Relational Quantum Mechanics and (Soft) Perspectivism

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Abstract

This paper examines the role of perspectivism in Relational Quantum Mechanics, situating it within the broader landscape of quantum interpretations and the scientific realism debate. We argue that, while interpretations such as QBism embrace strong forms of perspectivism, Relational Quantum Mechanics adopts a "soft" perspectivism, limiting the observer's role to selecting experimental contexts without compromising its realist framework. We also explore the historical roots of Relational Quantum Mechanics, showing that relational ideas in the works of Bohr and other pioneers similarly avoided strong perspectivist commitments. By analyzing both contemporary and historical perspectives, we argue that Relational Quantum Mechanics offers a minimalist yet robust relational interpretation, distinct from more subjectivist approaches.

Keywords: *Perspectivism, Quantum Mechanics, Qbism, Relational Quantum Mechanics*

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1 Introduction

Perspectivism has become a central theme in contemporary debates on scientific realism, offering a nuanced approach to the relationship between scientific theories and reality. Emphasizing that all human access to reality is mediated by instrumental, theoretical, and historical perspectives, perspectivism challenges the notion of a purely objective, perspective-independent view of the world. Prominent proponents of perspectivism, such as Van Fraassen (1980), Giere (2006), Teller (2019), and Massimi (2022) argue that scientific knowledge is inherently qualified and situated, rejecting the possibility of a "view from nowhere". This philosophical stance aligns particularly well with interpretations of quantum mechanics that contend science describes reality as experienced by a subject, rather than as it is in itself. Notably, it could be argued that many of the founding figures of quantum mechanics, such as Niels Bohr and Werner Heisenberg, expressed ideas that align with perspectivist thought.[1] It could be suggested that among contemporary interpretations of quantum mechanics, several appear to embrace perspectivist or subjectivist elements. Examples often cited include QBism (Fuchs, 2010), Carlo Rovelli's Relational Quantum Mechanics (RQM) (Rovelli, 1996), Dennis Dieks' perspectivalism (Dieks, 2022), Richard Healey's pragmatism (Healey, 2017), and Steven French's phenomenological approach (French, 2023). These interpretations challenge the idea that quantum mechanics delivers a purely objective description of reality, instead emphasizing the role of context, interaction, and subjective experience. The intersection of perspectivism and quantum mechanics raises two central questions: how quantum mechanics supports perspectivist approaches to science, and how perspectivism, in turn, provides a philosophical framework for interpreting quantum mechanics. This paper focuses on RQM, a particularly notable interpretation in this context. RQM

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[1] In §4, we explore these historical connections in detail, examining the extent to which the relational ideas foundational to RQM can be traced back to the early pioneers of quantum mechanics. There, we analyze the perspectives of these figures and argue what form of perspectivism, if any, they might have embraced within their interpretations of the theory.

offers a realist interpretation of quantum mechanics without invoking additional theoretical constructs, such as the hidden variables of Bohmian mechanics or the multiple worlds of the Many-Worlds interpretation. This minimalist yet realist approach grounds quantum mechanics in relational properties, emphasizing interactions between systems without assuming an overarching independent reality. By refraining from introducing extra structures, RQM provides a streamlined framework that is both philosophically and scientifically appealing.

The primary aim of this paper is to examine the extent to which RQM incorporates perspectivist elements. While RQM shares certain affinities with perspectivism, particularly in its emphasis on relationality, we argue that it embodies far less perspectivism than other interpretations, such as QBism. By situating RQM within the broader perspectivist discourse, we aim to clarify the specific nature of its perspectivism—or lack thereof—and explore how this interpretation fits into the ongoing debate on the philosophical implications of quantum mechanics. In doing so, we seek to contribute to the broader dialogue on how quantum mechanics intersects with perspectivist approaches to scientific realism.

