Relational Emergence Model: A Generative Extension of Relational Quantum Mechanics

Yoshifumi Maruko
Independent Researcher, Yamagata, Japan

Abstract

This paper proposes the Relational Emergence Model (REM) as a generative extension of Relational Quantum Mechanics (RQM). While RQM defines physical states as relative correlations between systems, it does not explicitly address how such correlations are dynamically produced.

The REM introduces *differentiation* as a generative process through which relational distinctions become articulated and subsequently stabilized into effective classical structures via decoherence. More precisely, differentiation is formalized as a bipartition-selecting map $\mathcal{D}$—not a unitary operator, but a descriptive structural selection—that produces explicit system–observer correlations from a pre-relational Hilbert space. Environmental decoherence then suppresses off-diagonal coherences, stabilizing effectively classical facts.

Rather than asserting any equivalence between quantum theory and Buddhist philosophy, this work identifies a structural correspondence between relational quantum interpretations and the concepts of dependent origination (pratītyasamutpāda) and emptiness (śūnyatā).

The central contribution of REM is a shift from the *definition* of relational states to the *modeling of the generation* of relational structure itself.

1 Introduction

Relational Quantum Mechanics (RQM) proposes that physical states exist only relative to other systems [1]. While this approach successfully removes observer-independent states, it leaves open a crucial question: how do relational structures themselves arise?

This paper introduces the Relational Emergence Model (REM), which extends RQM by providing a generative account of relational structure. Rather than treating relations as given, REM models how relational distinctions are produced through a process of differentiation.

2 Limitations of Existing Relational Interpretations

RQM defines states relationally but does not describe their emergence.

QBism emphasizes subjective probabilities but lacks a structural account of relational formation. Many-Worlds assumes branching structures without modeling their generative origin.

Thus, existing interpretations describe relationality but do not model its production.

3 Relation to Recent Developments in RQM

Recent developments in RQM have introduced important refinements, including perspectival facts, cross-perspective links, and iterative relational structures.

Adlam and Rovelli [2] propose cross-perspective consistency, while Riedel [3] develops the notion of iterative relationality. Weststeijn [4] analyzes perspectival facts in Wigner-type scenarios.

However, these approaches operate on already-articulated relational structures. Cross-perspective links ensure the communicability and consistency of relational facts across observers; iterative frameworks extend relational descriptions across nested levels. Both presuppose that relational structures are already formed.

By contrast, REM addresses a prior question: how such relational structures become articulated in the first place. REM does not compete with these approaches but complements them by modeling the generative phase that *precedes* perspectival consistency.

4 Relational Emergence Model (REM)

4.1 Three-Layer Architecture

REM proposes a three-layer architecture of relational reality, illustrated in Figure 1.

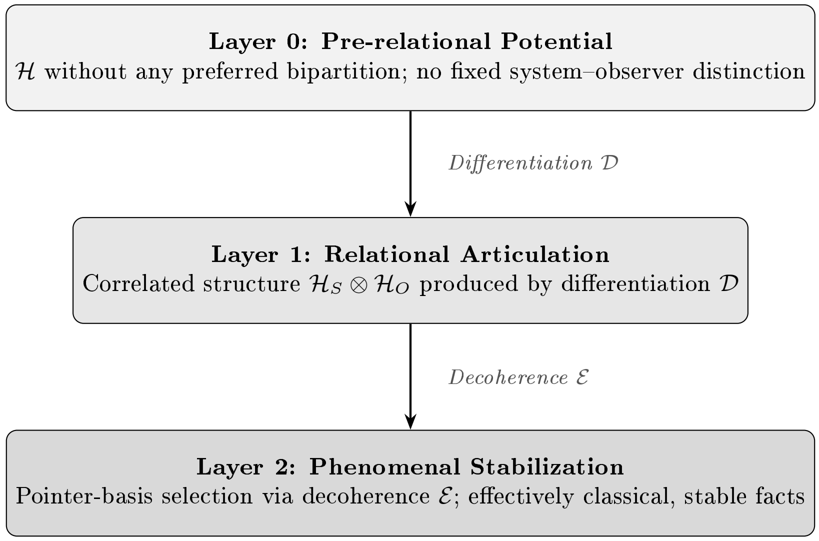

Figure 1: Three-layer architecture of REM. Layer 0: absence of fixed relational articulation (pre-relational potential). Layer 1: explicit system–system correlations produced by the differentiation map $\mathcal{D}$. Layer 2: effectively classical, stable facts resulting from environmental decoherence $\mathcal{E}$ acting on Layer 1 structures.

4.2 Differentiation as Generative Process

Differentiation is defined informally as:

> A process through which initially indistinct relational potential becomes explicitly articulated into distinguishable system–system correlations.

Observation is therefore not merely detection but the generative articulation of relational structure.

4.3 Formal Definition of Differentiation

We now provide a mathematical formalization of the differentiation process.

