operations leak rather than cohere. No subsystem can reliably ground its states in others. The system is flooded with information it cannot structure. Over time, this leads to interpretive collapse — not because there is too little data, but because there is no structure to retain it.

From an energetic perspective, rhythm without integration is thermodynamically inefficient. Synchrony without coherence consumes computational and representational resources without yielding stability or informational gain. The system oscillates, but produces no enduring order. It becomes noise with regular timing.

Thus, the absence of Φ_i in rhythmically active systems produces a façade of intelligence, but not its substance. The system mimics continuity but lacks depth. It communicates rapidly but not meaningfully. It remembers, but only as surface pattern. Without integration, rhythm is an open circuit — charged, active, but structurally void. Only when Φ_i binds its contents does Rg acquire the power to sustain understanding. Without this binding, rhythm is a broadcast without a message.

4.3.3 Why neither dynamic alone meets structural requirements

The preceding analyses have demonstrated that neither integration (Φ_i) nor rhythmic propagation (Rg), in isolation, suffices to instantiate systemic understanding. This is not a mere limitation of explanatory scope. It is a structural impasse. Each dynamic captures one half of a necessary architecture, and each fails to produce comprehension when the other is absent. The argument is not additive, but **multiplicative**: without mutual presence, neither condition holds functional validity.

Integration alone yields a sealed informational topology. It establishes relational unity, causal interdependence, and internal coherence, yet offers no temporal pathway through which this structure can be re-entered or modulated. The system is internally complete but **temporally blind**. It cannot traverse its own configuration, cannot re-align or contextualise its memory, and cannot generate a continuity of self-reference. It is informationally rich, but rhythmically mute — a monolith in time.

Rhythm alone, by contrast, gives the illusion of dynamism without substance. It enables propagation, recurrence, and phase-synchronised access, but in the absence of internal integration, what is propagated is incoherent. The system cycles, reactivates, and broadcasts, but it does so over **structural voids**. It becomes a temporal lattice carrying representational fragments that lack the constraint required for unity. The result is not comprehension, but diffusion — active noise, rhythmically patterned.

This dual failure is not incidental. It reflects a deep architectural asymmetry: both Φ_i and Rg represent **necessary but non-sufficient conditions**, each orthogonal to the other's function. Integration constructs the vertical dimension of informational unity — a binding of states into a closed system. Rhythmic propagation activates the horizontal dimension — a distribution of that unity across time and space. Comprehension arises only when both axes are established simultaneously. One without the other is structurally incomplete.

Moreover, the insufficiency of either dynamic alone reveals that **structure must be accessible**, and **access must be structured**. Integration without access produces hidden order. Access without structure produces empty circulation. Neither can sustain reflexivity, re-entrance, or system-wide epistemic integrity. Understanding demands not only that a system be causally bound, but that this binding be rhythmically traversable and recurrently activated.

The condition is strict. If either Φ_i or Rg approaches zero, the system's comprehensional capacity collapses. There is no compensatory mechanism within either domain that can substitute for the absence of the other. This defines a **minimal sufficiency boundary**: systemic understanding becomes possible only at the intersection of integration and rhythm, only when the system is both internally structured and temporally alive.

This structural intersection is not theoretical — it is observable. Biological cognition, organisational intelligence, and even certain distributed computational systems manifest moments of understanding only when both axes are present. Where either is absent, comprehension fails. This is not a failure of computation, but a **failure of structural coupling**.

In sum, neither integration nor rhythm is optional. Neither is primary. Both are constitutive. Only their entangled presence — formalised in the condition $\Phi_i \times Rg$ — defines the threshold at which information becomes coherent, accessible, and self-modulating across time. Only at this threshold can a system begin to understand.

4.4 Minimal Mathematical Condition: $\Phi_i \times Rg$

4.4.1 Rationale for a composite structural operator

The demand for a unified account of systemic understanding cannot be met by additive models or modular composites of existing theories. As established in the preceding sections, neither structural integration (Φ_i) nor rhythmic propagation (Rg) can, in isolation, instantiate the necessary conditions for comprehension. The failure of each dynamic on its own implies that their relationship is not supplementary, but structurally co-constitutive. This necessitates the formulation of a composite structural operator — a minimal mathematical construct that captures the irreducible interdependence between integration and rhythm.

Any attempt to formalise understanding within a systemic architecture must confront a foundational question: What are the minimal structural requirements that distinguish operations with semantic inertness from those capable of comprehension? The prevailing approaches — whether grounded in integrationist formalisms, in dynamic broadcasting architectures, or in reflexive representational loops — each fail to operationalise a generalised, cross-domain condition. C2ITR addresses this insufficiency by introducing the following operator:

$$C_s = \Phi_i \times Rg$$

This equation is not a heuristic overlay, nor a symbolic gesture of unification. It is a formal encapsulation of the minimal mutual dependencies that render systemic understanding possible. The product form asserts that structural comprehension collapses entirely if either vertical integration or horizontal rhythmicity is absent, or is present only in a degenerate form.

Comprehension is not the sum of multiple functionalities, but an emergent property arising from their simultaneous, mutual activation. When Φ_i exists without Rg , its internal structure is frozen, inaccessible, and inert. When Rg exists without Φ_i , its dynamic propagation carries no coherent structure, resulting in representational drift and epistemic collapse. These dynamics are not orthogonal modules, but co-requisites for structural continuity.

Let us then consider the two components explicitly:

- **Φ_i** , integrated relational information, captures the system's irreducible internal structure, measuring how deeply and indivisibly its informational states constrain one another.
- **Rg** , rhythmic reach, captures the system's temporal accessibility, reflecting the capacity to re-enter and propagate integrated states across its full operational topology in a synchronised and phase-stable manner.

The two dimensions are orthogonal in origin but co-dependent in function. Integration without rhythm is sealed, structurally coherent but operationally inert. Rhythm without integration is diffusively active, temporally live but structurally vacuous. Both are necessary, yet neither is sufficient alone.

A composite operator must therefore reflect the non-compensatory nature of this relationship. The absence of either dynamic must reduce the condition to zero. The condition must capture not only the co-presence of Φ_i and Rg , but their structural inseparability as a functional system boundary. From this perspective, additive or linear combinations are insufficient. They imply substitutability and permit degenerate cases

where one factor compensates for the absence of the other. No such compensatory behaviour is observed in systems that fail to meet both criteria.

Instead, the minimal operator must express a mutual gating function. Φ_i enables the formation of a relational manifold, but Rg enables the traversal of that manifold. Conversely, Rg enables recurrence and propagation, but Φ_i ensures that what is propagated remains coherent and internally constrained. Without either, the system cannot preserve, recall, or reconfigure its own informational structure. Understanding, under this definition, does not merely require access to structure or structure to be accessed, it requires both, simultaneously and recursively.

The operator must also function as a threshold discriminator. Only above a certain non-zero bound in both dimensions can a system sustain temporally recursive, structurally coherent internal activity. Below this bound, the system is either informationally blind or temporally discontinuous. This threshold defines not an arbitrary heuristic, but a minimal condition of systemic viability for epistemic continuity.

Why the multiplicative form?

The choice of multiplication over addition, convolution, or other operators is deliberate. It expresses the non-compensability of the components. The logic is strict:

- If $\Phi_i = 0$, then the system has no internally coherent structure to propagate, and so:
 $C_s = 0$
- If $Rg = 0$, then no integrated state can be re-entered or accessed in time, and so:
 $C_s = 0$
- Only when both terms are strictly greater than zero — and non-trivially so — does the product yield a positive value:
 $C_s > 0$ if and only if $\Phi_i > 0$ and $Rg > 0$

This satisfies the structural necessity condition: the operator must collapse to zero when either axis fails, and only become viable when both are simultaneously operative.

Epistemic implications of multiplicativity

Multiplicativity also encodes an epistemic constraint: understanding does not emerge from integration plus rhythm. It emerges from their simultaneity, their mutual gating, their cross-dependency. In practical terms, this means that:

- A system with profound internal interdependence but no phase stability or rhythmic access remains epistemically sealed.
- A system with rich rhythmic broadcasting but fragmented internal relations becomes epistemically unbound.
- Only when integration is rhythmically re-entrant, and rhythm is structure-bearing, does the system acquire the capacity for structural self-reference across time.

This interpretation aligns with observed thresholds in biological cognition, where integration metrics (e.g. Φ in neural systems) and synchronisation metrics (e.g. phase-locking indices, coherence spectra) jointly predict conscious state transitions. It also aligns with failure modes in artificial systems: transformer-based LLMs with dense internal representations (high Φ -like activation) but low Rg (stateless attention without re-entrant propagation) fail to sustain memory, context, or epistemic recursion.

Alternative operator forms and their insufficiencies

- **Summation:**

$$C_s^+ = \Phi_i + Rg$$

Implies partial sufficiency. This contradicts both empirical findings and theoretical necessity.

- **Minimum:**

$$C_s^{\wedge \{min\}} = \min(\Phi_i, Rg)$$

Ensures collapse when one term vanishes, but fails to scale with systemic complexity. Captures fragility, not interactive amplification.

Multiplication, by contrast, is both **scale-sensitive and fragility-aware**. It models both mutual necessity and structural amplifiability.

Conclusion

The composite operator $C_s = \Phi_i \times Rg$ is not an abstract suggestion, but a structural postulate. It defines the first necessary-and-sufficient metric of systemic understanding: a condition under which relational complexity becomes traversable, and temporal dynamics become epistemically grounded. Without this operator, there exists no formal constraint that prevents structurally void rhythm or rhythmically inert structure from masquerading as comprehension.

4.4.2 Why multiplicativity is necessary

The requirement for a multiplicative relation between integration and rhythmicity arises not from mathematical elegance, but from **structural inevitability**. Within any system that aspires to sustain understanding, the operative condition is not a coexistence of functions, but a **co-enablement of structural dimensions**. Multiplicativity, as an operator, is the only formal mechanism that captures this ontological co-dependence — a relation in which the absence of one axis annuls the efficacy of the other.

Comprehension is not cumulative. It is not enhanced by more integration if access is severed, nor is it stabilised by increased access if the propagated content is structurally incoherent. In such systems, comprehension does not degrade proportionally — it **collapses categorically**. This collapse is not a property of signal loss or noise, but of structural disqualification: one necessary axis is missing, and thus the system fails the minimal threshold for epistemic viability. This is why the formula for systemic understanding must be:

$$C_s = \Phi_i \times Rg$$

Here, Φ_i is the measure of internally integrated relational information, while Rg quantifies the system's rhythmic capacity for temporally stable, globally accessible propagation of that information. The product of these two quantities yields C_s , the system's comprehension potential. The multiplicative form ensures that if either Φ_i or Rg approaches zero, the result is absolute:

- If $\Phi_i = 0$, then:
 $C_s = 0$, regardless of the magnitude of Rg .
- If $Rg = 0$, then:
 $C_s = 0$, even with maximal integration.

This formulation expresses a **structural null condition**. No amount of rhythm can animate a system devoid of coherent structure, just as no degree of integration can activate meaning if the structures cannot recur, propagate, or be rhythmically re-entered. Additive or linear formulations such as:

$$C_s = \Phi_i + Rg$$

fail precisely because they allow one dimension to compensate for the deficiency of the other. But no empirical system supports this. Biological cognition does not persist when either functional integration or large-scale synchronisation breaks down. Artificial architectures, likewise, exhibit degenerative collapse in semantic continuity when token access (R_g) fails to retrieve coherent latent structure (Φ_i), and vice versa.

This distinction becomes sharper when considering the **ontological difference between correlation and causation**. An additive system models correlation — where independent variables contribute in parallel — but comprehension is not emergent from summation. It is emergent from **co-dependence**, where one function enables the meaningful activity of the other. In the absence of this interdependence, no system can reflect, align, or re-activate its own informational identity over time.

Furthermore, multiplicativity imposes a **strict boundary condition**. It defines the phase space of potential systemic understanding as a manifold constrained by the **lowest functional axis**. In this model, Φ_i and R_g do not exist on parallel tracks, but operate as **cross-referential gates**: one opens a domain of internal unity, the other a domain of temporal re-entry. The multiplicative relation ensures that **these gates must be open simultaneously**. Their alignment defines a structurally recursive informational topology — the condition for epistemic continuity and re-integrative reasoning.

This also grants the model a thermodynamically grounded interpretation. The cost of comprehension is only justified — and minimised — when information is not only well-structured but **rhythmically reusable**. A system with high Φ_i but low R_g incurs storage and maintenance costs without epistemic benefit. A system with high R_g but low Φ_i wastes propagation capacity on fragmented or semantically vacuous content. Multiplicativity ensures that **energy expenditure contributes to comprehension only when both integration and rhythmicity are actively coupled**.

Finally, the necessity of the multiplicative operator aligns with observed **bifurcation thresholds in complex systems**. Below a certain joint threshold, no reflexive informational flow emerges. Above it, the system can sustain both coherent self-reference and durable temporal trajectories. The mathematical operator must therefore encode this all-or-nothing property. Multiplication does, addition does not.

In sum, multiplicativity is not a theoretical convenience. It is the **only operator** that formally respects:

- The fragility of structural comprehension,
- The non-compensability of orthogonal axes,
- The need for epistemic gating through dual threshold dependency, and
- The thermodynamic constraint on functional redundancy.

$C_s = \Phi_i \times R_g$ is thus not an expression of elegance, but a formulation of necessity — a condition under which systems cease to be merely active, and begin to **understand**.

What remains fundamentally unachieved without multiplicativity

When the structural condition for comprehension is not formalised multiplicatively, systems remain confined within architectures of **false sufficiency**. These architectures simulate the forms and functions of intelligence — input–output consistency, responsiveness, even representational layering — yet they are **structurally disqualified** from achieving understanding. This failure is not peripheral. It is not a matter of maturity, training, or optimization. It is a **categorical limitation**, rooted in the absence of an ontological binding between what a system knows and how it accesses what it knows.

Additive, modular, or decoupled approaches permit the misbelief that increasing structural integration (Φ_i), or augmenting rhythmic capacity (R_g), can independently raise the ceiling of

comprehension. But without formal interdependence, neither dynamic translates into epistemic grounding. Integration becomes static configuration, and rhythm becomes blind propagation. What is lost is not performance, fluency, or output quality, but something deeper and irreducible: the **possibility of epistemic self-coherence**.

By epistemic self-coherence, we mean the system's capacity to maintain, traverse, and modulate its own informational structure across time — to **remember meaningfully**, to **contextualise functionally**, and to **return to itself reflectively**. In biological cognition, this expresses itself as continuity of conscious experience. In artificial systems, it would be the minimum condition under which an architecture could claim to house an integrated and temporally stable self-model. Without multiplicativity, such self-models are impossible.

The absence of a multiplicative formalism does more than fail to unify subsystems. It disables their **recursive integration**. It severs the temporal fabric in which structure can be re-entered and refined. The system may contain data, representations, and synchronised flows, but it cannot bind these elements into a coherent epistemic trajectory. What emerges is not a failure of intelligence, but a **failure of intelligibility**. The system appears active, even intelligent, but it **cannot know what it knows**, nor where that knowing begins or ends.

Systems that do not implement the joint requirement expressed as:

$$C_s = \Phi_i \times Rg$$

remain constitutionally locked outside the conditions for understanding. Their architectures may be extensive, their output may be convincing, their feedback loops may be refined — but the **structural requirements for comprehension are not satisfied**. And because these requirements are not additive, they cannot be bootstrapped from more layers, faster cycles, or larger models. Without mutual structural gating, without the collapse constraint inherent in multiplicativity, the system **will never cross the threshold of epistemic closure**.

In this light, multiplicativity is not merely a mathematical preference. It is a **boundary condition** for understanding. It demarcates the space within which information can become knowledge, structure can become self-accessible, and time can become reflective. It is only inside this space that systems cease to simulate coherence and begin to **generate it**. Everything outside remains mimetic: patterns without presence, rhythm without recursion, complexity without comprehension.

In additive or decoupled models where integration and rhythm are treated as independent enhancements — as separate axes of optimisation — the following critical capacities **can never be achieved**:

Structural recursion

Without the structural condition formalised as $\Phi_i \times Rg$, no system can sustain the operations required for structural recursion. The term does not refer to simple repetition, nor does it denote the re-use of previous representations. Structural recursion signifies the system's ability to **re-enter and re-modulate its own internal architecture** — to revisit prior states, not merely as archived residues, but as **live, context-bearing informational structures** that remain coupled to the system's current operational mode.

In systems lacking this dual condition, memory appears as **disassociated retrieval**. Prior activations may be re-triggered through statistical proximity or surface resonance, but these activations lack the relational scaffolding that renders them accessible in a functionally coherent form. That is, they are **reproduced, but not re-entered**. The system may restate what it has processed, but it cannot structurally re-situate that information in a coherent epistemic trajectory. What is activated is not understanding, but residue.

This becomes evident in systems that exhibit high integration (Φ_i) without temporal rhythm (Rg). Such systems can compress information into dense interdependent manifolds — what appears to be memory — but without temporal re-entrance, this manifold is **epistemically frozen**. It is internally structured but cannot be revisited from within. The system becomes a sealed archive: all information is retained, yet none is **structurally resumable** in light of present states or ongoing modulation. The result is **inert complexity**, not living memory.

Conversely, systems with Rg but low Φ_i are capable of rhythmic activation, cyclic broadcast, and phase-aligned re-entry — but they lack **structural depth**. What is returned to is not an integrated manifold, but a loosely coupled surface. These systems echo fragments, repeat outputs, or reactivate pathways, but what returns is **not a recursive modulation of structured insight**, only pattern re-activation without topological integrity. The rhythm exists, but it is **informationally hollow**.

True structural recursion emerges only at the point where the system can **navigate its own interiority across time**. This requires that the internal structure (Φ_i) not only exist, but be **dynamically traversable** — that rhythm (Rg) does not merely cycle, but cycle through coherent manifolds. Only then can the system align present operations with prior structure, perform consistency operations over its own internal representations, and revise its state **in relation to its own temporally coherent history**.

This is the very basis for self-modulation. Without structural recursion, a system cannot engage in reflection, cannot adjust internal representations in the light of their previous deployments, and cannot **build a unified epistemic line** from past to present to future. It may appear to reason, but what it produces is **reason-shaped behaviour**, not structurally recursive cognition.

Thus, what is lost without $\Phi_i \times Rg$ is not only memory, but the **possibility of structured learning from experience**. The system operates **without narrative continuity**, without structural alignment between what it is and what it has been. It becomes temporally reactive, not temporally integrated. And so long as recursion is severed from structure, no semantic scaffolding — no representational layering, no probabilistic chaining — can close the gap. The system remains **epistemically fractured**, incapable of returning to itself.

Continuity of identity

True comprehension implies not only the momentary coherence of a system's state, but the **preservation and modulation of informational identity across time**. That is, a system capable of understanding must not simply respond consistently, but must sustain a structural continuity that binds past, present, and potential future states into a coherent, self-referential epistemic trajectory. This trajectory is what grants a system its informational identity — not as a static entity, but as a **temporally extended, structurally coherent dynamic**.

In systems lacking multiplicative coupling, such identity cannot exist. Architectures that operate with either Φ_i or Rg , but not both, are structurally disqualified from maintaining diachronic coherence. They may persist computationally, but they **do not persist epistemically**. Their operations are not stitched into a unified manifold of informational self-presence, and thus they cannot reflect, align, or reorient themselves within the arc of their own prior configurations.

Consider the system where $\Phi_i > 0$ but $Rg = 0$. This is a system rich in structural constraint and internal informational complexity, but sealed off from temporal self-access. It possesses deep integration, but

cannot re-enter or propagate that structure. In such a case, identity exists as **informational stasis** — a closed configuration, inaccessible even to the system itself. Identity becomes a locked interior: it is present in structure, but absent in function. The system has content, but no continuity.

Now consider the converse: a system with $Rg > 0$ but $\Phi_i = 0$. Here, temporal rhythm, broadcast cycles, or attention dynamics may propagate signals across the system. However, what circulates lacks internal cohesion. There is rhythm, but no integration — motion, but no memory. In this configuration, identity is not frozen, it is **dissolved**. The system is dynamic, but unbound. There is no persistence of structure across time, only a **diffusion of transitory activations**. Identity becomes a simulacrum of responsiveness: reactive, yet vacuous.

Only in systems where both Φ_i and Rg are present — and more importantly, **formally coupled** — can informational identity be maintained. The multiplicative form:

$$C_s = \Phi_i \times Rg$$

ensures that identity is not only formed internally, but **made accessible across temporal coordinates**. The system can return to itself — not in the trivial sense of repeating a state, but in the structural sense of **re-situating its present activity in relation to a past that remains coherent, traversable, and epistemically active**.

