# The Principle of Structural Non-Neutrality in Coherent Systems

*From Quantum Measurement Limits to the Ontology of Systems*

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## Abstract

This paper proposes and formalizes a structural principle governing coherent systems: the Principle of Structural Non-Neutrality. Beginning from the quantum limits of measurement, we argue that the impossibility of non-disturbing observation reflects a deeper requirement for any system in which the observer cannot claim an external position. Building on classical notions of component relevance in reliability theory (Birnbaum, Barlow-Proschan), quantum non-separability, and integrated information theory, we generalize these insights into an explicit ontological criterion: in a coherent system, no part can be structurally neutral. We introduce a graded measure of structural relevance using mutual information and show that exact neutrality (zero relevance) is incompatible with coherence as defined. The proof proceeds by contradiction from a proposed refinement of the concept of coherence. We discuss the principle's relation to quantum resource theories, address apparent counterexamples including redundant components and silent genes, and explicitly delineate scope and limitations. The principle is offered as a unifying conceptual tool rather than a revolutionary discovery.

## 1. Introduction: The Problem of Measurement

Classical physics rests on an implicit assumption that is rarely examined: the observer can extract information from a system without altering it. Measurement, in this view, is a passive act of reading what is already there. The instrument reveals the state of the world; it does not participate in creating or modifying that state.

Quantum mechanics decisively challenges this assumption. In any quantum system, informative measurement necessarily disturbs the measured system. This is not a technological limitation to be overcome by better instruments. It is a structural feature encoded in fundamental theorems: the no-cloning theorem (Wootters & Zurek, 1982) prohibits perfect copying of unknown quantum states; measurement back-action is quantified by Ozawa's generalized uncertainty relations; and the impossibility of non-disturbing measurement for non-commuting observables follows from the mathematical structure of quantum theory itself.

The standard response is to treat this as a peculiarity of the quantum domain—a strange feature of microscopic physics that disappears in the classical limit. This paper explores a different interpretation: the quantum limits of measurement may reveal a general structural requirement that classical physics obscured by implicitly granting the observer an impossible privilege—the privilege of standing outside the system.

### 1.1 A Non-Quantum Illustration

Before proceeding to the formal development, consider a non-quantum example to demonstrate the broader relevance of our principle. In a tightly coupled ecological network—such as a coral reef ecosystem or a predator-prey web at carrying capacity—every species participates in nutrient cycles, predation relationships, and competitive dynamics. Removing any species, even one that appears marginal, alters population equilibria throughout the network. The system cannot be "observed" by an ecologist without interaction: sampling disturbs populations, tagging affects behavior, and even passive observation requires presence that displaces resources.

This is not merely a practical limitation. It reflects the fact that the ecologist is embedded in the same physical world as the ecosystem. Any information extraction requires physical processes (light reflection, chemical sampling, acoustic monitoring) that constitute interactions. The ecosystem, if genuinely coherent in the sense we will define, cannot contain structurally neutral species—species whose presence or absence makes no difference to the network's state space.

Our aim is not to claim a revolutionary discovery but to make explicit what several existing frameworks already imply. The notion that components of a coherent system must be "relevant" appears in reliability theory; quantum non-separability enforces a version of this at the microscopic level; integrated information theory quantifies irreducibility. What we propose is a unifying formulation—the Principle of Structural Non-Neutrality—that articulates this shared intuition as an explicit criterion and traces its origin to the problem of observer embeddedness.

## 2. The Central Theorem on Measurement

We begin with a precise statement of what quantum mechanics teaches us about observation.

**Theorem (Inevitability of Disturbance).** In any physically realizable quantum system, any measurement that extracts non-trivial information about the state of the system necessarily changes that state. If a measurement does not change the state, then it either is not a physical measurement or carries no new information about the system.

