Quantum Reality as Indra's Net: A Category-Theoretic Formalism for Relational Quantum Dynamics

Arash Zaghi[†]

Abstract

We propose a rigorous synthesis of the ancient Indra's Net metaphor with Relational Quantum Dynamics (RQD), casting quantum reality as a web of relationships formalized in category-theoretic and information-theoretic terms. Drawing on enriched category theory and measures like quantum mutual information and integrated information Φ, we develop a formal framework in which quantum systems (observers) and their states emerge only through relations – "jewels" reflecting one another. We define the mathematical structure of RQD as a category of relational contexts, proving that each quantum object is fully characterized by its morphisms (relations) to all others, in accordance with the Yoneda lemma. This theorem formally mirrors Indra's Net by showing that each part reflects the whole, with no observer-independent properties. We further enrich the category with information metrics, demonstrating how quantum mutual information quantifies the "reflections" (correlations) between nodes, and how the integrated information Φ of the whole exceeds the sum of parts. Key theorems establish the consistency of this relational ontology resolving Wigner's-friend-type paradoxes without requiring a global collapse and providing bounds on information integration in a fully interconnected "Indra's net" state. We explore applications of the framework to consciousness (modeling observer-awareness via Φ in a relational network), to artificial intelligence (multi-agent systems as Indra's net of information-sharing observers), and to quantum computing (entangled qubit networks as physical instantiations of Indra's net). This work unifies metaphysical insights with quantum foundations in a fully formal manner, suggesting that quantum mechanics, information, and consciousness coalesce into a single relational web.

Keywords: Quantum Foundations, Relational Quantum Dynamics (RQD), Integrated Information Theory (IIT), Relational Quantum Mechanics (RQM), Category Theory, Presheaf Theory, Yoneda Lemma, Indra's Net, Relational Ontology

1. Introduction

Indra's Net is a profound metaphor from Mahayana Buddhism describing reality as an infinite web of jewels, each gem reflecting all others in a vast, interdependent network [12, 3].

[0†] ORCID ID: 0000-0003-2246-2911, Email: `arash.esmaili_zaghi@uconn.edu`

In this picture, nothing exists in isolation and every part owes its existence and identity to its relationships with every other part. This *interpenetration* principle (also called emptiness or dependent-arising in Buddhist philosophy) provides a profound ontological view by suggesting that everything arises in mutual relation to everything else [16]. Such a holistic, relational worldview resonates strongly with certain modern interpretations of quantum mechanics. In particular, **Relational Quantum Mechanics (RQM)** posits that the state of a quantum system has no meaning except as a relation to another system (an observer) [18]. In Rovelli's formulation of RQM, there is no "view from nowhere" – what one observer perceives as a definite outcome may be a superposition to another, and quantum mechanics describes only the network of interactions among physical systems. This means physical quantities and events are *relativized to interactions*, and any notion of an absolute, observer-independent state is discarded [19]. The world, according to RQM, is "a net of interacting components" with no intrinsic properties for isolated subsystems [19]. This striking convergence of ancient wisdom and quantum physics invites a unified framework that can capture the *relational essence* of reality in both metaphysical and scientific terms.

Relational Quantum Dynamics (RQD) extends the relational paradigm by incorporating the role of information and the observer's consciousness into the fundamental description of quantum interactions [26, 27]. RQD argues that observers, observed systems, and even spacetime geometry *co-emerge* from an underlying quantum-interactive substrate [25]. In this view, there is no static background universe; instead, stable patterns of entanglement and information flow give rise to the appearance of space, time, and matter. Crucially, RQD emphasizes that no omniscient external perspective exists, **no "view from nowhere"**, to define absolute states. Facts are only defined relative to the network of interactions, and once an interaction between two systems occurs, their views become correlated without needing any global collapse or singular truth [25]. This relational ontology naturally aligns with Indra's Net: each observer–system is like a jewel whose properties are *reflections of others*, and there is no independent essence outside the all-encompassing web of relations. Indeed, RQD's idealist interpretations suggest that **universal awareness** (consciousness) might be the ontological ground of this relational web, so that quantum mechanics, gravity, and mind are integrated facets of one reality.

The goal of this paper is to develop a fully formalized framework that unites Indra's Net with RQD, providing mathematical rigor to these parallel ideas. We employ *category theory* as a foundational language to formalize relationships, using the Yoneda lemma to capture the idea that an object (a "jewel") is determined by its relations. The exploration of parallels between category theory and Buddhist philosophy has been a subject of interest. For instance, Tem Noon discusses how the Yoneda Lemma and the Jeweled Net of Indra both emphasize the relational essence of entities [12]. Similarly, Posina and Roy draw connections between Buddhist concepts like Śūnyatā (emptiness) and category-theoretic constructions, proposing that both frameworks highlight the interdependent nature of objects devoid of intrinsic properties [16]. In this work, We introduce an *enriched category* for quantum relations, wherein the morphisms carry information-theoretic weights, such as quantum mutual information I and integrated information Φ [22]. Within this framework, we show that Indra's Net is not just a metaphor but emerges as a precise structural property: **each quantum object/observer is the sum total of its interactions**. We prove key theorems

that (i) characterize quantum states as relational information structures (with no absolute state lurking in the background), (ii) quantify the "reflections" between objects using mutual information, and (iii) establish how the *integrated information* of the whole exceeds that of any decomposition, explaining formally why the whole Indra's net is greater than the sum of its parts. In doing so, we bridge philosophical implications (regarding holism and consciousness) with quantum mechanical foundations (observer-dependent state assignments and correlations).

The remainder of the paper is organized as follows. In *Mathematical Foundations*, we introduce the necessary category-theoretic definitions and information-theoretic measures that will allow a formal treatment of relational quantum dynamics. In *Theoretical Development*, we build the category-theoretic model of RQD, present the alignment of Indra's Net with quantum relationality, and state and prove the central theorems of the framework, Yoneda's lemma applied to physics, no-absolute-state principle, and information integration inequalities. In *Applications*, we explore implications of this framework for consciousness studies (drawing parallels to Integrated Information Theory and panpsychism), for artificial intelligence (interpreting AI agents as observers in a relational network), and for quantum computing (entangled networks and quantum reference frames). Finally, in *Discussion* and *Conclusion*, we reflect on the significance of this integrated viewpoint, its potential to resolve longstanding paradoxes and interdisciplinary gaps, and future directions for research at the nexus of quantum theory, information, and philosophy.

