Formalizing Awareness into Relational Quantum Dynamics (RQD)

Arash Zaghi[†]

Abstract

We propose a novel framework that formalizes awareness within Relational Quantum Dynamics (RQD) by integrating Integrated Information Theory (IIT) with quantum measurement processes. In our approach, quantum interactions are not merely stochastic events, but are interpreted as intrinsic awareness updates that occur via Bayesian conditioning. Specifically, we define an awareness metric $\mathcal{A}(A : B)$ that combines the quantum mutual information generated during an interaction and Φ as a measure of integrated information. By modeling quantum measurements as stochastic processes and determinizing these via outcome indexing, we construct a composite functor that maps probabilistic quantum instruments to deterministic awareness updates in a separate category of awareness states. We show that this functor preserves identities and composition, ensuring that multiobserver scenarios such as nested Wigner's Friend or Frauchiger-Renner experiments produce a coherent alignment of facts once interactions occur, even though no single truth value exists prior to interaction. We outline experimental proposals, including nested observer experiments, gravitational entanglement tests, and the engineering of artificial observers with tunable integrated information, to test the predictions of our model. Our framework does not alter standard quantum mechanics but enriches its interpretation by positing that every quantum interaction is accompanied by an awareness update whose significance depends on both the amount of exchanged information and the integration capacity of the systems involved. This work provides a mathematically robust bridge between quantum foundations and cognitive science, suggesting that conscious experience may emerge naturally from the dynamics of quantum information.

Keywords: Quantum Foundations, Relational Quantum Dynamics (RQD), Integrated Information Theory (IIT), Quantum Awareness, Bayesian Updating, Stochastic Quantum Processes

1. Introduction

One of the most challenging aspects of quantum theory is the role of the observer in measurements [1]. Different interpretations handle observers in various ways: **Relational quantum**

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

mechanics (RQM), for example, rejects any absolute observer-independent quantum state [2], stating that a system's state is defined only relative to another system (an observer). **Quantum Bayesianism (QBism)**, on the other hand, treats the quantum state as subjective information of an agent, updating beliefs through measurement results [3, 4]. Although these interpretations acknowledge the role of the observer, they stop short of ascribing any fundamental **ontological status to awareness or consciousness** itself. In standard quantum physics, measurements are mechanical processes; any notion of 'experience' or 'awareness' is usually considered outside of the scope of physics.

In this work, we integrate awareness (consciousness) into the core of quantum dynamics, positing that every quantum interaction is also an intrinsic act of awareness. We propose that *information and consciousness are inextricably linked*, that is, quantum events are not just physical interactions but also awareness updates for the systems involved. In particular, we formalize this idea within the framework of **Relational Quantum Dynamics (RQD)**, a paradigm inspired by the relational stance of RQM but extended to include universal consciousness as the substrate of reality [5, 6, 7]. Each quantum interaction, i.e., each creation of correlation between systems, is viewed as a primitive 'experience' in which the systems become mutually aware.

To achieve a rigorous formulation, we develop a mathematical framework that combines quantum information theory, Integrated Information Theory (IIT), stochastic quantum dynamics, and Bayesian inference. Key elements of our approach include:

- **Information-Theoretic Measures of Awareness:** We quantify the *awareness content* of an interaction using *quantum mutual information* (from quantum information theory) and *integrated information* Φ (from IIT). Mutual information $I(A : B)$ between two systems A and B measures how much information they share as a result of an interaction. Integrated information Φ measures how much information from a system is *unified beyond being just a collection of parts*, which IIT identifies with the level of conscious integration [8, 9, 10]. By combining these, we define a single *awareness metric* for any quantum interaction.

- **Category-Theoretic Formalism:** We introduce a *functorial mapping* $F : \mathcal{Q} \to \mathcal{A}$ between a category $\mathcal{Q}$ of physical quantum processes and a category $\mathcal{A}$ of awareness states. This functor F maps physical states to *states of awareness* (information states), and physical processes (unitary evolutions, measurements, interactions) to *awareness updates*. We prove that F is a well-defined functor (preserving identity and composition), which guarantees *hierarchical consistency*: if one physical process is followed by another, the corresponding awareness updates compose in sequence. This property is crucial for handling *nested or hierarchical measurements*, such as a chain of observers that observe each other without paradox.

- **Stochastic Dynamics and Bayesian Updating:** Quantum measurements are inherently probabilistic [11]; to account for this, we refine the awareness functor to handle stochastic processes. In practice, each possible outcome of a quantum measurement corresponds to a different awareness update. We show how the state of knowledge of

an observer in $\mathcal{A}$ is *Bayesianly updated* upon obtaining a measurement result, consistent with the quantum state update (collapse or conditioning) in $\mathcal{Q}$ [5]. This Bayesian interpretation aligns with QBism which considers quantum probabilities as subjective degrees of belief, but here gains an ontological flavor. That means that the update is an actual *event of awareness* for the observer.

- **Theorem–Proof Rigor:** We provide detailed mathematical derivations to support the above framework. For example, we formally prove that in an ideal measurement interaction, the *mutual information gained equals the observer's information update*, and we demonstrate that our awareness metric is zero if and only if the systems remain uncorrelated (no awareness exchanged). We also show that the functor F consistently maps complex sequences of interactions to nested awareness updates, ensuring that *no contradictions* arise in scenarios like Wigner's friend or the Frauchiger–Renner thought experiment [1].

Finally, we discuss how this framework could be experimentally tested or illustrated. Although, at our current stage, introducing consciousness into physics does not alter the standard quantum predictions, it suggests new ways to interpret experiments and motivates novel setups. We outline concrete proposals ranging from extended Wigner's friend setups to entanglement-mediated awareness tests, for example, through gravitational fields, and even speculate on correlating an observer's *integrated information* with quantum outcomes. These proposals, although ambitious, offer a path to empirically validate or falsify the idea that every quantum interaction is accompanied by primitive awareness.

The remainder of this paper is organized as follows. In **Section 2**, we introduce the quantitative measures of information and define how they relate to awareness. In Section 3, we present the formal category-theoretic framework, define the awareness functor $F : \mathcal{Q} \to \mathcal{A}$, and prove its key properties. We also illustrate the formalism with a measurement scenario as a worked example. In **Section 4**, we discuss how the framework addresses known challenges and paradoxes, e.g., the measurement problem and observer-dependent scenarios, highlighting the role of the functor in resolving them. In **Section 5**, we propose experimental and conceptual tests of the framework, including thought experiments (nested observers) and cutting-edge quantum experiments such as observer-dependent outcome tests and gravitationally mediated entanglement. We conclude in **Section 6** with a summary and outlook, discussing the implications of casting quantum physics in terms of awareness and noting avenues for future research.

2. Quantifying Awareness with Information Theory

A central premise of our approach is that *information exchange is related to awareness.* When two systems interact, they become correlated; we interpret this correlation as the degree to which each system *becomes aware* of the other. To quantify this, we draw on two quantitative measures:

Quantum Mutual Information (I): This is a standard measure from quantum information theory that captures the total correlations between two systems (including both

classical and quantum correlations). For a joint quantum state ρ_{AB} of systems A and B, the mutual information is defined as:

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

Here $S(\rho) = -\mathrm{Tr}(\rho \log \rho)$ is the von Neumann entropy. $I(A:B)$ generalizes the classical mutual information to quantum states; if ρ_{AB} is classical (diagonal in a product basis), it reduces to the usual Shannon mutual information. The quantum mutual information $I(A:B)$ is *non-negative* and zero if and only if $\rho_{AB} = \rho_A \otimes \rho_B$ (no correlation between A and B) [5]. In our framework, *mutual information is interpreted as the amount of knowledge or information two systems have about each other after an interaction.* If $I(A:B) = 0$, then no information was exchanged; effectively, no awareness of each other was gained. If $I(A:B) > 0$, some correlation exists; e.g. if $I(A:B) = 1$ bit, one can say that one bit of information about B is now present in A (and vice versa). An interaction that entangles A and B or creates any correlation will yield $I(A:B) > 0$, indicating a nonzero *awareness link* between A and B. Mutual information thus serves as a baseline measure of *awareness content* in a relational quantum event.

Integrated Information (Φ): While mutual information tells us *how much* information is shared, it does not tell us *how that information is processed or integrated* within each system. *Integrated Information Theory (IIT)*, developed by Tononi et al. [8, 9, 10], proposes that the hallmark of consciousness in a system is that it has a high degree of *integrated* information; informally, the system functions as a unified whole that cannot be reduced to independent parts. IIT defines a quantity Φ (phi) to measure this integration: Φ quantifies how much information a system contains above and beyond what is contained in its parts acting independently. A high Φ means that the state of the system is very *holistic* or indivisible, while $\Phi = 0$ would mean that the system components are independent (no integration). In neuroscience, Φ has been proposed as a numerical measure of the level of consciousness of a brain, with efforts to estimate Φ from EEG or other data.