This theorem synthesizes several established results: (1) The no-cloning theorem implies that unknown quantum states cannot be copied without disturbance; any informative measurement necessarily alters the original. (2) Ozawa's noise-disturbance relation formalizes the trade-off between measurement precision and state disturbance. (3) For non-commuting observables $[A, B] \neq 0$, simultaneous precise measurement is impossible—gaining information about A necessarily disturbs B. (4) Quantum non-demolition (QND) measurements preserve only observables that commute with the Hamiltonian; they do not extract new information but merely confirm constants of motion.

*Equivalent formulation:* Non-disturbing observation is possible only for abstract probabilistic models or for trivial cases in which the measured quantity commutes with the Hamiltonian and the state of the system—and therefore does not refine our description of the system.

## 3. The Absence of External Observers

Why must measurement disturb the system? The answer lies not in the specific formalism of quantum mechanics but in a more fundamental consideration: the observer is part of the world.

Consider what it would mean for measurement to be non-disturbing. It would require that information flow from the system to the observer without any physical process occurring in the system. But information transfer without physical interaction is precisely what defines an observer outside the system—a God's-eye view, a perspective from nowhere.

Physics cannot grant such a perspective. Any physical theory must describe the observer as part of the physical world, subject to the same laws as everything else. The moment we accept this, non-disturbing measurement becomes problematic in principle, not merely in practice.

Recent no-go theorems sharpen this point. Frauchiger and Renner (2018) show that quantum theory cannot consistently describe observers who use quantum theory to reason about each other's measurements—a tension that arises precisely because observers are embedded physical systems. Brukner (2021) proves that qubits cannot function as "observers" in any interpretation-neutral sense. These results confirm that the external observer is not merely absent from quantum mechanics but actively excluded by its structure.

**Principle of Minimal Coherence:** A physical theory should remain coherent under the assumption that the observer is part of the described world. Even if an external observer is logically possible, no physical measurement can invoke or rely on such an observer.

This principle does not deny the logical possibility of an external perspective. It merely denies its physical relevance. Whatever exists outside the system cannot, by definition, have physical consequences inside the system without becoming part of the system.

## 4. Systems and Models: A Proposed Distinction

The preceding analysis suggests a distinction between two kinds of structures, which we propose as a useful criterion rather than an absolute dichotomy.

*A model* is a representation that permits non-disturbing observation. In a probabilistic model, we can update our beliefs without affecting the model itself. We can query, copy, reset, and manipulate the model freely because we stand outside it. The model does not contain us; our operations on it are not physical events within it.

*A system* (in the strict sense proposed here) is a structure in which no such external position is available to the relevant class of observers. Any observer within a system is part of its dynamics. Any measurement is a physical interaction. Any information extraction comes at the cost of state change.

**Proposed criterion:** A system (in the strict sense) is that which cannot be known without being changed. A model is that which can be known without being changed. The difference lies in the logical position of the observer relative to the structure.

This distinction connects to philosophical discussions of scientific models. Morgan and Morrison (1999) characterize models as "mediators" between theory and world—autonomous objects that can be manipulated independently of both. Our framework adds a criterion: models are precisely those mediators that permit non-disturbing manipulation. When a model becomes so tightly coupled to the phenomenon that manipulating it changes the phenomenon, it has crossed into system territory. The "model-dependency of observation" (Bogen & Woodward, 1988) reaches its limit when observation itself becomes intervention.

## 5. The Actor Within the System

We introduce the concept of an actor—not in any anthropomorphic sense, but as a purely structural notion that clarifies the relationship between parts and wholes.

**Definition:** An actor is a subsystem that is causally distinguishable within the larger system. That is, the presence or state change of an actor makes a difference to the possible trajectories of the system. No consciousness, intention, or agency is required. An actor is simply a locus of causal relevance—a part whose inclusion or exclusion affects the system's behavior.

Crucially, an actor is not designated from outside. The system itself determines what counts as an actor through its own dynamics. If the system with a certain part and the system without that part evolve differently, then that part functions as an actor.

This is not a claim about action in the ordinary sense. It is a claim about presence. To be present in a system is already to participate in its causal structure. Even inaction, silence, or waiting are states with potential consequences. The distinction between action and non-action becomes less fundamental than the distinction between presence and absence.