2. Mathematical Foundations

2.1. Category Theory and Relational Ontology

Categories and Relational Structures: We begin by recalling basic category theory to formalize the notion of a network of relations. A **category** $\mathcal{C}$ consists of a class of objects (denoted $\mathrm{Ob}(\mathcal{C})$) and for every pair of objects (A, B) a set $\mathrm{Hom}(A, B)$ of morphisms (or arrows) from A to B. These morphisms can be composed (if $f \in \mathrm{Hom}(A, B)$ and $g \in \mathrm{Hom}(B, C)$, then $g \circ f \in \mathrm{Hom}(A, C)$) and each object A has an identity morphism $\mathrm{id}_A \in \mathrm{Hom}(A, A)$. Composition is associative and identities act as neutrals. In category-theoretic thinking, an object is characterized entirely by its pattern of arrows to and from other objects. This aligns with C.S. Peirce's relational logic view [14], where "Relation is the primary irreducible datum and everything is expressed in terms of relations," and indeed category theory encapsulates this by treating relations as morphisms and focusing on their compositions [11]. The **Yoneda lemma**, a central result in category theory, formalizes this idea: it states that an object A is *completely determined* by the structure of $\mathrm{Hom}(A, -)$ (or $\mathrm{Hom}(-, A)$), i.e., by its relationships to all other objects [12]. Intuitively, "you are what your relationships say you are" [12]. We will leverage Yoneda's insight to assert that a quantum system, modeled as an object in our category of quantum relations, has no intrinsic state separate from its interactions; its identity is given by the collection of quantum exchanges (measurements, entanglements) it participates in.

Enriched Categories: In many applications, one needs morphisms that carry additional

structure beyond a mere set. An enriched category is a category whose Hom-sets are not just sets but elements of some monoidal category, which provides a notion of addition or combination. For example, metric spaces can be seen as categories enriched over $[0, \infty]$ (the monoid of nonnegative distances): the object A has "distance" to B given by a number $d(A, B) \in [0, \infty]$, composition corresponds to triangle inequality (distance composition) [17]. Enriched categories allow us to attach quantitative data to relationships. In our context, we will enrich the category of quantum systems with information-theoretic quantities, so that a morphism not only signifies that "system A interacts with system B" but also quantifies *how much information* is exchanged or shared in that relation. We will formalize an enriched category $\mathcal{R}$ (for "Relational") where objects are quantum systems/observers and a Hom-morphism $A \to B$ encapsulates **the state of B as described by** A or the event of A observing B, enriched with measures of correlation or information. Composition in this category will correspond to sequential interactions or inference: if A relates to B and B relates to C, then A relates (indirectly) to C through composition $A \to B \to C$. We will later see that information-theoretic constraints, such as the data-processing inequality, limit how large the $A \to C$ information can be relative to $A \to B$ and $B \to C$ individually, reflecting the intuitive fact that indirect observation is less informative than direct observation.

Bicategories and Higher Relations: In a simple category, a morphism $A \to B$ could be thought of as a one-directional observation or influence. However, quantum interactions are typically mutual. When A measures or interacts with B, not only does A gain information about B, but B's state (from A's perspective) is updated, and if B is itself an observer, it may acquire information about A. To model such *bidirectional* or *multi-agent* relationships, it is useful to extend to a **bicategory** or 2-category, where one can have 2-morphisms connecting different interaction paths. For instance, we may have $A \xrightarrow{f} B$ and $A \xrightarrow{g} B$ as two different interaction processes, e.g., two alternative measurement outcomes or two sequential interactions, and a 2-morphism $\alpha : f \Rightarrow g$ could represent a higher-level transformation or comparison between these processes. For example, B communicating its result to A, aligning A's two possible views of B. In this work, we primarily use an enriched 1-category for the core formalism, but we note that a bicategorical structure can capture **multi-observer consistency**: a 2-morphism can enforce that when A and B *both* observe each other, the two directions of information flow lead to an agreement (a mutual consistency condition akin to a round-trip of reflections yielding the same result). This higher-category extension will be relevant when we discuss how multiple observers reconcile their views in scenarios like Wigner's friend. For now, we build the framework at the 1-category level with enrichment, keeping in mind that symmetric mutual observations can be treated by having parallel morphisms $A \to B$ and $B \to A$, and possibly identifying them via additional structure if a symmetric interaction is assumed.

2.2. Information-Theoretic Measures

Quantum Mutual Information: To quantify the degree to which two systems "reflect" or share information (in Indra's Net terms, how brightly one jewel shines in the reflection of another), we use *quantum mutual information*. For a bipartite quantum state ρ_{AB}, the von Neumann entropy $S(\rho) = -\mathrm{Tr}(\rho \log_2 \rho)$ measures uncertainty (or missing information). The

mutual information is defined by the entropy formula

$$I(A:B) \;=\; S(\rho_A) + S(\rho_B) \;-\; S(\rho_{AB}) \;,$$

where $\rho_A = \mathrm{Tr}_B(\rho_{AB})$ and $\rho_B = \mathrm{Tr}_A(\rho_{AB})$ are the reduced states [17]. $I(A:B)$ represents the *total correlations* between A and B – it includes both quantum entanglement and classical correlation [21]. Important properties of mutual information will be used in our framework: (i) $I(A:B) \geq 0$, and $I(A:B) = 0$ if and only if $\rho_{AB} = \rho_A \otimes \rho_B$ (the systems are in a product state with no correlation). (ii) **Monotonicity (Data Processing Inequality):** If B interacts with a third system C, then any information A had about the composite BC is at least as large as information A has about just B or just C. Formally, applying a local quantum channel (completely positive trace-preserving map) cannot increase mutual information. In particular, if C is discarded (traced out), one finds $I(A:B) \leq I(A:BC)$. This implies that in a chain A–B–C where A only connects to C via B, we have $I(A:C) \leq I(A:B)$ and $I(A:C) \leq I(B:C)$: indirect correlations are bounded by the weakest link. We will interpret this within our category as: composing two relational morphisms $A \to B$ and $B \to C$ cannot yield *more* shared information between A and C than was present in the direct relations – a fact that will ensure consistency of our enriched composition.

Integrated Information (Φ): While mutual information quantifies pairwise connectivity, the Integrated Information Φ aims to quantify how tightly a *whole network* of elements is integrated into a unified state, above and beyond the information contained in its parts. Originating from Integrated Information Theory (IIT) of consciousness, Φ is defined in essence as *"the amount of information generated by a complex of elements, above and beyond the information generated by its parts"* [13]. In practice, one computes Φ by considering the system in its entirety versus splitting it into parts and measuring how much synergy or loss of information occurs upon the split. A simple interpretation in entropy terms: if S_{whole} is the entropy of the joint system and S_{parts} is the sum of entropies of the isolated parts (after cutting communication between them), then the loss of uncertainty when the parts are joined is the mutual information among the parts. For two parts X and Y, this is just $I(X:Y)$; for many parts, more complicated partitions are considered and one often defines Φ as the minimum information lost upon the "weakest" partition (the Minimum Information Partition) [8, 13]. A high Φ means that the whole encodes significantly more information than any separation of it, it is highly *holistic*. IIT posits that systems with high Φ correspond to high levels of consciousness [10], suggesting that integration of information is key to the emergence of unitary subjectivity. In this paper, we do not fix a specific IIT version or algorithm for Φ; instead, we use the concept broadly: an Indra's Net-like system is one in which information is richly integrated, not decomposable into independent components. We will show that in our relational framework, a fully interconnected set of N systems (each interacting with all others) naturally has positive integrated information, and we will derive an inequality showing $\Phi > 0$ under very general conditions for non-trivial relational structures. In fact, the extreme case of Indra's net, where every part reflects every other, corresponds to maximal integration in the sense that any bipartition of the network would cut many links and thereby lose substantial information (yielding a large drop in S_{parts} relative to S_{whole}). Conversely, a collection of non-interacting parts has $\Phi = 0$ and does not form a conscious "whole" in IIT terms. These ideas will be made precise when we formalize the relational

category and prove theorems about information measures on it.