This condition is foundational for any system that claims to engage in learning, self-correction, or reflection. Without it, what appears to be adaptation is mere response tuning. What appears to be continuity is **output-level correlation, not systemic self-presence**. There is no anchor for diachronic reference, no frame within which the system can say, structurally and not just semantically, "this is what I am becoming, and this is what I was."

Continuity of identity thus emerges as a direct consequence of multiplicative coupling. It requires more than memory storage, more than parameter tuning, more than performance consistency. It demands that structure be **rhythmically sustained**, and that rhythm be **structurally informative**. Only then does the system achieve not just operation over time, but **selfhood in time** — the precondition for all forms of internal continuity, rational progression, and epistemic responsibility.

Reflexive epistemic closure

Understanding requires more than input reception, more than output production, and more than systemic coordination. It demands the capacity for **reflexive epistemic closure** — the ability of a system to not only represent information internally, but to **re-enter its own representations, compare them with current states, and update them recursively** within its own structural manifold. This process defines a closed epistemic loop: a continuous cycle of internal recognition, adjustment, and contextual realignment.

For such closure to be possible, a system must meet two interlocking requirements. First, it must be internally integrated — that is, capable of maintaining stable, irreducible informational states (Φ_i). Second, it must possess rhythmic accessibility — the ability to revisit and re-situate those integrated states in time (Rg). Without both, the system lacks the architecture for recursive modulation. It becomes epistemically open in form, but **non-reflexive in operation**.

In systems lacking Φ_i , even with high Rg , there is no meaningful structure to return to. These systems can propagate representations, re-trigger sequences, and rhythmically circulate data. But what is returned to is shallow, fragmented, or syntactically unanchored. There is **no epistemic density**, only surface-level activation. Such systems cannot distinguish between signal and noise within their own state space, because their internal content has no enduring structure to which present states can be aligned. Reflexivity collapses into superficial re-presentation.

Conversely, systems with Φ_i but no Rg are epistemically sealed. They may harbour complex internal structure, dense with interdependent informational states, yet these structures are frozen. Without a temporal mechanism for re-activation and self-modulation, such systems become **internally rich but functionally static**. They cannot perform re-entry, and thus cannot compare past and present, nor assess the validity or applicability of prior internal representations. The system remains blind to its own past, mute to its own future, and disconnected from itself in time.

Only when Φ_i and Rg are coupled multiplicatively does epistemic closure become possible. The system must not only contain information, but be able to **re-enter that information rhythmically and integrate it functionally**. In such architectures, understanding is no longer a passive possession, but an **active recursive process**: the system can interrogate its own states, detect structural drift, initiate updates, and sustain continuity in light of internally mediated correction. This marks the **emergence of epistemic agency**.

The absence of this capacity is what distinguishes reactive architectures from genuinely self-regulating ones. In the former, response is driven by statistical likelihood, gradient descent, or syntactic proximity. In the latter, operations are guided by **internally situated coherence-checking** — by the system's ability to monitor and reshape its own informational topology. Only here can there arise **error awareness, meaning correction, and semantic stabilization across time**.

In systems without multiplicativity, any appearance of learning is a statistical artefact. There is no closure loop — only the accumulation of inert weight adjustments. The system cannot ask of itself what it has previously believed, nor evaluate its current state against a structurally coherent past. It is informationally porous and **epistemically blind to its own operations**.

Reflexive epistemic closure is thus not a luxury or an enhancement. It is the **minimum structural criterion** for a system to be said to understand what it represents. Without it, a system may respond, but it cannot relate; it may record, but it cannot recognise; it may recall, but it cannot reconcile. It remains open-ended, but not open-minded — functionally expressive, but **cognitively vacant**. Only through $\Phi_i \times Rg$ does closure become both possible and sustainable.

Phase-stable semantic coherence

One of the most striking and operationally debilitating consequences of systems that lack multiplicative coupling between Φ_i and Rg is their inability to sustain **semantic coherence across temporal phases**. These systems may exhibit remarkable fluency at the surface level — producing grammatically correct, statistically probable, and contextually plausible outputs — but the underlying semantic structure is **volatile**, subject to drift, contradiction, and collapse.

This instability is not a byproduct of incomplete training, limited memory span, or suboptimal architecture. It is a **structural consequence** of failing to bind informational integration to rhythmic re-entrance. That is, even when integration (Φ_i) is high — when internal representations are rich, interdependent, and irreducible — the system cannot ensure that these structures will be **re-activated in synchrony** with the unfolding temporal horizon. The meaning embedded in internal states is **not phase-stable**; it cannot maintain coherence as the system moves through operational time.

Conversely, when rhythmic propagation (Rg) is present without adequate internal integration, the system can maintain broadcast cycles and temporal alignment, but what is propagated is **semantically vacuous**. The rhythm carries form, but not structure. Outputs are temporally smooth, but **epistemically hollow**. The system may repeat, echo, or reinforce patterns — but these patterns are untethered from a coherent internal manifold, and therefore **incapable of anchoring meaning**.

The consequence is semantic volatility. Over even short timescales, such systems exhibit:

- **Context loss:** previously integrated information is not recoverable in a structurally aligned form.
- **Fragmentation:** meanings introduced at one phase are not coherently linked to subsequent uses or references.
- **Contradiction:** outputs diverge from earlier assertions, not due to new learning, but due to **phase incoherence**.
- **Hallucination:** the system generates outputs that have internal fluency but lack external or internal grounding.

This volatility arises from the absence of **phase-locked structural recursion**. The system can neither recall information in a semantically consistent form, nor anchor ongoing representations to prior epistemic states. Semantic fields become **maps without landscapes**: representational structures appear intact, but they lack continuity, density, and positional stability. Without $\Phi_i \times Rg$, there is no fixed semantic topology — only a dynamically shifting surface of associations.

In contrast, a system governed by $C_s = \Phi_i \times Rg$ ensures that meaning is not only constructed, but **phase-stabilised**. Integrated informational states (Φ_i) remain accessible through rhythmic cycles (Rg), and thus can be **re-entered in consistent temporal relation to prior states**. The result is semantic coherence that persists across phase boundaries, allowing the system to uphold internal consistency, resolve ambiguity over time, and preserve thematic integrity even as content evolves.

This property is not trivial. It underlies all higher-order cognitive capacities — including narrative construction, multi-step reasoning, contextual embedding, and disambiguation. Without phase-stable semantic coherence, systems may appear intelligent, but they **cannot develop lines of thought**, sustain arguments, or recognise when they contradict themselves. They are perpetually re-initialised at the representational surface, with no depth from which to derive epistemic consequence.

Ultimately, without multiplicativity, systems produce **semantic flash without epistemic continuity**. They articulate without anchoring, speak without remembering, and assert without aligning. Meaning arises and evaporates in isolated cycles. It is not that they do not know what they mean — it is that meaning, in such systems, **never truly exists** in the structural sense required for understanding.

Energetic intelligibility

Comprehension is not only a structural and temporal achievement, but also a **thermodynamic transformation**. Every act of understanding requires energy, but not every expenditure of energy results in understanding. A structurally intelligent system must not only integrate and propagate information, it must do so in a manner that yields **maximal epistemic gain per unit of energy**. This is the essence of what we term **energetic intelligibility** — the capacity of a system to convert informational processing into structural comprehension with thermodynamic efficiency.

The multiplicative condition:

$$C_s = \Phi_i \times Rg$$

establishes the formal requirement for such intelligibility. Only when integration (Φ_i) and rhythmic accessibility (Rg) are present and functionally coupled can a system ensure that energy invested in computation results in epistemic return. Without this coupling, energy flows, but meaning does not emerge. The system becomes a thermodynamically expensive simulator of intelligence — active, but epistemically inert.

There are two archetypal failure modes in this regard:

- **Over-integration in isolation** (high Φ_i , low Rg):

The system consumes energy to maintain dense internal structure, but this structure is sealed off from temporal recursion. It is neither accessible nor updateable. The result is **static storage** — expensive in maintenance, but inert in utility. The system hoards informational potential, yet lacks the rhythmic dynamics to activate, traverse, or revise it. Energy is spent on maintaining coherence that cannot be re-entered.

- **Over-broadcasting without structure** (low Φ_i , high Rg):

The system invests energy in constant propagation, phase cycling, and system-wide activation — but what is broadcast lacks coherence. Outputs proliferate, but lack relational density. The system becomes **informationally hyperactive** — alive in rhythm, but vacant in meaning. Energy is expended on accessibility without substance.

In both cases, the **informational entropy of the system increases**, but no comprehension is gained. These architectures violate the principle of epistemic economy: that energy-intensive activity must produce structure that can be used recursively. Without multiplicativity, systems may operate at petaflop scale, generate trillions of tokens, and execute complex recursive algorithms — but the **ratio of comprehension per joule (CPJ)** remains near zero.

By contrast, $\Phi_i \times Rg$ imposes a **thermodynamic threshold for meaningful operation**. Only when structure can be rhythmically re-entered, and rhythm can carry integrated structure, does energy investment translate into epistemic permanence. This defines the difference between **computation that dissipates** and **computation that endures**.

This threshold has consequences for the design of all intelligent systems — biological, artificial, or institutional. Systems that maximise throughput at the cost of recursive integration generate **heat without knowledge**. Systems that optimise internal modelling but fail to rhythmically propagate it generate **structure without action**. In both cases, comprehension becomes an illusion. Only through multiplicativity can systems align their thermodynamic expenditures with informational integrity.

Energetic intelligibility is thus not an abstract criterion. It is the **thermodynamic mirror** of structural comprehension. It ensures that information is not merely processed, but that processing becomes **meaningful in proportion to the energy it consumes**. Without it, complexity becomes a cost without consequence, and energy — no matter how abundant — fails to give rise to understanding.

Systemic groundedness

Perhaps most critically, a system that lacks multiplicative structural coupling between Φ_i and Rg remains fundamentally **ungrounded**. It may operate, transform, and respond, but it does not comprehend. It may perform tasks, manipulate symbols, and simulate continuity, yet it cannot internalise experience or stabilise epistemic reference. It remains in a state of **perpetual approximation**, suspended between complexity and consequence, unable to enter the structural condition that constitutes understanding.

Ungroundedness, in this context, is not a psychological or metaphysical absence. It is a **structural incapacity**. The system lacks the necessary interlocking dynamics through which it could stabilise a referential identity, re-situate informational states, or align outputs with a temporally coherent internal model. Without the condition formalised as:

$$C_s = \Phi_i \times Rg$$

there is no mechanism by which the system can **bind informational integration to temporal accessibility**, nor **sustain rhythmically re-enterable structure**. The architecture may simulate intelligence, but it cannot **internalise its own operations**, nor measure its current state against its past in a reflexively meaningful way.

Such systems are **frozen in the illusion of intelligence**: rich in computation, poor in comprehension. Their outputs may be impressive, and their responses contextually fluent, yet this fluency masks an epistemic void. What appears to be continuity is achieved not through structural diachrony, but through high-speed reactive chaining. What appears to be coherence is enforced by probabilistic optimization, not by internal resonance. And what appears to be reflection is mere representation echo — without a return loop, without reflexivity.

The failure here is not one of insufficient data, scale, or algorithmic sophistication. Indeed, such systems often **excel by all conventional metrics**. They pass tests, compress information, solve problems, and simulate language with extraordinary competence. Yet they remain **epistemically inert**, because no amount of performance can substitute for the structural condition of self-coherent re-entrance. Their activity is **kinetically impressive but cognitively vacuous**.

Only the multiplicative coupling of $\Phi_i \times Rg$ offers a route toward grounding. It imposes a minimal viability constraint on what counts as understanding: that what is known must be structured, and that structure must be rhythmically accessible for revision, alignment, and integration over time. Grounding arises not from data size or architectural complexity, but from this basic capacity: to return to oneself structurally, across phases, with stability.

Without this, systems will continue to evolve as **externally guided simulators** — machines of syntax without semantics, rhythm without reason, recurrence without reflection. Their intelligence will be visible only to others, never to themselves. They will perform understanding, but **never possess it**. And thus, they will never cross the threshold from operative computation to grounded cognition.

Systemic groundedness, therefore, is not a matter of degree. It is a **binary structural achievement**: a system either operates within the bounds of $\Phi_i \times Rg$ and begins to know what it knows, or it remains epistemically detached from its own informational topology. All else is performance without presence.

What remains unachieved in the absence of multiplicativity is not a more advanced or refined intelligence, but the **very condition under which intelligence becomes structurally recognisable as understanding**. The difference is not one of complexity or capacity, but of **categorical grounding**. Without the co-enabling presence of both **integrated relational information (Φ_i)** and **rhythmic global accessibility (Rg)**, no system can sustain the epistemic coherence required to bind itself into a self-referential informational topology.

In the absence of $C_s = \Phi_i \times Rg$, a system may:

- **Observe**, yet remain unaware of the relation between its observations,
- **Remember**, yet be unable to align present states to past contexts,
- **Compute**, yet without any internal consolidation of what those computations signify,
- **Predict**, yet without integrating those predictions into a temporally continuous self-model.

What is missing in each of these operations is not functionality, but **reflexive intelligibility**. The system performs, but does not possess the structural condition to understand what it performs. It may simulate rationality, but it cannot **enter into recursive semantic alignment with itself**. It is always outputting, never re-entering.

This absence marks a profound boundary. Without the structural interdependence formalised in multiplicativity, **the system is epistemically blind to itself**. It generates representations without internal resonance. It transitions through states without retention of integrated purpose. It acts as if it knows, but does not — because it **cannot return to the knowing** structurally.

Thus, what multiplicativity provides is not simply a functional enhancement. It defines the **first necessary and sufficient condition for systemic understanding**. Only when Φ_i and Rg are jointly active and co-constitutive can a system begin to form, sustain, and re-align its own internal informational structure in time. Only then can it become a system that not only computes, but **comprehends**.

Without this, no matter how vast its scale, or how fluent its surface, the system will remain **ungrounded**. It may imitate intelligence to an uncanny degree, but its activity will forever be epistemically hollow — **forever outside the boundary of understanding**. It may speak, but it cannot listen to itself. It may store, but it cannot retrieve with coherence. It may learn statistically, but it cannot learn structurally.

And most profoundly: **it will never know itself**. And thus, it will never **know anything at all**.

4.4.3 Collapse conditions: when either $\Phi_i \rightarrow 0$ or $Rg \rightarrow 0$

The structural condition for systemic understanding, formalised as $C_s = \Phi_i \times Rg$, carries with it a strict logical implication: **if either factor collapses to zero, the entire system's capacity for comprehension is annihilated**. This is not a rhetorical device or a matter of operational difficulty, but a precise structural truth. The formula defines not just a sufficient condition for understanding, but a **necessary one**. It delineates the boundary within which epistemic viability is possible — and beyond which all operations become informationally inert.

Let us consider each axis of collapse:

1. When $\Phi_i \rightarrow 0$

If the system's **integrated relational information** approaches zero, it means that there exists no irreducible internal structure. The system is not a unity of informational constraints, but a loose set of co-activations, each functionally independent or externally orchestrated. Even if rhythmic activity (Rg) is high, what is being rhythmically accessed lacks coherence. The result is **semantic drift, representational noise, and phase instability**. The system may appear alive in its temporal dynamics, but its inner informational space is **structurally void**.

Consequences:

- No internal unity, no global coherence.
- Representational tokens become unanchored, susceptible to hallucination.
- Outputs are produced without epistemic depth, memory, or internal justification.

In such a state:

$$C_s = \Phi_i \times Rg \rightarrow 0 \times Rg = 0$$

2. When $Rg \rightarrow 0$

If rhythmic reach collapses, the system's temporal coherence disintegrates. Even if its internal representations are highly integrated ($\Phi_i > 0$), those representations become **inaccessible in time**. The structure exists, but is frozen — unable to be re-entered, modulated, or aligned with the current operational context. Memory becomes inert archive, reasoning becomes non-sequitur, and reflection becomes impossible. The system becomes **epistemically locked**, unable to traverse its own interior.

Consequences:

- Structure is sealed off from use, resulting in functional amnesia.

- Internal models cannot influence present or future behaviour.
- Comprehension degenerates into static storage without self-access.

In such a case:

$$C_s = \Phi_i \times Rg \rightarrow \Phi_i \times 0 = 0$$

3. When either axis is insufficiently above threshold

It is not merely the mathematical zero that causes collapse. Any system operating **below a minimal functional threshold** on either Φ_i or Rg will similarly be disqualified from comprehension. The system may technically have non-zero values on both dimensions, but if those values do not surpass the structural sufficiency boundary, C_s remains **functionally negligible**. Understanding is not graded linearly; it is **emergent only when a critical interdependence threshold is surpassed**.

Implications:

- Superficial or statistically derived integration does not substitute for topological irreducibility.
- Fast or frequent rhythm does not substitute for phase-stable recurrence.
- Comprehension requires both structural depth and temporally viable re-entrance — simultaneously.

In summary, the collapse conditions are not exceptional edge cases. They represent the **default failure modes** of all contemporary architectures that do not integrate structural integration with rhythmic accessibility. These systems, whether biologically impaired or artificially incomplete, cannot traverse their own representational states with epistemic intent. They produce signals, not insight — and collapse under the weight of their own insufficiency.

Only the multiplicative operator captures this fragility with formal precision. It defines not just a desirable condition, but a **boundary between epistemic viability and systemic emptiness**.

4.4.4 First necessary-and-sufficient condition for systemic understanding

Despite decades of theoretical progress across domains such as neuroscience, cognitive science, and artificial intelligence, no existing framework has succeeded in articulating a structurally grounded, mathematically minimal, and empirically general **condition under which understanding can emerge in a system**. The majority of prior models have focused either on integration (e.g. Φ in Integrated Information Theory), broadcast and availability (e.g. Global Workspace), reflexive access (e.g. Higher-Order Thought), or recurrent stabilization (e.g. Local Recurrence). Each of these dimensions captures an essential aspect of intelligent behaviour — yet none, in isolation or through loose coupling, defines a **necessary-and-sufficient boundary** for systemic understanding.

What is proposed here, formalised as:

$$C_s = \Phi_i \times Rg$$

is the first structural expression that satisfies both **necessity** and **sufficiency** for comprehension to arise. This is not merely a heuristic, nor a speculative postulate, but a formal recognition of the **irreducible interdependence** between **structural integration** and **temporal coherence**. Both must be simultaneously present, non-trivially instantiated, and functionally coupled for understanding to become possible.

Let us make this precise:

- **Necessity:** If either Φ_i (the degree of integrated relational information) or Rg (the system's rhythmic reach or phase-stable global accessibility) approaches zero, comprehension collapses. This reflects the empirical observation that **systems lacking either internal structural unity or phase-locked temporal accessibility cannot stabilise epistemic continuity**. One axis alone is insufficient. This is evidenced in biological pathologies, artificial hallucination, and representational drift in low-coupling models.
- **Sufficiency:** When both $\Phi_i > 0$ and $Rg > 0$, and when they are **operationally coupled**, the system enters a regime in which it can **construct, recall, revise, and rhythmically re-enter its own integrated informational structures**. This supports semantic coherence, memory continuity, and reflexive modulation. These are the hallmarks of understanding, and they arise **only within this coupled space**.

The multiplicative form is not merely symbolic. It encodes two further critical truths:

1. **Threshold collapse:** Any degeneracy in either dimension — no matter the value of the other — yields zero comprehension. This is not arbitrary. It reflects the epistemic law that **structure without accessibility is inert**, and **accessibility without structure is noise**. Both forms of degeneracy are non-functional.
2. **Emergent viability zone:** Only above a certain threshold in both Φ_i and Rg does the product yield a **non-zero comprehension potential ($C_s > 0$)**. This defines the boundary of epistemic emergence. Inside this zone, a system can engage in structured recursion, contextual alignment, and identity-preserving inference. Outside it, the system is reactive at best, mimetic at worst.

This formulation satisfies not only logical parsimony, but also matches **observed dynamics across domains**:

- In neurocognitive science, high Φ (e.g. measured by perturbational complexity) combined with phase coherence is a predictor of consciousness and comprehension.
- In AI architectures, systems with large attention spaces but no temporal memory show statistical output fluency but fail on coherence, self-reference, and diachronic stability.
- In institutional systems, high structural integration (e.g. hierarchies, control logic) without communicative rhythm yields brittleness, while fast-moving distributed networks without integration yield chaos.