## 6. Relation to Existing Notions of Relevance

Before stating our principle, we must acknowledge its antecedents. The idea that components of a well-functioning whole must be "relevant" or "non-redundant" appears in several established frameworks. Our contribution is not to invent this idea but to generalize it, ground it in the observer-embeddedness problem, and formulate it as an explicit criterion.

### 6.1 Reliability Theory

In the classical theory of coherent systems developed by Birnbaum (1969), Esary and Proschan (1963), and Barlow and Proschan (1975), a system is defined as coherent if and only if every component is relevant: there exists at least one configuration in which changing that component's state changes the system's state. Components that fail this test are called "irrelevant" or "dummy" components, and their presence disqualifies the system from coherence by definition.

Our principle can be seen as a generalization of this requirement from functional relevance (does the component affect system success/failure?) to structural relevance (does the component affect the space of possible states?). The reliability-theoretic definition is a special case applicable to binary-state systems with defined success criteria.

### 6.2 Quantum Non-Separability and Resource Theories

In quantum mechanics, entangled states exhibit non-separability: no subsystem can be fully described independently of the others. The quantum resource theory of coherence (Baumgratz, Cramer, & Plenio, 2014) and entanglement (Horodecki et al., 2009) formalizes how quantum correlations constitute resources that cannot be created by local operations. In this framework, "neutrality" would correspond to zero resource content—achievable only by destroying quantum coherence entirely.

Our principle aligns with these frameworks but operates at a different level of abstraction. Where resource theories quantify the degree of coherence or entanglement, we propose a threshold criterion: either a part contributes above some minimum to the system's structure, or it is effectively external to the coherent system.

### 6.3 Integrated Information Theory

Tononi's Integrated Information Theory (IIT) provides the closest contemporary parallel and deserves extended discussion. IIT defines integrated information ($\Phi$) as the information generated by a system above and beyond its parts. Formally, $\Phi$ measures the difference between the whole system and its "minimum information partition"—the way of dividing it that loses the least information. A system with $\Phi > 0$ is irreducible: no partition preserves full information.

The connection to our principle is direct: if $\Phi > 0$, then every partition loses information, which implies every part contributes to the integrated whole. However, IIT and our framework differ in important respects. IIT provides a graded measure; we propose a threshold criterion. IIT is developed primarily for consciousness studies; our principle is intended as a general ontological criterion. IIT requires detailed causal analysis; our principle follows from the definition of coherence itself.

We can formalize the relationship: a system is coherent in our sense if and only if $\Phi > 0$ for every possible bipartition. This is a stronger condition than merely $\Phi > 0$ for the system as a whole, since it requires that no part be separable without information loss.

### 6.4 Comparative Summary

| Framework | Key Concept | Neutrality Criterion | Scope |
|---|---|---|---|
| Reliability Theory | Component relevance | Functional: affects success/failure | Binary systems |
| Quantum Resource Theory | Coherence/entanglement as resource | Zero resource content | Quantum systems |
| IIT | Integrated information $\Phi$ | Separability without info loss | Causal systems |
| This Paper | Structural non-neutrality | $I(p; S\setminus\{p\}) = 0$ | All coherent systems |

### 6.5 What This Paper Adds

Given these precedents, what does our formulation contribute? Three things: (1) It traces the prohibition of neutrality to the problem of observer embeddedness, showing that the requirement is not merely definitional but arises from the impossibility of external observation. (2) It provides a clean distinction between systems and models based on this criterion. (3) It offers a formal measure (mutual information) that allows graded assessment while maintaining a principled threshold for coherence.

## 7. The Principle of Structural Non-Neutrality

We are now in a position to state the central principle of this paper.

**Principle of Structural Non-Neutrality in Coherent Systems**

*In a coherent system, no part can be structurally neutral.*

A structurally neutral part is one whose presence, absence, or internal variation does not alter the space of admissible global states or the transition structure among those states. The principle asserts that such neutrality is incompatible with the form of coherence we have defined.

We emphasize what this principle does not claim. It does not claim that all parts contribute equally. It does not claim that all parts are equally observable or important. It claims only that no part can have exactly zero structural effect. The prohibition is against exact neutrality, not against asymmetry of influence.