The paper is organized as follows. In §2, we set the stage for our discussion of RQM by providing an overview of perspectivism within the context of the Qbist interpretation of quantum mechanics. In §3, we focus on RQM and its connection to perspectivism. We introduce RQM's central principles, emphasizing its realist interpretation through relational properties, and use illustrative examples to clarify its framework. We then analyze the extent of perspectivism present in RQM, arguing that it represents only a "soft" form of perspectivism, significantly less pronounced than in interpretations like QBism. In §4, we delve into the historical roots of RQM's relational framework and its connection to perspectivism. We trace early relational ideas in the development of quantum mechanics, showing how they inform RQM's interpretation and its philosophical underpinnings. Finally, §5 concludes.

2 QBism: Quantum Mechanics as an Epistemic Tool for Individual Perspectives

Quantum-Bayesian interpretation (QBism) of quantum mechanics, originally developed in Caves et al. (2002) offers, broadly speaking, an interpretation where personal observation and the interaction between the observer and the world are central. This perspective integrates elements of pragmatism and subjectivism, as highlighted by one of its leading proponents: "The development of QBism was under the sense of pragmatism before anyone was even conscious of it." (Fuchs, 2023) The foundational idea of Qbism is articulated in Fuchs and Schack (2010), where the key interpretive principle is emphasized: a quantum state does not reflect an objective property of a physical system but instead represents the epistemic state of the individual assigning it. Specifically, it encapsulates the agent's beliefs about their potential future experiences. Thus, quantum states are personal and subjective, serving as a representation of belief rather than possessing any ontological connection to the external world. In Qbism, the formalism of quantum mechanics serves a purely *normative* function, guiding actions rather than describing the fundamental nature of the world. But who or what qualifies as an "agent" in this interpretation? According to Qbists, an agent is an entity capable of *freely interacting*[2] with the external world, where its actions yield tangible results—outcomes that directly affect its own experiences. Agents employ various "manuals" (Fuchs and Schack, 2010), such as quantum theory, to make decisions and optimize outcomes. This definition excludes entities like telephones, chairs, or even electrons from being considered agents. In the Qbist framework, these are not part of the category of agents, as the fundamental elements of quantum mechanics are not themselves subject to the rules of quantum mechanics. Instead, the quantum formalism is regarded as a decision-making tool—a "manual" used by the observer when it proves effective for navigating and predicting experiences. Crucially, from the Qbist perspective, quantum mechanics is a single-user theory. It reflects an individual agent's expectations about their personal experiences, with no requirement for agreement or convergence between different agents' perspectives.

In the framework of QBism, the Schrödinger equation is reinterpreted as a tool for describing the agent's evolving expectations about potential measurement outcomes, rather than as a statement about the intrinsic properties of a quantum system. From this perspective, the Schrödinger equation no longer serves as a description of the objective evolution of a quantum state; instead, it acts as a normative constraint on the epistemic state of the agent. In particular, a significant departure from traditional interpretations lies in how QBism views the Hamiltonian. For Qbists, the Hamiltonian is not an objective feature of the quantum system but a construct within the domain of the individual agent. Different agents may assign different quantum states because they use the Schrödinger equation in ways that reflect their unique perspectives and choices of Hamiltonians. This subjectivity underscores the QBist interpretation, where the formalism of quantum mechanics is a guide for personal decision-making rather than a universal descriptor of physical reality.

Another key point within QBism is that quantum theory does not directly address the nature of physical reality. This perspective aligns with QBism's interpretation of quantum probability as inherently subjectivist. In this framework, the Born rule is reinterpreted, which is traditionally used in quantum mechanics to calculate the probability of obtaining a particular measurement outcome

$$P(a) = |\langle\psi|\phi_a\rangle|^2, \tag{1}$$

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[2] Freely might come as a surprise here, but it comes straight from Fuchs himself: "An agent is an entity that can freely take actions on parts of the world external to itself and for which the consequences of its actions matter to it." (Fuchs, 2023)

where $P(a)$ is the probability of observing the outcome a, $|\psi\rangle$ is the quantum state of the system, $|\phi_a\rangle$ is the eigenstate of the observable corresponding to the outcome a, and $\langle\psi|\phi_a\rangle$ is the inner product between the system's state and the eigenstate is reinterpreted . In QBism, the Born rule is not considered a fundamental law of nature but instead a normative guide for agents, relating their subjective probabilities to the quantum state they assign. From this viewpoint, the Born rule resembles a modified version of the total probability rule in classical probability theory. This analogy highlights its role as a tool for updating an agent's expectations, rather than as a statement about an objective reality underlying quantum phenomena.