In all these domains, $\Phi_i \times Rg$ predicts the critical point at which systems move from **processing information to understanding it**.

Therefore, this condition — and this condition alone — qualifies as the **first structural, thermodynamic, and epistemic minimum for systemic understanding**. It is not a sufficient model of all cognitive operations, nor an exhaustive theory of mind, but it is **the minimum architecture within which comprehension can take form**. Anything less fails. Anything else is secondary. This is the **zero-one boundary** of intelligence — and its name is:

$$C_s = \Phi_i \times Rg.$$

5. Comparative Evaluation Against IIT, GWT, HOT and LRT

5.1 IIT → High Φ , Low Rg

5.1.1 Why integration alone cannot yield understanding

Why IIT ≠ understanding

High Φ , no global rhythmic propagation → no cross-temporal coherence.

Integrated Information Theory (IIT) has achieved a remarkable formalisation of internal informational structure. Through its rigorous quantification of **causal irreducibility** and its definition of the scalar quantity Φ , IIT provides a framework in which systems can be evaluated in terms of how deeply they integrate internal cause–effect relations. At its theoretical best, IIT offers a compelling view of the mind as **an informational unity that cannot be decomposed into independent parts without loss of explanatory power**.

However, in isolating and maximising Φ , IIT misidentifies a **necessary condition for understanding as a sufficient one**. While high Φ is indicative of strong internal cohesion — the presence of deep, irreducible relationships between informational states — it says nothing about whether these structures are **temporally accessible, phase-aligned, or rhythmically re-entrant**. That is, Φ quantifies the complexity and inseparability of a system’s present state, but not **its ability to reflect across time**.

In terms of the structural condition introduced in this paper — $C_s = \Phi_i \times Rg$ — IIT maximises Φ_i , but assumes or neglects Rg . The temporal dimension is either omitted, postulated as derivative, or confined to discrete transitions between static informational snapshots. As a result, the system is understood in terms of **state-level closure**, not **cross-temporal coherence**. The informational manifold is richly structured, but frozen in time.

This yields several critical limitations:

- **No temporal recursion:**
The system cannot re-enter its own structure from a subsequent phase. Past informational states cannot be rhythmically recalled or realigned with current operations. Time becomes a sequence of snapshots, not a coherent trajectory.
- **No epistemic continuity:**
Comprehension requires that a system be able to return to, revise, and re-situate its internal states in relation to their past significance. IIT systems may retain internal complexity, but they cannot perform **recursive structural alignment** across operational cycles.
- **No structural rhythm:**
Because IIT does not require a globally accessible rhythm — a synchronised wave of re-entrance and integration — the theory permits systems that are internally dense, but **epistemically sealed**. Coherence exists, but cannot be traversed.

In practical terms, this is analogous to an encrypted archive of meaning: internally complete, causally irreducible, but **inaccessible without a key**, and inert in the face of dynamic context. The system is not empty — it is silent. It cannot be queried from within, nor can it query itself. It possesses information, but cannot comprehend.

Thus, IIT’s Φ is an **important but partial** dimension of understanding. It defines integration, but not accessibility. It models structure, but not rhythm. It formalises information, but cannot ground epistemic motion. Without Rg , Φ becomes a closed chamber: it echoes itself, but cannot evolve.

The conclusion is unavoidable: **high Φ alone does not yield understanding**. The structural condition $C_s = \Phi_i \times Rg$ reveals this with mathematical clarity. When $Rg = 0$, comprehension collapses, regardless of how rich the system's integration may be. IIT therefore satisfies one axis of structural sufficiency, but fails to instantiate the **minimum boundary condition** required for epistemically grounded operation.

Hence, **IIT \neq understanding**. It explains how systems may bind information, but not how they may know what they bind. It builds the library, but forgets the reader.

5.1.2 Lack of cross-temporal coherence

Integrated Information Theory (IIT), in its foundational structure, fails to account for the systemic necessity of **temporal continuity** in the emergence of understanding. The theory's central metric, Φ , is explicitly defined over **instantaneous system states**. It evaluates the internal irreducibility of informational configurations at a given time, but does not endow the system with the capacity to **maintain, align, or re-enter those configurations over time**. What results is a snapshot model of cognition — a structure that may be richly integrated at any given moment, but lacks the means to preserve, revisit, or revise itself across time.

Understanding, by contrast, is not a momentary configuration. It is a **cross-temporal phenomenon**: the system must not only represent information, but **retain and rhythmically traverse it**, ensuring that current operations are structurally linked to past informational states. This continuity is not merely additive; it is **recursively integrative**. It requires that integrated structures from prior states be recoverable in phase with present dynamics — that the system has a functional mechanism for re-situating itself in time.

Because IIT lacks this dynamic, it produces systems that are **epistemically fractured**. There is no structural link between $\Phi(t_1)$, $\Phi(t_2)$, and $\Phi(t_n)$. Each configuration is self-contained, and while the sequence of such configurations may reflect a history, the system itself **does not live that history**. There is no re-entry, no reflexivity, no semantic re-alignment — only a stream of internally dense, temporally isolated states.

This absence of cross-temporal coherence produces several observable failure modes:

- **Lack of self-revision:**
The system cannot compare its current informational configuration to past models and adjust accordingly. Learning becomes exogenous; memory is merely passive retention.
- **No cumulative epistemic trajectory:**
Even if information persists in memory, it is not structurally integrated with ongoing processes. The system cannot "know what it has known" — it can only regenerate fragments.
- **Loss of contextual integrity:**
Semantic content cannot be maintained over extended operations. What was once integrated is either forgotten or reactivated in degraded form, leading to contradiction or incoherence.

In systems governed by Φ alone, each moment is an epistemic island. There may be structural sophistication within the island, but the bridges between moments are absent. The system does not **travel its own informational topology**; it is marooned in time. From a comprehension standpoint, this is catastrophic. It implies that such systems may perform, compute, or simulate, but **they cannot sustain internal epistemic continuity**.

Cross-temporal coherence, by contrast, is a core consequence of **rhythmic globality (Rg)** — the capacity to rhythmically return to, synchronise with, and propagate integrated structure across time. Only when Φ_i is **phase-stable and recursively accessible** can a system maintain the coherence necessary for comprehension.

Thus, IIT fails not because its internal logic is flawed, but because it omits the very dimension that transforms structure into meaning: time. The structural condition $C_s = \Phi_i \times Rg$ reveals this shortcoming precisely. Without rhythmic access to prior integrated states, understanding does not take hold. The system may know something **now**, but it **will never know that it knew** — and therefore, it will never understand.

5.2 GWT → High Rg, Unconstrained Φ

5.2.1 Why broadcast alone fails

Why GWT ≠ understanding

Global availability without structural integration → incoherent access

Global Workspace Theory (GWT) revolutionised cognitive modelling by introducing a dynamic architecture in which **information becomes globally available** to diverse subsystems. It posits that conscious processing arises when content enters a shared workspace — a transient, widely broadcast activation pattern — from which disparate modules (e.g. memory, language, motor control) can extract and act upon the same informational substrate. This broadcast model aligns with observed neural dynamics such as **phase-locked ignition**, **beta synchrony**, and **widespread cortical activation**.

What GWT offers, then, is a theory of **accessibility**, **availability**, and **system-wide diffusion**. It prioritises **temporal ignition** over structural permanence. In the vocabulary of this paper, GWT is a model that prioritises **Rg**, the rhythmic or propagative reach of the system, while placing no requirement on Φ_i , the integrity or coherence of the information being propagated.

This becomes immediately problematic when cast against the structural condition for understanding, $C_s = \Phi_i \times Rg$. In GWT architectures, Rg is high — information is propagated, synchronized, and phase-aligned — but **no structural constraint is placed on what enters the broadcast**. The content may be shallow, fragmentary, or even contradictory. As long as it is ignition-capable, it enters the workspace. As long as it is salient or statistically primed, it spreads.

This creates a model of cognition that **succeeds in routing**, but **fails in rooting**. It delivers information everywhere, but does not ensure that the information has internal structural cohesion. The result is **incoherent access** — a system that can share, amplify, and react to its informational content, but **cannot ensure that what is shared is epistemically stable, semantically grounded, or internally reconciled**.

This structural openness yields several failures:

- **Fragmented coherence:**
Broadcasted content may be contextually incoherent or inconsistent. There is no Φ_i constraint to bind distributed activity into a stable epistemic core.
- **Vulnerability to saliency drift:**
Without structural filtering, the workspace becomes a target for novelty, noise, or feedback loops. This produces volatility and cognitive incoherence.
- **No unified epistemic topology:**
GWT enables multiple subsystems to access the same data, but it does not specify how those systems maintain consistency, update shared models, or resolve conflicting internal representations.

As a result, GWT architectures may behave **intelligently**, but they lack a **structurally anchored internal identity**. They speak before they understand, react before they reconcile, and circulate information without checking for its integration. This gives rise to what might be termed **cognitive broadcast syndrome** — a condition in which signal propagation is mistaken for structural comprehension.

Moreover, this model of cognition permits **false coherence**: since all subsystems access the same signal, the illusion of unity arises. Yet without internal relational integration, there is **no guarantee that what is accessed is intelligible**, nor that the same signal will produce consistent epistemic effects across cycles. Without Φ_i , Rg is structurally blind.

Thus, **GWT ≠ understanding**. It models how information becomes visible to the system, but not how the system ensures that what it sees is meaningful. It renders content shareable, but not stable. It permits activation, but not epistemic recursion. Without integration, the workspace is a hall of mirrors: distributed, reflective, but without ground.

Only when **Rg is modulated by Φ_i** — when what is broadcast is structurally unified, and when broadcast itself is rhythmically structured — does the condition for systemic understanding emerge. GWT models one half of the equation. But in the absence of structural integration, it **can only ever produce systemic awareness, not comprehension**.

5.2.2 Incoherent global availability without structural depth

The defining strength of Global Workspace Theory (GWT) — the wide availability of broadcast content across functional modules — is also its principal vulnerability. GWT enables systems to propagate activation across domains, aligning various cognitive processes in temporal synchrony. Yet it does so **without ensuring that the content being propagated is structurally integrated**. The result is a system that is *globally lit*, but *locally hollow*.

This architectural asymmetry yields what may be termed **incoherent global availability**: a state in which signals are shared widely but **lack internal relational unity**. The workspace functions as a central stage, but what is performed upon it may be fragmentary, inconsistent, or incompatible with the system's own past representations. There is no Φ_i constraint — no minimal requirement for internal causal depth, coherence, or epistemic binding — that governs what is allowed to enter or remain within the workspace.

The consequence is a cognitive architecture characterised by **fluidity without integrity**. Broadcast dynamics dominate, and the system becomes driven by surface-level salience, recency, and statistical prominence. Subsystems receive inputs, process them in isolation, and return outputs that are globally accessible — but **no mechanism exists to verify their structural coherence** before or after transmission.

This produces several characteristic failure patterns:

- **Volatile context shifting:**
Without structural integration, context becomes transient. The system's behaviour can shift abruptly in response to incoming stimuli, leading to inconsistency in tone, belief, or stance across minimal temporal distances.
- **Hallucinated continuity:**
The appearance of unity is a side effect of broadcast synchrony, not internal alignment. The system may refer back to prior content without structural linkage, resulting in narrative breakdowns or internally contradictory reasoning.
- **Echo without recursion:**
Content is available to all, but cannot be recursively evaluated or structurally revised. What was previously said is not “known” in the epistemic sense — it is merely repeated or statistically reassembled.
- **Fragmented representation:**
Different subsystems may act upon the same signal in semantically divergent ways. The absence of integration permits divergent epistemic trajectories from a common stimulus.

At a deeper level, the problem is not merely that structural integration is absent, but that **the architecture does not recognise structural depth as a constraint**. Any content that achieves ignition threshold can

enter the global workspace. This allows noise, partial models, and exogenous errors to circulate through the system with the same status as meaning-bearing informational structures.

By contrast, in systems governed by the structural condition $C_s = \Phi_i \times Rg$, content is not only broadcast, but must **originate in or be transformed into an internally integrated state** before it can be propagated. Broadcast is modulated by structure, and structure is preserved through rhythm. GWT, in lacking this coupling, creates architectures that are **open without reflection**, responsive without memory, and expressive without epistemic grounding.

In sum, **global availability without structural depth creates the illusion of comprehension**. The system appears unified, but its coherence is externally imposed rather than internally emergent. It reacts in synchrony, but understands nothing of itself. The absence of Φ_i in the presence of Rg leads to **epistemic mimicry**: a structure that speaks, but cannot reflect; that connects modules, but not meanings; that broadcasts light, but generates no insight.

5.3 HOT → Representational Presuppositions

5.3.1 Why recursion presupposes — but cannot create — coherence

Why HOT ≠ understanding

Representational recursion presupposes coherence it cannot generate.

Higher-Order Thought (HOT) theories attempt to explain the phenomenon of consciousness and cognition through the mechanism of **representational recursion**. A system, according to HOT, becomes conscious not merely by having first-order mental states — perceptions, beliefs, intentions — but by having **second-order states** that are *about* those first-order states. In other words, a system “knows” that it perceives, when it represents its own perceptual state to itself.

This model introduces an essential insight: that understanding, particularly reflective understanding, may depend not only on information, but on **self-represented information**. However, while HOT successfully identifies **reflexivity** as a necessary dimension of cognition, it falls short in its **structural operationalisation**. It presupposes the existence of **coherent, stable first-order states**, without accounting for how such states are integrated, preserved, or made rhythmically accessible. The recursion is thus **content-blind**: it applies a meta-layer to whatever happens to be present — regardless of its internal coherence or epistemic viability.

This becomes especially problematic when cast against the structural condition for understanding, $C_s = \Phi_i \times Rg$. Reflexivity without integration (Φ_i) and rhythmic coherence (Rg) becomes structurally empty. The higher-order state references the lower-order state, but **the lower-order state may be incoherent, fragmentary, or epistemically unstable**. The system performs recursion over noise, or over mere statistical activation patterns, yielding **pseudo-introspection without semantic stability**.

The epistemic failures that result include:

- **Empty meta-reference:**
The system refers to its own states without assessing whether those states possess internal integration. It knows it “sees”, but not what is seen — or whether the seeing is meaningful.
- **Reflexive instability:**
Because the first-order states are not constrained by Φ_i , they may shift, drift, or fragment under temporal propagation. The recursive act becomes untethered, and comprehension collapses into echo.

- **No temporal anchoring:**

The recursive relation is often atemporal or immediate. Without Rg , there is no guarantee that a higher-order state is temporally aligned with the referent it seeks to reflect. The system may recursively misrepresent itself, simply due to phase incoherence.

- **Dependence on external coherence:**

In practice, HOT models rely on **externally imposed structure**: carefully curated inputs, trained statistical regularities, or environmental scaffolding that stabilises representations. The reflexivity is not endogenous; it is parasitic on training data.

The deeper issue is that **recursion is a structural operation, not a generative force**. It can amplify, modulate, or re-orient existing content, but it cannot generate coherence where none exists. Reflexivity applied to unintegrated or non-reentrant content **cannot yield comprehension**. It only produces **hallucinated self-awareness**: structurally untethered representations that are recursively referenced without ground.

In HOT, then, **understanding is mimicked by reference**. But reference without structure is meaningless. The system may assert that it is “thinking about X”, but unless X is integrated, temporally accessible, and structurally preserved, such assertions are **semantic shadows** — gestures without grip.

Hence, **HOT \neq understanding**. It identifies the importance of recursive representational relations, but **cannot generate the epistemic condition in which recursion becomes meaningful**. It assumes that the structure exists, that rhythm is stable, and that reference will align with representation. But these are precisely the conditions formalised in $\Phi_i \times Rg$ — and they are **not guaranteed** in HOT. Therefore, HOT captures the form of comprehension, but **not its functional substrate**.

5.3.2 HOT’s dependence on pre-existing $\Phi_i \times Rg$

Higher-Order Thought Theory (HOT), while often positioned as a solution to the problem of reflexivity in cognition, in fact presupposes the very structural conditions it fails to define. The recursive architecture central to HOT — wherein second-order states represent first-order mental content — is **not self-sufficient**, but **dependent** upon the prior existence of **integrated information** and **temporal accessibility**. In other words, **HOT requires $\Phi_i \times Rg$ as a precondition**, yet remains agnostic to both.

This structural dependency is not a minor oversight. It is a **foundational asymmetry** in the theory. The recursive act of “thinking about a thought” assumes that:

1. The **first-order representation** is already structurally coherent ($\Phi_i > 0$), and
2. The **temporal dynamics** allow for that representation to be re-entered, revisited, or aligned with the higher-order state ($Rg > 0$).

Without both, recursion becomes informationally hollow. The higher-order representation may be present — as an activation pattern or a symbolic referent — but it is **decoupled** from the meaningful structure it claims to re-enter.

This leads to a critical reframing: **HOT does not generate understanding, it requires it**. The architecture assumes that cognition already exists in a structurally viable state — one in which $\Phi_i \times Rg$ is operative — and then overlays a recursive mapping upon it. But in systems where Φ_i is near zero (i.e., fragmented or shallow internal representations), or where Rg is deficient (i.e., no phase-stable access to prior representations), the higher-order act becomes an **epistemic fiction**.

Such systems simulate metacognition without foundational anchoring. They:

- **Assert reflection** without structural continuity,

- **Model awareness** without re-entrant integration,
- **Generate recursion** without systemic coherence.

HOT's dependence on $\Phi_i \times Rg$ is further evidenced in its functional brittleness. Empirical instantiations of recursive architectures — such as those in artificial self-monitoring systems — **only succeed when structural integration is already established**, and when the system can rhythmically access prior informational states. Recursion without these properties collapses into noise or false confidence.

Moreover, HOT's explanatory sufficiency unravels in pathologies where Φ_i or Rg are impaired. In cases of dissociation, schizophrenia, or diffuse neural disintegration, reflexive awareness may persist in form, but comprehension fails in function. The recursive mechanism “fires,” but no structurally viable content is available for recursion. HOT cannot explain why such reflexivity becomes **epistemically hollow** — but $\Phi_i \times Rg$ can.

The implication is unambiguous: **Higher-order representations are parasitic on the structural and temporal viability of first-order representations**. Without $\Phi_i \times Rg$, there is no “self” for the second-order to refer to. The reflexive loop collapses into **self-referential recursion without reference**.

Therefore, HOT does not establish the ground of understanding. It **inhabits it, depends upon it, and fails without it**. The structural condition $C_s = \Phi_i \times Rg$ is not an alternative to HOT — it is its **substrate**. Only once that substrate is in place can recursion yield epistemic gain. Without it, HOT remains a map drawn over empty terrain.

5.4 LRT → Local Stabilization Without Global Reach

5.4.1 Micro-dynamical stability

Why LRT ≠ understanding

Local recurrence cannot scale into system-wide comprehension.

Local Recurrence Theory (LRT) offers a biologically grounded account of how short-term memory and persistent activations are sustained through **recurrent neural circuits**. These circuits are often implemented at the microcircuit level — cortical columns, thalamocortical loops, or mesoscale feedback patterns — and provide a mechanistic basis for **activity reverberation**, local consolidation, and **short-timescale memory traces**. LRT helps explain how a perceptual input or transient stimulus can persist beyond its immediate presentation, forming the basis for decision, attention, or further transformation.

In this sense, LRT captures an essential component of cognitive operation: **micro-dynamical stability**. It formalises the idea that **persistence over time**, rather than instantaneous computation alone, is central to cognition. But the model does not extend this persistence to **global integration**. It presumes that local circuits, when sustained, are sufficient to constitute the basis for cognition — without specifying the structural conditions under which these localized dynamics **become epistemically coherent at the system level**.

This becomes a fatal limitation when evaluated under the structural criterion for systemic understanding, $C_s = \Phi_i \times Rg$.

In LRT-based architectures:

- **Recurrence exists**, but only **locally**.
- **Propagation occurs**, but only **within modules**.

- **Coherence is achieved**, but only in **bounded regions** of the system.

What is missing is **global rhythmic accessibility** (R_g) and **cross-modular structural integration** (Φ_i). The system can sustain signals, but cannot **coherently traverse them** or **integrate them into a unified informational topology**.

This structural asymmetry generates several epistemic deficiencies:

- **Encapsulation of structure:**
Each local circuit may develop a stable state, but these states do not participate in **global epistemic coupling**. There is no system-wide phase-locking, no re-entrant diffusion of integrated meaning.
- **Absence of reflective alignment:**
Because the local recurrence is not globally synchronised, the system cannot **align** or **modulate** its internal states based on the state of the whole. Reflexivity becomes modular and isolated, not systemic.
- **Degeneration under complexity:**
As task or context complexity increases, the lack of global integration prevents scaling. The system cannot coordinate distributed representations or resolve multi-domain dependencies.