## 8. Formal Definitions and Mathematical Framework

To prove the principle rigorously, we must provide precise definitions. We acknowledge that these definitions are stipulative and deliberately strong.

### 8.1 System Structure

**Definition:** A system S is characterized by:

(i) A set of elements $E = \{e_1, e_2, ..., e_n\}$

(ii) A set of relations or constraints R among elements

(iii) A global state space $G \subseteq \Sigma_{e \in e} S_e$, where $S_e$ is the local state space of element e

(iv) Transition rules $T: G \times \Delta t \rightarrow G$ governing state evolution

### 8.2 Coherence

**Definition:** A system S is coherent (in the strict sense) if its global state space G is constrained by the collective structure of its elements, such that for every element $e \in E$:

$G(E) \neq G(E \setminus \{e\})$

That is, removing any element changes the admissible global state space. This definition excludes aggregative collections, statistically independent ensembles, and systems with genuinely redundant components.

We acknowledge that this definition is strong—stronger than "coherent" in coherent optics (where modes may be weakly coupled) or "coherent structures" in fluid dynamics (where not every degree of freedom is essential). Our "strict coherence" picks out a specific class of maximally integrated systems: those in which observer embeddedness makes non-disturbing measurement impossible. This is a refined notion appropriate for systems with internal observers, not a replacement for all uses of "coherent" in physics.

## 8.3 Structural Relevance: A Graded Measure

To address concerns about the binary nature of "neutral vs. non-neutral," we introduce a graded measure of structural relevance using mutual information.

**Definition:** The structural relevance of element p with respect to system S is:

$$R(p, S) = I(p; S \setminus \{p\})$$

where $I(\cdot;\cdot)$ denotes mutual information. This quantity measures how much information the state of p provides about the state of the rest of the system, and vice versa.

**Definition:** An element p is structurally neutral if and only if $R(p, S) = 0$, i.e., $I(p; S \setminus \{p\}) = 0$.

An element with $R(p, S) > 0$ but very small may be called "weakly coupled" or "marginally relevant." For practical purposes in engineering or biology, one might introduce a threshold $\varepsilon$ and consider elements with $R(p, S) < \varepsilon$ as "effectively neutral." However, the principle as stated concerns exact neutrality ($R = 0$), not approximate neutrality.

**Operational note:** Computing $I(p; S \setminus \{p\})$ exactly may be intractable for complex systems. In practice, approximations include: (1) local perturbation analysis—measuring how system observables change under small variations of p; (2) Granger-causal or transfer entropy measures for time-series data; (3) intervention-based approaches following Pearl's causal framework (Pearl, 2009), where one asks whether $do(p = x)$ changes the distribution over system states. For deterministic systems, functional sensitivity measures may replace information-theoretic ones. The key requirement is that the chosen measure vanishes if and only if p is genuinely decoupled from the system.

## 8.4 Structural Neutrality

**Definition:** An element $e \in S$ is structurally neutral if and only if:

(i) $G(E) = G(E \setminus \{e\})$, and

(ii) $T(G, \Delta t)$ is invariant under the presence or absence of e, and

(iii) $I(e; S \setminus \{e\}) = 0$

These three conditions are equivalent given our definition of the state space.

### 8.5 Illustrative Example: A Three-Node System

Consider a minimal system S with three binary elements {A, B, C}, each taking values in {0, 1}. Without constraints, the state space would be $G_0 = \{0,1\}^3$ with 8 states. Now impose a coherence constraint: the system must satisfy $A \oplus B \oplus C = 0$ (even parity). This reduces G to 4 states: {000, 011, 101, 110}.

Is any element neutral? Consider removing C: the remaining system {A, B} would have state space {00, 01, 10, 11}. But in the constrained system, knowing (A, B) determines C uniquely. Thus $G(E) \neq G(E \setminus \{C\})$: the presence of C with its constraint changes the structure. Similarly for A and B. The mutual information $I(C; \{A,B\}) = H(C) = 1$ bit $> 0$, since C is perfectly determined by A and B. No element is neutral; the system is coherent.