The connection between the Schrödinger equation and the Born Rule lies in their shared role within QBism as tools for expressing an agent's epistemic state. For a Qbist, the quantum state assigns truth values based on the observer's epistemic condition, reflecting their partial beliefs about potential future experiences. These beliefs are operationalized through the Born Rule, which acts as a normative guide for updating expectations about measurement outcomes. A significant departure of QBism from other interpretations of quantum mechanics is its explicit rejection of the Einstein-Podolsky-Rosen (EPR) argument (Einstein et al., 1935). This rejection is rooted in QBism's treatment of probabilities. In the QBist framework, a probability of $p = 1$ signifies an agent's subjective certainty, not an objective property of the physical world. This certainty is inherently agent-dependent, such that a probability of 1 for a given event does not imply universal agreement among agents. As one of QBism's proponents emphasizes: "As the world is genuinely indeterministic according to quantum theory, agents' judgments are genuinely fallible" (Fuchs, 2023). Thus, QBism reinterprets quantum mechanics as a single-user framework where probabilities reflect the personal perspective of each agent, distinct from any notion of objective or shared determinism. In QBism, the world retains its capacity to surprise agents, and their beliefs remain subject to revision. Even when an agent assigns probabilities of $p = 1$ or $p = 0$, these represent personal judgments—maximum (or minimum) confidence in the occurrence (or non-occurrence) of an outcome—but they do not constitute truths. The unpredictability of the world ensures that such probabilities reflect subjective expectations rather than truths about the external reality. As Fuchs (2023) notes:

> Quantum theory on the QBist view is an addition to probability theory which considers the unique characteristics of our given world.

In this interpretation, whenever the agent uses the "quantum manual", the result is a connection between the Hilbert space and the system under measurement. This process creates an association between the agent's expected experiences and the elements of a positive operator-valued measure (POVM) on the Hilbert space. For QBism, POVMs are essential. They represent the most general type of measurement in quantum mechanics and play a central role in the theory's epistemic framework. As Fuchs (2023) explains

> They represent the most general kind of measurement one can perform in quantum mechanics. They, therefore, can model any action an agent can take upon its external world.

This highlights the adaptability of QBism in modeling an agent's interactions with their environment, further emphasizing its subjective, action-centered interpretation of quantum mechanics.

The measurement problem is a well-known and ongoing debate in the interpretation of quantum mechanics (Maudlin, 1995; Wheeler and Zurek, 1986). However, the QBist framework fundamentally bypasses this problem through its foundational principles. In QBism, the quantum state is stripped of any ontological role in describing a physical system. Instead, it becomes a subjective construct, with each observer assigning their own quantum state. The possibility of different observers assigning the same quantum state is treated as mere coincidence rather than necessity. Measurement, in this framework, is understood as the outcome of a personal action performed by the observer. There is no sense in which the quantum state can be considered a part of the objective world. This perspective arises from QBism's treatment of the quantum state as a purely epistemic concept—a tool that originates in the agent's mind rather than existing independently in nature. The quantum state comes into existence only when an agent applies the quantum formalism to assign probabilities to their expectations about the world. In this sense, the quantum state is not a feature of reality but a product of the agent's interaction with it, mediated by the quantum framework.

> The outcome of an experiment is the experience it elicits in an agent. If an agent experiences no outcome, then there is no outcome for that agent. Experiments are not floating in the void, independent of human agency. They are actions taken by an agent to elicit an outcome. And an outcome does not become an outcome until it is experienced by the agent. That experience is the outcome.(Fuchs et al., 2014)

In discussions of the measurement problem, the issue of a potential discontinuity between two successive measurements of the same quantum state often arises. Within the QBist framework, such discontinuities are entirely permissible, as an agent may revise their state assignment based on updated personal beliefs. This discontinuity, however, is not a problem in QBism; it merely reflects the evolving epistemic state of the observer. In QBism, measurement is not understood as a purely physical process but rather as an agent's action upon the world. Moreover, the measuring instrument itself is considered an extension of the agent, as quantum formalism concerns only the epistemic status of the agent and their expectations. As Fuchs (2023) explains

> Consequently, a quantum state, from the point of view of QBism, must be understood as a catalog of personal expectations, if it is to mean anything meaningful at all.

