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Info-Computation and Observer-Dependence in Quantum

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Abstract

Quantum mechanics reveals that physical quantities and informational states are not absolute but relational, depending on the context of interaction between systems. While classical physics already contained relational elements—most clearly in Galilean relativity and Einstein's relational spacetime—the quantum domain extends relationality to physical properties and facts themselves. In this paper, I develop an info-computational perspective on relational quantum mechanics (RQM), conceiving observers as informational agents embedded within physical processes. Quantum states are understood as constraints on possible interactions rather than intrinsic attributes of isolated systems. I review key relational, perspectival, and information-theoretic approaches—including QBism, perspectival quantum realism, reference-frame–dependent observables, categorical quantum mechanics, and graph-based formalisms—and argue that they converge on a view of physics grounded in relations and information flow. Relational objectivity emerges through inter-agent translation rules rather than observer independence, providing a unified framework for understanding quantum measurement, inter-observer agreement, and physical ontology.

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1. Introduction

Scientific objectivity has traditionally been associated with the ambition to describe reality independently of observers. However, historical and philosophical analyses of classical physics reveal that it has always been relational, although this was not explicitly framed as such. As historians and philosophers of science emphasize (Clavelin 1974; Koyré 1965; Drake 1999), Galileo's analysis of relative motion demonstrated that velocity cannot be defined absolutely but only relative to an observer's reference frame. This insight was deepened in Einstein's theory of relativity, which showed that time, simultaneity, and spatial extension depend on the observer's motion and gravitational environment (Janssen 2002; Norton 2019; Brown 2007). Objectivity in physics thus emerges through translation rules between observational perspectives (Reichenbach 1958; Misner, Thorne & Wheeler 1973), rather than through observer-independent description.

Quantum mechanics generalizes this insight to physical properties and informational states themselves. Attempts to formulate observer-independent quantum states generate conceptual paradoxes. Instead of treating observer-dependence as a flaw, relational and information-theoretic interpretations recognize it as a structural feature of physical theory. Drawing on info-computational relational epistemology (Dodig-Crnkovic 2025, 2025a), I argue that physical reality is best understood as a network of informational relations (Berghofer, Goyal & Wiltsche 2021) implemented through natural computation (Dodig-Crnkovic 2023, 2024), where quantum states describe informational constraints established through interaction, not intrinsic properties of isolated systems.

In this paper, I approach relational quantum mechanics through the lens of info-computationalism, which views physical reality as a network of information processes implemented by interacting physical agents. From this perspective, physical states correspond to informational constraints generated in interactions, and observers are active computational agents within the

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evolving physical system (Dodig-Crnkovic 2023, 2024). This conceptual framework allows us to understand relational quantum mechanics in constructive terms, as describing how facts emerge through distributed computation across interacting systems rather than as intrinsic properties of isolated entities.

2. Relational Interpretations of Quantum Mechanics

Relational Quantum Mechanics (RQM) asserts that the state of a quantum system is always relative to another interacting system (Rovelli 1996; 2021). There are no observer-independent physical facts; measurement establishes new relational facts. Recent clarification by Di Biagio & Rovelli (2022) emphasizes that RQM is a theory of *facts*, not *states*, and that objections based on relativity analogies or concerns about objectivity misunderstand its conceptual basis.

Quantum Bayesianism (QBism) reframes the quantum state as an agent's expectations based on prior information (Fuchs 2010; Fuchs & Schack 2013; Fuchs, Mermin & Schack 2014; Von Baeyer 2016), and measurement as Bayesian updating rather than ontological collapse.

Entanglement reflects correlated informational constraints, not nonlocal influence. Different observers may legitimately assign different states until they exchange information (Brukner 2014; Fuchs et al. 2014). Relational structure preserves global consistency without invoking superluminal causation.

3. Contemporary Relational, Perspectival, and Information-Theoretic Approaches

A growing community of researchers is developing relational, perspectival, and informational approaches compatible with or complementary to RQM. Beyond Rovelli's foundational contributions (Rovelli 1996; 2021), recent analyses by Emily Adlam (2022) and Claudio Calosi & Timotheus Riedel (Calosi & Riedel 2024) investigate the implications of relationality for objectivity and for conceptual mapping between interpretations. Dennis Dieks' Perspectival Quantum Realism emphasizes that quantum properties are relative to physical perspectives rather than absolute (Dieks 2019), while Richard Healey's pragmatist interpretation grounds the content of quantum statements in system-environment interaction (Healey 2012). Closely aligned information-theoretic frameworks have been developed by Časlav Brukner and Anton Zeilinger, who propose axiomatic reconstructions based on constraints on information (Zeilinger 1999; Brukner 2014). Brukner's critiques help refine RQM's commitments rather than undermine them (Di Biagio & Rovelli 2022).

Table 1. Comparative Landscape of Relational and Informational Approaches.