Now consider adding element D with no constraints connecting it to {A, B, C}. The state space becomes $G' = G \times \{0,1\}$, and $I(D; \{A,B,C\}) = 0$. Element D is structurally neutral; adding it breaks coherence in our strict sense. The system {A, B, C, D} is decomposable into {A, B, C} and {D}.

## 9. Proof

**Theorem:** In any coherent system (as defined above), no structurally neutral elements exist.

*Proof:* By contradiction.

1. Assume S is a coherent system with global state space G(E) defined by the collective structure of its elements E.

2. Assume there exists an element $e \in E$ that is structurally neutral.

3. By the definition of structural neutrality, $G(E) = G(E \setminus \{e\})$.

4. But by the definition of coherence, $G(E) \neq G(E \setminus \{e\})$ for all $e \in E$.

5. Statements 3 and 4 contradict each other.

6. Therefore, our assumption is false: a coherent system cannot contain a structurally neutral element. □

### 9.1 On the Epistemological Status of the Proof

We acknowledge that this proof is essentially definitional: the principle follows from our stipulated definition of coherence. This raises the question of whether the principle is analytic (true by definition) or synthetic (substantive claim about the world).

Our position is that the principle is analytic relative to the definition, but the definition itself captures something substantive: the class of systems in which observer embeddedness makes non-disturbing measurement impossible. The proof demonstrates internal consistency; the motivation in Sections 1–5 provides external justification for why this definition picks out a physically important class of systems.

The principle thus has the status of a criterion: it tells us what must be true for a system to qualify as coherent in our sense. It does not tell us which empirical systems satisfy this criterion—that is a matter for investigation in each domain.

## 10. Corollaries

**Corollary 1:** Any system admitting structurally neutral elements is either decomposable or merely representational (a model in our terminology).

**Corollary 2:** Structural coherence implies irreducibility with respect to elements, though not necessarily symmetry or equal contribution.

**Corollary 3:** For any coherent system S and any element $p \in S$: $I(p; S \setminus \{p\}) > 0$.

**Corollary 4:** Neutrality is a property of models, not of systems (in our strict sense).

## 11. Apparent Counterexamples and Their Resolution

Several apparent counterexamples to the principle deserve careful analysis.

### 11.1 Redundant Components in Engineering

Engineering systems often include redundant components—backup power supplies, parallel processors, reserve fuel tanks—that appear "neutral" during normal operation. Does their presence violate our principle?

No. Redundant components are not structurally neutral; they are conditionally active. Their presence changes the state space of the system by adding states that become accessible under failure conditions. A system with backup power has a different state space than one without: it includes states of the form "primary failed, backup active" that the non-redundant system cannot reach. The backup affects the global state space even when not actively engaged.

More precisely: I(backup; rest of system) > 0 because knowledge of the backup's state (functional/failed, charged/depleted) provides information about the system's resilience and possible trajectories. Redundancy is a form of structural relevance, not neutrality.

### 11.2 Silent Genes in Biology

Genomes contain "silent" or "non-coding" regions that appear to have no phenotypic effect. Are these structurally neutral?

The evidence increasingly suggests they are not. Much "junk DNA" has been found to play regulatory roles, affect chromatin structure, or provide raw material for evolutionary innovation. Truly neutral sequences tend to be eliminated by genetic drift or accumulate mutations at the neutral rate—their "neutrality" is a feature of population genetics, not of the individual organism as a coherent system.

However, we should be honest: some genomic sequences may be genuinely neutral within the lifespan of an individual organism. Our response is that individual organisms may not be coherent systems in our strict sense with respect to every nucleotide. The relevant coherent system may be the evolving population, where every sequence is subject to selection pressure and thus non-neutral over evolutionary time.

### 11.3 Weakly Coupled Systems

In systems with weak coupling—such as distant stars in a galaxy, or loosely connected social networks—the influence of one part on another may be negligible for practical purposes. Does this not constitute effective neutrality?