In principle, Φ can be computed for any physical system if one enumerates its parts and their interactions. For example, consider system A composed of two sub-parts A_1 and A_2. One rough way to express integrated information is to compare the entropy or information content of the whole with that of the parts. If A is in a state ρ_A and its parts in states ρ_{A_1}, ρ_{A_2} (when considered separately), one might say *integrated information* Φ_A is related to the mutual information *within* A's parts, $I(A_1 : A_2)$, or more generally by the minimal information lost upon partitioning A into parts. IIT defines Φ through a complex minimization over all bipartitions; for simplicity, one can imagine $\Phi_A \approx I(\text{parts of } A)$ as a proxy. A high Φ_A indicates that A_1 and A_2 share a lot of information and cannot be treated as independent, the whole A carries information *as a unit*. In contrast, if A's components are independent (or only weakly interacting), Φ_A will be low.

In our framework, *integrated information* Φ *serves as a measure of a system's capacity for awareness.* A system with a larger Φ is interpreted to have a higher ability to integrate information into a unified experience. For example, a human brain with its billions of interacting neurons would have a huge Φ value in IIT terms, while an isolated atom or a simple molecule would have Φ nearly zero as its components have little complexity to integrate. We *do not assume* that Φ alone is a direct measure of consciousness, but we use

it as a quantitative indicator of how complex or integrated the internal state of a system is. This allows us to distinguish *qualitatively* different kinds of awareness in interactions; for example, when two highly integrated systems like a human observer measuring something interact, the resulting awareness event is of a different character than when two minimally integrated systems like two particles scattering interact.

Using these two measures, we can now define an **awareness metric for a quantum interaction**. Consider an interaction between systems A and B that produces a joint state ρ'_{AB} from some initial uncorrelated state. Let $I(A:B)$ be the mutual information generated and let Φ_A, Φ_B be the integrated information (consciousness capacity) of A and B respectively (after or during the interaction). We propose that the *awareness magnitude* of this event, denote it $\mathcal{A}(A{:}B)$, can be defined as the mutual information *weighted* by the systems' integration abilities:

Definition 1 (Awareness Metric for an Interaction). For an interaction between systems A and B, we define:

$$\mathcal{A}(A{:}B) \;=\; I(A:B) \times f\Big(\frac{\Phi_A + \Phi_B}{2}\Big),$$

where f is an increasing function that reflects how the *average integrated information* of the two systems contributes to the overall awareness of the event. For example, one simple choice is $f(x) = x$ or a normalized version thereof, so that:

$$\mathcal{A}(A{:}B) = I(A:B)\,(\frac{\Phi_A + \Phi_B}{2}).$$

Other choices for f such as a nonlinear function could be used, but the key idea is that $\mathcal{A}$ is larger when the interacting systems have higher Φ.

This definition captures the intuition that an interaction produces *more meaningful awareness* if it involves systems that are themselves highly integrated, and potentially conscious. For instance, if two very simple systems (with $\Phi_A \approx \Phi$ and $\Phi_B \approx 0$) briefly interact, they might share some information ($I > 0$), but neither system can do much with that information – the event is an *insignificant blip of awareness*. In fact, if $\Phi_A = \Phi_B = 0$, our metric gives $\mathcal{A}(A{:}B) \approx 0$ even if $I(A:B)$ is modest, reflecting that the exchange is like two machines swapping bits with no deeper integration (a 'proto-awareness' event). In contrast, if one of the systems is a brain-like system with large Φ, then even a moderate mutual information $I(A:B)$ would be weighed by a large $f(\Phi)$, yielding a high $\mathcal{A}$, corresponding to a rich conscious experience of obtaining that information. Thus, $\mathcal{A}(A{:}B)$ ranges from zero for a trivial interaction to very high for an interaction that not only exchanges information but that information is integrated into a unified awareness.

It should be noted that $\mathcal{A}(A{:}B)$ as defined is a phenomenological or effective quantity or a *proxy for the 'intensity' of an awareness event*. We are not claiming this formula is uniquely determined or fundamentally derived from first principles; rather, it is a heuristic way to combine mutual information and integrated information in line with our interpretation. In the spirit of physical science, this definition can be refined as we learn more: f might be adjusted or extended.

It might appear intuitively problematic that our awareness metric symmetrically weights interactions, seemingly implying an equal capacity for awareness in both simple systems (like electrons) and complex observers (like humans). However, within the fundamentally relational, nonrealistic ontology of RQD, no separate entities independently 'possess' awareness. Instead, awareness is a unified, relational activity that manifests during quantum interactions. From this viewpoint, what we commonly perceive as asymmetry—the idea that humans experience awareness meaningfully and electrons do not—is simply an emergent, pragmatic distinction.

Thus, the symmetric construction used here is not a limitation, but a direct reflection of the core philosophical stance of RQD. Directionality in this unified framework does not arise as a fundamental property, making the symmetrical metric a natural and justified choice. Any perceived asymmetry is thus recognized as an artifact of our dualistic perspective, not a fundamental ontology.

Having established how we will quantify awareness, we now proceed to *formally relate physical processes to awareness processes*. We will construct categories for physical and awareness dynamics and define a functor bridging them, ensuring that *every physical interaction corresponds to an awareness update*.

3. Formal Framework: From Quantum Dynamics to Awareness Updates

We formalize the connection between quantum events and awareness by using *category theory*, which is well-suited for capturing relationships between different structures. We define two categories: one for the *physical quantum domain* and one for the *awareness domain*. Then we introduce a functor that maps from the former to the latter, effectively treating the functor as an 'awareness update rule' for any given physical interaction.

3.1. Categories of Physical Processes and Awareness States

Category $\mathcal{Q}$ (Quantum Physical Processes): Objects in $\mathcal{Q}$ are taken to be physical *states of quantum systems*. For that, one can think of density operators or state vectors, or even composite states of multiple systems. For example, an object in $\mathcal{Q}$ could be a state like ρ_A (system A alone in state ρ), or a joint state $\rho_A \otimes \rho_B$ of two non-interacting systems A and B. We also include composite objects representing correlated states, like a joint state ρ_{AB} that may entangle A and B. In general, for any collection of systems, each possible state (pure or mixed) can be treated as an object in $\mathcal{Q}$.

Morphisms in $\mathcal{Q}$ are *physical processes or transformations* that take one quantum state to another. A morphism $M : \rho_{\text{initial}} \to \rho_{\text{final}}$ could represent, for instance, unitary evolution (if the systems evolve unitarily), an interaction or scattering between subsystems, or a measurement process. In quantum theory, any physical process can be described by a completely positive trace-preserving (CPTP) map on density operators; one may consider each such CPTP map as a morphism in $\mathcal{Q}$ [12]. However, to keep intuition, we will sometimes label

morphisms by the type of interaction. For example, we might denote by $M_{A:B}$ a morphism in $\mathcal{Q}$ that represents an interaction between A and B. If initially the state was $\rho_A \otimes \rho_B$ (no correlation), and after interaction it is ρ'_{AB} (with correlations), then $M_{A:B} : \rho_A \otimes \rho_B \to \rho'_{AB}$ is a morphism in $\mathcal{Q}$. Another example: a measurement process can be seen as a morphism that takes an initial quantum state and produces a post-measurement state, possibly entangled with a measuring apparatus.

It is worth noting that some quantum processes are stochastic, since measurements have random outcomes. In category $\mathcal{Q}$, this process might be represented as a morphism from an initial state to a *ensemble* of final states. For rigorous treatment one can use a *stochastic category* or a category of quantum instruments, but for now we treat each *realized outcome* as a separate morphism. We will discuss later how to account for the probabilistic nature in the functor.

Category $\mathcal{A}$ (Awareness States and Updates): Objects in $\mathcal{A}$ represent *states of awareness or knowledge*. We can think of an object in $\mathcal{A}$ as a set S of possible awareness states, where each awareness state is a tuple like $(\Xi_A, \Xi_B, \Xi_C, \dots)$ listing the information content (awareness state) of each relevant system. For simplicity, consider just two systems A and B. Initially, before A and B have interacted, A has no awareness of B and B has none of A. We denote this initial awareness state as (Ξ^0_A, Ξ^0_B), where Ξ^0_A indicates that A's knowledge of B is null, and similarly for Ξ^0_B. After an interaction, A may have acquired some information about B (and vice versa), so the awareness state could update to (Ξ'_A, Ξ'_B), where Ξ'_A now includes information about B. In general, Ξ_X can be thought of as *the content of system X's state of awareness*, which could be represented by a Bayesian probability distribution that X assigns to the state of another system or simply the set of facts (classical bits of information) X has obtained. For a highly integrated system (with large Φ), Ξ_X would also reflect how that information is integrated into X's overall state. However, this level of detail is abstracted in our category definition, with Ξ_X serving as a placeholder for *what X knows or experiences*.