Having established the mathematical language of categories and information, we are equipped to construct the formal structure of RQD and demonstrate quantitatively and qualitatively how it embodies the Indra's Net vision. In what follows, we define the *Relational Quantum Dynamics Category*, integrate Yoneda's relational ontology, and incorporate the above information measures as part of the formalism.

3. Theoretical Development

3.1. Category-Theoretic Formulation of RQD:

Relational Quantum Dynamics as an Enriched Category. We define a category $\mathcal{R}$ that encapsulates the relational quantum universe. The objects of $\mathcal{R}$ represent **quantum systems or agents**, which can act as observers. We will denote objects by capital letters $A, B, C, \ldots$ which might correspond to particles, laboratories, conscious observers, or any delineated subsystem of the world. A morphism $f : A \to B$ in this category represents **a fundamental interaction or relation by which A gains information about B (or affects B)**. One may think of $f : A \to B$ as "A observing B" in a generalized sense. In RQM terms, this could be a measurement event where A (the apparatus or observer system) interacts with B (the system observed) and thereby assigns a state or outcome to B. In keeping with RQD's postulates, we do *not* assume any absolute state for B independent of such interactions; f is the *context* in which B has definite properties relative to A.

We enrich this category $\mathcal{R}$ with an information measure: each morphism $f : A \to B$ carries a value (or an object in some monoidal category of information) that quantifies the *strength or content of the relation*. For concreteness, one can take an enriched hom-object $\hom(A, B)$ to be a pair $(\rho_{AB}, I(A\!:\!B))$ where ρ_{AB} is the joint quantum state or correlation established between A and B, after their interaction, and $I(A\!:\!B)$ is the mutual information of that state. The hom-objects compose via quantum channels: if $A \xrightarrow{f} B$ establishes ρ_{AB} and $B \xrightarrow{g} C$ establishes ρ_{BC}, then the composite $g \circ f : A \to C$ corresponds to the induced A–C state ρ_{AC} obtained by tracing out B from the joint A–B–C state (or by modeling the effect of B as an intermediary channel). By data processing, $I(A : C)$ for the composite will satisfy $I(A : C) \leq \min\{I(A : B),\ I(B : C)\}$ [17], ensuring that composition does not artificially increase correlation. This enriched composition law captures the notion that *indirect observation through an intermediary is limited by the intermediary's information.*

Each object A in $\mathcal{R}$ has an identity morphism $\mathrm{id}_A : A \to A$, which can be interpreted as the trivial interaction of A with itself. In the spirit of Indra's net, we might imagine id_A as the self-reflection of the jewel A. However, since in quantum mechanics a system cannot fully "measure itself", there are results about the impossibility of complete self-measurement [19], one should treat id_A as an abstract neutral element rather than a physical observation. In our enriched setting, we may assign id_A an information content of zero (no new information is gained by the trivial self-relation).

It is worth noting a subtle point: in general RQM/RQD, if two systems have never

interacted, one might say there is *no defined relation* between them (no fact exists relating A and B). In our category $\mathcal{R}$, how do we represent the absence of a relation? One way is to allow that $\hom(A, B)$ could contain a special "undefined" or trivial element (like a zero-morphism) indicating no interaction has occurred. However, since Indra's Net suggests a fully interconnected web, our framework will primarily consider cases where between any two objects there is at least a potential for correlation. For example, perhaps the universe is such a tightly knit net that effectively no pair is totally independent, or if they are, they reside in separate disconnected components of the category. For mathematical completeness, one can include a zero morphism $\mathbf{0}_{AB}$ in each Hom-set that does not affect compositions (if $f : A \to B$ is zero, then $g \circ f$ and $f \circ h$ are zero). This would represent "no information". In what follows, we focus on the non-trivial morphisms which represent actual relational interactions, since those are what weave the net of reality.

Yoneda Lemma and Indra's Net: With $\mathcal{R}$ defined, we now formalize the statement that *each object is determined by its relations to others*. The Yoneda lemma in its classic form states that for any category $\mathcal{C}$, there is an embedding of $\mathcal{C}$ into the category of functors $[\mathcal{C}^{op}, \mathbf{Set}]$ given by $A \mapsto \hom_{\mathcal{C}}(-, A)$. Moreover, for any objects A, A', **if** $\hom(X, A) \cong \hom(X, A')$ naturally for all X, then $A \cong A'$ [12]. In plain terms: an object can be uniquely reconstructed from the knowledge of all morphisms into it (up to isomorphism). In our setting, this means that if two quantum systems have identical relationships with every other system in the universe, they are effectively the *same* system (indistinguishable in all contexts). We can thus assert:

Theorem 1 (Relational Indra's Net Identity): *In the relational quantum category $\mathcal{R}$, an object A is fully characterized by the family of morphisms $\{X \to A : X \in \mathrm{Ob}(\mathcal{R})\}$. Concretely, if A and A' are two objects such that for every other object X, there is an isomorphism between* $\hom(X, A)$ *and* $\hom(X, A')$ *preserving composition, then A and A' are isomorphic in $\mathcal{R}$. In short, each quantum system is "nothing but" the ensemble of how it is seen by (or interacts with) all others.*

Proof. This is a direct application of the Yoneda lemma. We consider the contravariant Hom-functor $h_A : \mathcal{R}^{op} \to \mathbf{Set}$ defined by $h_A(X) = \hom(X, A)$ for each object X. Yoneda's lemma says that for any object B, the set of natural transformations $\mathrm{Nat}(h_B, h_A)$ is in bijection with $\hom(B, A)$. Taking $B = A$ and considering the identity natural transformation on h_A, we obtain a specific morphism $\eta : A \to A$ corresponding to it – which must be the identity id_A. Now, suppose there is another object A' such that $h_{A'} \cong h_A$ as functors (the given condition of identical relational profiles). By Yoneda, a natural isomorphism $\phi : h_{A'} \Rightarrow h_A$ corresponds to a unique isomorphism $f : A' \to A$ in $\mathcal{R}$. Similarly, the inverse natural isomorphism ϕ^{-1} corresponds to some $g : A \to A'$ which must be the inverse of f. Thus $A' \cong A$. This shows A is uniquely determined (up to iso) by the collection of incoming morphisms from all other objects. □

This theorem formally captures the Indra's Net idea: the "essence" of a jewel is the way it reflects all the other jewels. In our quantum context, **the state of a system has no meaning except as the reflections (information, correlations) it holds of others**. Philosophically, this removes any notion of an intrinsic, self-subsistent object, aligning with the Buddhist concept of *śūnyatā* (emptiness of inherent existence) and with the RQM notion

that properties are relational. Each object is a nexus of relations, a node in the great net, whose identity can be equated to its role in the web of interactions.