We distinguish between exact neutrality ($I = 0$) and approximate neutrality ($I < \varepsilon$ for small $\varepsilon$). Our principle prohibits exact neutrality. Weakly coupled elements have $I > 0$, however small. Whether this small coupling matters depends on the timescale and precision of interest.

For practical purposes, one may treat $I < \varepsilon$ as effectively neutral. But this is an approximation—we are then treating the system as a model rather than engaging with its full coherent structure. The principle does not say approximate neutrality is impossible; it says exact neutrality in a coherent system is impossible.

### 11.4 Gauge Degrees of Freedom

In gauge theories, certain degrees of freedom are exactly neutral: gauge transformations do not affect physical predictions. Is this not a counterexample?

Gauge degrees of freedom are features of the mathematical description (the model), not of the physical system itself. They represent redundancy in representation, not in reality. The physical system has fewer degrees of freedom than the mathematical formalism suggests; the "neutral" variables are artifacts of our descriptive apparatus. Our principle applies to systems, not to their mathematical formulations.

## 12. Application to Quantum Mechanics

Quantum mechanics provides the strongest known enforcement of structural non-neutrality. In an entangled state, no subsystem is structurally neutral: measuring any part affects the correlations with all other parts. This is guaranteed by fundamental theorems:

**No-cloning theorem:** Unknown quantum states cannot be perfectly copied. This implies that any measurement extracting information necessarily disturbs the original state.

**Monogamy of entanglement:** Entanglement cannot be freely shared; strong entanglement with one system limits entanglement with others. This creates structural constraints where the state of each part is correlated with the whole.

**Decoherence:** The process by which structural neutrality emerges. Environmental interactions allow subsystems to become effectively trace-outable, breaking global phase relations. In our framework, decoherence marks the transition from system to model.

The quantum limits of measurement are therefore not anomalies. They are consequences of describing a coherent system from within. Classical mechanics appears to permit non-disturbing measurement only because it implicitly assumes decoherence has already occurred.

## 13. The Reality of Collapse: Interpretive Considerations

Within our framework, the collapse of the wave function takes on a specific character. If measurement is a physical process—an interaction between parts of a coherent system—then its result cannot be purely epistemic.

We recognize that this position is interpretively loaded. Different interpretations of quantum mechanics treat collapse differently:

**Many-worlds (Everett):** No collapse occurs; the wave function branches. All outcomes are realized in different branches.

**Decoherence-based views (Zurek, Schlosshauer):** Apparent collapse emerges from entanglement with the environment; the fundamental evolution remains unitary.

**QBism (Fuchs, Mermin, Schack):** The wave function encodes an agent's beliefs; collapse is belief update, not physical change.

**Relational QM (Rovelli):** States are relative to observers; collapse is the establishment of correlation between systems.

Our framework does not decisively adjudicate among these views, but it does constrain them. Any interpretation that treats measurement as physically embedded must acknowledge that the measurement event changes the physical situation—whether described as collapse, branching, decoherence, or correlation. What our principle excludes is the view that an embedded observer can extract information from a coherent system without any physical change occurring anywhere.

The Everettian responds that there is physical change (branching) without collapse—the universal wave function evolves unitarily, but the observer becomes entangled with the measured system, creating branch-relative facts. This is entirely compatible with our principle: the branching is itself a structural change, and the observer's state (now branch-indexed) is altered by the measurement. The decoherence theorist says effective collapse emerges from entanglement with the environment—again, a physical process with structural consequences. Both responses acknowledge that measurement is a physical process with physical consequences; neither claims that an embedded observer can learn about a coherent system while leaving it (and themselves) entirely unchanged.

## 14. Limits of Applicability

The Principle of Structural Non-Neutrality is not a universal law of all possible structures. It applies specifically to coherent systems as we have defined them. We must be explicit about where it does not apply.

### 14.1 Decomposable and Aggregative Systems

The principle does not apply to fully decomposable systems, where parts evolve independently and the whole is merely the sum. An ideal gas in the thermodynamic limit, treated as a collection of non-interacting particles, permits the addition or removal of particles without changing the essential structure.