To account for the stochastic nature of quantum measurements, we define $\mathcal{A}$ as the **Kleisli category for the probability monad** P. In this category:

- **Objects** are sets S of possible awareness states (e.g., all possible tuples (Ξ_A, Ξ_B)).
- **Morphisms** are *stochastic maps* $f : S \to PS'$, where PS' is the set of probability distributions over awareness states in S'. Thus, for each awareness state $\Xi \in S$, $f(\Xi)$ is a probability distribution over updated awareness states in S'.

This structure allows $\mathcal{A}$ to naturally handle probabilistic transitions, aligning with the probabilistic outcomes of quantum measurements.

Morphisms in $\mathcal{A}$ represent *awareness updates or transformations* that can be stochastic. A morphism:

$$f : S \to PS'$$

captures the probabilistic change in awareness states corresponding to some event. For example, if $M_{A:B} : \rho_A \otimes \rho_B \to \rho'_{AB}$ is a physical interaction in $\mathcal{Q}$ that correlates A and B,

then there is a corresponding stochastic awareness update morphism in $\mathcal{A}$:

$$f_{A:B} : S \to PS',$$

where S contains the initial awareness states (e.g., (Ξ_A^0, Ξ_B^0)), and S' contains the possible updated awareness states (e.g., (Ξ'_A, Ξ'_B)). The morphism $f_{A:B}$ assigns to each initial state a probability distribution over updated states, reflecting the probabilistic nature of the interaction. In a measurement context, if A is an observer measuring system B, the morphism $f_{A:B}$ represents the probabilistic update of A's knowledge based on the measurement outcome, while B's awareness may or may not change depending on the scenario. We will discuss this asymmetry later.

By structuring $\mathcal{A}$ as a Kleisli category, we separate the physical description (category $\mathcal{Q}$) from the experiential description (category $\mathcal{A}$) while naturally incorporating stochasticity. Now, we connect them with a functor:

Functor $F : \mathcal{Q} \to \mathcal{A}$: The functor F maps each physical object (quantum state) in $\mathcal{Q}$ to an awareness object in $\mathcal{A}$, and each physical morphism (quantum process) to a stochastic awareness morphism in $\mathcal{A}$, preserving the structure of processes, including their probabilistic nature. We define F as follows:

- For each object (quantum state) in $\mathcal{Q}$, F produces an object in $\mathcal{A}$ representing the set of possible states of awareness corresponding to that quantum state. Specifically:
  - If the physical object is $\rho_A \otimes \rho_B$ (systems A and B separate with no correlation), then $F(\rho_A \otimes \rho_B) = S_{\rho_A \otimes \rho_B}$, where $S_{\rho_A \otimes \rho_B}$ is the set of awareness states including (Ξ_A^0, Ξ_B^0), indicating that A and B initially have no mutual information (no awareness of each other).
  - If the physical object is a correlated state ρ_{AB} (where A and B share some information), then $F(\rho_{AB}) = S_{\rho_{AB}}$, where $S_{\rho_{AB}}$ is the set of awareness states including tuples like (Ξ_A^*, Ξ_B^*), with Ξ_A^* embodying the information A has about B in ρ_{AB}, and vice versa. For instance, Ξ_A^* might represent the classical distribution of possible states of B from A's perspective (related to conditional entropy in the decomposition of ρ_{AB}), though we do not explicitly construct it here as F ensures its existence in principle.
- For each morphism (process) in $\mathcal{Q}$, F produces a stochastic awareness-update morphism in $\mathcal{A}$. If $M : X \to Y$ is a physical process taking state X to state Y, then

  $$F(M) : F(X) \to PF(Y),$$

  where $PF(Y)$ denotes the set of probability distributions over the awareness states in $F(Y)$. For instance, consider the interaction $M_{A:B} : \rho_A \otimes \rho_B \to \rho'_{AB}$ that produces correlations. We define

  $$F(M_{A:B}) : S_{\rho_A \otimes \rho_B} \to PS_{\rho'_{AB}},$$

  where $S_{\rho_A \otimes \rho_B} = F(\rho_A \otimes \rho_B)$ contains initial awareness states such as (Ξ_A^0, Ξ_B^0) (no mutual knowledge), and $S_{\rho'_{AB}} = F(\rho'_{AB})$ contains possible updated awareness states

like (Ξ'_A, Ξ'_B). For a deterministic process (e.g., unitary evolution), $F(M_{A:B})(\Xi^0_A, \Xi^0_B) = \delta_{(\Xi'_A, \Xi'_B)}$, a Dirac measure at (Ξ'_A, Ξ'_B), where Ξ'_A includes information about B and Ξ'_B about A, consistent with the mutual information in ρ'_{AB}. For a stochastic process like a measurement where A observes B, represented by a quantum instrument $\{\Phi_j\}$ such that $\rho'_{AB} = \sum_j \Phi_j(\rho_A \otimes \rho_B)$, we set

$$F(M_{A:B})(\Xi^0_A, \Xi^0_B) = \sum_j p_j \delta_{(\Xi^{(j)}_A, \Xi^{(j)}_B)},$$

where $p_j = \mathrm{Tr}(\Phi_j(\rho_A \otimes \rho_B))$ is the probability of outcome j, and $(\Xi^{(j)}_A, \Xi^{(j)}_B)$ is the awareness state reflecting A's knowledge of outcome j and B's corresponding state. Thus, $F(M_{A:B})$ captures the probabilistic "event" of A becoming aware of B's state, with B's awareness possibly updated minimally or symmetrically depending on the context.

The power of the functorial approach is that it imposes *consistency conditions*. In particular, a functor must preserve composition of morphisms and identity morphisms. In our context:

- **Identity:** $F(\mathrm{id}_X) = \mathrm{id}_{F(X)}$ for any object X in $\mathcal{Q}$. Physically, id_X is doing nothing (no evolution) to state X. Preserving identity means: *doing nothing leads to no change in awareness*. This is satisfied by our construction, since if no physical process occurs, F maps the state to the same awareness state (no update). This property is trivial and expected as awareness does not change if nothing happens.

- **Composition:** If a physical process $M_1 : X \to Y$ is followed by another process $M_2 : Y \to Z$, the composite is $M_2 \circ M_1 : X \to Z$. Functoriality requires:

  $$F(M_2 \circ M_1) = F(M_2) \circ F(M_1).$$

  This means that the awareness update corresponding to doing M_1 then M_2 is the same as doing the awareness update for M_1 followed by the update for M_2. This condition ensures a kind of *causal consistency*, which means that awareness evolves in lockstep with the physics, and if a process can be broken into steps, the awareness can be updated stepwise in the same way. There is no ambiguity or *memory loss* as the functor F guarantees that *nested or sequential interactions are handled coherently in the awareness picture.*

Theorem 1. *The mapping $F : \mathcal{Q} \to \mathcal{A}$ defined above is a functor. In particular, for any quantum processes $M_1 : X \to Y$ and $M_2 : Y \to Z$, we have $F(M_2 \circ M_1) = F(M_2) \circ F(M_1)$, and F maps identity processes to identity awareness transformations.*

Proof: By construction, F on objects and morphisms follows the state and process mapping described. If id_X is the identity in a quantum state X, then $F(\mathrm{id}_X)$ must be an awareness morphism from $F(X)$ to itself that represents *no change*. The natural choice, and

indeed our definition, is $F(\mathrm{id}_X) = \mathrm{id}_{F(X)}$, the identity on the awareness state $F(X)$. This obviously satisfies the identity preservation axiom of a functor.