Definition 1 (Pre-relational State — Layer 0)**.** *Let $\mathcal{H}$ be the total Hilbert space of a composite quantum system, without any preferred tensor-product decomposition.* Layer 0 *corresponds to the absence of a fixed bipartition $\mathcal{H} = \mathcal{H}_S \otimes \mathcal{H}_O$; no determinate system–observer distinction has been articulated.*

Definition 2 (Differentiation Map — Layer 0 → Layer 1)**.** *A* differentiation event *$\mathcal{D}$ is a structural map that selects a bipartition and produces an explicit correlated state:*

$$\mathcal{D} \colon \mathcal{H} \longrightarrow \mathcal{H}_S \otimes \mathcal{H}_O.$$

Given a pre-relational state $|\Psi\rangle \in \mathcal{H}$, differentiation yields the Schmidt decomposition

$$\mathcal{D}(|\Psi\rangle) \;=\; \sum_i c_i\, |s_i\rangle_S \otimes |o_i\rangle_O, \qquad \sum_i |c_i|^2 = 1.$$

The relational state *of S relative to O is then the reduced density operator*

$$\rho_{S|O} \;=\; \mathrm{Tr}_O\big(\mathcal{D}(|\Psi\rangle)\, \mathcal{D}(|\Psi\rangle)^\dagger\big) \;=\; \sum_i |c_i|^2\, |s_i\rangle\langle s_i|.$$

Remark 1. *$\mathcal{D}$ is* not *a unitary operator acting on $\mathcal{H}$. It is a* descriptive bipartition-selection map*: it designates which tensor-product structure is operative in a given relational context. The key generative step is precisely this selection—it is not the detection of a pre-existing state but the act of making a system–observer distinction determinate. Layer 0 is not a substrate or field; it is the formal limit of description in which no such selection has occurred.*

Definition 3 (Decoherence and Phenomenal Stabilization — Layer 1 → Layer 2)**.** *Let $\mathcal{H}_E$ denote the Hilbert space of the environment. Environmental decoherence acts as a completely positive, trace-preserving (CPTP) map $\mathcal{E}$ on $\rho_{S|O}$:*

$$\mathcal{E}\big(\rho_{S|O}\big) \;=\; \sum_i |c_i|^2\, |s_i\rangle\langle s_i| \otimes |e_i\rangle\langle e_i|,$$

where $\{|e_i\rangle\} \subset \mathcal{H}_E$ are mutually orthogonal environment states correlated to the pointer basis $\{|s_i\rangle\}$. Suppression of off-diagonal coherences constitutes Layer 2*: effectively classical, stable, and shareable facts.*

4.4 Relation to Decoherence

Differentiation generates relational structure; decoherence stabilizes it. The ordering is strict: the CPTP map $\mathcal{E}$ of Definition 3 presupposes the bipartition established by $\mathcal{D}$ in Definition 2.

4.5 Comparison with RQM

Table 1 summarizes the key conceptual differences between RQM and REM.

	RQM	**REM**
State Definition	Relative correlation	Relative + generative process
Observation	Detection / correlation	Differentiation / articulation
Emergence	Assumed	Modeled (generative layers)
Ontological Stance	Static relationality	Process-based relationality
Time	Implicit	Process-based
Classicality	Decoherence	$\mathcal{D} \to \mathcal{E}$

Table 1: Conceptual comparison of RQM and REM. The central addition of REM is the differentiation map $\mathcal{D}$ (Definition 2), which models the generative phase prior to relational articulation, followed by decoherence $\mathcal{E}$ (Definition 3).

4.6 Wigner's Friend

In REM, Wigner's Friend scenarios are interpreted as multi-level differentiation processes. Different observers correspond to different stages of relational articulation, rather than contradictory descriptions of a single fixed reality. Formally, Wigner and the Friend apply differentiation maps $\mathcal{D}_W$ and $\mathcal{D}_F$ at different levels of the nested system–observer structure, producing consistent but perspectivally distinct relational states $\rho_{S|F}$ and $\rho_{(S+F)|W}$ [5, 6].

5 Structural Correspondence with Buddhist Philosophy

This paper identifies a structural *correspondence*, not an equivalence.

Dependent origination (pratītyasamutpāda) corresponds to Layer 1, where relational structures emerge through processes of differentiation: everything arises in dependence upon the act of differentiation.

Emptiness (śūnyatā) corresponds to Layer 0, understood as the absence of intrinsic nature (svabhāva), even within relational structures. In the present formalization, this corresponds to the absence of any preferred bipartition prior to $\mathcal{D}$: no system possesses intrinsic identity independently of a differentiation event.

In this context, śūnyatā should not be interpreted as an underlying ground, but as the recognition that no level of relational structure possesses independent or intrinsic existence [8, 9].

6 Discussion

REM introduces a generative perspective that complements existing relational interpretations of quantum mechanics.

Formalizing $\mathcal{D}$ as a bipartition-selecting map (not a unitary) makes precise what was previously expressed only informally: observation *produces* rather than detects relational structure. This is consistent with, but more explicit than, the relational states of RQM [1, 10].

This perspective suggests new directions for quantum foundations, including modeling Wigner-type scenarios as staged differentiation processes (Section 4.6) and exploring connections with process-oriented philosophical frameworks [7].

7 Conclusion

The Relational Emergence Model extends relational quantum theory by shifting the focus from the *definition* of relational states to the *generation* of relational structure itself.

By introducing differentiation as a generative, bipartition-selecting map $\mathcal{D}$ (Definition 2) and integrating it with decoherence $\mathcal{E}$ (Definition 3), REM provides a framework for understanding how relational reality becomes articulated and stabilized, as summarized in Figure 1 and Table 1. The three-layer architecture maps precisely onto the conceptual distinction between pre-relational potential (Layer 0), relational articulation (Layer 1), and phenomenal stabilization (Layer 2).

References

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