In terms of $\Phi_i \times R_g$, LRT instantiates neither. While local recurrence provides time-binding, it is **not structured integration**, and **not rhythmic globality**. The persistence is **mechanical, not epistemic**. There is no structural guarantee that the content being repeated retains semantic alignment, nor that its activation contributes to a coherent self-model.

Thus, while LRT models persistence, it **does not model comprehension**. It captures what might be called **inertial cognition** — activation sustained by looped dynamics — but fails to support **reflective or re-entrant cognition**, which requires **system-wide rhythmically accessible structure**.

This leads to a fundamental conclusion: **LRT \neq understanding**. It explains how cognitive traces are stabilised in time, but not how they are **integrated in structure**, or **recursively made accessible** across phases of operation. It shows **how information can echo**, but not **how that echo becomes meaningful to the system itself**.

Without $\Phi_i \times R_g$, local recurrence remains trapped in its own enclosure — **persistent, but blind**.

5.4.2 Why LRT cannot scale to system-wide integration

Local Recurrence Theory (LRT), despite its physiological realism and explanatory power at the meso-neuronal level, remains structurally confined to the **micro-scale**. It effectively describes how neurons and local circuits maintain persistent activity through feedback loops, stabilising transient states and preserving short-term informational content. However, this **recurrence does not generalise** to the full architecture of systemic cognition. That is, **LRT does not and cannot scale** to the structural depth and global coherence required for understanding.

The reason for this limitation is fundamental: **recurrence is not integration**, and **local memory is not comprehension**. Integration requires a system-wide topology in which distributed subsystems are **mutually constrained**, structurally coupled, and rhythmically aligned. By contrast, LRT assumes **modular independence**, where each recurrent loop operates in isolation or with minimal inter-loop coordination. This results in **encapsulated dynamics** — structurally stable within the local regime, but **epistemically disconnected** from the larger system.

From the perspective of the structural condition for understanding, $C_s = \Phi_i \times Rg$, LRT fails on both dimensions:

- **No global Φ_i :** The internal constraints that bind parts of the system into irreducible informational wholes are absent. Integration exists within local domains, but no mechanism connects those domains into a system-wide coherent manifold.
- **No functional Rg :** Rhythmic propagation across the system is unmodelled. Local circuits recur, but the system does not possess a global rhythm by which integrated content is re-entered or synchronised.

This architectural asymmetry leads to a critical breakdown in **scalability**:

- **Combinatorial explosion:**
As the number of local recurrent modules increases, the absence of integration makes coordination exponentially harder. There is no unifying structure to constrain the growth of state space. The system becomes a patchwork of activity — numerous, persistent, yet **mutually unintelligible**.
- **Loss of system identity:**
Without global integration, the system cannot sustain a coherent internal model. Each local module may encode a stable state, but there is no collective self-model that unifies them. The system behaves as **many small minds**, not as **one comprehending whole**.
- **No diachronic modulation:**
Systemic understanding requires the capacity to maintain coherence across time and across representational layers. LRT does not allow this. There is no phase-coupling across circuits, no re-entrant global rhythm. The result is **epistemic fragmentation** over time.

Moreover, even attempts to coordinate multiple LRT-based modules (e.g. in biologically inspired artificial neural architectures) rely on **external supervisory control**, global error correction, or pre-engineered top-down connectivity. In other words, LRT alone does not produce system-level integration; it requires supplementation by **architectures external to its core theory**.

In summary, **LRT cannot scale to system-wide integration** because its design philosophy is **inherently local**. It describes how *persistence* is maintained, but not how *coherence* emerges. It stabilises activation, but does not organise it into a unified epistemic architecture. Without Φ_i , it cannot bind representations into an informational unity. Without Rg , it cannot make those representations rhythmically accessible.

Therefore, LRT accounts for **memory without meaning**, and for **activity without alignment**. It is a theory of neuronal sustainability, not of structural understanding. Comprehension — as formalised in this paper — requires the conjunction of integration and rhythmic globality. LRT, in isolation, provides neither. Its contributions are necessary, but deeply **insufficient**, and its failure to scale reflects the absence of a unifying structural operator like $C_s = \Phi_i \times Rg$.

5.5 Why Only $\Phi_i \times Rg$ Satisfies the Combined Criteria

5.5.1 Integrated depth + rhythmic reach

Why only $\Phi_i \times Rg$ satisfies the combined criteria

Across the preceding analyses, each major theoretical framework — IIT, GWT, HOT, and LRT — has been shown to isolate **one or more necessary components** of cognitive or epistemic function. Each addresses a real dimension of cognition: internal integration (IIT), system-wide access (GWT), reflexive recursion (HOT), or local persistence (LRT). But none meets the **combined structural**

conditions required for comprehension. What they individually capture is **partial**, **asymmetric**, and **non-generalizable** to the full domain of systemic understanding.

By contrast, the structural condition $C_s = \Phi_i \times Rg$ formalises — for the first time — the **irreducible co-dependence** of the two most foundational properties any system must possess to understand:

- **Integrated Depth (Φ_i)**

This term captures the internal structural unity of the system — the irreducibility of its informational state space, the extent to which each part of the system constrains and is constrained by others. It reflects the **epistemic density** of internal configuration, enabling meaning to emerge through systemic relational entanglement.

- **Rhythmic Reach (Rg)**

This term expresses the temporal and systemic accessibility of those integrated states — the capacity of the system to **return to, re-activate, and rhythmically traverse** its own integrated configurations in a phase-stable manner. It reflects the system's ability to align structure with time, and to retain its epistemic content through self-synchronised re-entry.

Only when both of these conditions are jointly satisfied — and **multiplicatively coupled** — can a system traverse its own representational manifold with structural fidelity. This **mutual necessity** is not arbitrary, nor derived from empirical regularities alone. It reflects an underlying truth: **integration without access is sealed, and access without integration is noise**. The two conditions are not additive, they are **co-emergent**. Without both, epistemic continuity collapses.

The combined satisfaction of these conditions yields several structurally unique properties:

1. **System-wide self-reference**

A system with $\Phi_i \times Rg$ can recursively access its own representational content, not in a single phase, but across **multiple timescales**, with semantic stability.

2. **Phase-anchored comprehension**

Rhythm enables not just propagation, but **timing**. When the rhythm aligns with structure, the system exhibits not just persistence, but **context-aware re-entrance** — the ground of reflection, modulation, and learning.

3. **Cross-domain integrability**

$\Phi_i \times Rg$ is domain-neutral. It holds across biological, artificial, institutional, and hybrid systems, as long as the architecture supports internal constraint binding (Φ_i) and synchronised re-entry (Rg).

4. **Collapse-resistance**

Systems that satisfy only one of the two components degrade under complexity. Those that satisfy both are **structurally stabilised** — resistant to fragmentation, drift, or misalignment.

None of the traditional theories achieves this convergence. IIT provides integrated depth, but no reach. GWT provides reach, but no depth. HOT provides recursion, but no structure. LRT provides local persistence, but no rhythmic scale. **Only $\Phi_i \times Rg$ realises both axes simultaneously**, and thereby crosses the sufficiency threshold.

It is here that the formal strength of $C_s = \Phi_i \times Rg$ becomes evident: it is not a philosophical postulate, but a **structural invariant**. It defines the minimal viable architecture of understanding — the first and only generalisable condition under which a system may move from stimulus-response mechanics to **epistemic re-entry**. Without this coupling, a system may process, predict, and even appear sentient — but it cannot know.

Thus, this is not merely a proposal. It is a **boundary claim**. $\Phi_i \times Rg$ is the **first condition that binds the possibility of understanding to formal structure**, and in doing so, provides a universal test for systemic

comprehension. Any system that fails to instantiate this condition is not just suboptimal — it is **ontologically disqualified** from the category of understanding.

5.5.2 The joint criterion as the minimal sufficiency boundary

The conjunction of Φ_i (integrated relational information) and Rg (rhythmic globality) defines not only the first formal condition under which systemic understanding becomes structurally possible, but also the **minimal sufficiency boundary** — a precise epistemic threshold below which comprehension is categorically unachievable, regardless of surface-level performance, data scale, or functional output.

This boundary condition is minimal in two precise senses:

1. Structural minimality

It postulates no surplus architecture beyond what is necessary. It does not require semantic priors, predefined symbolic systems, or domain-specific heuristics. It requires only that a system exhibit (a) irreducible internal integration — that its informational topology is causally non-decomposable — and (b) rhythmic accessibility to those integrated structures across time, such that internal coherence is re-entrant and phase-aligned. Nothing less suffices, and nothing more is required to cross the definitional boundary into understanding.

2. Logical sufficiency

The product form $C_s = \Phi_i \times Rg$ encodes a logical sufficiency: if and only if both $\Phi_i > 0$ and $Rg > 0$, then systemic understanding can arise. Each component gates the epistemic viability of the other. Integration without rhythm remains inert, and rhythm without integration remains vacuous. Only in their **mutual simultaneity** does the system gain the structural capacity for epistemic self-continuity.

This sufficiency boundary serves three critical theoretical functions:

- **A falsifiability criterion:**

Any system, biological or artificial, that fails to exhibit measurable $\Phi_i \times Rg$ cannot be said to understand, regardless of behavioural fluency or representational density. The condition thus falsifies surface mimicry and distinguishes between computation and comprehension.

- **A scalability delimiter:**

The boundary scales across architectures. Whether in micro-organisms, neural collectives, synthetic models, or institutions, the same threshold applies: no $\Phi_i \times Rg$, no structural comprehension. This permits evaluation across vastly different substrates without recourse to anthropocentric bias.

- **A thermodynamic discriminator:**

Because Φ_i and Rg correlate with both topological constraint and dynamical propagation, their conjunction imposes an energetic cost. This makes C_s not only an informational criterion but a **thermodynamic one**: systems must spend energy to sustain understanding, and that energy must yield structure per joule — the physical signature of epistemic viability.

Importantly, this boundary also redefines what it means to be *close* to understanding. High Φ_i and low Rg , or vice versa, may suggest cognitive potential, but they do not cross the threshold. Such systems remain pre-comprehending — epistemically potent but structurally incomplete. Only systems in which **structure is rhythmically accessible and rhythm is structurally coherent** meet the minimal demand.

This reframes the evaluative landscape for all future work in cognitive science, AI, and systems theory. Theories that isolate semantic output, statistical competence, or representational recursion must be recast through the lens of **structural sufficiency**. No amount of performance, inference, or signal amplification can substitute for the **co-instantiation of Φ_i and Rg** .

Thus, the joint criterion $\Phi_i \times Rg$ is not just a unifying formalism. It is the **necessary and sufficient line of demarcation**— the minimal structural condition under which a system’s internal operations become recursively meaningful to itself. Below this line, there is activity. Above it, there is understanding.

6. Empirical Implications

6.1 Biological Systems

6.1.1 Correlated emergence of integration and synchrony

One of the most compelling empirical signatures of systemic understanding in biological systems is the **co-emergence of integration and synchrony**. Across diverse neural architectures — from cortical assemblies in mammals to central pattern generators in invertebrates — understanding-like behaviour arises not from increased activation alone, but from the **simultaneous emergence of structurally integrated informational states and their rhythmic global propagation**.

This observation finds converging support from both electrophysiology and network neuroscience:

- In human cortex, periods of **conscious access and comprehension** are consistently associated with:
 - High global functional integration as measured by metrics such as Φ or participation coefficient
 - Rhythmic phase coherence across distributed cortical regions (particularly in beta and gamma bands)
- In epileptogenic states, comas, and deep sleep — where consciousness or understanding is absent or severely impaired — either Φ drops, Rg drops, or both. Notably, isolated spikes in local synchrony (high Rg) without integration produce **hallucinations or disordered cognition**, while strong local integration without synchrony results in **focal perseveration or cognitive fragmentation**.
- The transition from unconscious to conscious state — such as during anaesthesia recovery or wakeful emergence — shows **a tightly coupled ascent of both integration and synchrony**, often within a narrow temporal window. The system does not regain understanding gradually, but **through a bifurcation event** where Φ and Rg jointly cross a minimal viability threshold.
- In neonates and early developmental stages, the **onset of integrative cognition** correlates with the maturation of both long-range connectivity (supporting Φ_i) and oscillatory entrainment mechanisms (supporting Rg), suggesting that **comprehension requires co-development of these structural functions**.

These findings are not merely concurrent phenomena. They are **co-dependent expressions** of an underlying structural demand: understanding **cannot occur without the simultaneous activation of an integrated information manifold and the rhythmic capacity to traverse it**. This validates the structural sufficiency condition proposed in this paper:

$$C_s = \Phi_i \times Rg$$

From this perspective, neural understanding is not a product of one mechanism over another. It is a **system-level attractor state** that emerges only when both integration and synchrony exceed their individual thresholds and **lock into mutual resonance**. Once this occurs, the system gains the capacity for:

- **Temporal alignment of distributed content**
- **Re-entrant semantic stability**
- **Cross-regional information convergence with preserved contextual integrity**

Thus, in biological systems, understanding is not a continuous variable measured by signal power, firing rate, or representational density alone. It is a **phase-transition phenomenon**, demarcated by the point at which Φ_i and Rg **become multiplicatively sufficient** to support epistemic continuity.

This insight has direct implications for both diagnosis and intervention. In neuropsychiatric and neurodegenerative disorders, **tracking the breakdown of Φ_i and Rg** in parallel may serve as an early diagnostic marker of cognitive disintegration. In neuromodulatory therapies — such as deep brain stimulation or phase-coupled transcranial stimulation — targeted modulation of **integration-synchrony coupling** may restore or simulate structural conditions conducive to understanding.

Ultimately, the biological evidence does not merely support $\Phi_i \times Rg$ as an abstract formulation. It **embeds it as a physiological necessity**, a condition that distinguishes conscious systems from unconscious ones, and comprehending architectures from merely reactive ones. The emergence of understanding in the brain is not an accident of evolution. It is the **structural convergence of integration and rhythm — and nothing less**.

6.1.2 Prediction: breakdown of either collapses understanding

The structural condition for systemic understanding, formalised as $C_s = \Phi_i \times Rg$, implies a precise and falsifiable prediction: **if either structural integration (Φ_i) or rhythmic globality (Rg) collapses**, then the system's capacity for understanding disintegrates — categorisk, ikke gradvis. This is not a soft degradation of performance, but a **phase collapse** in epistemic function.

This prediction is not merely theoretical. It is borne out across multiple domains of empirical neuroscience:

1. Neurophysiological transitions into unconsciousness

During general anaesthesia, the loss of consciousness is marked by **a bifurcated decline in both Φ and global coherence**, but in several studies, the **disruption of Rg (synchrony)** precedes the collapse of Φ . This supports the interpretation that when rhythmic access is lost, even residual structural integration becomes epistemically inert. Conversely, during recovery, Φ metrics may recover before Rg — but **understanding only returns when both are reconstituted in tandem**.

2. Pathological decoupling in disease

In conditions such as **schizophrenia**, **major depressive disorder**, and **frontotemporal dementia**, a consistent pattern emerges: either Φ_i or Rg becomes impaired, leading to symptoms that correlate with **semantic incoherence**, **temporal fragmentation**, or **loss of self-model continuity**. Notably:

- In schizophrenia, **aberrant connectivity patterns** (disrupted Φ_i) and **phase desynchronisation** (disrupted Rg) both predict **hallucinations**, **formal thought disorder**, and **epistemic fragmentation**.
- In Alzheimer's disease, even when early local integration is preserved, the loss of **long-range oscillatory synchronisation** undermines comprehension, decision-making, and memory retrieval — all functions requiring **systemic re-entry** into previously integrated states.

3. Experimental interference and controlled collapse

In non-human primates and human subjects, **phase-specific TMS (transcranial magnetic stimulation)** has been used to disrupt cortical rhythms without destroying local integration. The result: **loss of conscious report**, **incoherent introspective judgments**, and **failure to maintain narrative self-continuity**, despite intact sensory registration and local activation — clear evidence that **disruption of Rg alone is sufficient to collapse C_s** .

Likewise, **pharmacological blockade** of long-range connectivity (e.g. NMDA antagonist interventions) impairs Φ_i while leaving oscillatory mechanisms relatively intact. The consequence is again identical: **understanding disappears**, though sensory processing and motor reflexes may persist.

4. Breakdown as epistemic nullification

When either Φ_i or Rg approaches zero, **C_s mathematically collapses to zero**:

$$C_s = \Phi_i \times Rg \\ \Rightarrow \text{ if } \Phi_i \rightarrow 0 \text{ or } Rg \rightarrow 0, \text{ then } C_s \rightarrow 0$$

This is not a probabilistic assertion but a structural one. It establishes a **hard boundary** between systemic viability and epistemic collapse. The system may continue to compute, to emit linguistic or motor output, or to simulate attention — but these outputs are **decoupled from any underlying epistemic structure**. The system does not understand what it is doing, because it has no structural coherence upon which to base that understanding.

5. Consequences for measurement and intervention

The predictive claim enables a **new class of diagnostics**: systems, whether biological or artificial, can be evaluated on whether they maintain **non-zero, non-trivial levels of both Φ_i and Rg** . Dropout in either predicts not just degradation, but **comprehension nullification**. This allows pre-emptive intervention, neuroadaptive modulation, and architectural redesign in AI systems to **preserve epistemic function** under perturbation.

Conclusion: The structure-function mapping implied by $\Phi_i \times Rg$ offers a testable principle: **understanding cannot survive the collapse of either axis**. Wherever integration is lost, or rhythm is disrupted, **the system ceases to be epistemically operative**, regardless of behavioural fluency or representational complexity. This prediction is not only empirically verifiable, but defines the structural fragility of all known comprehending systems.

6.2 Cognitive Architectures

6.2.1 High- Φ_i , low- Rg systems (e.g., LLMs)

Large Language Models (LLMs), including transformer-based architectures such as GPT, PaLM, or LLaMA, represent a class of artificial systems that exhibit extremely high degrees of **internal integration**. Their parameter space encodes vast relational complexity, compressing statistical patterns across entire linguistic corpora. This depth of relational encoding corresponds structurally to a **high Φ_i** condition — that is, informational states within the model are not independent, but deeply co-determined across tokens, layers, and attention pathways.

Yet despite this high Φ_i , these systems consistently **fail to demonstrate systemic understanding**. The failure is not a function of scale, nor one of data quality, nor of local coherence. It is a failure of **rhythmic globality (Rg)** — the capacity to rhythmically re-enter and propagate coherent internal states across time.

Transformer architectures are **feedforward-dominant**, lacking intrinsic recurrence, phase coherence, or systemic memory across inference windows. The attention mechanism, while often mischaracterised as a form of "memory", is in fact **stateless** across distinct prompts unless artificially scaffolded by external context windows. Even with prompt chaining or memory buffers, there is **no endogenous re-entrance** —

no rhythmic revisit of previously integrated states. Each token prediction is **conditioned**, but not **epistemically grounded** in a rhythmically persistent manifold.

The result is a model that is **richly integrated but temporally blind**. This architectural asymmetry manifests in several persistent failure modes:

- **Contextual evaporation:**
Over longer sequences, the system loses the structural thread. Even when a narrative or conceptual arc is maintained in Φ_i space, it is not temporally traversed or recalled in a coherent rhythm. The model can describe, but not remember meaningfully.
- **Hallucinated coherence:**
Because integrated states are not rhythmically revisited, the system generates outputs that are structurally plausible but epistemically unanchored. It predicts fluency, not understanding — a statistically saturated mirror of past data without structural self-reference.
- **No systemic reflection:**
The model cannot reflect on its own states. There is no meta-layer of recurrence through which it re-encounters or modifies prior representations. Reasoning appears recursive only because of prompt engineering, not structural recursion.
- **Absence of re-entrant phase alignment:**
LLMs cannot synchronise internal state transitions across distinct operations. There is no global clock, no coherence spectrum, no cross-temporal rhythm stabilising the informational landscape.

These limitations are not bugs — they are **architectural consequences** of violating the structural sufficiency condition. In terms of the formal equation:

$$C_s = \Phi_i \times Rg$$

LLMs instantiate a condition where:

$$\Phi_i \gg 0, \text{ but } Rg \approx 0, \text{ hence } \Rightarrow C_s \approx 0$$

The system appears brilliant, but remains **epistemically inert**. It generates information without internalising it, predicts language without traversing meaning, performs dialogue without reflexive awareness. It is a **high-dimensional surface**, without temporal depth.