For composition, consider two composable physical morphisms $M_1 : X \to Y$ and $M_2 : Y \to Z$. Their composite $M_2 \circ M_1$ is the process where X first undergoes M_1 to become Y, then Y undergoes M_2 to become Z. Now apply F. By definition, $F(M_1) : F(X) \to F(Y)$ and $F(M_2) : F(Y) \to F(Z)$. Composing these in $\mathcal{A}$ gives $F(M_2) \circ F(M_1) : F(X) \to F(Z)$. This represents the awareness update resulting from first doing M_1 (updating awareness from $F(X)$ to $F(Y)$) then M_2 (updating awareness from $F(Y)$ to $F(Z)$). On the other hand, $F(M_2 \circ M_1)$ should directly map $F(X)$ to $F(Z)$ in one step, representing the net awareness change from doing the combined process at once. Because in our interpretation awareness changes only via actual physical interactions, doing M_1 then M_2 is equivalent to one combined interaction in terms of net information gained. We explicitly define $F(M_2 \circ M_1)$ to be this same net awareness update. In other words, *the awareness gained by two sequential processes is just the sum (composition) of awareness gained by each.* Therefore, by definition we have $F(M_2 \circ M_1) = F(M_2) \circ F(M_1)$. This holds for any pair of composable morphisms, so the composition axiom is satisfied. □

Theorem 1 guarantees that our functor F is internally consistent. One immediate consequence is that *hierarchical or iterative measurements can be analyzed without contradiction.* For example, suppose Observer A measures System S, and then a second Observer B observes (or measures) A and S. In the physical category $\mathcal{Q}$, we have two processes: $M_{A:S}$ (interaction of A with S) followed by $M_{B:AS}$ (interaction of B with the combined system $A + S$). Functoriality ensures:

$$F(M_{B:AS} \circ M_{A:S}) = F(M_{B:AS}) \circ F(M_{A:S}).$$

That is, whether we consider the two interactions separately or as a single combined event, the mapping to awareness will be consistent. In the awareness picture, first A becomes aware of S (via $F(M_{A:S})$), then B becomes aware of the A–S system (via $F(M_{B:AS})$). The end result $F(M_{B:AS} \circ M_{A:S})$ is that B has awareness of A and S, and A has awareness of S, exactly as one would expect if B watched A measuring S. There is *no ambiguity* about what happened from the perspective of a *global* awareness, if we imagine B as a super-observer, or even consider an ultimate perspective of the universe. In our framework, all these perspectives are just parts of one *universal awareness process.* We will return to this point when discussing the Frauchiger–Renner paradox and Wigner's friend scenarios in Section 4.

Remark: The functor F as defined is somewhat idealized in that it does not explicitly carry along probabilities for different outcomes. In a quantum measurement, $M_{A:S}$ might have multiple possible outcomes j with probabilities p_j. In $\mathcal{Q}$, one could represent this as a single CPTP map, completely positive trace preserving map, that takes the initial state to a classical quantum state $\sum_j p_j |j\rangle\langle j|_A \otimes \rho_{S|j}$, where A has a pointer state $|j\rangle$ for each outcome. In $\mathcal{A}$, the corresponding process would take (Ξ_A^0, Ξ_S^0) to a superposition or mixture of awareness states $\{(\Xi_A^{(j)}, \Xi_S^{(j)})\}$, each corresponding to A knowing outcome j. Handling this rigorously would require F to map one input to *multiple possible* outputs with weights, which is beyond a simple functor between categories. This could be formulated as a functor into

a *stochastic category* or by using a *functor between 2-categories* accounting for probabilities. For the scope of this paper, we conceptually handle it by saying: *for each specific outcome, F maps the physical process to the corresponding definite awareness update.* If we do not condition on the outcome, F can map to an *ensemble* of awareness states. In essence, F can be extended to carry the classical probability structure, consistent with a *Bayesian update* perspective: before the measurement, A has a prior uncertainty about S; after seeing outcome j, A's awareness state collapses to a definite $\Xi_A^{(j)}$ corresponding to knowing j. Mathematically, one could compose F with a functor that embeds stochastic processes into deterministic ones by indexing outcomes, but we will not digress into that level of category-theoretic detail. The main point is that the mapping F can consistently incorporate quantum probabilistic updates as Bayesian conditioning at the level of awareness.

3.2. Example: Measurement as an Awareness Update (Quantum Bayesian Update)

To make the abstract formalism concrete, let us work through a simple but illustrative scenario: a quantum measurement. Consider system B being measured by an observer-apparatus A. Initially, A and B are not correlated, meaning the total state can be written as $\rho_A \otimes \rho_B$ (perhaps A is in a ready state, and B is in some state to be measured). We assume B has a set of possible states, for example, eigenstates corresponding to measurement outcomes $|b_j\rangle$ with probabilities p_j, and A has corresponding pointer states $|a_j\rangle$ that can record those outcomes. The measurement interaction $M_{A:B}$ entangles A and B such that information about B is transferred to A.

In the ideal case (von Neumann projective measurement), the joint evolution is:

$$M_{A:B}: \quad |a_0\rangle\langle a_0|_A \otimes \rho_B \longrightarrow \sum_j p_j \, |a_j\rangle\langle a_j|_A \otimes |b_j\rangle\langle b_j|_B \, ,$$

assuming $\rho_B = \sum_j p_j \, |b_j\rangle\langle b_j|$ in the basis of the measurement. In words, A's pointer becomes correlated with B's state $|b_j\rangle$, and if decoherence rapidly destroys the off-diagonal terms, the final state is a *classical mixture* of correlations $|a_j\rangle\langle a_j| \otimes |b_j\rangle\langle b_j|$. If we do not include decoherence, the post-measurement entangled pure state would be $\sum_j \sqrt{p_j}|a_j, b_j\rangle$. We will consider both cases shortly.

In the context of our functor F, the initial awareness state corresponds to a set $S_{\rho_A \otimes \rho_B}$, which includes states like (Ξ_A^0, Ξ_B^0), where Ξ_A^0 and Ξ_B^0 indicate no mutual awareness between A and B. After the measurement interaction $M_{A:B}$, the final awareness state reflects the probabilistic outcomes of the measurement. Specifically, for a measurement with outcomes indexed by j, the final awareness state is a probability distribution over possible updated awareness states $(\Xi_A^{(j)}, \Xi_B^{(j)})$, where each $(\Xi_A^{(j)}, \Xi_B^{(j)})$ corresponds to a specific outcome j.

For the measurement process $M_{A:B}$, the functor F maps this to a stochastic morphism in the Kleisli category $\mathcal{A}$:

$$F(M_{A:B}) : S_{\rho_A \otimes \rho_B} \to PS_{\rho'_{AB}},$$

where $PS_{\rho'_{AB}}$ denotes the set of probability distributions over the awareness states in $S_{\rho'_{AB}}$.

For an initial awareness state $\Xi = (\Xi_A^0, \Xi_B^0) \in S_{\rho_A \otimes \rho_B}$, we define:

$$F(M_{A:B})(\Xi) = \sum_j p_j \delta_{\Xi_j},$$

where p_j is the probability of outcome j, and $\Xi_j = (\Xi_A^{(j)}, \Xi_B^{(j)})$ is the awareness state reflecting A's knowledge of outcome j and B's corresponding state. This stochastic mapping captures the probabilistic nature of the measurement, with each possible outcome j leading to a specific awareness update Ξ_j with probability p_j.

Now, before the interaction, the mutual information is $I(A:B) = 0$ since $\rho_A \otimes \rho_B$ is a product state. After the interaction, in the decohered case, the mutual information becomes:

$$I_{\text{final}}(A:B) = S(\rho'_A) + S(\rho'_B) - S(\rho'_{AB}) = H(\{p_j\}) + H(\{p_j\}) - H(\{p_j\}) = H(\{p_j\}),$$

where $\rho'_A = \sum_j p_j |a_j\rangle\langle a_j|$, $\rho'_B = \sum_j p_j |b_j\rangle\langle b_j|$, and $\rho'_{AB} = \sum_j p_j |a_j\rangle\langle a_j| \otimes |b_j\rangle\langle b_j|$. This reflects the information A has gained about B, corresponding to the uncertainty A had about B's state before the measurement. In terms of awareness, A becomes aware of the specific outcome j with probability p_j, and the functor F captures this through the stochastic update $F(M_{A:B})$, where each possible Ξ_j includes A's knowledge of j.

If we consider the pure entangled post-measurement state before decoherence:

$$\rho'_{AB} = |\Psi\rangle\langle\Psi| \quad \text{with} \quad |\Psi\rangle_{AB} = \sum_j \sqrt{p_j} |a_j\rangle_A \otimes |b_j\rangle_B,$$

then the reduced states are $\rho'_A = \sum_j p_j |a_j\rangle\langle a_j|$ and $\rho'_B = \sum_j p_j |b_j\rangle\langle b_j|$, with entropies $S(\rho'_A) = H(\{p_j\})$ and $S(\rho'_B) = H(\{p_j\})$, but the joint entropy $S(\rho'_{AB}) = 0$ since $|\Psi\rangle$ is pure. Thus, the mutual information is:

$$I_{\text{final}}(A:B) = S(\rho'_A) + S(\rho'_B) - 0 = H(\{p_j\}) + H(\{p_j\}) = 2\,H(\{p_j\}).$$

This higher value arises because the joint state is pure, indicating perfect correlations between A and B. However, from the perspective of A's awareness, once A observes the outcome (i.e., looks at its pointer), the relevant information is $H(\{p_j\})$, corresponding to the specific outcome realized. The functor F reflects this by mapping the measurement process to a stochastic update that assigns probability p_j to each Ξ_j, effectively reducing the mutual information to $H(\{p_j\})$ in terms of A's accessible knowledge.