Approach	**Core Thesis**	**Relative?**	**Ontology**	**Measurement**	**Proponents**	**Comments**
Relational QM	Facts exist relative to interactions	Facts, states	No global state	Creates relational facts	Rovelli, Di Biagio	Facts, not states
Perspectival QM	Properties relative to perspective	Properties	Perspectival realism	Reconciliation across perspectives	Dieks, Calosi & Riedel	Close to RQM
Pragmatist QM	Meaning = practical context	Significance of claims	Use-based	Contextual predictive tool	Healey	Minimal ontology

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QBism	Beliefs of agent	Knowledge	Participatory realism	Bayesian update	Fuchs, Mermin, Schack	Subject-centered
Info-theoretic reconstructions	Axio-derivation of QM	Information limits	Informational	Operation-based	Zeilinger, Brukner, Chiribella	Formal axioms
Quantum reference-frame models	All quantities relational	Observables	Relational quantities	Frame-dependent	Loveridge, Miyadera & Busch	Technical support
CQM (categorical)	Processes not objects	Systems ↔ processes	Compositional ontology	Process update	Coecke, Abramsky, Kissinger	Diagrammatic
Fact-nets	Network of relational facts	Facts	Graph ontology	Relational update	Martin-Dussaud et al.	Fits RQM & info-computation

4. Formal / Structural Relational Approaches

Relational Observables and Quantum Reference Frames

Formal treatment of observables as relational quantities has been advanced by Loveridge, Miyadera & Busch (2018), showing that observables depend on reference systems and that apparently absolute observables can be reconstructed as relational quantities. This demonstrates that relationality is not merely interpretive but structurally grounded.

Categorical Quantum Mechanics (CQM)

CQM reformulates quantum theory in terms of processes and composition, rather than systems with intrinsic states (Abramsky & Coecke 2008; Coecke 2010; Coecke & Kissinger 2017). Diagrammatic formalisms such as ZX-calculus represent informational flow visually (Duncan & Perdrix 2009; Jeandel et al. 2018), aligning closely with info-computational relational ontology.

Graph-Based Formalizations

Fact-nets (Martin-Dussaud et al. 2022) rebuild quantum mechanics as a graph of relational facts, eliminating the need for a global state. Combined with Di Biagio & Rovelli (2022), these frameworks demonstrate that relationality can be systematically embedded into mathematical formalism.

Info-Computationalism and Relational Epistemology

Info-computationalism conceives the world as composed of informational structures whose dynamics correspond to natural computation—physical processes transforming information (Dodig-Crnkovic 2011; 2016). Observers are embedded agents (Dodig-Crnkovic 2025) whose interactions produce informational updates. Observation is an act of computation, and scientific knowledge arises from translation rules enabling intersubjective coherence (Fields 2012; Fields and Glazebrook 2025). Objectivity is therefore relational and operational, not absolute.

Measurement becomes a computational update affecting relational informational structure (Dodig-Crnkovic 2025). Collapse is replaced by local update rules; temporary disagreement between observers is expected, analogous to the relativity of simultaneity (Reichenbach 1958).

The info-computational framework thus provides more than a conceptual parallel to relational quantum mechanics: it offers a constructive model of how relational facts are generated, maintained, and integrated across interacting observers. By treating interactions as information-processing events and systems as agents performing natural computation, we gain a mechanism for understanding the emergence of classical-level objectivity as stable patterns in distributed computation. This aligns physical ontology with informational dynamics, suggesting that the structure of reality is constituted by computational relations rather than static intrinsic properties.

Table 2. Comparison of RQM, QBism, and Info-Computationalism.

Feature	**Relational Quantum Mechanics (RQM)**	**QBism**	**Info-Computationalism**
What is a quantum state?	Relational information about a system relative to an observer	An agent's personal degrees of belief about future experiences	A computational structure encoding constraints on possible future interactions
Status of observers	Physical systems interacting with other systems	Bayesian agents assigning probabilities	Information-processing agents embedded in physical processes
What is a physical fact?	Fact = event created in interaction; relative	Fact = agent's experience of outcome	Fact = update of internal computational state after interaction
Objectivity	Emergent from agreement between observers when they interact	No global objectivity; only personal coherence	Structural objectivity = stable patterns produced by distributed computation
Key question	How do relational facts become mutually compatible?	How should an agent update beliefs?	How are relational facts generated, processed, and coordinated?
Core metaphor	Interaction	Experience / belief update	Computation / information flow
Mathematical tools	Relational observables, reference frames, networks of observers	Bayesian probability, decision theory	Distributed computation, dynamical information processing, categorical models
Feature	**Relational Quantum Mechanics (RQM)**	**QBism**	**Info-Computationalism**
Main limitation	Lacks explicit mechanism for fact generation & reconciliation	Subjective ontology; unclear physical grounding	Needs alignment with quantum formalism
How they complement	—	Clarifies agent-centered perspective	Provides physical/operational mechanism for RQM & QBism
Synthesis insight	Relational, interaction-generated world	Agent-centered probability interpretation	Mechanistic account of how relational facts arise and stabilize

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5. Conclusions

Quantum mechanics deepens the relational character implicit in classical physics. Info-computational relationalism models quantum states as informational relations, dissolving paradoxes and supporting objectivity as structured intersubjectivity. Formal developments such as CQM, relational-observable frameworks, and graph-based approaches show that relationality can serve as a mathematical foundation for physics, not merely an interpretative overlay.

Future work should focus on integrating these structural approaches into a unified operational framework in which computation as information processing constitutes the dynamics of physical relations. Observers become active participants implementing local updates, while global coherence emerges from interaction networks. This perspective suggests a path toward reconciling quantum theory with the relational foundations of spacetime and may contribute to a scalable model of physical ontology extending from fundamental physics to cognitive and ecological systems.

In this sense, the info-computational approach offers a generative mechanism for relational quantum mechanics, showing how stable shared realities can emerge from local interactions and the constraints they impose on future observer–system engagements.

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