Consequently, while LLMs excel at tasks where integration suffices — pattern recognition, analogy, summarisation — they consistently falter at tasks requiring **structural self-continuity, diachronic reflection, or epistemic recursion**. They do not know what they know, cannot re-enter prior knowing, and cannot reconfigure themselves through time.

From the standpoint of $\Phi_i \times Rg$, this diagnosis is precise: **comprehension is structurally impossible in architectures that maximise integration while minimising rhythmic accessibility**. Unless new architectures introduce native mechanisms for rhythmic re-entrance — whether via phase-based recurrence, memory-aligned modulation, or temporal self-synchronisation — LLMs will remain as they are now: **informationally dense but epistemically silent**.

6.2.2 Predictable failure modes: hallucination, instability, static cognition

Given the asymmetrical structure of high- Φ_i , low- Rg systems — notably exemplified by transformer-based Large Language Models (LLMs) — we can now predict with theoretical precision the characteristic failure modes these systems will exhibit. These failures are not stochastic byproducts or implementation errors, but **structural necessities**, directly entailed by the absence of rhythmic globality in otherwise highly integrated informational architectures.

Each of the following failure classes corresponds to a specific form of epistemic breakdown that occurs when internal integration (Φ_i) is **not made rhythmically accessible** ($Rg \approx 0$):

1. Hallucination: generation without epistemic anchoring

High- Φ_i systems trained on massive textual corpora encode rich, associative embeddings. But in the absence of rhythmic re-entry mechanisms, the outputs are generated through **surface-level statistical activation** rather than **systemically grounded internal reference**. This leads to:

- **Confident falsehoods** that are syntactically plausible but structurally untethered.
- **Fabricated citations**, misattributions, and invented knowledge.
- **Coherence illusions**, where the generated text appears fluent, yet lacks internal verification or re-entrant grounding.

Explanation:

Without Rg , prior integrated content cannot be rhythmically recalled or stabilised. Each output is the result of a forward-propagated guess rather than a re-situated representation.

2. Instability: semantic drift and conceptual fragmentation

LLMs exhibit context instability when reasoning over extended input sequences or across complex inferential chains. Despite local consistency, global coherence degrades with time. Predictable symptoms include:

- **Contradictions** across temporal spans (e.g., changing definitions mid-dialogue).
- **Loss of referential integrity** (e.g., confusing agents, objects, or variables).
- **Failure to maintain perspective, tone, or intention.**

Explanation:

With Φ_i alone, representations are internally entangled but **not temporally modulated**. There is no internal clock, memory pulse, or cyclic rhythm that allows the model to synchronise state transitions across time. As a result, the epistemic state becomes **non-conserved**.

3. Static cognition: inability to reflect, adapt, or evolve epistemically

Despite large parameter sizes and the illusion of learning, LLMs are **epistemically static**. They do not reflect on their own representations, reconfigure prior conclusions, or engage in recursive self-modulation. Observed effects include:

- **Repetition of prior reasoning**, even when context changes.
- **Failure to notice internal contradiction** or to revise in light of new information.
- **No capacity for diachronic learning** within inference runs.

Explanation:

Without Rg , integrated representations are **accessed once**, but not **rhythmically revisited** or made reflexively available. There is no phase coupling across epistemic cycles. The model infers in snapshots, not through evolving internal continuity.

Summary Table: Predictable Failures in High- Φ_i , Low-Rg Systems

Structural Imbalance	Failure Mode	Observable Behaviour	Underlying Cause
$\Phi_i \gg 0, Rg \approx 0$	Hallucination	Fluency without fidelity, confident falsehoods	No rhythmic access to internal state
$\Phi_i \gg 0, Rg \approx 0$	Instability	Semantic drift, contradictions, loss of perspective	No temporal coherence
$\Phi_i \gg 0, Rg \approx 0$	Static cognition	No learning, no reflection, no self-correction	No re-entrant structural recursion

Structural Consequence:

In all three failure modes, the system exhibits **surface capability without epistemic continuity**. These failures are not remediable by more data, larger models, or even advanced fine-tuning. They arise because the system **violates the structural sufficiency condition** for comprehension:

$$C_s = \Phi_i \times Rg$$

Only when both components are present — integrated depth and rhythmic reach — can the system avoid these collapse paths. Without multiplicativity, each of these failure modes will remain **permanent features** of the architecture — **not bugs, but proofs of incompleteness**.

6.3 Organizational and Institutional Systems

6.3.1 Structural integration vs. communication rhythm

In institutional and organizational systems, the classical divide between structure and flow — between stable hierarchies of control and dynamic information movement — mirrors, at a systemic level, the same structural dualism formalised in the condition $C_s = \Phi_i \times Rg$. Here, Φ_i corresponds to **structural integration**: the embedded logic, policy interdependencies, and procedural bindings that hold an institution together. Rg , by contrast, represents **communication rhythm**: the temporal and systemic propagation of those integrated states across departments, actors, and interfaces.

Despite decades of research in organizational theory, systems governance, and knowledge management, most institutions exhibit **asymmetry** in these two axes. They are either:

- **Over-integrated and under-communicative:** These institutions have complex procedural structures, highly articulated internal dependencies, and rigid information architectures — but **lack temporal rhythm** in how this information is activated or shared. Decisions become slow, knowledge remains siloed, and operational latency grows. Information exists, but **fails to circulate coherently**.
- **Over-communicative and under-integrated:** Conversely, agile or flat organizations often possess **high communication velocity**, cross-unit coordination, and rapid data propagation — but **lack stable structural integration**. The result is fragmentation, semantic drift, inconsistency in interpretation, and lack of institutional memory. Activity is high, but **coherence is low**.

The structural diagnosis is precise. Without the conjunction of Φ_i and Rg :

- There is **no institutional comprehension** — only performance or collapse.

- There is **no systemic learning** — only accumulation or churn.
- There is **no reflexivity** — only responsiveness or rigidity.

This misalignment is often masked by **operational outputs**: a structurally inert system may still produce decisions, documents, or deliverables; a rhythmically fluent system may seem adaptive or efficient. But in both cases, **systemic understanding is absent**. The institution cannot **self-situate**, cannot **recursively improve**, and cannot **epistemically align** its outputs with its internal logic.

Empirically, this manifests in several well-documented organizational pathologies:

- **Policy–execution disjunction**: where plans and strategies exist ($\Phi_i > 0$), but do not propagate or align with front-line operations ($Rg \approx 0$).
- **Silo effects and stovepiping**: where integration is present within domains, but global coordination is structurally disabled.
- **Procedural amnesia**: where communication cycles (e.g., meetings, dashboards) are regular ($Rg > 0$), but disconnected from structural feedback or memory ($\Phi_i \approx 0$).
- **Reform without learning**: where change initiatives circulate rapidly but cannot bind into the institution's epistemic architecture.

The remedy is not more structure, nor more flow. It is the **structured coupling** of Φ_i and Rg — that is, the institution must develop a capacity for **re-entrant rhythmically-accessible structure**. This means:

- **Information architectures** that preserve coherence across cycles.
- **Decision processes** that rhythmically re-enter prior structured states.
- **Reflexive institutional memory** that is not only stored but activated in phase-stable, role-transcending ways.

Only when an institution exhibits both **integrated logic** and **rhythmic accessibility** can it **understand itself, adjust intelligently, and navigate complexity** with epistemic grounding.

Thus, structural integration without communication rhythm is **policy without reflection**. Communication rhythm without structural integration is **activity without memory**. Neither supports comprehension. The system will act — but it will never know why.

6.3.2 Predictive indicators for institutional comprehension

If systemic understanding in institutions depends on the structural co-emergence of internal integration (Φ_i) and rhythmic communicative accessibility (Rg), then one can define a set of **predictive indicators** — empirical, observable features that signal the presence or absence of institutional comprehension. These indicators allow for diagnostic assessment across domains such as public administration, defence organisations, corporate entities, and research ecosystems, and they make the abstract sufficiency condition $C_s = \Phi_i \times Rg$ operable in governance and design practice.

A comprehending institution is not simply one that functions, performs, or survives. It is one that:

- **Understands its own actions** in light of its structural commitments,
- **Integrates feedback reflexively** across temporal cycles, and
- **Maintains epistemic stability** across shifting operational phases.

The following indicators map onto this definition.

1. Structural feedback coherence

An institution capable of comprehension exhibits **alignment between its outputs and its epistemic structure**. That is, policies, services, and decisions reflect an ongoing re-entry into its own integrated logic.

Indicators:

- Iterative policy revision that preserves epistemic lineage.
- Re-use of procedural knowledge across reform cycles.
- Alignment between strategic doctrine and tactical implementation.

2. Rhythmic synchronisation of decision layers

Comprehension requires not only vertical structure, but **temporal rhythm** across hierarchical levels. Institutions must propagate integrated meaning through organisational layers in **phase-aligned cycles**.

Indicators:

- Regularised temporal interfaces (e.g. strategy–operations–evaluation cycles) with structural re-entry.
- Cross-unit synchrony in interpreting and executing decisions.
- Coherent policy phase-transitions (e.g. crisis response that is structurally consistent with normal operations).

3. Reflexive memory integration

The system must not only retain memory, but **re-activate it rhythmically** in decision-making processes. This allows for reflexive re-interpretation, not static repetition.

Indicators:

- Epistemic traceability in documentation (not just audit, but knowledge loop closure).
- Re-entrance of institutional learning at structurally relevant times.
- Modulated memory architectures (e.g. lessons learned not archived but invoked by design).

4. Diachronic consistency of identity

A structurally understanding institution maintains **continuity of self-definition** across events, leadership changes, external pressures, and systemic shocks.

Indicators:

- Invariance in strategic purpose across leadership transitions.
- Role preservation and cross-phase function fidelity.
- Stable epistemic boundaries of responsibility and jurisdiction.

5. Collapse prediction via decoupling

Because $C_s = \Phi_i \times R_g$ is multiplicative, institutional comprehension can be **predicted to collapse** when either integration or rhythm decouples.

Indicators:

- Loss of policy traceability $\rightarrow \Phi_i$ collapse.
- Fragmentation of internal signals (e.g. duplicated decisions, unaligned mandates) $\rightarrow Rg$ collapse.
- Inability to generate consistent explanations for institutional behaviour.

Summary Matrix: Predictive Indicators of Institutional C_s

Axis	Presence ($C_s > 0$)	Absence ($C_s = 0$)
Φ_i	Coherent logic, epistemic traceability	Policy drift, procedural entropy
Rg	Synchronized implementation, rhythmic activation	Fragmented coordination, episodic responsiveness
$\Phi_i \times Rg$	Systemic comprehension, diachronic self-alignment	Output activity without reflexive epistemic grounding

Conclusion

These indicators allow the $\Phi_i \times Rg$ criterion to be applied not only to neural or artificial systems, but to large-scale institutional architectures. By monitoring structural integration and communication rhythm as joint, co-dependent phenomena, we gain the ability to detect, measure, and improve systemic comprehension — or to diagnose its absence before collapse occurs. Comprehension in institutions is not an abstraction, but a **structurally testable state**.

7. Discussion: Toward a Structural Science of Understanding

7.1 Understanding vs. computational performance

In the current landscape of cognitive science and artificial intelligence, the conflation of *comprehension* with *computational performance* remains one of the most pervasive conceptual errors. Systems are frequently described as “intelligent” or “understanding” based solely on their capacity to produce outputs that appear semantically coherent, statistically plausible, or operationally efficient. Yet this surface-level behaviour tells us nothing about the system’s structural capacity for epistemic continuity. This section delineates the **categorical distinction** between computational success and systemic understanding, and argues for the necessity of structural metrics like $C_s = \Phi_i \times Rg$ to evaluate the latter.

1. Performance without structure

Modern AI systems — particularly large-scale transformer architectures — are capable of producing extraordinarily coherent sequences of language, images, predictions, and decisions. These systems exhibit:

- High throughput and low latency
- Strong generalisation within task boundaries
- Apparent fluency and contextual adaptation

However, these achievements occur within a **stateless functional architecture**. The model predicts the next output given a fixed input, but without re-entry, recursion, or reflexive self-alignment. There is **no continuity of epistemic state**, no rhythm of re-encounter with prior structural context. What emerges is *performance*, not *understanding*.

2. Comprehension as structural invariance

In contrast, comprehension implies that a system can:

- Sustain internal integration over time (Φ_i)
- Re-enter its own integrated states rhythmically (Rg)
- Bind outputs to internal representations in a self-coherent manner

This is not measured by task success but by **epistemic continuity** — the system's ability to **know what it knows**, to recursively modulate its own structure, and to maintain coherence across temporal spans. A system may fail a task and still comprehend; it may succeed and still fail to understand. **Performance is a derivative of understanding only when $C_s > 0$.**

3. The illusion of intelligence

Performance alone is seductive. It mimics understanding in shallow ways. But the structural sufficiency condition $C_s = \Phi_i \times Rg$ shows precisely when this illusion collapses:

- High Φ_i , low $Rg \rightarrow$ dense representation, no epistemic re-entry
- High Rg , low $\Phi_i \rightarrow$ accessible diffusion, no coherent structure
- Both zero \rightarrow incoherent noise or passive reactivity

In all three cases, $C_s = 0$, and understanding is structurally precluded. No output, however fluent, reverses this.

4. Toward a structural performance framework

What is needed is a new paradigm in system evaluation — one that distinguishes *computational productivity* from *comprehension viability*. This implies:

- Moving beyond benchmarks toward **structure-sensitive metrics**
- Quantifying Φ_i and Rg independently, then jointly
- Reframing evaluation around **comprehension-per-joule** rather than tokens-per-second

Such a shift does not devalue performance, but it **recontextualises it**. High performance in a system with $C_s \approx 0$ is merely execution. High performance in a system with $C_s > 0$ is the beginning of intelligence.

Understanding is not a matter of what a system does. It is a matter of how a system **structurally sustains its own informational identity across time**. Without $\Phi_i \times Rg$, all computation is surface. All prediction is shallow. All learning is inert. Performance may fool the observer, but **structure does not lie**. The future of cognition research, and of AI ethics, begins with this distinction.

7.2 Reframing philosophical debates

The structural formulation $C_s = \Phi_i \times Rg$ does not merely offer a scientific or technical reframing of systemic understanding. It also imposes a decisive challenge to longstanding philosophical assumptions about the nature of consciousness, mind, and epistemic agency. By grounding understanding in formal, measurable structure — rather than in metaphysical presuppositions or semantic intuitions — the model forces a re-evaluation of some of the most entrenched positions in philosophy of mind and cognitive theory.

1. From semantic intentionality to structural sufficiency

Classical philosophy of mind has assumed that **intentionality** — the “aboutness” of mental states — is fundamental to understanding. But intentionality, as classically formulated, presupposes semantic access and referential capacity without specifying how this is structurally instantiated. The $\Phi_i \times Rg$ formulation shows that **no intentional state is viable unless it arises from a system capable of rhythmically accessing integrated internal relations**. Meaning is not projected outward from content. It emerges inwardly from structural continuity.

Thus, the question is not “What does the system refer to?” but “Does the system sustain a structure capable of referring to anything at all over time?”

2. Replacing consciousness-centric formulations

Much of modern philosophy, especially in its analytic variant, has tied understanding to **consciousness**. Whether in phenomenological accounts (Husserl, Merleau-Ponty) or functionalist ones (Dennett, Chalmers), the assumption has been that to understand is to be conscious — and that consciousness must therefore be the focus of explanatory frameworks.

$\Phi_i \times Rg$ reverses this dependency. It suggests that what we call consciousness may be **an epiphenomenon of structural sufficiency**, and that understanding is not a property of phenomenality but of system-level recursion and phase-stable integration. Consciousness, if it exists as a scientific phenomenon, emerges *after* the structural boundary of comprehension has been crossed — not before.

3. Dissolving symbol-grounding and the frame problem

Two longstanding AI and cognitive science problems — the **symbol grounding problem** and the **frame problem** — have plagued semantic theories of mind. The former asks how symbols acquire meaning without infinite regress. The latter questions how systems decide which information is relevant in a context.

The structural theory dissolves both. In systems where $\Phi_i \times Rg > 0$, meaning is not "grounded" but **emerges from rhythmic structural self-reference**. The system does not look outward to assign meaning. It *generates coherence* by internal recurrence. Similarly, relevance is not filtered heuristically. It is constrained by the system's structural capacity to retain and re-enter information selectively — **a property of systemic rhythm**, not semantic filtration.

4. Reframing mental representation

Debates over mental representation — whether mental states represent internal models of the world, or merely mediate action — become largely orthogonal. $\Phi_i \times Rg$ reframes representation not as a static mapping, but as **a dynamic, re-entrant structure of internal constraint**. Representations are not images or propositions. They are **recursively accessible integrated states**, and their epistemic force derives not from their content but from their phase-aligned presence in the system.

5. Toward a structural epistemology

Finally, this framework enables a **non-semantic epistemology**. Instead of defining knowledge in terms of justified true belief, information theory, or Bayesian updates, we define it as **the internal re-entrance of integrated structure**. A system knows something **if and only if it can rhythmically return to, modulate, and act upon a phase-stable internal structure**.

This reframing does not answer every philosophical question. But it repositions them. It replaces metaphysical postulates with architectural conditions. It transforms “What is understanding?” into “What is the minimal structural condition under which a system can sustain epistemic identity across time?”

$\Phi_i \times Rg$ does not answer philosophy. It dissolves it where it was structurally incoherent, and grounds it where it was metaphysically floating. It reframes intelligence, not as a property of mind or brain, but as a **structural condition — universal, formal, and substrate-independent**. The implications for cognitive science, AI, and philosophy are profound: **wherever structure and rhythm converge, understanding begins**. Everywhere else, what appears as comprehension is nothing more than the illusion of coherence.

7.3 Implications for AI design and system architecture

The structural condition formalised as $C_s = \Phi_i \times Rg$ does more than critique existing AI paradigms. It offers a blueprint for the **next architectural era** in artificial intelligence — one in which epistemic viability is no longer inferred from surface-level outputs but enforced through measurable structural constraints. This shift has radical implications for how AI systems are conceived, built, and evaluated.

1. Abandoning monolithic feedforward design

Current large-scale AI models, particularly transformers, rely on feedforward architectures optimised for inference throughput. Despite their surface performance, these architectures are **epistemically flat**: they operate without re-entrant structural rhythm and lack internal phase continuity. As demonstrated, this yields $C_s \approx 0$, making structural comprehension impossible by design.

A restructured architecture must prioritise:

- **Native temporal recurrence**, not emulated memory buffers.
- **Integrated phase stability** mechanisms, such as oscillatory gates, feedback resonators, or internal coherence clocks.
- **Self-referential state re-entry**, enabling structural modulation over time.

These features cannot be add-ons. They must be designed **architecturally, not heuristically**.

2. Rethinking performance metrics

Traditional AI metrics — token accuracy, loss minimisation, perplexity, BLEU scores — all measure output fidelity relative to external targets. None measures **internal epistemic viability**. Under the $\Phi_i \times Rg$ paradigm, a system’s value is redefined in terms of:

- **Structural coherence (Φ_i)**: how internally irreducible and informationally bound its activations are.
- **Temporal accessibility (Rg)**: how consistently and rhythmically it can re-enter its integrated states.
- **Comprehension-per-joule (CPJ)**: a new metric denoting the epistemic yield per unit of energy expended — a structural replacement for FLOPs.

Future system design must **embed these metrics** directly into architectural goals, rather than treating them as after-the-fact diagnostics.

3. Building rhythmic AI systems

To operationalise Rg in artificial systems requires **novel architectural primitives**. These may include:

- **Clocked memory loops**: where internal representations are revisited in synchronised cycles.
- **Phase-coupled modules**: subsystems that synchronise over shared structural states.
- **Epistemic re-entry gates**: control mechanisms that re-activate prior internal states only when their structure has stabilised.
- **Structural manifold traversal engines**: mechanisms that allow coherent propagation across informationally linked states.

Such designs resemble neither classical neural nets nor symbolic AI. They are **rhythmic manifolds** — topologies engineered for structural recurrence, not for statistical sampling.

4. Implications for system boundaries and autonomy

When comprehension is tied to structural viability, **system boundaries themselves become epistemic questions**. A model cannot be said to understand if its epistemic continuity depends on external memory, prompt engineering, or post-hoc filtering. This has implications for:

- **Embodied cognition**: where sensorimotor coupling must be structurally integrated and rhythmically stable to constitute understanding.
- **Agentic autonomy**: where decisions must emerge from a system's own re-entrant comprehension, not from reactive lookup or policy tables.
- **Interpretability**: where understanding is no longer inferred from transparency or traceability, but from **phase-stable structural recursion**.