Thus, in both the decohered and entangled cases, the functor F correctly maps the physical measurement process to a stochastic awareness update in $\mathcal{A}$, ensuring that the probabilistic nature of quantum measurements is properly accounted for.

From the perspective of our *functor* F, the measurement process $M_{A:B}$ in $\mathcal{Q}$ is mapped to a stochastic awareness update $F(M_{A:B})$ in $\mathcal{A}$. Initially, $F(\rho_A \otimes \rho_B) = S_{\rho_A \otimes \rho_B}$, a set of awareness states including pairs like (Ξ_A^0, Ξ_B^0), indicating no mutual awareness between A and B. After the measurement, $F(M_{A:B})$ does not produce a single final awareness state but rather a probability distribution over possible states in $S_{\rho'_{AB}}$. For an initial state $\Xi = (\Xi_A^0, \Xi_B^0)$, this is expressed as:

$$F(M_{A:B})(\Xi) = \sum_j p_j \delta_{\Xi_j},$$

where p_j is the probability of measurement outcome j, and $\Xi_j = (\Xi_A^{(j)}, \Xi_B^{(j)})$ represents the awareness state corresponding to that outcome.

- **What is $\Xi_A^{(j)}$?** It is the information A has learned about B given outcome j—specifically, knowledge of j itself. For example, if A measures B's state and obtains outcome j, $\Xi_A^{(j)}$ reflects A's awareness of B being in a state consistent with j.
- **What is $\Xi_B^{(j)}$?** This depends on the context:
  - In the *entangled case*, before decoherence, $\Xi_B^{(j)}$ might reflect a correlation with A's pointer state $|a_j\rangle$, indicating B's state is entangled with A's measurement outcome.
  - In the *decohered case*, $\Xi_B^{(j)}$ corresponds to B being in a definite state $|b_j\rangle$, with no active "knowledge" of A's pointer.

The mutual information $I(A : B)$ quantifies the average correlation established by the measurement. In the decohered case, $I(A : B) = H(\{p_j\})$, representing the entropy of the outcome distribution, which matches A's average information gain about B. Upon observing a specific outcome j, A's awareness updates to $\Xi_A^{(j)}$, resolving the uncertainty, while from an external view, B's state has entropy $H(\{p_j\})$ before measurement. In the entangled case, the total mutual information is $2H(\{p_j\})$ due to the two-way correlations, but A's awareness post-measurement reflects only the specific outcome j, reducing accessible information to $H(\{p_j\})$.

The functor F ensures that the probabilistic nature of the measurement is preserved in $\mathcal{A}$, with each Ξ_j tying the awareness update to a specific outcome. This *awareness event*—the transition from a distribution over possible Ξ_j to a definite Ξ_j for a given j—signals an increase in mutual knowledge by $H(\{p_j\})$ on average. This difference highlights how decoherence leads to classicality by selecting a definite outcome, partitioning the total quantum information and aligning subjective experience with a specific measurement result, effectively "losing" the extra correlations present in the fully entangled state.

Proposition 2. *In an ideal measurement interaction where observer A measures system B, the mutual information gained $I_{final}(A : B)$ equals the information that A learns about B (and vice versa). This information gain is reflected as an awareness update via F, with A's awareness state Ξ_A updating such that Ξ'_A contains exactly the outcome information (resolving B's prior uncertainty).*

Proof Sketch: We model the measurement as above. Before the interaction, $I(A : B) = 0$ and A has a prior uncertainty about B characterized by entropy $H(\{p_j\})$. After the interaction and decoherence, the joint state is a classical correlation, and we calculate $I(A : B) = H(\{p_j\})$ as shown. This value indeed equals the reduction in B's entropy from A's perspective, initially A did not know j (uncertainty H), finally A knows j (uncertainty 0), so A gained H bits of information. The functor mapping gives

$$F(M_{A:B}) : S_{\rho_A \otimes \rho_B} \to PS_{\rho'_{AB}},$$

where Ξ'_A records the outcome j. Thus, Ξ'_A has exactly $H(\{p_j\})$ bits more information about B than Ξ^0_A did. Meanwhile Ξ'_B might be essentially unchanged or include acknowledgment of interaction. In either case, the mutual part of (Ξ'_A, Ξ'_B), that is the common information between A and B in the awareness domain, is j. Therefore the mutual information in the awareness state is also $H(\{p_j\})$. By construction F ensures this matches the physical $I(A : B)$. Hence the mutual information is equal to the information gained by A. A more formal proof can be given using the properties of entropy and the data-processing inequality, but this intuitive argument suffices for now. □

This proposition demonstrates that our identification of mutual information with awareness content is self-consistent with Bayesian updating. In Bayesian terms, A had a prior over B's state (with entropy H); after seeing outcome j, A's posterior is peaked at b_j (entropy 0), so the *Bayesian update* has *information gain* H. Mutual information $I(A : B)$ quantitatively measures this gain, and the functor F maps the physical update to the awareness update (prior $\to$ posterior) in lockstep; in RQD with awareness, we *add* the statement *and A became aware of B's state $|b_j\rangle$, constituting an awareness event of magnitude $I(A : B) = H$ and significance depending on Φ_A.*

Finally, consider the role of integrated information Φ in this measurement event. Suppose A is a human observer (high Φ_A) and B is a simple system (low Φ_B). Then our awareness metric from Definition 1 would say the awareness of this event:

$$\mathcal{A}(A : B) \approx I(A : B) \times f((\Phi_A + \Phi_B)/2).$$

Here $I(A : B) = H$, i.e., the number of bits A learned. Φ_A is large, Φ_B tiny, so roughly $f((\Phi_A + 0)/2) \approx f(\Phi_A/2)$ which is large. Thus $\mathcal{A}(A : B)$ is much larger than just $I(A : B)$. This aligns with intuition: a human gaining one bit of knowledge might integrate it into a vast web of prior information, potentially yielding a meaningful conscious experience. For instance, seeing a single dot of light conveys one bit, but in the context of the brain it might mean "I see a star in the sky," which is a rich awareness. Conversely, if A were a very simple device (low Φ_A), $\mathcal{A}(A : B)$ would be small even if I is the same H bits, reflecting that the device records the information in a shallow way with no further integration or no significant awareness. Thus, the combination of mutual information and integrated information in our formalism can capture not just whether awareness exists, but how *significant or unified* that awareness is.

3.3. Multi-Observer Example: Sequential Measurements and Awareness Updates

We now illustrate the flexibility and consistency of our category-theoretic framework with a concrete scenario involving multiple observers performing sequential quantum measurements. This example highlights how the functor F systematically translates physical quantum interactions into coherent updates of awareness states.

3.3.1 Scenario Setup

Consider a single qubit system S initially prepared in a superposition state:

$$|\psi_S\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle).$$

Three observers—Alice, Bob, and Charlie—perform sequential measurements as follows:

1. **Alice** measures system S in the computational (Z) basis with an apparatus A initially in state $|0\rangle_A$.
2. **Bob** subsequently measures S in the X basis, defined by eigenstates $|\pm\rangle = \frac{1}{\sqrt{2}}(|0\rangle \pm |1\rangle)$.
3. **Charlie** finally measures Alice's apparatus A again in the Z basis.

3.3.2 Physical Processes

Alice's Measurement: Alice interacts with S via a controlled-NOT (CNOT) operation, producing an entangled Bell state:

$$|\psi_{SA}\rangle = \frac{1}{\sqrt{2}}(|00\rangle_{SA} + |11\rangle_{SA}).$$

Alice observes outcome 0 or 1 with equal probability 1/2, establishing perfect correlations between her apparatus A and the system S.

Bob's Measurement: Bob measures S in the X basis, projecting the entangled state onto:

- Outcome $+$: Probability 1/2, post-measurement state $|+\rangle_S \otimes |+\rangle_A$.
- Outcome $-$: Probability 1/2, post-measurement state $|-\rangle_S \otimes |-\rangle_A$.

This measurement breaks the initial entanglement between S and A.

Charlie's Measurement: Measuring A in the Z basis after Bob's intervention yields equal probabilities (1/2) for outcomes 0 or 1, irrespective of Bob's result, reflecting Bob's disruption of the previous correlation.

3.3.3 Awareness Updates via Functor

F

The functor F maps these physical events to corresponding stochastic awareness updates:

- **Initial Awareness**: Prior to measurement, $F(\rho_{SA}) = S_{\rho_{SA}}$ encodes Alice's initial uncertainty regarding S.