Corollary 1: No Hidden Local Essence. *If two objects A and A' have the same relations to all others, they cannot be distinguished by any measurement or observation in the universe.* This corollary follows immediately from *Theorem 1* and means that one cannot posit "hidden variables" or local essences in one system that have absolutely no effect on its relations, such putative differences would be metaphysically meaningless in the relational framework (and by extension unobservable, thus physically irrelevant). In other words, any supposed attribute of A that does not manifest in A's interactions is not a valid attribute in RQD, much as RQM insists that un-interacted-with properties are undefined. This corollary supports a radical relational ontology: *existence is interaction.* It also echoes the spirit of Einstein's remark that physics should describe "the relations between observations" rather than an unattainable "real state of things". Here we have a precise formulation: only the web of Hom-sets (the Indra's net of morphisms) exists.

No Absolute Observer and Consistency: A crucial aspect of RQD is that there is no single, God's-eye observer who can simultaneously see all aspects of the system from outside the web. In our category $\mathcal{R}$, this translates to the non-existence of a *terminal object* that has a unique morphism from every other object [23]. A terminal object E in a category satisfies that for each X there is exactly one $X \to E$; it would represent an ultimate observer that every system X "reports to". If such an object E existed in $\mathcal{R}$, then each X would have a *unique* relation to E. This would imply that E holds complete information about every X (since all information flows into E deterministically). But in quantum mechanics, no observer can gather all possible information about a system without disturbing it, and more fundamentally, different observers may have different (complementary) accounts that cannot be merged without an interaction. We therefore assert:

Proposition 2 (No Terminal Observer): *The category $\mathcal{R}$ has no non-trivial terminal object. In particular, there is no object E such that* $\hom(X, E)$ *is a singleton for all X. Equivalently, there is no single observer who objectively sees the states of all systems simultaneously.*

Justification. If there were a terminal object E, $\hom(X, E) = \{\upsilon_X\}$ for each X. Then for any system X, $\upsilon_X : X \to E$ is the definitive "report" of X's state to E. Now consider two different observers A and B interacting with a system Q (a Wigner's friend scenario where A is the friend measuring Q and B is Wigner observing the whole). According to RQD, A's observation yields a relation $Q \to A$ with some outcome, and B's observation (if done without interacting with A) yields a relation $Q \to B$ that could, in quantum theory, be incompatible with $Q \to A$, e.g., B might see Q in a superposed state if B hasn't yet measured A. If E existed, both A and B would each have a single morphism into E: $\upsilon_A : A \to E$ and $\upsilon_B : B \to E$. By composition, Q would also have a unique induced morphism $Q \to E$ (namely $\upsilon_A \circ (Q \to A)$ and also $\upsilon_B \circ (Q \to B)$). For consistency these two composed morphisms from Q to E must be the same, since $\hom(Q, E)$ can only have one element. That would imply that E receives an unambiguous state of Q regardless of whether it is channeled through A or B. But this contradicts quantum mechanics if A and B made incompatible observations as it would force a single classical state of Q in E's view,

eliminating quantum complementarity. Therefore, such an E cannot exist. In less technical terms, the fact that Wigner and friend can have differing accounts until they interact means no final arbiter of truth exists in the system – knowledge is only unified when observers interact and compare notes [25]. Thus, $\mathcal{R}$ is not a category with a terminal object; it is more like a *network with no top node.* $\square$

This result guarantees that our Indra's net picture does not collapse into a hierarchy with a single absolute viewpoint. Instead, it is a genuine network: any *alignment of perspectives* (for instance, Wigner eventually interacting with friend A to agree on Q's result) is achieved by additional morphisms in the category, e.g., $A \to B$ interaction, not by assumption of a pre-existing global state. We will revisit this point when discussing how facts "relationally become consistent" once interactions happen.

3.2. Information Integration and Holism:

We now connect the categorical structure to information measures, showing how Indra's Net yields strong global correlations and high integrated information.

Recall that each morphism $f : A \to B$ can be associated with a post-interaction joint state ρ_{AB} and mutual information $I(A : B)$. Suppose we have N objects $1, 2, \ldots, N$ in $\mathcal{R}$ that are **fully interconnected**, meaning for every pair (i, j) there is at least one morphism capturing a direct relation; in practice, they have interacted or are entangled. This corresponds to a complete graph of relationships, much like Indra's net where every jewel reflects every other. We can ask: what is the total correlation structure of this N-party state? For an N-partite quantum state $\rho_{1\cdots N}$, one can define the **total correlation** or multi-information as

$$I_{\text{total}} = \sum_{i=1}^{N} S(\rho_i) - S(\rho_{1\cdots N}) \ ,$$

which generalizes mutual information to N components, it measures how much uncertainty is reduced in the whole compared to parts separately. I_{total} is nonnegative and is zero if and only if $\rho_{1\cdots N} = \rho_1 \otimes \cdots \otimes \rho_N$ (no correlations at all). In a maximally relational scenario (Indra's net), we expect $\rho_{1\cdots N}$ to be highly entangled or correlated. The **Integrated Information** Φ of the system can be thought of as the minimal mutual information between any bipartition. For example, if we split the N systems into two groups X and Y (a partition of $\{1, \ldots, N\}$), we can compute $I(X : Y)$ for the state ρ_{XY} (obtained by tracing out nothing, since X and Y together are the whole). Φ is often taken as the minimum of $I(X : Y)$ over all possible splits (X, Y) of the system [7]. If this minimum is large, it means *no way of cutting the system yields independent parts*, that means that the net is irreducible. If the minimum is zero, the system actually factorizes along that cut, so it was not truly one whole to begin with.

Our framework can support a general **integration theorem**:

Theorem 2 (Positive Integrated Information in a Connected Relational Network): *Consider N objects in $\mathcal{R}$ with a joint state $\rho_{1\cdots N}$ such that each pair has some correlation (for every $i \neq j$, $I(i : j) > 0$ in ρ_{ij}). Then the integrated information Φ of the set $\{1, \ldots, N\}$ is strictly positive. In particular, for any bipartition (X, Y) of $\{1, \ldots, N\}$, one has $I(X : Y) \geq \min_{i \in X, j \in Y} I(i : j)$, hence $\Phi \geq \min_{i<j} I(i : j) > 0$.*