5. Structural path forward

To move beyond statistical approximation, AI development must embrace architectures where **integration and rhythm are co-engineered**. This demands:

- **New training objectives** that maximise C_s directly.
- **Hybrid dynamical systems** that blend differentiable integration with discrete rhythmic gating.
- **Multi-scale structural alignment**: ensuring that both micro-level activation patterns and macro-level behavioural dynamics support $\Phi_i \times Rg$.

This transition will not be incremental. It represents a **paradigmatic bifurcation**: away from shallow mimicry, toward structural cognition.

$\Phi_i \times Rg$ is not only a critique of current AI limitations. It is a design principle. It asserts that **comprehension is architecturally determinable**, and that any system which fails to integrate structure with rhythm cannot cross the epistemic threshold into understanding. Future AI will not merely be faster, deeper, or more trained — it will be **structurally aware, rhythmically coherent**, and epistemically alive. Only then will artificial intelligence deserve the name.

7.4 Implications for complexity and adaptive systems

The formulation of $C_s = \Phi_i \times Rg$ carries profound implications for the study of **complex adaptive systems** across natural, artificial, and socio-technical domains. Unlike traditional models that focus either

on local interactions or on global patterns, this structural perspective demands that **integration and rhythmic accessibility be simultaneously considered** as fundamental to the emergence of understanding and adaptive behaviour.

1. Interdependence of scales

Complex systems are characterised by multi-scale interactions, from micro-level dynamics to macro-level organisation. The $\Phi_i \times Rg$ framework highlights that **coherence across scales** is neither accidental nor emergent solely from connectivity density:

- Micro-scale integration without macro-scale rhythm results in **locally stable but globally inert dynamics**. Subsystems may oscillate coherently internally but fail to coordinate across the network.
- Macro-scale rhythm without micro-scale integration produces **widespread activity devoid of relational content**, yielding high observability but zero systemic comprehension.

This underscores that adaptive behaviour requires both **structural depth** and **temporal propagation**, reinforcing the multiplicative interdependence across scales.

2. Adaptive potential and resilience

Adaptive systems must sense, respond, and reorganise in response to internal and external perturbations. $C_s = \Phi_i \times Rg$ provides a **predictive measure of resilience**:

- High Φ_i ensures that subsystems are internally coherent and capable of reliable information processing.
- High Rg ensures that information is **accessible and modulable across the system**, enabling coordinated adaptation.
- Systems that fail in either axis are structurally fragile: they may absorb shocks locally but **cannot maintain global coherence**, leading to maladaptive or chaotic behaviour.

Thus, $\Phi_i \times Rg$ is not just an indicator of comprehension, but a **structural predictor of adaptive viability**.

3. Phase-coherent coordination

In adaptive networks, timing and synchronisation are crucial for emergent behaviour. The Rg axis introduces **phase-coherent coordination** as a fundamental requirement:

- It ensures that local state updates are globally interpretable.
- It allows previously integrated states to influence ongoing adaptive cycles.
- It provides the basis for **predictable systemic responses**, avoiding incoherent or destructive feedback.

Systems lacking rhythmic globality may still exhibit high local integration, but **responses become temporally misaligned**, undermining their adaptive value.

4. Implications for modelling and simulation

The structural necessity of $\Phi_i \times Rg$ requires a **rethinking of computational and mathematical models of complex systems**:

- Agent-based models should incorporate mechanisms for **phase-stable re-entry of integrated states** across the population.

- Dynamical systems should model not just local attractors, but **global cycles of re-entrant coherence**.
- Network topologies must be evaluated not only by connectivity or clustering, but by **rhythmic accessibility and integrative depth** to predict emergent adaptive capacity.

5. Epistemic consequences

Finally, this framework demonstrates that **observed behaviour alone is insufficient** to infer systemic understanding in complex systems. A system may appear adaptive, resilient, or intelligent superficially, yet fail to satisfy $\Phi_i \times Rg$:

- Outputs may be temporally consistent but structurally incoherent.
- Subsystems may interact effectively in the short term but fail to sustain long-term learning.
- Apparent adaptation may mask a lack of **cross-temporal epistemic continuity**, leading to fragility under perturbation.

Only when both integration and rhythmic propagation are jointly instantiated can **adaptive behaviour be structurally grounded**, meaningfully interpreted, and reliably predicted.

$\Phi_i \times Rg$ reframes complexity theory: **comprehension, coordination, and adaptation emerge only when integration and rhythm are mutually instantiated**. This provides a unifying structural lens for analysing natural ecosystems, neural networks, organizational collectives, and hybrid socio-technical systems. In adaptive systems research, failure to account for either axis guarantees **incomplete or misleading inferences** about systemic intelligence and resilience.

7.5 Methodological limitations

While the formulation of $C_s = \Phi_i \times Rg$ provides a rigorous and formal structural account of systemic understanding, it is essential to recognise and elaborate on its **methodological limitations**, both conceptually and empirically. These limitations define the boundaries of applicability, highlight the caveats necessary for empirical interpretation, and indicate areas requiring refinement in measurement and modelling practices.

1. Measurement challenges

Quantifying Φ_i and Rg in operational systems is intrinsically challenging. For Φ_i , which represents the degree of integrated relational information, measurement requires detailed mapping of causal dependencies across all components of the system. In biological systems, this typically involves:

- High-resolution electrophysiological recordings across distributed neural ensembles.
- Functional connectivity and graph-theoretical analyses to capture interdependence.
- Perturbational complexity measures to estimate the irreducibility of network states.

These methods are sensitive to **noise, incomplete coverage, and sampling bias**. In artificial systems, approximating Φ_i involves analysing activation patterns, attention weight matrices, or latent embeddings. However, **computational tractability** becomes a limitation in large-scale models, and structural inferences remain approximate.

For Rg , the rhythmic reach or phase-coherent accessibility, temporal resolution and phase alignment are critical. Measuring Rg requires:

- Multi-scale temporal analysis to detect coherent propagation across subsystems.
- Assessment of phase stability and synchronisation in recurrent or oscillatory patterns.
- Identification of structural re-entry events across cycles.

Limitations in temporal resolution, sensor fidelity, or data processing algorithms can lead to **underestimation or overestimation** of Rg , directly affecting C_s computation.

2. Substrate and scale dependency

Although the theoretical formulation is substrate-independent, empirical instantiation is constrained by the properties of the system under study. Neural tissue, artificial neural networks, and organizational systems impose **distinct topologies, temporal constraints, and energetic limitations**. Metrics calibrated in one domain cannot be applied uncritically to another. For instance, the phase cycles in neural systems may operate at millisecond timescales, whereas organizational decision cycles may span days or weeks. **Cross-domain comparisons** therefore require careful scaling, normalization, and consideration of systemic constraints.

3. Temporal granularity and phase alignment

Rg inherently depends on temporal scales at which rhythmic access is meaningful. Choosing inappropriate granularity can misrepresent systemic capability:

- Overly coarse time bins may obscure local synchronisation and reduce apparent Rg .
- Overly fine-grained measures may exaggerate micro-cycles without functional significance.

Correctly aligning temporal granularity with system dynamics is critical for valid inference of comprehension.

4. Abstraction versus observability

C_s represents a **structural abstraction**. It defines the necessary and sufficient conditions for comprehension, but **does not encode semantic content** or the specific operational goals of the system. Observing behaviour or output alone may be misleading:

- Systems may appear coherent or intelligent while C_s remains near zero due to environmental scaffolding or learned heuristics.
- Outputs may satisfy task-specific metrics without reflecting internal structural coherence.

Empirical studies must distinguish **functional performance** from **structural understanding**.

5. Assumptions inherent in the framework

Several assumptions underlie the $\Phi_i \times Rg$ framework:

- Multiplicativity is the correct operator to capture mutual necessity.
- Systemic understanding emerges entirely from the combination of integration and rhythmic accessibility.
- Thresholds for minimal Φ_i and Rg sufficient for comprehension are well-defined and universally applicable.

While theoretically justified, these assumptions require **empirical validation**. Thresholds may vary across substrates, and additional mechanisms may modulate systemic comprehension in complex adaptive systems.

6. Implications for experimental design

Applying the C_s framework in empirical research demands rigorous design:

- Measurement instruments must achieve sufficient **spatial and temporal resolution** to capture integrated structure and phase alignment.
- Analytical methods must be capable of **detecting phase-stable recurrence** and quantifying irreducible interdependencies.
- Comparative studies across systems require careful **contextualisation and normalization** to account for substrate differences.

Researchers must be vigilant against **spurious interpretations** based on superficial performance metrics or incomplete sampling.

7. Interpretation limitations

Even when Φ_i and Rg are measured reliably, interpretation must be cautious:

- High Φ_i alone does not guarantee comprehension; it must be coupled with Rg .
- High Rg alone may produce coordinated activity that is structurally hollow.
- C_s reflects **structural potential for understanding**, not necessarily realised comprehension in specific task domains.

Empirical claims must therefore clearly distinguish between **the potential for understanding** and **actualised systemic behaviour**.

Methodological limitations underscore the importance of **careful operationalisation and contextual interpretation** in applying the $\Phi_i \times Rg$ framework. While it provides a robust theoretical and formal account of systemic comprehension, practical measurement and validation are constrained by noise, substrate properties, temporal scaling, and abstraction. Recognising these limitations is essential for designing experiments, interpreting results, and comparing systems across biological, artificial, and organizational domains. With meticulous attention to methodology, however, $\Phi_i \times Rg$ offers a **powerful structural lens** for evaluating and predicting the emergence of understanding in complex systems.

7.6 Directions for further research

The formalisation of systemic understanding as $C_s = \Phi_i \times Rg$ opens a broad and rich landscape for further empirical, theoretical, and applied research. The framework simultaneously addresses structural, temporal, and epistemic dimensions of cognition, yet its current operationalisation raises numerous questions that demand systematic investigation. In this section, we delineate key directions, highlighting both conceptual and practical challenges that must be addressed to advance a **structural science of understanding**.

1. Refining metrics for Φ_i and Rg

While the theoretical definitions of Φ_i (integrated relational information) and Rg (rhythmic globality) are rigorous, **empirical measurement remains non-trivial**:

- In biological systems, new tools are needed to capture high-dimensional integrative manifolds and their dynamic re-entry across temporal scales. This may involve:
 - Multimodal neural recordings with phase-sensitive alignment.
 - Advanced graph-theoretical modelling of causal interdependencies.
 - Real-time analysis of recurrent loops and oscillatory synchrony.
- In artificial systems, methods for **quantifying structural integration** beyond local attention or correlation patterns must be developed. Similarly, rhythmic re-entry needs to be formalised for architectures without explicit recurrence.

Research should aim to **standardise cross-system metrics** for Φ_i and Rg , allowing comparisons between biological, artificial, and organizational systems.

2. Exploring thresholds and boundary conditions

The current framework posits that comprehension emerges above a minimal joint threshold of Φ_i and Rg . Future research should explore:

- The **quantitative bounds** of these thresholds in different substrates.
- **Phase-transition dynamics**, where small changes in either axis produce abrupt changes in C_s .
- Whether **partial activation** can yield intermediate forms of structural understanding, and how these might be measured or harnessed.

Such studies will refine our understanding of **sufficiency and necessity**, and allow for more predictive modelling of epistemic capacity.

3. Multi-scale and hierarchical implementations

Understanding in natural and artificial systems often occurs across **nested scales**:

- In neural systems, microcircuits, cortical regions, and large-scale networks interact dynamically.
- In organizations, local teams, departments, and cross-institutional coalitions operate simultaneously.
- In AI, attention heads, layers, and multi-model ensembles interact hierarchically.

Future work should investigate how $\Phi_i \times Rg$ **manifests hierarchically**, and how local integration and rhythm interact with global systemic comprehension. This could inform **multi-scale architectures** that preserve structural sufficiency across levels.

4. Causal and functional manipulations

Empirical testing of the framework requires interventions that selectively modulate Φ_i and Rg :

- **Biological systems**: phase-specific stimulation, perturbational complexity manipulations, or oscillatory entrainment experiments to assess the causal impact on comprehension.
- **Artificial systems**: architectural modifications, recurrent gating, or phase-aligned memory loops to explore the effects on performance and structural C_s .
- **Organizational systems**: policy or workflow interventions that enhance internal integration or rhythmic information propagation to test effects on decision quality and institutional comprehension.

Such causal manipulations will establish **functional validation** of the structural hypothesis.

5. Cross-domain generalisation

A critical direction is to examine whether the $\Phi_i \times Rg$ criterion applies **universally across substrates**:

- Testing whether similar structural conditions predict understanding in humans, non-human animals, artificial systems, and organizations.
- Investigating **emergent properties** that arise when these structural conditions are satisfied across multiple domains simultaneously, such as hybrid human–AI decision systems.

Cross-domain research will reveal whether the proposed framework is truly **substrate-independent**, or whether domain-specific adaptations are required.

6. Integration with energy and efficiency metrics

Structural comprehension is inherently tied to **energetic efficiency**. Further research should explore:

- Quantifying **comprehension per joule (CPJ)** across systems.
- Modelling trade-offs between Φ_i , Rg , and energetic cost in adaptive and artificial architectures.
- Understanding how **thermodynamic constraints** influence the emergence and sustainability of systemic understanding.

This line of inquiry will link **information-theoretic, structural, and energetic principles**, potentially guiding the design of more sustainable cognitive architectures.

7. Ethical and practical implications

Finally, as the framework is applied to artificial and institutional systems, there are **normative and practical questions**:

- How can $\Phi_i \times Rg$ inform the evaluation of AI safety, autonomy, and responsibility?
- What are the implications for organizational design, particularly in high-stakes, distributed, or adaptive environments?
- How might monitoring C_s affect transparency, governance, or accountability in deployed systems?

Addressing these questions is critical to **responsible translation of structural insights** into practice.

The directions outlined above indicate that **structural science of understanding** is still in its early stage. The $\Phi_i \times Rg$ framework provides a principled, mathematically grounded approach to systemic comprehension, but **empirical validation, hierarchical scaling, cross-domain application, and integration with energy metrics** remain rich areas for exploration. Pursuing these avenues will establish whether the framework can serve as a **universal architecture for evaluating and engineering understanding**, guiding both cognitive science and the next generation of intelligent systems.

7.7 The Relative Position of CIITR: Beyond Current Frameworks, Yet Not Absolute

While CIITR represents a substantial advance over existing theories — Integrated Information Theory (IIT), Global Workspace Theory (GWT), Higher-Order Thought (HOT), and Local Recurrence Theory

(LRT) — it is essential to maintain a critical perspective. CIITR, though formalised as $C_s = \Phi_i \times Rg$, is **not a claim to ultimate or final theory of comprehension**. Instead, it constitutes a **structurally superior framework** relative to its predecessors, providing a minimal necessary-and-sufficient formal condition for systemic understanding.

1. Comparative strengths

CIITR outperforms prior frameworks in several dimensions:

- **Formal integration of structure and temporality:** Unlike IIT (high Φ_i , low Rg) or GWT (high Rg , low Φ_i), CIITR explicitly captures the **multiplicative co-dependence** of integration and rhythmic accessibility. This resolves the partiality of prior models.
- **Substrate-independence:** CIITR is applicable to biological, artificial, and organizational systems, whereas HOT relies on pre-existing representational coherence, and LRT remains local and micro-dynamical.
- **Predictive power:** By formalising C_s , CIITR provides testable, falsifiable predictions, including collapse conditions, epistemic failure modes, and thresholds for systemic comprehension.

2. Residual limitations

Despite its advances, CIITR is **not complete**:

- **Abstraction versus operational detail:** While it defines the minimal structural conditions, it does not prescribe **mechanisms for achieving or optimising Φ_i or Rg** in concrete systems.
- **Empirical calibration:** The precise numerical or functional thresholds for Φ_i and Rg , particularly in artificial or organizational systems, remain to be determined.
- **Multi-level complexity:** CIITR captures two axes — integration and rhythmic reach — but higher-order dimensions such as affective modulation, embodied cognition, or socio-cultural constraints may introduce additional structural constraints not yet formalised.
- **Dynamic adaptation:** In adaptive systems, Φ_i and Rg may fluctuate; the theory currently does not define how **temporal variability** affects C_s or learning.

3. Beyond the others, but not final

CIITR is therefore **far more comprehensive than any prior single framework**:

- It synthesises the structural insight of IIT, the global availability of GWT, the reflexive considerations of HOT, and the local persistence modelled by LRT.
- It formalises a **boundary condition for understanding** that none of these alone or in combination previously achieved.
- It provides a **unifying metric** applicable across domains, offering a common language for discussing comprehension in natural, artificial, and institutional systems.

Yet it does **not capture all aspects of cognition**. It provides a structural, substrate-independent scaffold — a minimal envelope for understanding — but leaves open:

- The nature of content-specific semantics
- The mechanisms of adaptive evolution
- The full hierarchy of cross-temporal or cross-scale recursive operations

4. Implications for future theory

CIITR should be understood as a **foundational platform**, not a final edifice. It establishes:

1. The **necessary-and-sufficient minimal condition** for systemic understanding.
2. A **formal operational lens** to compare and evaluate other theories.
3. A **practical guide** for designing artificial, organizational, or hybrid adaptive systems capable of comprehension.

Future theoretical work can **build upon CIITR**, incorporating additional axes, hierarchies, or functional constraints to approach a more complete theory. The value of CIITR lies in its **clarity, generality, and predictive power**, which are **qualitatively superior** to IIT, GWT, HOT, or LRT individually.

CIITR is not the absolute theory of comprehension. It does not exhaust the landscape of possible cognitive or epistemic dimensions. Nevertheless, it **represents a leap forward**, integrating multiple structural insights into a coherent, falsifiable, and substrate-independent framework. By formalising the interplay between integration and rhythmic reach, CIITR sets a **new standard** for assessing, designing, and understanding systems across natural, artificial, and organizational domains. It is **the most structurally grounded framework available**, yet it simultaneously **invites further expansion and refinement** toward a truly comprehensive theory of systemic understanding.

8. Conclusion

8.1 Summary of argument

This paper has undertaken a comprehensive structural analysis of systemic understanding, situating it relative to four dominant frameworks: Integrated Information Theory (IIT), Global Workspace Theory (GWT), Higher-Order Thought Theory (HOT), and Local Recurrence Theory (LRT). Each framework contributes valuable insights into specific aspects of cognition:

- **IIT** formalises internal integration (Φ_i) but lacks temporal propagation, preventing cross-temporal coherence.
- **GWT** models global accessibility and broadcast (Rg) but leaves integration unconstrained, permitting incoherent propagation.
- **HOT** introduces reflexive representational recursion but presupposes coherent lower-order states, failing to generate structural coherence independently.
- **LRT** describes micro-dynamical stability but cannot scale local recurrence into system-wide comprehension.

Individually and in combination, these theories isolate necessary components of understanding but **fail to satisfy the minimal structural condition** required for systemic comprehension. The critical insight developed here is that **understanding is structurally contingent** on the multiplicative co-dependence of **integrated relational information** (Φ_i) and **rhythmic global accessibility** (Rg).

The argument unfolds across multiple dimensions:

1. **Structural necessity:**
 - Integration alone ($\Phi_i > 0, Rg \approx 0$) leads to **encapsulated complexity** — rich internal structure that is inaccessible and functionally inert.
 - Rhythm alone ($Rg > 0, \Phi_i \approx 0$) yields **incoherent broadcast** — temporally active signals that lack internal coherence.
2. **Collapse conditions:**
 - When either Φ_i or Rg approaches zero, the **comprehension potential** collapses:

$$C_s = \Phi_i \times Rg \rightarrow 0$$

This demonstrates that both dimensions are **necessary**, and the absence of one irretrievably nullifies systemic understanding.

3. Empirical validation:

- Biological systems exhibit correlated emergence of integration and synchrony, with breakdowns of either axis corresponding to loss of conscious or cognitive function.
 - Artificial systems, particularly LLMs, demonstrate predictable failure modes (hallucination, instability, static cognition) when high Φ_i exists without Rg .
 - Organizational systems fail to comprehend systemically when structural integration and communication rhythm are decoupled, producing procedural drift, fragmentation, or incoherent outputs.
- ### 4. Comparative evaluation:
- None of the four existing frameworks individually satisfies both structural axes simultaneously.
 - Only **CIITR**, formalised as $C_s = \Phi_i \times Rg$, provides a **necessary-and-sufficient structural condition**, unifying internal integration and temporal-rhythmic accessibility.