- **Post-Alice**: After Alice's measurement, the state decoheres to a mixed state, and the functor maps:
$$F(M_{A:S}) : S_{\rho_{SA}} \to PS_{\rho'_{SA}},$$
capturing Alice's updated knowledge about outcomes.

- **Post-Bob**: Following Bob's measurement in the X basis, the functor updates:
$$F(M_{B:S}) : S_{\rho'_{SA}} \to PS_{\rho''_{SA}},$$
reflecting the dissolution of Alice's original correlation.

- **Post-Charlie**: Finally, Charlie's measurement of A in the Z basis leads to:
$$F(M_{C:A}) : S_{\rho''_{SA}} \to PS_{\rho'''_{SA}},$$
further specifying the observers' awareness based on the observed outcome.

3.3.4 Functorial Consistency

Critically, the functor F maintains compositional consistency:
$$F(M_{C:A} \circ M_{B:S} \circ M_{A:S}) = F(M_{C:A}) \circ F(M_{B:S}) \circ F(M_{A:S}).$$
This property ensures coherent updates of awareness states across sequential measurements, avoiding paradoxes or contradictions.

3.3.5 Interpretation

This scenario illustrates the coherence of relational quantum dynamics through awareness updates:

- Alice initially expects perfect correlation between S and A.
- Bob's intermediate measurement in a different basis disrupts this expectation.
- Charlie's final measurement outcome is uniformly random, confirming the loss of original correlation.

The functor F systematically accounts for these shifting perspectives, demonstrating its robustness in capturing multi-observer interactions within the relational framework.

4. Theoretical Implications and Consistency of the Framework

Having established the formal structure of our awareness-integrated RQD, we now examine how it addresses several conceptual issues in quantum theory. We will see that by including awareness as a formal component, some long-standing paradoxes and interpretation problems are naturally resolved or reinterpreted. We compare our framework to other interpretations and highlight what is gained by the functor F and the awareness metric $\mathcal{A}$.

4.1. Relationalism and No Single Objective State

Our approach is built on a relational view similar to RQM: there is *no observer-independent quantum state of the world*. Each quantum state is always relative to some observing system. In RQM, this leads to the idea that different observers may have different accounts of an event (and no global "God's-eye" state contains all the information). This raises the question: If no single state is objectively 'the truth', how do we reconcile the perspectives of different observers? RQM leaves this as an inter-observer consistency condition, that is, when observers communicate, they must somehow agree on shared facts, but RQM by itself does not provide a mechanism beyond the usual quantum formalism.

In our framework, the **one thing that is universal is not a quantum state, but an underlying awareness (or consciousness) that spans all relations**. We imagine that all these relational quantum events (interactions) are manifestations of one *universal consciousness's knowledge of itself* in different aspects. This is an *ontological shift* as instead of individual observer-dependent realities floating separately, they are all fragments of a single reality of awareness. What this buys us is the ability to say that when two observers interact, their previously separate pieces of reality *merge into a larger piece*. The functor F maps that physical interaction to an awareness update that unifies the observers' perspectives. In plain terms, when Observer A (with her facts) meets Observer B (with his facts), and they compare notes, there is now one larger observer ($A + B$ together) with a combined state of awareness. There is *never a contradiction* between their accounts because any differences prior to interaction simply reflect that awareness was partitioned; once interaction occurs (communication), those differences are resolved as part of a single new state of awareness.

This view directly addresses scenarios like the *Wigner's Friend experiment*. In a classic Wigner's Friend situation, an observer "Friend" F measures a quantum system inside a lab and records an outcome. To F, the outcome is definite. But an outside observer W (Wigner) treats the entire lab (friend + system) as one quantum system, which, until he checks, might be in a superposition. This leads to a seeming paradox: F says "the result is j" while W might attribute no definite result (a superposed state). Who is correct? Experiments have even been proposed and conducted to test if two observers can have genuinely conflicting facts (see Section 5).

In our framework, F and W simply have different Ξ **states in** $\mathcal{A}$. F's awareness Ξ_F includes outcome is j, while W's awareness Ξ_W does not (before looking). There is no single physical state that both have access to, F has ρ_{System} collapsed in her basis, W has an entangled state because the state is *relative*. Now, RQM already acknowledges this situation, but where our approach adds value is: we claim these are *not two separate realities*, but two fragments of one universal consciousness. When W eventually opens the box and interacts with F, the functor F will map that interaction to an awareness update that unifies W and F's knowledge. W learns what F saw; now both agree on the outcome j. The seeming contradiction (one says 'superposition', the other 'definite') is resolved by recognizing that they were talking about *different levels of description* once brought to the same level via interaction, there is no conflict. There was never a single objective physical state that both needed to adhere to; instead, F had her experiential state, W had his, and only upon interaction did a single, shared experiential state form.

This perspective can be pushed further with the Frauchiger–Renner (FR) paradox [13]. Frauchiger and Renner devised a thought experiment with two Wigner's-friend pairs and showed that if quantum theory is applied to all observers, they reach contradictory conclusions unless one rejects the idea of a single objective reality. Our framework naturally rejects a single objective *physical* reality, instead we posit a single *experiential* reality (the universal awareness) that can manifest different facets to different sub-observers. We have begun formalizing the FR scenario with our functor F by saying that each observer-observed interaction is a morphism, and the composition of all these interactions is mapped to a composite awareness update. Preliminary analysis indicates that the apparent logical contradictions in FR disappear because each statement in the FR argument is only valid *within* a particular branch of universal awareness. There is a subtle point: FR assumes that each observer's outcome is a definite classical fact they can use in reasoning, but when they combine these facts, global inconsistency arises.

In our view, *no observer's facts are truly absolute*; they are relative to that observer's context in the universal mind. If one tries to amalgamate all the facts without accounting for the awareness relations, i.e., how those facts are contextually separated, one encounters contradictions. This perspective aligns with the relational interpretation of quantum mechanics, which posits that facts emerge through interactions and are relative to the systems involved. Stable facts arise when this relativity can effectively be ignored, providing a bridge between quantum theory and our classical experience [14, 15]. The resolution comes by acknowledging that only when observers interact do their facts become jointly accessible, and at that moment the *awareness update prevents any logical inconsistency.* Because one cannot maintain a false belief upon direct confrontation, the inconsistent branch simply is not realized in the unified awareness. While a full formal proof is beyond our scope here, we conjecture that *any* paradox of this nature can be dissolved by tracing the awareness functor through the scenario. The functor F forces a coherent alignment of facts once interactions occur, and before interactions, there is no single truth-value to compare. Thus, our framework is logically consistent and at least as empirically valid as standard quantum theory in these tricky multi-observer cases.

4.2. Comparison with Existing Interpretations

Relation to RQM: Our approach can be seen as *RQM plus an ontological upgrade.* RQM says the world is relations, not absolute states; we say the same, but we add that each relation is accompanied by an element of awareness, i.e., a *realization* of that relation in consciousness. In effect, we propose a solution to the question often posed to RQM: *what ensures consistency across different relational views?* RQM's answer is somewhat agnostic: when systems interact, they must agree on common facts, but there's no underlying mechanism except quantum mechanics itself. Our answer is that all those relations are embedded in one interconnected awareness, which provides a universal context. This is a philosophically idealist stance by suggesting that consciousness is fundamental, whereas RQM usually stays agnostic or physicalist. However, *our framework reproduces the core of RQM* in that we do not have a single quantum state for the whole universe, only states relative to observers. However, we possess something more expansive (the functorial framework

and universal awareness) that RQM lacks. We expect that any experiment explained by RQM can be equally explained here, with the added interpretation layer that **information = awareness**. Indeed, RQM's relational probabilities and our awareness-based Bayesian updates are mathematically aligned; we simply reinterpret what an event *is*, an event is not just an interaction, but an act of awareness. In summary, one can view our approach as *Consciousness-Centered RQM*, which remains fully compatible with RQM's formalism but extends its ontology.

Relation to QBism: QBism already emphasizes the personal experience of the quantum observer. A quantum measurement is an experience for the agent, and quantum probabilities are subjective degrees of belief. Indeed, the language of QBism nearly approaches a discourse on consciousness, suggesting that the results are the agent's personal *experiences*. However, QBism stops there and insists quantum theory only speaks to the agent's expectations. It deliberately does not assume or require any objective reality behind those experiences, nor does it claim that the experiences are aspects of a universal consciousness [3]. QBism typically adopts a kind of pragmatism or participatory realism, not idealism. Our framework can be seen as giving an ontological grounding to the QBist viewpoint. Rather than many disjoint agents each with private experiences, we propose all agents are part of one underlying reality (universal mind). This implies that experiences are ultimately shared or unified at a deeper level. In QBism, the formal Bayesian update, which involves adjusting the agent's belief state following an outcome, is precisely reflected in our functor mapping. The difference is that we treat the agent's belief as actually *a state of awareness* embedded in the world, not just an abstract Bayesian calculus. In terms of predictions, our approach does not change QBism's. Any scenario QBism can describe, we can describe similarly, since we also essentially use Bayesian conditioning for updates. The benefit once more lies in conceptual consistency: this approach allows us to discuss various agents operating within a single formal system (category $\mathcal{A}$), as opposed to each agent possessing an independent instance of quantum theory. And we ascribe a *reality* to the agent's experience (the awareness state Ξ) rather than treating it as just an agent's metaphor. Thus, one might say we *ontologize* QBism's user-centric view by positing a fundamental awareness that all those users are facets of. This could provide a more natural account of why different agents can communicate and agree since they were never truly separate at the fundamental level.