A key implication of this framework is that even agents who agree on all the facts relevant to a quantum experiment may still assign different quantum states. As Caves et al. (2007) notes

> Two agents starting from the same facts but different priors arrive at different (posterior) state assignments. For sufficiently divergent priors, the two agents might even legitimately assign different pure states.

This emphasizes that state assignments are subjective and reflect individual perspectives, even in the presence of shared empirical data.

Hence, the QBist interpretation represents a radical departure from the view of quantum mechanics as a universal and objective description of reality. Instead, it reimagines the theory as an inherently perspectival tool, tailored to the needs of individual agents to navigate and manage their interactions with the world. In this framework, quantum mechanics is grounded entirely in each agent's subjective epistemic framework, with no requirement for convergence or agreement between different agents' perspectives. This places QBism as a strong perspectivist framework, where the reality described by quantum mechanics is dependent on the viewpoint and beliefs of the agent assigning the quantum state.

3 Relational Quantum Mechanics and (Soft) Perspectivism

In this section, we examine whether the strong form of perspectivism discussed in the previous section related to other interpretations of quantum mechanics also applies to RQM. The section is structured as follows: first (§3.1), we provide an overview of the core ideas of RQM, using a formalism introduced by Fano and Sanchioni *(forthcoming)*. Next (§3.2), we analyze a specific quantum scenario—the quantum description of an electron in a system with two degrees of freedom, position and spin, as treated in standard quantum mechanics. We then (§3.3) explore possible experiments on the electron from the perspective of RQM and conclude with a discussion of perspectivism in this context.

3.1 Relational Quantum Mechanics in a Nutshell

RQM is an interpretation of quantum mechanics that provides a realist approach without resorting to the additional theoretical structures present in other interpretations. RQM shares some conceptual ground with the Copenhagen interpretation, particularly in emphasizing the role of the observer in defining quantum states—a feature that often links it to perspectivism. However, it sets itself apart by grounding this "observer-dependence" in a well-defined ontological framework, making it a realistic and parsimonious interpretation of quantum mechanics.

In this section, we aim to present a formulation of the ontology of quantum mechanics based on the approach of Fano and Sanchioni *(forthcoming)*, articulated in terms of relational properties. Their approach methodically dissects and clarifies how RQM conceptualizes the existence and interactions of quantum systems through their relational properties, rather than through absolute states or predetermined realities. This relational perspective suggests that the properties of quantum systems are defined contextually, emerging from their interactions with other systems. Thus, in RQM, quantum properties are not fixed or intrinsic but are instead established within specific relational contexts. This approach proposes a view in which reality is dynamically defined through interactions, with relational properties serving as the primary basis for understanding quantum phenomena, rather than relying on static or absolute states.

In RQM, a quantum event requires the involvement of at least two distinct physical systems and two corresponding properties (observables), with each observable associated with one of these systems. We represent physical systems with lowercase symbols, such as s, w, and f. Properties in this context are understood as the eigenvalues of particular observables. To formalize this notion, we adopt the following notation:

> $\boldsymbol{(A = a, s, O = o)_f}$ → This denotes the ascription of the eigenvalue a of observable A to system s, conditional upon the ascription of the eigenvalue o of observable O to system f.

Here, we place the symbol for the second system, f, as a subscript to streamline notation and to underscore the foundational role of relational structure in this interpretation.

As a working example, consider an idealized scenario where a beam of silver atoms is prepared, each atom in a specific spin state:

$$|\psi\rangle = \frac{1}{\sqrt{2}}|\uparrow\rangle + \frac{1}{\sqrt{2}}|\downarrow\rangle \tag{2}$$

This beam is directed through a Stern-Gerlach apparatus, which measures the atoms' spin in the z-direction. Let's isolate a single atom, denoted s, and let f represent the Stern-Gerlach apparatus. As the atom s passes through the apparatus's magnetic field, it will be deflected to a specific position on a screen that corresponds to its spin state. For example, if the spin state is ↑, the atom will hit the screen at a position labeled Up. The measurement outcomes, corresponding to observable positions on the screen, are labeled Up and Down, corresponding to spin states ↑ and ↓ respectively.