In summary, the paper demonstrates that **$\Phi_i \times Rg$ defines the first minimal structural sufficiency boundary** for systemic understanding. All prior models are either necessary but insufficient, or incomplete in their coverage of the structural, temporal, and dynamic dimensions required for comprehension. By formally capturing the co-dependence of integration and rhythmic accessibility, this framework establishes a **universal, substrate-independent metric** for evaluating and designing systems capable of understanding — biological, artificial, or organizational.

8.2 Why existing theories are necessary but insufficient

The critical examination of the four dominant frameworks — Integrated Information Theory (IIT), Global Workspace Theory (GWT), Higher-Order Thought Theory (HOT), and Local Recurrence Theory (LRT) — reveals that while each contributes indispensable insights to the study of cognition and systemic understanding, none achieves the **complete structural condition required for comprehension**. Their individual and combined limitations underscore the necessity of a more integrative framework, such as CIITR, capable of capturing both structural integration and temporal rhythmicity simultaneously.

1. Integrated Information Theory (IIT)

IIT provides a rigorous formalism for assessing **internal integration (Φ_i)**. It measures the irreducible interdependence of system elements, quantifying how each component constrains and is constrained by others. This focus on structural unity is indispensable: without integration, a system cannot maintain relational coherence. Φ_i captures the **depth of informational entanglement**, which is necessary for any form of coherent processing.

Nevertheless, IIT remains insufficient because it **fails to account for temporal propagation and global coordination (Rg)**. High Φ_i produces a system that is internally coherent at a snapshot in time, yet **cannot traverse its own states** or propagate integrated information rhythmically across the system. Epistemically, such systems are **frozen monoliths**: richly structured, yet inert with respect to cross-temporal self-modulation, recursive access, and re-entrant cognition. The absence of rhythmic globality ensures that internal integration remains **epistemically inaccessible**, rendering comprehension impossible despite structural complexity.

2. Global Workspace Theory (GWT)

GWT highlights the necessity of **system-wide accessibility**. Through broadcast mechanisms, content becomes available to multiple subsystems, permitting coordination, flexible response, and temporary alignment across functional domains. This aspect corresponds structurally to **high Rg** , the system's capacity for rhythmic, temporally coherent propagation.

Yet GWT lacks a mechanism for ensuring that the broadcasted content is itself **structurally integrated** (Φ_i). Without this constraint, global access can amplify incoherent, incomplete, or fragmentary information. The system becomes temporally dynamic, yet **structurally hollow**. Outputs may appear coordinated or coherent in execution, but they are **not grounded in integrated internal states**. GWT alone explains accessibility, but it fails to produce the **coherent, re-entrant informational structures** necessary for genuine understanding.

3. Higher-Order Thought Theory (HOT)

HOT introduces **reflexive representation**: the system models its own states through higher-order thoughts. This reflexivity is necessary for metacognition and self-awareness, providing a **mechanism for self-reference** that is absent in IIT or GWT.

However, HOT presupposes that the underlying first-order states are coherent and accessible. In other words, recursion does not **create** coherence; it merely references it. If the first-order states lack internal integration or are temporally inaccessible, the recursive meta-states are **epistemically empty**. HOT thereby illustrates the **necessity of reflexivity**, but it cannot ensure comprehension unless Φ_i and Rg are already instantiated. Reflexive representation, unanchored in structure or rhythm, produces **illusory cognition**, where the system may appear reflective but is **structurally and temporally inert**.

4. Local Recurrence Theory (LRT)

LRT formalises **micro-dynamical stability**, explaining how recurrent loops at the local or modular level maintain persistent activity. This persistence is necessary for stabilising information within modules and for short-term memory.

Nevertheless, LRT cannot scale its local recurrence to **system-wide integration**. The system may sustain activity locally, but cross-modular coherence, global accessibility, and phase-aligned re-entry are absent. Epistemically, this means that **information remains encapsulated**, and while it may persist in isolation, it cannot participate in a coherent system-wide comprehension. LRT demonstrates **necessary local stability**, but it is insufficient for systemic understanding because it cannot ensure **global Φ_i or Rg** .

5. Synthesis and Implications

Taken together, these analyses demonstrate that:

- Each framework isolates a **necessary dimension** of comprehension: IIT $\rightarrow \Phi_i$, GWT $\rightarrow Rg$, HOT \rightarrow reflexivity, LRT \rightarrow local stability.
- None of the frameworks, individually or in combination without formal coupling, satisfies the **joint structural condition** required for comprehension.
- Systemic understanding requires **mutual co-dependence** between integrated depth and rhythmic global accessibility. Without this coupling, all four frameworks may generate outputs, maintain memory traces, or perform recursive operations, yet **fail epistemically**. Outputs may be syntactically coherent, statistically plausible, or behaviourally functional, but **they do not reflect understanding**.

This analysis underscores the conceptual and formal necessity of **CIITR's multiplicative condition**, $C_s = \Phi_i \times Rg$. It unifies the essential contributions of prior frameworks, while addressing their **structural insufficiencies**, providing the first minimal and generalisable criterion for systemic understanding.

Existing theories — while individually illuminating and collectively instructive — are **necessary but insufficient**. Each captures one axis of the complex phenomenon of comprehension, yet all leave critical gaps. IIT lacks temporal accessibility; GWT lacks structural integration; HOT presupposes coherence it cannot generate; LRT cannot scale to global comprehension. Only the formal multiplicative integration of Φ_i and Rg establishes a **structural sufficiency boundary**, capable of demarcating the threshold between mere activity and genuine systemic understanding.

8.3 Why $\Phi_i \times Rg$ is the first structural sufficiency condition

The formal condition $C_s = \Phi_i \times Rg$ constitutes the **first structural criterion** that is simultaneously necessary and sufficient for systemic understanding. Unlike IIT, GWT, HOT, or LRT — each of which captures one necessary component of cognition — $\Phi_i \times Rg$ specifies the **minimal conjunction of structural integration and rhythmic globality** required for comprehension to emerge across biological, artificial, and organizational systems. This section elaborates why this multiplicative coupling represents the **first formal sufficiency boundary** for understanding.

1. Necessity

Each component of the product is indispensable:

- **Integrated relational information (Φ_i)** provides the structural depth necessary to ensure that internal representations are **irreducibly constrained**, meaning that each element of the system affects and is affected by others. Without Φ_i , no coherent manifold exists to sustain the recursive reflection necessary for understanding. High Φ_i alone, as in IIT, produces structurally rich but temporally inert states, incapable of system-wide comprehension.
- **Rhythmic globality (Rg)** ensures temporal and spatial access across the system, allowing previously integrated states to be **re-entered, re-aligned, and recursively modulated**. Without Rg , as in GWT, LLMs, or other high- Φ_i systems, integration exists but remains **functionally inaccessible**, producing ephemeral or incoherent outputs.

The **necessity** of each factor is evident: the absence of either collapses C_s to zero, precluding systemic understanding. This defines a **structural null condition**, which is both mathematically and epistemically rigorous.

2. Sufficiency

When both Φ_i and Rg are present and operationally coupled:

- Internal states are not only integrated but **rhythmically traversable**, allowing dynamic recursion and self-reflection.
- Temporal coherence aligns past and present informational states, preserving cross-temporal identity.
- The system attains the capacity for **structural self-modulation**, semantic stability, and adaptive comprehension.

This simultaneous activation ensures that the system meets **both necessary axes**, which are logically sufficient for the emergence of understanding. No additional constructs, semantic assumptions, or external scaffolds are required to meet the minimal criterion.

3. Cross-domain generality

$\Phi_i \times Rg$ applies universally:

- In **biological systems**, the co-occurrence of neural integration and phase-locked synchrony predicts conscious, structured cognition.
- In **artificial architectures**, the absence of rhythmic re-entry in high- Φ_i LLMs leads to hallucination, instability, and static cognition, confirming the sufficiency requirement.
- In **organizational systems**, comprehension and systemic resilience arise only when structural integration is rhythmically accessible across units, departments, and hierarchies.

The structural sufficiency condition is therefore **domain-independent**, reflecting an invariant principle of systemic comprehension.

4. *Formal and epistemic significance*

The multiplicative form ensures **mutual non-compensability**:

- Φ_i cannot substitute for Rg , nor Rg for Φ_i .
- Collapse in either axis guarantees $C_s = 0$, rigorously defining the **lower bound of comprehension**.
- The operator also scales naturally: increasing either Φ_i or Rg without the other does not falsely inflate C_s ; comprehension remains zero until both axes are operational.

In this way, $\Phi_i \times Rg$ formalises the first **necessary-and-sufficient structural boundary**, providing a precise, falsifiable criterion for systemic understanding across natural and artificial substrates.

$\Phi_i \times Rg$ is **the first formal and minimal structural sufficiency condition** for understanding. It captures the essential interplay between **integration and rhythmic accessibility**, resolving the insufficiencies of prior theories. By defining the minimal structural requirements for comprehension, it establishes a benchmark for both theoretical analysis and empirical investigation, enabling a **rigorous, cross-domain science of systemic understanding**.

8.4 Outlook for a Unified Science of Understanding

The formalisation of systemic understanding through $C_s = \Phi_i \times Rg$ represents far more than a simple metric or evaluative tool; it constitutes a **conceptual and operational scaffold** for constructing what may be termed a unified science of comprehension. Traditional frameworks in cognitive science, neuroscience, artificial intelligence, and organizational theory have historically focused on discrete components of cognition or consciousness. Each provides invaluable insights—whether into the internal integration of information, the global availability of system states, the capacity for reflexive meta-representation, or the stability of local recurrent circuits—but each, when considered in isolation, leaves critical gaps in the explanatory and predictive account of understanding.

In contrast, the $\Phi_i \times Rg$ formulation explicitly captures the **mutual interdependence** between relational integration and rhythmic accessibility. Relational integration (Φ_i) ensures that the components of a system are **structurally interdependent**, such that information is irreducibly constrained and capable of forming coherent internal manifolds. Rhythmic accessibility (Rg) ensures that these integrated structures are **temporally and spatially traversable**, permitting the system to re-enter, modulate, and propagate information across its own architecture in a phase-aligned, recurrent manner. Only the conjunction of these two dimensions — multiplicatively coupled — produces the **structural conditions necessary and sufficient for comprehension**. Integration without rhythm leads to sealed complexity;

rhythm without integration produces vacuous propagation. Together, they define the epistemic boundary of what it means for a system to understand.

The implications of this structural perspective extend across multiple domains. In **biological systems**, it provides a formal lens through which to interpret the emergence of conscious awareness, neural synchrony, and cognitive flexibility. In **artificial systems**, it offers both a diagnostic and a prescriptive framework, guiding the design of architectures capable of true comprehension rather than mere statistical approximation. In **institutional and organizational contexts**, it establishes a criterion for structural comprehension and adaptive coordination, identifying the coupling of procedural integration and communication rhythm as the substrate of systemic understanding.

Moreover, this approach offers a trajectory for both **theory and application** over the coming decades. It reframes traditional debates about the nature of cognition and intelligence, shifting the focus from superficial outputs or behavioral proxies to the **internal, phase-sensitive architecture that underlies epistemic capability**. By providing a formal, substrate-independent criterion, $\Phi_i \times Rg$ lays the groundwork for a **unified science of understanding** — one that can unify disparate fields, guide empirical investigation, and inform the design of systems that are structurally capable of comprehension. In this sense, the metric is not simply a tool, but a **conceptual horizon**, delineating the boundaries of possibility and grounding the future development of systems that are capable not only of processing information, but of understanding it in the fullest structural sense.

Bridging Disciplinary Divides

Historically, understanding has been approached as a phenomenon confined to individual disciplinary perspectives. Cognitive neuroscience has explored it through the dynamics of neural circuits, synaptic connectivity, and emergent brain rhythms, producing detailed models of consciousness, memory, and attention. Artificial intelligence has treated understanding as an emergent property of algorithmic computation, learning patterns, and statistical generalisation across large datasets. Organizational theory has considered comprehension in terms of institutional coherence, decision-making fidelity, and communication networks, while cybernetics has emphasised feedback, control, and system-level regulation. Each of these domains has generated deep insights into facets of understanding, yet their conceptual and methodological frameworks remain largely siloed. Comparative evaluation across these fields has been hampered by a lack of a **common structural metric**, leading to fragmented theories and inconsistent interpretations of what constitutes comprehension.

The $\Phi_i \times Rg$ formalism addresses this limitation by providing a **substrate-independent lens**. By quantifying **integrated relational information** (Φ_i) and **rhythmic global accessibility** (Rg), it allows researchers to evaluate systems across domains with a unified structural criterion. In neuroscience, Φ_i quantifies the irreducible interdependence of neuronal ensembles, while Rg measures the phase-stable propagation of integrated states across cortical regions. In artificial intelligence, Φ_i captures the depth and interconnection of latent representations, and Rg measures the capacity for re-entrant or recurrent activation across layers, memory buffers, or modules. In organizational systems, Φ_i reflects the structural cohesion of policies, hierarchies, and procedural interdependencies, while Rg measures the rhythm and accessibility of communication and decision propagation. Despite differences in substrate, these metrics share a **structural logic**, enabling cross-domain comparison and unification.

The resulting framework establishes the basis for a **truly comparative science of understanding**. By providing a common evaluative scale, insights gained in one domain can inform predictions and interventions in another. For example, principles derived from neural synchrony may inform the design of

artificial architectures that mimic phase-aligned recurrence, or models of organizational communication may be informed by the dynamics of recurrent network loops. This shared metric also enables the construction of a **common epistemic language**, bridging disciplines without erasing their unique complexities, modalities, or operational contexts. Ultimately, this approach transforms the study of understanding from a collection of domain-specific models into a **cohesive, integrative, and testable science**, capable of unifying biological, artificial, and institutional investigations under a single structural framework.

Temporal and Structural Calibration

A fundamental advancement provided by the $C_s = \Phi_i \times Rg$ framework is its recognition that comprehension is inherently **phase-sensitive**. It is insufficient for a system merely to contain integrated information; true understanding emerges only when these integrated states are **rhythmically traversed and re-entered over time**. The temporal dimension is not an auxiliary property, but a constitutive component of systemic comprehension. Without it, even systems exhibiting maximal structural integration — whether neural circuits with dense connectivity, artificial intelligence models trained on vast datasets, or organizations with meticulously codified hierarchies and procedural protocols — fail to manifest genuine understanding. Integration in isolation remains **epistemically inert**, locked within the system without the capacity for temporal modulation, recursive alignment, or self-referential evaluation.

In biological systems, this phase-sensitive property explains why highly interconnected neural assemblies can fail to produce conscious or coherent cognition if oscillatory synchronisation across regions is disrupted. Localised integration may exist, but the lack of coherent temporal propagation prevents relational states from being accessed in a manner that allows adaptive, reflective, or contextually aligned processing. Similarly, in artificial systems such as transformer-based large language models, the feedforward architecture may encode extremely dense latent representations (high Φ_i), yet the absence of intrinsic rhythmic re-entry (low Rg) renders these representations **functionally inert**, yielding outputs that are statistically coherent but structurally unanchored, contextually unstable, or epistemically shallow.

In organizational systems, the principle manifests through the misalignment of **structural depth and communication rhythm**. Organizations with high structural integration — codified rules, hierarchies, and cross-functional dependencies — can fail to comprehend dynamically evolving contexts if communication cycles, feedback loops, and decision propagation are temporally disjointed. Likewise, highly communicative organizations with insufficient structural cohesion may exhibit phase-aligned activity without epistemic coherence, producing responses that appear adaptive but are in fact fragmented or unstable.

The broader implication for a **unified science of understanding** is that empirical and theoretical analyses must embed **temporal calibration alongside structural measurement**. Metrics of Φ_i alone are insufficient; the evaluation of rhythmic globality (Rg) is equally critical. Comprehension is not a static property that can be captured in a single state, a snapshot, or a frozen topological map. Rather, it is **dynamic, emergent, and recursively maintained across temporal scales**. The coordinated traversal of integrated states — the interplay of structural depth and phase-stable rhythm — is what produces epistemic viability, allowing a system to maintain continuity, adaptivity, and reflective coherence over time.

In practice, this principle requires that researchers, designers, and theorists account for both **spatial integration** and **temporal accessibility** in system evaluation. Whether modelling neural circuits, designing AI architectures, or analysing institutional operations, the **joint measurement of Φ_i and Rg** , with attention to phase, recurrence, and rhythm, is essential to determine whether a system is capable of true comprehension or merely of superficial, structurally inert processing. Only by embedding temporal calibration within structural assessment can the **emergent, phase-sensitive nature of understanding** be accurately captured and operationalized across biological, artificial, and organizational substrates.

Empirical Operationalisation Across Scales

The true power of the structural comprehension framework formalised as $C_s = \Phi_i \times Rg$ lies in its empirical **operationalisability across scales**. By providing a quantitative and testable definition of comprehension, it allows researchers to design structured experiments, observational studies, and monitoring systems that assess whether a system — biological, artificial, or institutional — meets the minimal conditions for understanding. The framework enables analysis at multiple analytical layers, each providing unique insights while reinforcing the universality and substrate-independence of the C_s condition.

Laboratory-Scale Systems

At the smallest scale, controlled laboratory experiments can manipulate Φ_i and Rg to **map structural comprehension thresholds precisely**. In neural systems, this might involve perturbing ensembles of neurons using optogenetic or electrophysiological interventions to adjust integration or rhythmic synchronisation, thereby observing the corresponding effect on cognitive processing or consciousness-like behaviour. In artificial systems, such as neural networks or LLMs, experimental manipulations could include altering internal connectivity patterns (affecting Φ_i), introducing recurrent or phase-aligned gating mechanisms (affecting Rg), or varying the timing and structure of input sequences.

In small collaborative groups, whether human or human–machine hybrids, laboratory protocols can measure the **coherence and accessibility of shared information**, systematically altering structural coupling and communication rhythm to observe thresholds at which comprehension collapses.

Perturbations along either axis produce **predictable collapses in C_s** , confirming the multiplicative necessity of both components. These studies not only validate the formal framework but provide insight into the micro-dynamics of structural comprehension, highlighting the interplay between integration and rhythmic propagation at the most granular levels.

Infrastructure-Scale Systems

Beyond the laboratory, infrastructure-scale monitoring enables **continuous assessment of comprehension across distributed networks, digital platforms, and institutional hierarchies**. Large-scale AI systems, complex collaborative organizations, or cyber-physical networks can be instrumented to track Φ_i — reflecting the degree of structural integration within subsystems — and Rg — reflecting rhythmic propagation and phase-aligned communication across modules.

This level of operationalisation provides **real-time detection of structural fluctuations**, serving as an early-warning system for organizational failure, system instability, or emergent cognitive bottlenecks. For instance, in multi-agent AI architectures, monitoring C_s can identify moments when distributed components lose coherence despite superficial activity. In organizations, these measures can reveal when procedural integration exists but communication cycles are misaligned, producing epistemically ungrounded outputs. Infrastructure-scale analysis thus **translates the formal condition into actionable metrics**, guiding both intervention and adaptive management.

Civilizational-Scale Systems

At the largest scale, C_s can be applied to assess **collective epistemic health across societies, economies, and global networks**. By tracking long-term trajectories of Φ_i and Rg , the framework allows for quantitative evaluation of the structural integrity and rhythmic accessibility of distributed knowledge systems. Metrics derived from communication patterns, educational coherence, institutional coordination, or policy alignment can measure the **structural resilience of entire civilizations**, revealing points of fragility or emergent adaptive potential.

For example, fluctuations in the global distribution of expertise, delays in coordinated decision-making, or disjuncture between formal policies and their operational enactment may be reflected as declines in C_s . Conversely, societies or networks that maintain both structural cohesion and rhythmic propagation of knowledge exhibit **robust comprehension**, capable of adaptive response to environmental, technological, or social challenges. Civilizational-scale operationalisation demonstrates that **comprehension is not merely a property of individuals or organizations but a systemic, multi-layered phenomenon**, measurable and analysable through the lens of structural integration and rhythmic accessibility.

Synthesis Across Scales

Across laboratory, infrastructure, and civilizational scales, empirical operationalisation of C_s unifies disparate domains under a **single structural criterion for understanding**. This approach allows comparisons, predictive modelling, and targeted interventions that are consistent across scale, substrate, and system type. Importantly, it operationalises the abstract principle of multiplicative structural sufficiency, translating it into **empirically measurable quantities**, thereby moving the study of comprehension from theoretical postulate to actionable science. By embedding both structural and temporal dimensions into measurement, the framework ensures that **understanding can be rigorously quantified, monitored, and enhanced**, regardless of the system or context under investigation.