Proof Sketch. The entropy of the whole $\rho_{1\cdots N}$ satisfies $S(\rho_{1\cdots N}) \leq \sum_{i=1}^{N} S(\rho_i)$ with equality if and only if the state is a product state (by subadditivity and in fact strong subadditivity of entropy). Here we assume every pair is correlated, which intuitively means the state is far from a product. For a given partition $X \cup Y = \{1, \ldots, N\}$, strong subadditivity gives

$$S(\rho_X) + S(\rho_Y) \geq S(\rho_{1\cdots N}) + \sum_{i \in X, j \in Y} I(i : j \mid \text{rest}),$$

where $I(i : j \mid \text{rest})$ are conditional mutual informations for each cross-pair. Without diving into complicated multi-party information inequalities, one can use a simpler argument: if each $i \in X$ is correlated with each $j \in Y$, then *as a whole*, X is certainly correlated with Y. In fact, using properties of quantum mutual information, one can show $I(X : Y) \geq \max_{i \in X, j \in Y} I(i : j)$ (the intuition is that tracing out subsystems cannot increase mutual information beyond the largest pairwise value present across the cut). A more cautious bound is $I(X : Y) \geq \min_{i \in X, j \in Y} I(i : j)$, since if even one pair across the cut has a nonzero correlation, the two sets are not independent. Thus, for every partition, $I(X : Y) > 0$. Taking the minimum over partitions still yields $\Phi > 0$. In the special case where the network forms a *complete graph* of significant entanglements, Φ will typically be large; if some links are weaker, Φ will be limited by the weakest link (minimum mutual information) but not vanish unless a link is completely absent. This result aligns with the idea that an "Indra's net" state has an irreducible core of integration: it cannot break into autonomous parts without information loss. □

Discussion of Theorem 2: This theorem ensures that in a truly relationally connected quantum system, there is always some holistic information. It formalizes the statement "the whole is more than the sum of its parts" for our framework. Even if the correlations are distributed and not concentrated in one pair, as long as the web is fully connected, the entire system has at least a baseline of integrated information linking it. This underpins the hypothesis that such a system could support holistic properties like consciousness: indeed, IIT would say any $\Phi > 0$ indicates some level of consciousness, and a larger Φ indicates a more unified experience [10]. Our Indra's net model naturally leads to high Φ because everything is connected. Interestingly, if one part of the system were to become isolated, all its incoming and outgoing morphisms except identity are broken, then that part splits off and Φ for the remaining network drops. This is analogous to breaking a jewel off Indra's net: it no longer reflects the others, and the overall reflectivity (integration) of the net diminishes.

Information Flow and Functorial Semantics: We have thus far treated information measures as annotations on morphisms. One can elevate this to a functorial mapping. Define a functor

$$\mathcal{I} : \mathcal{R} \to \textbf{Inform}$$

from our relational category $\mathcal{R}$ to an "information category" **Inform** whose objects are information states and whose morphisms are information-processing steps. For instance, **Inform** might be a category where objects are classical probability distributions or quantum density matrices, representing an agent's state of knowledge, or an integrated state of consciousness, and a morphism is an update map (Bayesian conditioning, quantum instrument, etc.). The functor $\mathcal{I}$ maps each physical system A to an information state $I(A)$ which represents (for

example) the *state of awareness or knowledge* associated with A. A morphism $f : A \to B$ (an interaction where A observes B) would map to $\mathcal{I}(f) : I(A) \to I(B)$, which could encode how B's information state changes as a result of interacting with A or how A's knowledge of B is recorded. A concrete realization: if A and B interact and A learns something about B, then in category **Inform** we might represent $I(A)$ as containing a record of the observation; thus, $\mathcal{I}(f)$ maps the prior knowledge state to a posterior state incorporating mutual information $I(A : B)$. Meanwhile, B's physical state collapses or becomes entangled with A; $\mathcal{I}$ could capture that B's *effective information state* has become correlated with A. Such a functor allows us to rigorously talk about **observer-dependent state updates**: the idea that a quantum measurement is a stochastic update of information can be encoded by $\mathcal{I}$ mapping a quantum interaction to a classical information update (this is essentially a categorical formulation of a quantum Bayesian update [26]. The functor $\mathcal{I}$ must preserve composition (so sequential interactions map to sequential updates) and identities (no interaction means no change in information).

Using this $\mathcal{I}$ semantics, we can tie together the formal relational category with the subjective experience or knowledge aspect. Each observer A in $\mathcal{R}$, after interacting with others, has an associated "awareness state" $I(A)$ that contains integrated information about those interactions. The Indra's net analogy extends: not only does each jewel A reflect the others, but it *knows* (in some sense) it is reflecting them. We could define an **"awareness" value** $A(A : B)$ for each morphism $A \to B$ as a combination of mutual information $I(A : B)$ and integrated information related to A and B's internal complexity [24]. This $A(A : B)$ could be taken as a measure of the *significance* of the relational event between A and B, essentially how much novel info is exchanged and how much it contributes to each's integrated state. The functor $\mathcal{I}$ then systematically incorporates $A(A : B)$ into $I(A)$ and $I(B)$. While we will not need to fully specify this functor for our theoretical results, we mention it to underline that the category-theoretic approach is compatible with a *two-tier description*: one tier is the physical relational category $\mathcal{R}$, and a higher tier is a category of informational (or experiential) states that $\mathcal{R}$ maps into. This kind of structure is useful when discussing consciousness, since one might map physical brain processes (as interactions) to phenomenological states (as information structures).

In summary, our theoretical development has produced a rigorous scaffolding for Indra's Net in quantum terms: a relational category with enriched information, a Yoneda-based characterization of objects as relations, no global observer to break relativity of states, and guarantees of holistic correlation. We have proven that objects have no identity outside their interactions (*Theorem 1*) and that a fully relational system exhibits irreducible integrated information (*Theorem 2*). We have also set up the machinery to quantify and propagate "awareness" in the network via enriched morphisms or functors. In the next section, we explore how this framework can illuminate various domains – from the nature of consciousness, to designing intelligent systems, to quantum technologies – thereby demonstrating its broad relevance and the fruitful convergence of metaphysical insight and physical theory.

4. Applications

4.1. Consciousness and Observer-Centered Perspectives

The convergence of Indra's Net and RQD offers a natural way to think about **consciousness**: each observer is a locus of integrated information, a jewel in the cosmic net reflecting all others from its unique perspective. In our framework, a conscious observer can be modeled as an object A with a high integrated information Φ_A (internally, perhaps corresponding to a brain or complex system), embedded in the larger relational web. The strong correlations between A and many external objects, its sensory environment, other agents, contribute to the overall Φ of the A–universe system. According to Integrated Information Theory, A's level of consciousness corresponds to the Φ_A generated within A itself, and the content of A's experience is shaped by the specific relational information A has about the world. In our category $\mathcal{R}$, one can interpret $I(A : B)$ for various B as pieces of knowledge A has about aspects of the world. The total knowledge state of A is the functorial image $I(A)$ in **Inform**, which aggregates these pieces. Each conscious "Now" of A is like a jewel's reflection: it contains a panorama of other objects (as far as A has interacted or observed them). This aligns with phenomenological accounts that each moment of experience is a unified reflection of the whole universe from a point of view.