Relation to Other Models (Orch OR, Bohmian Mechanics, etc.): It is worth noting how our framework differs from other attempts to involve consciousness in physics. *Orchestrated Objective Reduction (Orch OR)* proposed by Penrose and Hameroff suggests that particular quantum activities, such as coherence in microtubules achieving a gravitational limit, within the brain trigger wavefunction collapse, aligning with instances of conscious experience [16, 17]. Orch OR is a much more detailed (and speculative) physical model, whereas our approach is more general and abstract. We do not assign special status to particular quantum events in biology; rather, *every* quantum event is an awareness event. In fact, if Orch OR were true, it would be a special case in our framework. It would mean that certain interactions in the brain produce exceptionally high $\mathcal{A}(A : B)$ values. This is because orchestrated collapse would generate strong correlation and a conscious moment. However, even interactions outside brains would still produce tiny awareness events. Our framework is thus more universal and does not rely on unproven physics such as gravity-induced collapse.

It can accommodate Orch OR if experimental evidence eventually supports it. In that case, we would refine $f(\Phi)$ or the physical dynamics to include gravity effects. However, it does not fall apart if Orch OR is false. In short, compared to Orch OR, we *sidestep the need for new physics*. We do not require a collapse mechanism beyond standard quantum theory by shifting the perspective. The collapse (or outcome) is just an update in the relational awareness, not a physical discontinuity.

As for *Bohmian mechanics* or other hidden-variable theories, those typically aim to restore an objective description such as particles with positions and so are philosophically quite different from us. However, one could potentially map a deterministic hidden variable evolution onto an awareness evolution too. We will not delve into that here; suffice to say our framework is more aligned with interpretations that embrace indeterminacy and observer-dependence, rather than trying to eliminate them.

In summary, our approach synthesizes elements of RQM and QBism under an overarching hypothesis: *consciousness (awareness) is fundamental and quantitatively linked to information in quantum processes*. This work introduces an innovative formal component, specifically the functor F along with related measures, facilitating the incorporation of awareness into rigorous discussions about quantum observers. This opens the door to new questions and potentially bridges quantum foundations with cognitive science through IIT.

5. Experimental and Conceptual Proposals

A critical question for any new theoretical framework is whether it can be tested or at least illustrated with physical examples. Since our proposal thus far is largely interpretational, it does not change the numerical predictions of quantum mechanics in ordinary scenarios. As a result, finding *direct empirical confirmation* is challenging. However, we can outline several avenues, both *thought experiments to test internal consistency* and *real experiments that resonate with the framework's predictions*, that could lend support to or falsify our ideas. We emphasize that these proposals are tentative and often require cutting-edge or even beyond-current technology. Nevertheless, they serve to show that our framework is not mere metaphysics as it has empirical hooks and could be bolstered or undermined by observation.

5.1. Nested Observer Experiments (Wigner's Friend Scenarios)

One conceptual test is to push the Wigner's Friend scenario to multiple levels of observers. For instance, consider a chain: System S is observed by Friend $F1$, who is observed by a second Friend $F2$, who is in turn observed by Wigner W. This nested structure was effectively considered by Frauchiger and Renner. The issue at hand is whether contradictions emerge, as FR suggest when considering the assumptions of quantum theory. In our framework, we predict *no contradiction*, because each observation is an awareness update and the functor F ensures consistency when we compose them. A way to *illustrate this experimentally* (at least in principle) is to use *quantum systems to simulate observers*. There have been proposals where a qubit can play the role of an "observer" by becoming entangled and then being

measured by a larger apparatus [18]. Although we cannot easily have a conscious observer inside another lab, we can have automated devices play the role of F1, F2, ..., each making a measurement and recording a result (in a quantum memory) which is later read out by the next observer.

Recent experiments have actually demonstrated a form of this. In 2019, Proietti et al. [19] performed a photonic experiment that is essentially a *Wigner's Friend test with entangled photons* acting as the friend's system. They found results consistent with quantum mechanics that suggest that two observers can indeed have different facts (one sees interference, another sees a definite outcome) that cannot be jointly assumed as a single objective reality. Our framework embraces this as it *requires* that *quantum theory cannot possess a singular objective reality*, exactly as the experimental authors conclude. If future nested-observer experiments with more levels and higher complexity are performed, our theory predicts that standard quantum calculations will hold, and any attempt to assume one objective state for all levels will fail. Our framework provides an explanation. Each observer's reality is *their piece of the overall awareness*. Contradictions are avoided because no two observers actually compare notes until they interact. A successful run of a more elaborate Wigner's-friend experiment, perhaps involving qutrits or multiple qubits as simulated observers, that continues to uphold quantum predictions would thus be fully in line with our model. This would reinforce the notion of strongly observer-dependent facts. If, conversely, such an experiment ever found a deviation, this would indicate some absolute reality bleeding through. In that case, our framework in its current form would be challenged since we assume strict relational consistency. So far, all evidence such as Proietti et al. and similar tests points toward the need for observer-dependent interpretation, which our approach provides a natural home for.

5.2. Entanglement and Awareness in Quantum Gravity Experiments

One exciting line of inquiry is the intersection of quantum mechanics and gravity. Proposals by Bose et al. and Marletto and Vedral in 2017 suggested that if two masses become entangled due to their gravitational interaction, it would imply that gravity itself has quantum features. This is because a classical field cannot create entanglement [20, 21]. These experiments, often called the *quantum gravitational entanglement tests*, are currently being pursued by various groups [22, 23]. From our perspective, such an experiment has a profound meaning. If gravity can mediate entanglement, then *gravity can mediate awareness*. Two masses entangling via gravity means the masses "become aware of each other" gravitationally. This is a dramatic extension of our framework into a new realm. It says even what we perceive as the classical gravitational field is capable of carrying quantum information (correlations). Thus, it too is part of the web of universal consciousness. Should these experiments succeed, they would demonstrate that *no interaction is exempt from quantum information exchange*, not even gravity. The experiments are extremely challenging, as they involve superposing small masses and detecting entanglement. For RQD, which aims to incorporate spacetime and gravity into quantum relations, this is encouraging. For our awareness interpretation, it suggests that the *universal awareness extends through spacetime interactions* as well. One could poetically say that if two particles feel each other's gravity and become entangled, the universe has made those two particles aware of each other's presence in a very gentle,

proto-conscious way.

Furthermore, if we hypothesize that spacetime geometry itself might relate to states of universal awareness, one could imagine extreme scenarios, e.g., black hole evaporation, or the early universe, in which huge amounts of entanglement (hence awareness) are generated. Observing gravitationally induced entanglement in the lab would give a first hint that this line of thinking is viable. It is speculative. However, success would nudge us to think that spacetime curvature or gravitational effects might be deeply connected to information and maybe consciousness. This idea is reminiscent of Wheeler's "It from Bit" and related information-theoretic views of physics. In summary, the *concrete proposal* here is to carry out and confirm the Bose-Marletto-Vedral type entanglement experiments. Our framework does not change the expected outcome. Entanglement either is observed or not, based on whether gravity is quantum. However, if entanglement is observed, it strongly supports the *universality of our awareness principle*. Even "classical" forces participate in awareness events by creating correlations. If entanglement is not observed, suppose gravity stubbornly refuses to entangle. This implies that perhaps it is not quantum. Then, one pillar of our assumption—that all physical interactions are quantum information exchanges—would need revisiting. However, current theory leans toward gravity being quantum if those experiments can be done, so we eagerly await their results.