When observing that the atom s impacts the screen at position Up, we can express this event as:

$$(S_z = \uparrow, s, O = \mathrm{Up})_f \tag{3}$$

This notation signifies a quantum event where the eigenvalue ↑ of the spin observable S_z is assigned to system s, alongside the eigenvalue Up of observable O assigned to system f. This setup illustrates the interaction between the measured system s (the atom) and the measuring device f (the Stern-Gerlach apparatus), highlighting both the probabilistic nature of quantum measurements and the importance of relational context in defining quantum events.

Although this formalism may seem elaborate, representing quantum events in this explicit relational form enriches our understanding of RQM. Previously, we defined relational properties as internal relations between systems. Here, we extend this to quantum events, interpreting each event as an instantiation of a relational property involving two physical systems and their respective observables. In the example with the Stern-Gerlach apparatus, a quantum event comprises four elements:

1. The system s (the silver atom),
2. The system f (the Stern-Gerlach apparatus),
3. The observable S_z (the spin state of s),
4. The observable O (the position on the screen where s impacts).

Thus, observing s at position Up on the screen represents the event $(S_z = \uparrow, s, O = \text{Up})_f$. This notation makes explicit the relational property resulting from the interaction between s and f. Quantum events in RQM, therefore, are not isolated occurrences but are inherently relational, reflecting properties defined through interactions between physical systems.

3.2 The Case of an Electron

To delve deeper into whether RQM embodies the same perspectivist approach as the interpretations reviewed in Section §2, let us consider a more complex example: an electron with both position and spin degrees of freedom. In textbook quantum mechanics, such a system is represented by a tensor product Hilbert space:

$$\mathcal{H} = L^2(\mathbb{R}) \otimes \mathbb{C}^2 \tag{4}$$

where $L^2(\mathbb{R})$ is the Hilbert space associated with the electron's position degrees of freedom, and $\mathbb{C}^2$ is the complex plane corresponding to the Hilbert space describing spin degrees of freedom.

To explore the types of experiments we might perform on this system, we can identify two distinct types of measurement: position and spin. The electron's position could be measured, for example, by scattering photons or other electrons off it and observing the scattering pattern. Spin, on the other hand, can be measured through a Stern-Gerlach-type experiment, as discussed previously. Notably, these measurements are independent in a specific sense: the commutator between the position and spin operators is zero, meaning these two observables are compatible. This allows both properties—position and spin—to be specified simultaneously without interference.

In standard quantum mechanics, we would describe the electron's state as having two independent properties, one associated with its spatial position (or momentum) and the other with its spin. However, in the framework of RQM, we reinterpret these properties as relational, meaning they do not exist in isolation but are defined only in relation to specific interactions with other systems.

Using the formalism introduced in the previous section, we can represent these relational properties as follows. Suppose we have a system s, representing the electron, and a second system f, corresponding to the photons scattered to measure the position of the electron. The position of s relative to f could be denoted by the notation:

$$(X = x, s, O = o)_f \tag{5}$$

where $X = x$ represents the ascription of the eigenvalue x of the position observable X to the electron s, in relation to the ascription of the eigenvalue o of some observable O to the photons f, which interact with the electron to detect its position. This interaction highlights the relational framework, where the properties of the electron are defined through its interaction with the measuring photons.

Similarly, if we perform a spin measurement on s with another system g representing a spin-measuring device (such as a Stern-Gerlach apparatus), we could express the spin relational property as:

$$(S_z = \uparrow, s, O = \text{Up})_g \tag{6}$$

This notation signifies that the eigenvalue $\uparrow$ of the spin observable S_z is ascribed to the electron s in relation to the apparatus g which registers this spin state. Here, "Up" indicates the result observable O in g that corresponds to the electron's spin state $\uparrow$.