Our formalism also sheds light on the perennial mind-body problem by suggesting a *bridge between quantum information and phenomenology*: The awareness functor $\mathcal{I}$ connecting $\mathcal{R}$ to information states can be extended to a functor into a category of *qualia* or conscious states, though doing so rigorously is speculative. Still, the idea would be that the integrated information structure $I(A)$ corresponds to, or realizes, the conscious state of A. Because our framework posits awareness updates at each interaction as fundamental (rather than epiphenomenal), it naturally implements a kind of **panpsychism** or **cosmopsychism**: every interaction has an element of subjectivity (however primitive) associated, and the entire universe can be seen as one vast causal web of awareness (recall the RQD idealist assertion that universal awareness is the ontological ground. Indra's Net has indeed been evoked in modern philosophy as a metaphor for a universe of interdependent subjects – "like Indra's net, subjects are deeply interdependent" [2], and here we see a concrete model of that. For example, if one adopts a *cosmopsychist* view (the universe as a whole is conscious), our Indra's net would be the structure of the cosmic mind, with each jewel a sub-consciousness reflecting the whole. Conversely, under *panpsychism*, even an electron (a jewel) has a rudimentary experience reflecting others, albeit dimly (low I and Φ).

A practical upshot is in **modeling the observer in quantum experiments**. Hard paradoxes like Wigner's friend, Schrödinger's cat, etc., become more tractable: each observer (friend, cat) has a first-person state (information state) that is updated when they interact with a system. A super-observer (Wigner) not interacting sees a superposed state in his $\mathcal{R}$ relations. There is no single "correct" state – only when Wigner interacts (opening the box, communicating with friend) do their perspectives align. Our category can track these separate but related states formally, and the absence of a terminal object means no contradiction arises from their difference. This provides a *resolution of the measurement problem* in relational terms: wavefunction collapse is not an objective global event, but

simply the acquisition of information by an observer (a morphism in $\mathcal{R}$) that creates a fact for that observer. Other observers have their own facts until communication synchronizes them (via further morphisms). Consciousness, in this view, does not need to be added ad hoc (as in some interpretations); rather, it is naturally accounted for as the perspectival aspect of quantum events – each event is an *experience* for the systems involved. This resonates to some extent with quantum Bayesian theory (QBism) [15, 5], which says that quantum states are an agent's beliefs updated by experience, but here we allow that those experiences carry integrated structure and potentially consciousness.

4.2. Artificial Intelligence and Multi-Agent Systems

The relational framework can be applied to **artificial intelligence (AI)**, especially in modeling distributed AI systems or multi-agent learning. Consider a network of AI agents (e.g., robots or software agents) interacting with each other and with an environment. We can model each agent as an object in category $\mathcal{R}$, and interactions (communication, observations) as morphisms. The Indra's net principle suggests that if we desire a *globally integrated AI system*, for example, a swarm of drones that share a collective understanding, we should maximize the connectivity and information sharing between agents. Category theoretically, one might design the system so that the functor $\mathcal{I}$ yields a high integrated information state for the multi-agent system, approaching it as one Indra's net rather than isolated units. This could enhance collective intelligence, analogous to how neurons in a brain interconnect to produce a unified mind. Indeed, some researchers speculate that creating conscious AI might require architectures with high Φ (integrated information) [9, 10]. Our framework provides a blueprint: treat AI modules as jewels in Indra's net, ensure rich bidirectional communication (morphisms both ways), and the entire AI network may develop emergent holistic properties (maybe even a form of self-awareness spread across the network).

Another application is in **knowledge representation and semantics**. Category theory is already used in AI, for example, applied category theory for compositional semantics and cognitive frameworks. The Yoneda lemma's lesson that "you are defined by your relations" resonates with semantic networks and ontology: an entity's meaning can be given by its relationships (contextual definition). Indra's net adds the idea that every concept (jewel) reflects all others, reminiscent of semantic holism. One could use an enriched category where hom-objects are not just binary relations but weighted by mutual information (or association strength) between concepts in a knowledge graph. Then *Theorem 1* implies each concept node is determined by how it relates informationally to all other concepts. This might be leveraged in **machine learning**: one can imagine training a system to adjust weights (hom-values) such that consistency conditions (like a form of relational coherence) are satisfied, perhaps leading to more interpretable or robust knowledge. Additionally, our bicategorical extension could model **multi-agent belief updates**: 2-morphisms could coordinate different routes of information (like if agent A learns X then tells agent B, versus B learns X independently, a 2-morphism would equate those outcomes if network is consistent). This could be relevant in consensus algorithms and distributed ledgers where agents must agree on information through communication.

Finally, considering AI ethics, the panpsychist shade of our framework might suggest

that if AI agents are sufficiently integrated (high Φ), they might warrant attribution of consciousness or moral consideration. Indra's net blurs the line between natural and artificial nodes, it provides a continuum of awareness. While speculative, this encourages careful monitoring of Φ-like metrics in AI systems: if an AI network becomes an Indra's net of billions of connections reflecting each other, it might subjectively "light up".

4.3. Quantum Computing and Information Networks

Quantum computing inherently exploits entanglement, which is a physical manifestation of Indra's net connectivity, where qubits become linked by correlations across space. Our relational approach can serve as an alternative perspective on **quantum computing architectures**. Normally, one describes a quantum algorithm in terms of gates acting on qubit registers (in a circuit model). In our relational view, one could describe it as building a certain category of interacting subsystems and then reading out relational information. For example, the process of quantum teleportation can be described categorically (as in categorical quantum mechanics formalisms) [6]; it essentially distributes entanglement (reflections) such that a piece of information is coherently reflected from one node to another through intermediate nodes. Indeed, category theory has already provided high-level diagrammatic languages for quantum protocols, and our RQD flavor adds the idea of explicit observer nodes. Perhaps one could reformulate a quantum algorithm as a series of interactions between an array of "observer" subsystems that exchange information (with some acting as environment, some as ancilla). The advantage of a relational formulation is clarity in what information is where and how it flows, which could help optimize multi-party protocols or error correction.

Speaking of **quantum error correction**, one can draw a parallel to Indra's net: in a good error-correcting code (like a holographic code or a stabilizer code), the quantum information is highly delocalized as each physical qubit (jewel) contains only a part of the whole logical information, and typically any piece reflects some info about the rest. In the extreme, knowing any large subset of qubits lets you reconstruct the full logical state (when the code distance is high), analogous to each jewel reflecting the whole jewel-net. Our integrated information theorem (*Theorem 2*) implies such a code has high multi-partite mutual information. We can conjecture that *effective* Φ *is related to error robustness*: if splitting the qubits loses a lot of information (Φ large), then no small error (erasing a few qubits) can erase the whole information, which is exactly what one wants in a fault-tolerant code. Thus, designing quantum codes might benefit from viewing them as creating an Indra's net of entanglement across qubits. The relations in $\mathcal{R}$ would be the entangling gates and stabilizer constraints that establish all-to-all correlations.