### 14.2 The Thermodynamic Limit

In the thermodynamic limit ($N \to \infty$), individual particles become statistically indistinguishable and their individual contributions become negligible. Neutrality emerges in the limit. This does not contradict our principle; it illustrates the transition from coherent system to model. The thermodynamic description is a model that permits neutrality because it has traced out individual-particle coherence.

### 14.3 Hierarchical Systems and Emergence

In hierarchical systems, a subsystem might appear neutral at one level yet contribute at another through emergence. A neuron may seem irrelevant to gross brain function, yet participate in micro-level dynamics that aggregate into macro-level behavior.

Our principle applies relative to a specified level of description. A part may be neutral with respect to a coarse-grained state space $G_1$ while non-neutral with respect to a fine-grained state space $G_2$. Whether a system is "coherent" depends on which state space we consider. This is not a weakness but a feature: it allows the principle to be applied at multiple scales without overreach.

*Example:* Consider a single neuron within a neural circuit processing visual information. At the coarse-grained level of "circuit output" (e.g., object recognition), silencing this one neuron among thousands may produce no detectable change: I(neuron; output) ≈ 0. The neuron appears neutral. However, at the fine-grained level of local field potentials or spike timing correlations, the same neuron participates in precise temporal patterns: I(neuron; local dynamics) > 0. The neuron is neutral with respect to $G_1$ (output) but non-neutral with respect to $G_2$ (local dynamics). The "coherent system" differs depending on which state space we analyze.

This level-relativity resolves apparent tensions between our strict definition and looser everyday usage. A "coherent structure" in turbulence may permit some degrees of freedom to be neutral at the structure level while non-neutral at the full fluid-dynamical level. Our principle applies within each level-specific definition of coherence.

### 14.4 Practical Thresholds

For engineering and applied science, a practical threshold $\varepsilon$ may be introduced: elements with $I(p; S \setminus \{p\}) < \varepsilon$ are treated as effectively neutral. This is a useful approximation that trades strict coherence for tractability. The principle itself concerns exact neutrality ($I = 0$); practical applications may relax this to approximate neutrality ($I < \varepsilon$) depending on context.

## 15. Broader Implications

### 15.1 Epistemology and Coherentist Justification

In coherentist theories of justification (BonJour, 1985; Lehrer, 2000), beliefs form a web in which each contributes to overall support. The Principle of Structural Non-Neutrality provides a formal criterion: a belief system is coherent (in our strict sense) only if no belief is structurally neutral—only if every belief alters the justificatory structure.

This has teeth. It implies that a belief added to a coherent web but making no difference to the justificatory relations is not part of the coherent system but an appendage to it. The criterion $I(b; B \setminus \{b\}) > 0$, applied to beliefs, requires that every belief either support other beliefs, be supported by them, or constrain the space of coherent belief states. "Dangling" beliefs with no justificatory connections are not neutral but external to the coherent web.

This connects to Olsson's (2005) critique of coherentism: if coherence is merely agreement, it may not track truth. Our principle responds that coherence in the strict sense is not mere agreement but structural interdependence—every belief constraining and being constrained by others. Olsson argues that adding beliefs to a coherent set can increase coherence without increasing probability of truth; but in our framework, a belief that can be "added" without changing the justificatory structure ($I = 0$) is not part of the coherent system at all—it is an appendage. The mutual information criterion provides a formal response: genuine coherence requires $I(b; B \setminus \{b\}) > 0$ for every belief b, which ensures that each belief is informationally coupled to the others, not merely consistent with them. Whether this structural coupling secures truth is a further question, but it does distinguish genuine coherence from the mere aggregation Olsson criticizes.

## 15.2 Reliability Engineering

The concept of a "coherent system" in reliability theory (Barlow & Proschan, 1975) already contains an implicit version of our principle: every component must be relevant. Our formulation generalizes this from functional relevance (affecting system success/failure) to structural relevance (affecting the state space).