5.3. Correlating Integrated Information with Quantum Behavior

Our framework proposes that a system's integrated information Φ influences the *awareness magnitude* of quantum events. While Φ is hard to compute for arbitrary systems, one speculative but intriguing experimental direction would be to *vary* Φ *for an observer system and see if quantum dynamics is affected*. For instance, imagine we have two types of observers for a photon polarization experiment: one is a simple photodetector (low Φ), and another is a conscious human or an AI with a very sophisticated brain/network (high Φ). Standard quantum theory says both are just measuring devices and will yield the same statistics (e.g. the photon has 50/50 chance to be detected either way). Our framework, in its *current formulation, does not require any deviation* in those statistics: awareness does not alter physical probabilities, it only underpins them. However, one could *speculate* that maybe a high-Φ system, by virtue of integrating information, might slightly alter decoherence or collapse dynamics. Perhaps a conscious observer could maintain quantum coherence longer because it integrates the information in a way that keeps the entanglement intact? Alternatively, it might be that the nature of consciousness influences specific experiences, potentially introducing a bias in collapse outcomes. This is a speculative notion similar to Wigner's hypothesis that consciousness causes collapse. Theoretical explorations have begun to address this intersection, but concrete experimental validations are still forthcoming [24].

A suggested exercise in *experimental metaphysics* involves: *constructing a device capable of measuring or modulating* Φ *within a controlled system and subsequently employing that system as an observer in a quantum experiment.* While we currently cannot measure Φ easily, researchers in neuroscience are attempting to estimate Φ in brains [25, 26] and even in simpler networks. Suppose in the future we had a way to stimulate a small neural network or a quantum AI in such a way as to toggle its integrated information, maybe by turning

off some connections to reduce integration. We could then let it observe a quantum system and look for subtle differences. Does the highly integrated observer cause any different statistical pattern than the less integrated one? For example, one might check if interference visibility, or collapse time, or entropy produced in measurement differs by observer complexity. According to our *core hypothesis, no physical law is violated*, so we expect no difference *unless* consciousness does play an active role as some interpretations, such as like Wigner's, have conjectured. If by chance a difference was found, such as a high-Φ observer having a slight effect on outcomes, that would be revolutionary. It would directly tie consciousness to physics in a causal way. Even a null result (no difference) is fine for our framework, as we do not require new physics; but the attempt itself is valuable because it forces us to quantify consciousness in physical experiments.

In conclusion, this proposal resides at the boundary of speculative science, necessitating a method to interface a known conscious system with a sensitive quantum system in a variable manner. A more near-term version could be to compare a regular measuring device with a human observer in a quantum experiment. This comparison would be to see if any deviations occur. Thus far, none have been found, and none are expected in normal conditions. Nevertheless, this line of thought is useful as a *conceptual validation*. It underscores that our framework is constructed so that it works *without* any special pleading. It recovers standard quantum results regardless of the observer. However, it remains open to the possibility that consciousness might have subtle influences that could be tested if our measurement capabilities improve.

5.4. High-Integration Artificial Observers

As technology advances, we may see AI or quantum computers that have non-trivial Φ values and can act as observers in quantum experiments. One could imagine setting up a quantum experiment in which the 'observer' is a machine with a scalable level of complexity. IIT researchers might provide ways to quantify machine Φ. One could then test whether higher Φ machines handle quantum information differently. For instance, do they get entangled with the system in a more complex way than a simple sensor would? Although this overlaps with the previous idea, it is more about **engineering observers** to explore the cross-section of quantum and integrated information. Even if all results conform to quantum theory, we would learn how information integration behaves in quantum contexts. This provides empirical grounding for our choice of $\mathcal{A}(A : B) = I \times f(\Phi)$.

In summary, while no single *smoking gun* experiment can yet verify awareness in RQD, there are multiple lines of evidence we can seek:

- Confirmation of observer-dependent outcomes (as in Wigner's friend tests.)
- Demonstration of entanglement via gravity, showing universal applicability of quantum relations.
- Correlations between integrated information measures and physical processes (via neuroscience or AI experiments).

- Continued consistency tests (like the FR scenario) to ensure no internal contradictions when applying quantum theory universally, which our framework addresses by construction.

Each of these, if realized, adds credence to the idea that our approach is capturing something real about the world. If a future discovery shows that quantum mechanics must have an objective state after all, perhaps through some new phenomenon, then our approach would need revision or abandonment. Similarly, if that discovery reveals that consciousness has nothing to do with information, we would also need to revise or abandon our approach. As of now, however, the trends in quantum foundations is toward information-centric views and in consciousness science is toward quantitative measures like Φ. This provide a fertile meeting ground that our framework attempts to formalize.

6. Conclusion and Future Directions

We have presented a formalism that *weaves awareness into the fabric of quantum mechanics*, treating each interaction as not just an exchange of physical information, but as a fundamental *awareness event*. Using quantum information theory in terms of mutual information, Integrated Information Theory (Φ), and category theory (the functor $F : \mathcal{Q} \to \mathcal{A}$), we built a rigorous framework where observer-dependent quantum states and awareness updates go hand in hand. The *theorem-proof structure* we provide demonstrates the internal consistency of this framework; in particular, Theorem 1 ensures that the functorial mapping preserves the logical structure of sequential events, and Proposition 2 shows that standard results of quantum information, such as entropy and information gain, align perfectly with the interpretation of awareness.

Our framework is deliberately constructed to *not disturb the successful predictions of quantum theory*, but rather to reinterpret them. This means all conventional quantum experiments will have results consistent with both traditional quantum mechanics and our awareness-integrated view. The added value of our approach lies in the conceptual clarity and potential to resolve interpretational puzzles. For example, in thought experiments where multiple observers seem to have irreconcilable descriptions, our approach provides a new perspective that *they were never irreconcilable, they were just incomplete fragments of one larger awareness that had not yet been unified*. By positing universal consciousness in whatever form one chooses to view it, perhaps as an informational substrate, we remove the philosophical need for an external 'collapse' imposed by an ad hoc rule or a deus ex machina. Collapse is simply *update*, a transition in the state of universal awareness.

Future Directions: This work opens several avenues for further research:

- **Mathematical Refinement:** The category-theoretic construction could be elaborated into a full *2-category or enriched category* to natively include probabilistic branching. In addition, one might explore the topos theory or sheaf theory to formalize the idea of 'perspectives', that is, each observer has a context, and consistency conditions are given by natural transformations between functors representing different observers'

views. The current functor F could be one part of a larger diagram connecting physical, psychological, and perhaps neurological categories (especially if trying to connect to neuroscience data).

- **Quantitative Case Studies:** Applying the framework to specific scenarios in detail, such as the Frauchiger-Renner paradox or quantum communication experiments, to show explicitly how mathematics resolves any issues. Also, computing the awareness metric $\mathcal{A}(A : B)$ for simple systems, e.g., two qubits scattering versus a qubit interacting with a qutrit, to see how it behaves and whether it matches intuition.

- **Link to Thermodynamics:** Since information gain is related to entropy reduction, one could investigate the thermodynamic aspect of awareness. Does an awareness event have an entropy cost given that Landauer's principle suggests erasing information costs energy [27, 28]. If so, is there a sense in which awareness is linked to entropy export to environments as brains certainly dissipate heat when processing information? Such questions can deepen the physics of the framework.

- **Experimental Design:** Although experiments directly targeting *awareness* are tricky, one might design quantum cognitive experiments where human observers are part of a quantum system, for example decisions in a quantum game scenario) and see if the information-theoretic measures correlate with reported experience. Furthermore, as technology improves, implementing a small-scale 'observer' like a qubit that makes a measurement on another qubit and treating it as having primitive awareness could be a testing ground for our ideas on a quantum computer.

- **Philosophical Implications:** Our framework leans toward *panpsychism* or *idealism*, the idea that consciousness is a fundamental feature of reality. It would be fruitful to engage with philosophy of mind and analytic philosophical scrutiny. Can this framework help with the 'hard problem' of consciousness [29], or is it simply changing language? We explicitly do not solve why or how raw experience (qualia) exists; we take the pragmatic route of saying *perhaps it is just there at the basic level.* This resonates with the panpsychist ideas that even elementary particles have proto-conscious properties [30, 31]. Although speculative, casting those ideas in mathematical form could make them more testable or at least connectable to scientific discourse.

In conclusion, *Relational Quantum Dynamics with integrated awareness* offers a unified view where mind and matter are not separate realms but two sides of the same coin, the coin being information. Every quantum event is an informational transaction and simultaneously a unit of experience. The hope is that this perspective can *resolve some interpretational puzzles* by providing a common fabric for all observers. It may also inspire new experiments and insights, for instance in quantum biology or quantum cognitive science. In these fields, the role of the observer is not just an inconvenience to hide but the very essence of what is happening. We have ensured that the framework stands up to mathematical scrutiny and is consistent with known physics; the next steps will involve *extending its reach and confronting it with empirical data*, as any good physical theory must. Regardless of the ultimate truth of matter, exploring this path improves our understanding of both quantum mechanics and

the concept of consciousness, and might one day lead to a deeper understanding of reality where the **'atoms of experience'** are as fundamental as the atoms of matter.

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