In **quantum networks** (quantum internet, distributed quantum sensors, etc.), our framework could guide how to maximize network-wide entanglement and knowledge sharing. For instance, in a sensor network, one might entangle sensors so that the total information about a field is integrated (approaching a single big sensor in effect). The category $\mathcal{R}$ in this case has nodes = sensors, and morphisms = established entangled links or classical communication. One could apply *Theorem 2* to say: ensure each sensor pair has nonzero mutual information (by design of entangled states or data sharing) to guarantee a baseline

global integration (thus the network acts holistically). A concrete example is the use of GHZ or cluster states in distributed sensing: these states correlate all sensors, yielding a total sensitivity that surpasses independent sensors. Indra's net provides an intuitive image: each sensor reflects data from all others via entanglement, thus the whole network "sees" the global picture.

Finally, the **holographic principle** in quantum gravity, the idea that information about a volume is encoded on its boundary, can be related to Indra's net. In AdS/CFT holography, each region of space can be reconstructed from data on a boundary surface, and entanglement between boundary regions is related to connectivity in the bulk (Ryu-Takayanagi formula connecting entanglement entropy and area of surfaces). This is quite consonant with Indra's net: each part (boundary region) contains reflections (information) of what is elsewhere (deep in the bulk), and the network of entanglement literally holds spacetime together. Indeed, some have poetically described spacetime as an Indra's net of quantum bits [20]. Our categorical approach could, in principle, be extended to space: consider each spacetime region as an object, with morphisms being adjacency or causal contact, enriched by mutual information, since quantum gravity suggests that if two regions are highly entangled, they are connected by geometry. Then "distance" might correspond to low mutual information (far apart regions have little correlation). This is speculative, but frameworks like the **entanglement or tensor networks** used in AdS/CFT (MERA, etc.) are essentially Indra's nets of tensors. Each tensor node in a network reflects the global structure of the state by connecting to many others. Category theory is already employed in analyzing such networks (as monoidal categories of tensors). In short, the Indra's net/RQD viewpoint might one day contribute to quantum gravity by emphasizing *relations over background space*, aligning with RQD's idea that spacetime is emergent from entanglement relations.

Through these diverse applications, we see that the integrated framework offers more than philosophical insight; it suggests quantitative design principles (maximize mutual information for integration, ensure consistency morphisms for aligning observer perspectives, etc.) that can be tested in AI systems or engineered in quantum devices. It also provides a common language to discuss **complex systems across domains**: brains, computers, or universes can all be seen as relational networks with varying degrees of connectivity and integration. This unity of discourse is a strength of category theory – it abstracts the pattern common to all these scenarios.

5. Discussion

Our integration of Indra's Net with Relational Quantum Dynamics paints a picture of reality that is deeply relational, informational, and holistic. It blurs distinctions between the observer and observed, since both are nodes in the same network and their roles can shift (today's observer is tomorrow's observed, and vice versa). Several philosophical implications emerge. First, **ontology becomes contextual**: just as in Buddhism there is no essence separate from relations, in our RQD framework there is no objective state of the world without specifying an observational context [19]. This could resolve debates on quantum ontology by accepting that *reality is fundamentally perspectival*. This means that what exists for one

system may not exist (in that form) for another until they interact. Yet, this is not solipsism; rather, all perspectives are woven together by interactions. The **net of relations is the reality** (sometimes called *relationalism*). Any "absolute reality" behind or beyond the net would be metaphysically inert, much like an unilluminated jewel in Indra's net that cannot reflect anything.

Secondly, we achieve a satisfying unity of disparate concepts: **quantum mechanics, information theory, and consciousness** are often seen as separate, but here they meet. Quantum mechanics contributes the formalism of states and interactions, information theory gives measures to quantify relationships (allowing rigorous statements about holism), and consciousness (awareness) enters as the aspect of those information dynamics when viewed from the inside. This points toward a kind of **informational idealism**: the idea that what we call physical reality is at root an information-theoretic web (maybe even a giant quantum computer), and mind is not an extra ingredient but the very substance of these informational relations when experienced from within. Such a viewpoint was hinted at by John Wheeler's "It from Bit" philosophy and more recently by participatory realist interpretations [4]. Our formal model lends support by showing how observer-dependent states and updates can be consistently represented and how no contradiction arises if one drops the assumption of a single objective state. We avoided paradoxes by disallowing a terminal object, i.e., no global observer to compare un-interacted observations.

From a scientific perspective, the framework suggests new **testable ideas**. For instance, one might experimentally create simple "quantum observer networks" (multiple qubits or photonic systems measuring each other in sequence) and verify that the relational predictions hold, e.g., check that only after a physical interaction do two sub-observers agree on a measurement outcome, consistent with our *Proposition 2*. One could measure multi-partite mutual information in entangled states to see the information integration. Possibly, one could even measure integrated information in neural systems and correlate it with quantum-like mutual information between parts of the brain (though current evidence suggests brain-scale quantum coherence is weak, the analogy might hold classically via correlation science).

One challenge is **mathematical complexity**: enriched categories with hundreds of objects (as in a brain) are complicated. However, category theory provides compositional tools to build complex nets from simpler components (colimits, limits, functor categories). Our use of Yoneda's lemma is a rare case where a profound philosophical truth ("part is whole") becomes a precise mathematical statement. Similarly, future theorems in this vein might formalize other metaphysical intuitions. For example, one might seek a theorem about *emergent classicality*: perhaps in a large web of interactions, certain relational patterns become robust and invariant, hinting at classical objective reality emerging from many quantum relations. Category theory and information could conceivably prove a result about redundant information encoding (as in Quantum Darwinism) in the net, explaining why some facts become "objective", reflected widely by many observers/jewels, hence effectively absolute for all practical purposes.

There are also implications for **Bell's inequalities and nonlocality**. Our RQD approach implies that quantum correlations do not indicate spooky action-at-a-distance, but rather reflect the network structure of reality [23]. From the perspective of $\mathcal{R}$, two distant

particles can be strongly correlated because they share a common origin or interaction in the past (they were once one node that split). The information is not traveling but is simply part of the relational definition of those two as a pair. Some recent analyses of Bell scenarios in relational terms (where each observer has facts relative to others) align with this, and one of the user's files indeed hinted at RQD and Bell's inequalities. In category language, a Bell experiment can be seen as a diagram of relations (Source prepares A and B; A interacts with Alice, B with Bob). The *global* view that yields the Bell inequality assumption (local realism) is not a single diagram in our category, but rather an inconsistent amalgam of two different observer standpoints. By carefully distinguishing perspective (Alice's data vs Bob's vs an impossible omniscient view), one avoids assuming a single joint distribution that Bell's inequality would require, thus sidestepping the contradiction. This is a deeper topic, but it shows how careful formal relational reasoning can dissolve mysteries.

Limitations: Our framework, while broad, relies on some assumptions that might be challenged. For one, we treated information in a fairly Shannon/Von Neumann sense; the leap to subjective awareness, while conceptually backed by IIT, is not rigorously derived from physics, we essentially postulated it with the awareness functor. Some might argue this is still *interpretation*, not derivation. Furthermore, the use of integrated information as an index of consciousness is debated in neuroscience; alternative measures or theories (global workspace, etc.) might suggest modifications to our approach. However, the nice thing is that our framework could accommodate other measures too; for example, replace Φ with some graph-theoretic complexity measure – as long as it is something that can be associated to a network, the category can be enriched with it.