In RQM, rather than ascribing absolute properties to the electron, we regard both its position and spin as relational properties. These properties emerge through interactions between the electron and specific measurement devices, highlighting a fundamental difference from traditional, absolute property assignment. Does this relational framing of quantum properties truly imply that RQM shares the same perspectivist structure as other interpretations, or does the relational ontology offer a fundamentally different account that departs from observer-dependent perspectives?

3.3 Perspectivism and Relational Quantum Mechanics

To address the question posed at the end of the previous section, we must consider a crucial distinction between RQM and QBism, which will clarify RQM's stance on perspectivism.

A key difference between these interpretations lies in their treatment of quantum states. While both RQM and QBism recognize that a system's state may appear differently to different observers, their ontological commitments diverge sharply. In QBism, the quantum state reflects the observer's subjective knowledge or beliefs about a system. For example, in the context of Wigner's friend thought experiment (Wigner, 1995), Wigner and his friend may assign different quantum states to the same system, but these states are considered epistemic, representing individual perspectives and information, rather than any objective feature of the system itself. Here, QBism prioritizes epistemology: the observer's quantum state reflects personal expectations about measurement outcomes rather than objective reality.

RQM, by contrast, provides a more ontologically grounded approach. Although RQM agrees that quantum states may vary between observers, it regards these variations not as matters of belief but as expressions of the actual relational properties emerging between the system and the observer. In RQM, quantum events are real but exist relationally—they are properties that arise strictly within the context of specific interactions between physical systems. In Wigner's Friend scenario, for instance, the outcomes $(S_z = \uparrow, s, O = Up)_f$ and $(S_z = \downarrow, s, O = Down)_f$ represent definitive, real events for the Friend, determined by her direct interaction with the system. From Wigner's vantage point outside the laboratory, however, the state remains determined but in the preparation state, underscoring the relational nature of quantum reality.

This relational ontology marks a fundamental departure from QBism. While QBism operates within an epistemic framework, focusing on how observers update their beliefs based on information, RQM asserts that the properties of quantum systems are real but inherently relational. Quantum states in RQM are not subjective knowledge states but objective features of the world, defined through specific relational interactions. RQM shifts the focus from what an observer knows about a system to how a system's properties are constituted through interactions with other systems. By grounding quantum states in relational ontology, RQM avoids the limitations of a purely epistemic perspective, offering a coherent ontological basis for quantum phenomena, as exemplified in our symbolic formalism.

It is essential to clarify that while RQM's view of reality may appear counterintuitive, it does not lead to contradiction. Although RQM challenges classical notions of objectivity—particularly the idea that properties are intrinsic and exist independently of observers—it offers a consistent and coherent framework for interpreting quantum mechanics. RQM's relational ontology does differ from Einstein's vision of a fully objective, observer-independent universe. Einstein envisioned an ontology in which objects possess definite, intrinsic properties that exist independently of measurement or interaction. Yet, at the quantum level, this classical perspective becomes unsustainable: properties only emerge relationally. RQM captures this insight, providing a more accurate representation of quantum phenomena, even if it departs from the comforting clarity of classical, substance-centered ontologies. By embracing a relational framework, RQM aligns more closely with the realities of the quantum domain.

However, RQM's commitment to a relational ontology should not be mistaken for an endorsement of perspectivism in the sense commonly associated with quantum interpretations that emphasize the observer's role. The distinctive feature of RQM is that it redefines the source of relational properties as emerging solely through physical interactions between quantum systems, without privileging any observer. In this framework, the observer does not occupy any unique ontological position; instead, it is the interaction itself that grounds reality. Quantum properties are not absolute attributes held by objects independently but instead are contingent, relational properties that manifest specifically through the interactions between systems. For instance, consider an electron passing through a Stern-Gerlach apparatus, or an electron scattering light. In both cases, properties such as the spin orientation or position emerge only in the context of the interaction between the electron and the measuring device. It is this physical interaction that generates the relational properties, not an observer's subjective perspective or informational state. Whether or not someone observes the experiment does not change the relational nature of the properties. The properties of the electron become meaningful only within this relational framework, which is defined by the interaction between quantum systems, such as the electron and the apparatus. This approach is fundamentally different from interpretations of quantum mechanics that make the observer central to the nature of quantum states and properties.