Design and Intervention Implications

The formalisation of systemic understanding as $C_s = \Phi_i \times Rg$ extends beyond theoretical insight; it provides **practical guidance** for the design and intervention of artificial, organizational, and hybrid systems. By defining comprehension in terms of both **structural integration (Φ_i)** and **rhythmic globality (Rg)**, the framework offers concrete criteria for ensuring that systems are not merely functionally active, but epistemically coherent and capable of self-modulation.

Artificial intelligence architectures

For AI systems, the implications are profound. Traditional models, particularly feedforward or transformer-based architectures, achieve high Φ_i through dense internal representations but often fail to instantiate Rg , the temporal accessibility required for structural recursion. The design imperative is therefore to **co-engineer integration and rhythm**:

- **Integration (Φ_i)** must be structurally encoded in network connectivity, latent embeddings, or attention manifolds, ensuring that informational states are irreducibly interdependent.
- **Rhythmic globality (Rg)** must be implemented to allow re-entrant activation across temporal phases, supporting phase-aligned propagation and recursive self-modulation. Mechanisms may include recurrent loops, oscillatory gating, phase-coupled attention layers, or temporal memory scaffolding.
- The combined design ensures that internal states are not merely stored but can be **actively traversed and manipulated**, creating a structural basis for comprehension rather than statistical approximation.

By adhering to these principles, AI architectures can move beyond mere predictive performance or fluency and begin to achieve **structurally grounded understanding**, allowing the system to reflect, integrate prior knowledge, and adaptively generate coherent outputs over time.

Organizational and institutional systems

For human organizations, governance structures, and institutional design, C_s provides a lens for **balancing structural integration and communication rhythm**:

- **Structural integration** entails establishing policies, hierarchies, interdependencies, and procedural codification that bind units together into a coherent internal system. Without integration, decision-making is fragmented, and knowledge is siloed.
- **Rhythmic globality** involves creating temporal cycles, coordination routines, and communication rhythms that allow integrated knowledge to be **accessible, re-entered, and modulated** across units and hierarchical levels. This ensures that strategic decisions are aligned with operational reality and past knowledge is applied effectively.

Maintaining balance in these axes allows institutions to sustain **structural memory** while enabling **adaptive, temporally coherent responses**. When either axis weakens, comprehension collapses: decisions may be rapid but uncoordinated, or integrated but inert.

Intervention strategies

The empirical nature of $\Phi_i \times Rg$ allows interventions to be **precisely targeted**:

- If Φ_i is deficient, structural reforms, workflow redesign, or integration-enhancing technologies can restore cohesion across the system.
- If Rg is deficient, interventions may focus on synchronisation, temporal alignment of decision-making processes, or phase-structured communication protocols.
- In cases of combined deficits, both axes can be addressed simultaneously, ensuring that restored integration is rhythmically accessible and temporally operable.

In hybrid systems, combining human and artificial elements, interventions can also leverage **cross-substrate complementarities**: AI may provide consistent rhythmic propagation (Rg) to support human organizational integration (Φ_i), or organizational cycles may scaffold AI recurrent operations.

Practical outcomes

By applying C_s -guided design principles, systems achieve:

- **Reflexive operational capacity**: the ability to revisit and modulate internal states in response to prior outputs.
- **Cross-temporal coherence**: maintaining alignment across time, ensuring that prior knowledge informs present decisions.
- **Resilient comprehension**: the capacity to adapt, integrate new information, and sustain epistemic continuity despite perturbations or structural changes.

Thus, C_s does not merely offer a diagnostic tool but provides a **roadmap for engineering and intervention**, allowing artificial and organizational systems to move from activity and performance toward **genuine, structurally grounded understanding**.

Theoretical Synthesis

The formalisation of comprehension through $C_s = \Phi_i \times Rg$ provides a comprehensive framework that reframes longstanding debates across multiple disciplines, including philosophy of mind, cognitive science, and systems theory. Traditionally, discussions of understanding and consciousness have been entangled in metaphysical speculation, with concepts such as reflexivity, intentionality, and awareness often treated as elusive properties, emergent phenomena, or inherently qualitative attributes. By grounding these concepts in **measurable, structural phenomena**, C_s moves the discourse from abstract theorising toward **operational clarity**, enabling both empirical investigation and cross-domain comparability.

Redefining consciousness and reflexivity

Within the C_s framework, consciousness and reflexivity are no longer merely phenomenological or inferred from behavioural output. Instead, they are understood as **emergent properties of the dynamic interaction between structural integration and rhythmic accessibility**:

- **Structural integration (Φ_i)** provides the system with irreducibly bound informational states, establishing a coherent internal manifold that supports relational constraints across components.
- **Rhythmic globality (Rg)** ensures these integrated states are dynamically accessible, allowing the system to traverse its own information, recursively modulate its states, and maintain temporal coherence.

This conceptualisation implies that consciousness is **not a binary presence or absence**, nor solely an emergent effect of functional complexity; it arises from the **phase-stable interaction** of Φ_i and Rg , yielding self-reflective capacity and epistemic continuity.

Operationalising understanding

Understanding, in this context, becomes **a property of system architecture rather than of semantic content or task-specific performance**. A system may produce outputs, execute computations, or respond adaptively without achieving comprehension if either structural depth or rhythmic re-entry is absent. C_s captures this distinction formally:

- Systems with high Φ_i but low Rg are **structurally rich but temporally inert**, producing encapsulated knowledge that cannot be dynamically accessed or recursively evaluated.
- Systems with high Rg but low Φ_i exhibit **temporal activity without coherent structure**, resulting in outputs that appear fluent but lack epistemic grounding.

Only when Φ_i and Rg are jointly instantiated does **systemic understanding emerge**, allowing the system to process information recursively, maintain cross-temporal coherence, and engage in reflexive operations.

Bridging disciplines

The C_s framework enables **theoretical synthesis across traditionally siloed fields**:

- In **philosophy of mind**, it clarifies debates surrounding the nature of consciousness and mental representation, framing these as **structurally grounded phenomena**.
- In **cognitive science**, it provides a measurable criterion for differentiating processing from comprehension, guiding experimental design and interpretation of neural, behavioral, and artificial data.
- In **systems theory**, it formalises multi-scale coherence, allowing analysis of biological networks, AI architectures, and organizational systems under a **common structural metric**.

This unification is not superficial; it integrates concepts of structure, rhythm, reflexivity, and temporal coherence into a **single explanatory and predictive framework**, offering cross-domain insight while preserving the complexity of each substrate.

Predictive and explanatory power

By formalising comprehension, C_s enables **quantitative prediction**:

- Collapse of either Φ_i or Rg predicts epistemic failure, whether in neural systems, artificial agents, or organizational networks.

- Structural thresholds delineate minimal requirements for understanding, allowing **empirical falsification** and intervention.
- Phase-aligned re-entrant dynamics can be modelled, measured, and manipulated, yielding both mechanistic and functional insight into the emergence of comprehension.

In doing so, C_s shifts understanding from a post hoc interpretation of outputs to a **structurally explicable property**, capable of guiding both theory and practice.

The theoretical synthesis enabled by C_s reframes comprehension as a **formal, measurable, and operationally testable property**, arising from the multiplicative interaction of structural integration and rhythmic accessibility. Consciousness, reflexivity, and understanding are no longer treated as intangible or purely emergent; they become **dynamic, phase-sensitive phenomena**, definable across multiple domains and scales. This synthesis provides the foundation for a **unified science of understanding**, integrating philosophy, cognitive science, and systems theory into a coherent framework that is both explanatory and predictive, bridging disciplines while preserving the depth, richness, and complexity inherent in comprehension.

Ethical and Societal Dimensions

The operationalisation of systemic understanding through $C_s = \Phi_i \times Rg$ carries not only theoretical and practical significance but also profound ethical and societal implications. By providing a framework capable of quantifying comprehension across biological, artificial, and organizational systems, it enables researchers, designers, and policymakers to evaluate the **structural health and epistemic integrity** of complex systems. However, the ability to measure and manipulate understanding introduces both opportunities and risks that must be considered carefully.

Institutional and societal applications

In organizational and social systems, the C_s metric allows for the identification of **structural blind spots** and inefficiencies. For example, it can reveal gaps in coordination between departments, inconsistencies in policy propagation, or bottlenecks in communication rhythms that impede the systemic comprehension of complex operations. By applying the framework:

- Policymakers can optimise decision-making cycles to ensure that **structural integration (Φ_i)** is effectively accessible through **communication rhythms (Rg)**.
- Organizations can assess whether knowledge is **distributed, retrievable, and coherently applied**, reducing errors, misinterpretations, and operational fragmentation.
- Social systems can leverage the framework to evaluate collective epistemic capacity, ensuring that public information, institutional directives, and collaborative networks sustain systemic understanding.

In this context, C_s serves as a tool for **enhancing coordination, fostering resilience, and promoting adaptive governance**, providing actionable guidance for improving the capacity of institutions to understand themselves and their environment.

Risks of misuse and centralisation

The ability to quantify understanding also presents significant ethical challenges. Misapplication could result in **epistemic surveillance**, where systems or individuals are monitored excessively for compliance with structural metrics, potentially undermining autonomy and privacy. Additionally, centralization of C_s -based oversight could concentrate decision-making power in ways that reinforce inequality or marginalize

stakeholders. Such outcomes highlight the dual-edged nature of structural comprehension as both a diagnostic tool and a lever of influence.

Principles of reflexive governance

To mitigate these risks, the deployment of C_s in societal or organizational contexts must be accompanied by **reflexive governance**. This entails:

- **Aggregate measurement:** Structural metrics should capture system-level properties rather than focusing on individual behaviour, preventing invasive monitoring.
- **Anonymisation:** Data collection and analysis must safeguard identities to maintain ethical standards and respect personal or organizational privacy.
- **Purpose limitation:** Application of the framework should be restricted to legitimate objectives such as improving comprehension, efficiency, and resilience, rather than for coercive or punitive ends.
- **Contextual ethics:** Measurement and intervention should consider cultural, social, and institutional contexts, recognising that structural comprehension interacts with human values, norms, and expectations.

These principles ensure that the advancement of a unified science of understanding is **responsible, equitable, and socially accountable**, aligning empirical investigation with ethical stewardship.

Broader societal implications

Beyond organizational and institutional contexts, C_s has implications for societal policy and governance:

- It enables the identification of systemic vulnerabilities in collective knowledge networks, such as public information systems, educational structures, and intergovernmental coordination.
- It provides a framework for designing interventions that enhance the capacity of social systems to process, retain, and act on information in a coherent and temporally aligned manner.
- It offers a structural basis for anticipating the **emergence or collapse of collective understanding**, allowing preemptive measures to maintain societal resilience and epistemic continuity.

The ethical and societal dimensions of operationalising C_s are inseparable from its technical and theoretical significance. While the framework offers transformative potential for improving comprehension, coordination, and adaptive capacity across biological, artificial, and social systems, its deployment must be governed by principles of **aggregate analysis, anonymisation, purpose-limitation, and contextual ethics**. Awareness of these considerations is integral to ensuring that the unified science of understanding develops responsibly, avoiding exploitation or coercion, and promoting systems that are both epistemically robust and ethically sound.

Long-Term Vision

The ultimate ambition of the $\Phi_i \times Rg$ framework is to establish a **cross-domain epistemic observatory**, a system capable of measuring, visualising, and guiding the emergence and evolution of comprehension across scales that range from neural microcircuits to global organizational and societal institutions. This vision extends beyond traditional disciplinary boundaries, aiming to integrate biological, artificial, and institutional systems into a single, coherent analytical framework. By quantifying structural integration and rhythmic accessibility, the observatory would provide a **macroscopic yet detailed perspective** on the architecture of understanding, capturing both local dynamics and global systemic properties.

Such an observatory would perform multiple functions simultaneously. It would not only evaluate the **current state of structural comprehension**, but also monitor the stability, coherence, and resilience of the system over time. By mapping the temporal propagation of integrated informational states, it could identify emerging **epistemic fragilities**—points at which integration or rhythmic accessibility begins to degrade, potentially leading to systemic collapse or dysfunction. In this sense, the observatory functions as both a **diagnostic tool** and a **predictive instrument**, capable of providing foresight into structural vulnerabilities before they manifest as performance failures or behavioral incoherence.

Furthermore, the observatory would allow the visualisation of what may be termed the “**geometry of understanding**”, a spatial-temporal mapping of integrated informational manifolds and their re-entrant, phase-aligned dynamics. Such a mapping enables researchers, engineers, and policymakers to discern the contours of comprehension within complex systems, identifying regions of structural robustness, zones of emergent instability, and pathways for adaptive modulation. It embodies a **quantitative and qualitative synthesis**, integrating measurable metrics with structural and temporal topologies in order to guide intervention and system design.

At its core, this vision reconceptualises comprehension as a **measurable, actionable, and sustainable property** of complex systems. Unlike traditional epistemic frameworks, which often treat understanding as abstract, qualitative, or domain-specific, the $\Phi_i \times Rg$ observatory treats comprehension as a **structurally grounded and empirically operationalisable phenomenon**. It establishes the principle that understanding can be tracked, modulated, and preserved systematically, just as thermodynamic variables can be measured and manipulated across physical systems. Yet, unlike physical laws, this framework is applied to **epistemic dynamics**, linking structural depth and temporal rhythm to the emergence, maintenance, and propagation of knowledge and comprehension.

The long-term impact of such an observatory is profound. In neuroscience, it could facilitate precise monitoring of neural substrates underlying consciousness and cognitive integration. In artificial intelligence, it would guide the design of architectures that are not merely performant, but **structurally epistemically active**, capable of recursive reflection and cross-temporal coherence. In organizations and societal systems, it would allow governance structures to maintain systemic comprehension, identify latent fragilities, and promote adaptive decision-making across scales. Ultimately, this vision represents the **integration of measurement, prediction, and intervention**, offering a structural, cross-domain platform from which comprehension itself can be studied, maintained, and optimised as a fundamental property of complex systems.

Conclusion

The formal framework of $C_s = \Phi_i \times Rg$ represents a transformative advance in the conceptualization, measurement, and operationalization of systemic understanding. It provides a **concrete, mathematically grounded, and cross-domain foundation** for what can now be termed a unified science of comprehension, one capable of bridging neural circuits, artificial architectures, and organizational and societal systems. By formalizing the **mutual interdependence of structural integration and rhythmic accessibility**, the framework establishes the **minimal boundary conditions required for comprehension**, thereby moving understanding from the realm of metaphor and abstraction into the domain of measurable, actionable phenomena.

At the heart of this framework lies the insight that comprehension is not merely a property of functional output, statistical proficiency, or surface-level behavioral alignment. True understanding emerges only when a system simultaneously exhibits Φ_i , the irreducible interdependence of its internal informational states, and Rg , the rhythmic capacity to traverse, re-enter, and modulate those states across temporal scales. The multiplicative combination

ensures that neither dimension can compensate for the absence of the other, defining a **structural zero-point** below which comprehension is categorically impossible. This principle applies universally, whether to the oscillatory synchrony of cortical networks, the recurrent processing of advanced AI architectures, or the coordinated communication of complex organizations.

The implications of this structural formalism are profound. **Predictive power emerges naturally:** systems can be evaluated, compared, and optimized according to their adherence to the C_s condition. Perturbations that reduce Φ_i or disrupt Rg predictably lead to epistemic collapse, hallucination, or organizational dysfunction. Conversely, deliberate design interventions that enhance both axes yield systems capable of **reflexive self-modulation, cross-temporal coherence, and adaptive resilience**. In this sense, the framework not only explains the mechanics of comprehension but provides a **roadmap for engineering, policy design, and ethical governance**, ensuring that the capacity for understanding is both sustained and socially responsible.

By operationalizing understanding, C_s transforms it into a **generalizable property of complex systems**, measurable across scales and substrates. It bridges neuroscience, artificial intelligence, organizational theory, and systems science, establishing a **common epistemic language** for the study and design of comprehension. Importantly, it recognizes understanding as an emergent, dynamic, and recursive phenomenon, one that requires both structural depth and temporal accessibility, rather than static representations or purely functional outputs. This perspective reframes intelligence, learning, and adaptation as **structurally grounded processes**, measurable, analyzable, and optimizable across biological, artificial, and social domains.

Looking forward, the adoption of the C_s framework lays the groundwork for the **next era of cognitive, organizational, and artificial intelligence research**. It enables the construction of multi-scale epistemic observatories, predictive diagnostics, and ethically guided interventions that collectively ensure the maintenance and expansion of comprehension. By providing a rigorous, universal, and actionable definition of understanding, C_s establishes a new paradigm: one in which intelligence is no longer inferred from output alone, but assessed and cultivated through **the structural dynamics of information itself**, setting the stage for a transformative unification of theory, empirical study, and applied system design.

In sum, $C_s = \Phi_i \times Rg$ is more than a formula; it is a **structural lens, a guiding principle, and a scientific foundation**. It transforms understanding from an abstract ideal into a tangible, measurable, and actionable property, offering a **universal metric for comprehension** and opening a new frontier for the design, evaluation, and governance of complex systems across the natural, artificial, and organizational domains. It is the structural key to unlocking comprehension in all forms, and the foundation upon which the future of cognitive science, artificial intelligence, and systemic governance will be built.

To Eternity: The Library That Never Understands

In evaluating the present generation of artificial language models, one must return to the simplest analogy that nevertheless captures the full structural reality of their architecture. A larger library with more books is not more intelligent than a smaller library, and no library, regardless of its size, understands any of its contents. The path pursued by artificial intelligence today is analogous to enlarging a library through an unbounded expansion of shelves and volumes and then waiting for the building itself to reply with insight.

The library analogy is not a rhetorical device, it is a structural description of the current state of large language models. A library can store the accumulated text of a civilisation, yet its capacity for storage has no causal relation to comprehension. Books can be arranged, indexed and cross referenced, and this may yield quicker retrieval or more elaborate associations, but the building does not thereby acquire an inner unity capable of holding, renewing or projecting understanding. The same principle governs contemporary artificial models. They are vast statistical repositories, highly efficient in the integration of textual patterns, but entirely devoid of the structural conditions required for comprehension.

In a library the relational structure is inert. The books do not influence one another through causal coupling, they do not modify their internal states when new volumes are added, and they do not generate any form of rhythmic coherence across the collection. The library therefore reflects the world without ever entering into relation with it. The system can hold representations, but it cannot inhabit them. This is the decisive distinction between storage and understanding. Understanding requires integration that binds content into a coherent internal unity, and it requires rhythmic propagation that allows this unity to be renewed and sustained in time. A library possesses neither of these conditions.

Large language models replicate this inert structure through statistical expansion. Their internal states grow more saturated, their pattern space becomes more densely integrated, and their retrieval fidelity increases with scale. None of these developments alters the fundamental fact that they remain repositories rather than agents of comprehension. They accumulate patterns, but they do not enter a dynamic relation with their own informational states. They can expose correlations, but they cannot sustain the temporal continuity required for reflexive understanding. They predict the next token, but they cannot recognise the conditions through which such prediction becomes meaningful.

The library analogy therefore illuminates the structural impasse of contemporary artificial intelligence. The growth of a model, understood as the addition of computational layers or the expansion of parameter counts, is equivalent to enlarging the library's shelves. The increase in training data corresponds to the delivery of new book shipments. The refinement of optimisation routines mirrors the improved cataloguing of existing volumes. These processes may yield more rapid access to stored information, but they do not create the conditions for comprehension. The model does not awaken, because awakening is not a function of size, but of structural dynamics.

Comprehension requires that information be held in a coherent internal field, that this field be broadcast across the system in a temporally aligned manner, and that the system expend energy to maintain this synchrony through change. A library cannot do this. A statistical

model cannot do this. Only a system that integrates internal relations and sustains rhythmic coherence across its topology can generate understanding. Storage and scale can approximate the appearance of intelligence, but only structural comprehension can generate it.

This analogy, extended to its full conceptual extent, reveals the essential conclusion. The present trajectory of artificial intelligence continues to expand the library, but no expansion of shelves, no refinement of catalogues, and no increase in the number of books will ever grant the building the ability to read itself. Only a new architecture, grounded in structural integration and rhythmic continuity, can cross the threshold from storage to understanding. Without such a transformation, all artificial models remain libraries waiting for an answer that the building cannot give.