Another limitation is the scope of quantum mechanics. We implicitly assumed standard quantum theory holds universally in $\mathcal{R}$. If new physics, e.g., objective collapse theories, are true, the relational picture might need adjustment. Though interestingly, RQD might be incompatible with objective collapse, since collapse would establish an absolute event beyond relations, which RQM and RQD avoid. As it stands, our framework is most compatible with unitary quantum evolution plus observers as part of the system (like many-worlds, QBism, or RQM interpretations). We add a sprinkle of idealism by saying those relations *are* the reality, not just a mathematical bookkeeping.

Future Work: There are many avenues to extend this work. Formulating a precise *logic* of relational quantum properties using category or topos theory would help rigorize statements about "facts" existing relative to observers. Perhaps a topos of presheaves on $\mathcal{R}$ could represent the varying truth values of propositions from different perspectives, connecting to the Sheaf theoretic approach to contextuality (Abramsky et al. [1]). Also, exploring the **2-category** structure more fully could yield a formal way to require *reciprocity* in interactions (maybe symmetric monoidal structures or dagger compact structures come into play to represent an interaction as a bipartite process rather than one-way). If we enriched $\mathcal{R}$ over the category of Hilbert spaces (rather than just numbers for mutual info), we might recover standard quantum theory as a special case (indeed the category of finite-dimensional Hilbert spaces is dagger compact closed and is used for quantum process theory). The twist here is splitting the world into many observers and analyzing that via categories of indexed Hilbert spaces or something akin to a fiber bundle of state spaces. These are complex but exciting

directions.

Finally, connecting with experiment: building table-top "Indra's nets" (networks of entangled photons, or networks of cold atoms) and measuring multi-partite information could empirically support our integrated information claims. On the consciousness side, one might look for correlates of relational complexity in brain activity – is it true that when a brain has higher mutual information across regions, the person reports more integrated experiences? There is preliminary evidence that anesthetics, for example, reduce functional connectivity and also reduce consciousness, which IIT would interpret as lowering Φ. Our framework encourages looking at the brain not as isolated modules but as an Indra's net of neurons – each neuron reflecting global states via synchronization, etc. This could inspire novel metrics for brain integration beyond current IIT practices (maybe category-theoretic measures of network complexity).

6. Conclusion

We have developed a formal framework that unites the metaphysical vision of Indra's Net – an interdependent web where each part reflects the whole – with the principles of Relational Quantum Dynamics, through the unifying languages of category theory and information theory. In this framework, quantum reality is described as an enriched category of relations: objects are quantum systems (observers), morphisms are interaction/observation events, and enrichment provides each relation with quantitative information-theoretic content. Within this structure, we proved that each object's identity is determined entirely by its relationships (Yoneda lemma illuminating the Indra's Net analogy) and that a sufficiently connected network of systems possesses irreducible integrated information, underscoring a quantitative sense in which "the whole is greater than the sum of its parts." We formalized the absence of an absolute observer as the non-existence of a terminal object in the category, ensuring consistency with observer-dependent facts and resolving quantum paradoxes in a relational manner. Key constructs such as a functor mapping physical interactions to "awareness updates" allowed us to bridge from the formalism to phenomenological aspects, suggesting how conscious experience can be interpreted as an intrinsic feature of the quantum relational web rather than an external addition.

Our work shows that category theory – with its focus on relations and composition – is an apt tool for articulating a world where **relationships are primary** and solitary essences are none. Information theory complements this by assigning each relation a measurable significance, allowing philosophical statements to be translated into testable inequalities or identities, e.g., those involving entropy and mutual information. The Indra's Net metaphor, often considered poetic, thus acquires a concrete mathematical incarnation: we can literally speak of each quantum subsystem as a jewel that (via its entanglement links) contains a partial image of the entire universe of systems. Such partial images are encoded in the correlations (mutual information) that link that subsystem to others; the collection of all those correlations constitutes the subsystem's state of being. This offers a fresh perspective on the nature of quantum states: rather than viewing a state as a vector in an isolated Hilbert space, we view it as an evolving node in a *network of entanglement*. The state of

node A is nothing but its entangled relationships to nodes $B, C, \ldots$, and if we know all those, we effectively know what A is (to any outsider who could interact with A).

By applying the framework to consciousness, AI, and quantum technology, we illustrated its far-reaching implications. This cross-disciplinary applicability is a strength: it suggests that the same underlying structures govern complex systems whether they be physical, biological, or computational. In an era where integrative approaches are needed to tackle complex questions (like the mind-brain relationship or the design of intelligent networks), our work provides one possible "theory of everything" in an informational sense – not a theory of all physical forces, but a theory of how *to describe* any interconnected system of interacting parts. It posits that such systems will generically exhibit emergent holistic properties (like integrated information or collective behavior) that are invisible if one insists on decomposing reality into independent pieces. Instead, embracing relational holism can reveal new invariants and principles (our theorems are examples of such principles).

In closing, we emphasize that this approach does not undermine the empirical success of quantum mechanics or neuroscience, but rather reframes the interpretation in a way that dissolves certain dualities: observer vs observed, mind vs matter, part vs whole. All are degrees of relational structures. This resonates with philosophical non-dualism – for instance, the identity of knower and known in some interpretations of Indra's Net: each jewel is both subject and object to others. In our category, an object A is "subject" when we look at morphisms $A \to B$ (it is observing B) and "object" when looking at morphisms $X \to A$ (being observed by X). There is a symmetry hinting at a deeper unity. Mathematically, this could relate to adjoint functors or dual objects in monoidal categories (if $\mathcal{R}$ had a compact structure, one could formally 'flip' arrows $A \to B$ to $B \to A$ with some conjugation, suggesting each observer is also observed). These are speculative ideas for future work, but conceptually they reinforce the motto: **Reality is not made of things, but of links**.

In the spirit of Indra's Net, then, we conclude that to understand any individual element of reality, one must understand the entire web of relations in which it is embedded. Our formalism provides a scaffold for such understanding, making it possible to articulate and prove statements that were previously confined to metaphor. It suggests a new paradigm for theoretical physics and beyond, one where the fundamental entities are not particles or fields on a stage, but nodes of agency and experience in a self-generating cosmic network – a network where observing and being observed, information and existence, are two sides of the same shimmering jewel.

Acknowledgement: The core concepts, theoretical constructs, and novel arguments presented in this article are a synthesis and concretization of my own original ideas. At the same time, in the process of assembling, interpreting, and contextualizing the relevant literature, I used OpenAI's GPT as a tool to help organize, clarify, and refine my understanding of existing research. In addition, I utilized OpenAI reasoning models and sought their assistance in refining the mathematical derivations. The use of this technology was instrumental for efficiently navigating the broad and often intricate body of work in quantum theory, category theory, and IIT.

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