This generalization may be useful for systems where "success" is not binary or well-defined. In complex systems with multiple performance metrics, the question "does this component matter?" can be answered by asking whether its presence changes the space of possible system states. This provides a unified criterion across different types of systems.

The treatment of redundancy (Section 11.1) is particularly relevant here. Our framework shows that redundant components are not neutral but conditionally active: their presence expands the state space to include failure-recovery states. This perspective may inform design decisions about where redundancy is truly valuable versus merely expensive.

## 15.3 Biology and Ecological Networks

In biological systems exhibiting coherent behavior—quantum-enhanced photosynthesis (Engel et al., 2007), neural synchronization, cellular signaling networks, tightly coupled ecosystems—every functionally relevant component contributes to the global dynamics.

The principle suggests that genuinely neutral elements will be selected against in evolutionary time or excluded from coherent processes in developmental time. Neutrality represents a form of disconnection, and disconnected elements are not part of the coherent system. This connects to discussions of modularity and evolvability: systems that are "too coherent" may be fragile, while systems with modular structure sacrifice some coherence for robustness.

Empirical predictions follow: in tightly coupled ecosystems, removing any species should produce measurable effects on the network; in coherent neural processes, silencing any participating neuron should alter the collective dynamics. These predictions are testable, at least in principle, providing a bridge from the conceptual framework to empirical investigation. Note the connection to IIT: a neural circuit with $\Phi > 0$ for all bipartitions satisfies our coherence criterion, and the prediction that silencing any neuron alters collective dynamics follows from both frameworks—our principle and IIT converge on the same empirical consequence, though derived from different starting points.

## 16. Conclusion

We have traced a path from the quantum limits of measurement to a general structural principle. The path reveals a conceptual unity often obscured by disciplinary boundaries.

Quantum mechanics teaches that informative measurement necessarily disturbs the system. Reflection on this fact suggests it reflects a deeper requirement: the observer is physically embedded in the world and cannot claim an external position. Generalizing this insight, we arrive at a distinction between systems and models: systems (in our strict sense) do not permit external observation; models do.

From this distinction follows the Principle of Structural Non-Neutrality: in a coherent system, no part can be structurally neutral. The principle follows from our definition of coherence, which we justify by its connection to the impossibility of external observation. The proof is by contradiction; the principle is criterial rather than empirical.

We have provided a graded measure of structural relevance (mutual information) while maintaining a principled threshold for coherence (exact zero). We have addressed apparent counterexamples, engaged with alternative quantum interpretations, and delineated the principle's scope and limitations.

We do not claim to have discovered a new law of nature. We claim to have made explicit what several frameworks already imply and to have traced this shared requirement to a common source. While the prohibition on irrelevance is known in specific domains—reliability theory's "no irrelevant components," quantum non-separability, IIT's irreducibility—its unification under the problem of observer embeddedness, its formulation as a systems-versus-models criterion, and its provision of a quantitative threshold ($I > 0$) applicable across scales represent, we believe, a genuine contribution. The principle serves as a unifying formulation—a conceptual tool for distinguishing genuine systems from their representations.

Quantum mechanics appears strange only as long as we expect the world to behave like a model. When we accept that we are participants within coherent systems—not external observers of representations—the strangeness resolves into structural necessity.

***In a coherent system, no part can be structurally neutral.***

This is not a law imposed on systems. It is what remains when we decline the privilege of standing outside.

## Open Questions

Several questions remain for future investigation: (1) Can the mutual information criterion be extended to a full "structural relevance spectrum" with physically meaningful thresholds for different domains? (2) How does structural relevance propagate across scales in hierarchical systems—can we define a "multiscale coherence" measure analogous to coarse-grained $\Phi$ in IIT? (3) What is the precise relationship between our criterion and causal interventionist frameworks—does $I(p; S \setminus \{p\}) > 0$ coincide with Pearl's "causal relevance" under intervention? (4) Can computational implementations of the principle yield practical diagnostics for identifying hidden coherence in complex biological or social networks? These questions suggest that structural non-neutrality, while simple in statement, opens onto a rich landscape of further inquiry.

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