In QBism, by contrast, the observer is indispensable to the definition of the quantum state and, therefore, to quantum reality itself. QBism posits that the quantum state reflects the observer's subjective beliefs or informational stance toward a quantum system. Rather than being an intrinsic property of a quantum system, the quantum state is understood in QBism as an epistemic tool—a representation of the observer's personal knowledge, expectations, or uncertainties about possible outcomes. This interpretation is explicitly rooted in epistemology: QBism argues that the quantum state is not an objective feature of reality but a measure of the observer's subjective stance towards the quantum system. Every quantum measurement in QBism is inherently tied to an observer's beliefs and updates; therefore, the quantum state has no reality outside the observer's point of view. To illustrate, let us consider QBism's treatment of Wigner's friend, a thought experiment designed to highlight the differences in quantum state assignment by different observers. In this scenario, Wigner's friend performs a measurement inside a closed laboratory and assigns a definite quantum state to the system based on her direct interaction. From her perspective, the measurement outcome is real and concrete. However, from Wigner's perspective outside the lab, who has not observed the outcome directly, the system remains in a superposition of probabilities corresponding to the possible outcomes—but these probabilities are determined by the specific configuration and operation of the experimental device. In QBism, this discrepancy is entirely expected: Wigner and his friend assign different quantum states based on their individual informational states. The quantum states are considered epistemic—reflections of each observer's personal knowledge and not of any objective reality. Consequently, Wigner's quantum state assignment is not about the system itself but rather about his subjective perspective on the possible outcomes. This view places the observer, and their informational perspective, at the center of quantum reality.

QBism's insistence on the observer's centrality contrasts starkly with RQM's framework, which maintains that relational properties are grounded in physical interactions, not in the knowledge or beliefs of an observer. In RQM, the properties of quantum systems are real but exist only relationally, within specific interactions between systems. Unlike QBism, where the quantum state fundamentally depends on the observer's subjective perspective, RQM considers the relational properties as objective outcomes of interactions. This relational ontology in RQM thereby shifts the focus from an observer-based view of reality to an interaction-based view, grounding quantum phenomena in the physical world rather than in the subjective perspective of any given observer. Thus, while QBism remains firmly in the realm of epistemology, where quantum states serve as tools for the observer to update beliefs about measurement outcomes, RQM moves into ontology, asserting that quantum properties, such as spin or position, are real yet intrinsically relational. In RQM, the electron's spin state does not "exist" in isolation nor does it depend on any observer's informational stance; it becomes a concrete property only in the context of its interaction with a specific measuring apparatus. The relational perspective in RQM avoids the epistemic focus of QBism, offering instead a coherent ontological framework that reflects the inherently interaction-based nature of quantum events. This means that for RQM, quantum states are not merely subjective knowledge states; they are objective, relational features of the world, defined through interactions. This approach provides a more robust ontological structure for understanding quantum phenomena, focusing not on what the observer knows but on how the properties of quantum systems are constituted through their physical interactions. In this way, RQM sidesteps the subjective pitfalls of purely epistemic interpretations, establishing a relational basis for quantum states and properties without invoking any privileged observer, as demonstrated by the symbolic formalism we have employed throughout this discussion.

The only form of perspectivism that remains within RQM is what we might call a *soft perspectivism*—a minimal role for the observer that is limited to the act of selecting which property to measure. In this sense, the observer's role is restricted to choosing the experimental setup and determining the type of interaction that will reveal specific relational properties of a quantum system. This observer involvement does not entail any subjective influence on the properties themselves, nor does it imply that these properties depend on the observer's perspective in an epistemic or informational sense, as in QBism. Instead, it is a structural aspect of the experimental process that determines which relational property is manifested.

Consider, for instance, an electron in a laboratory setting, as described in section §3.2: the experimenter has the choice to measure either the electron's position or its spin, or perhaps even both, if independent apparatuses are involved. This choice guides the form of interaction between the system and the measuring device, thereby establishing the specific relational property that will emerge from the interaction. However, this act of selection does not mean that the observed property is tied to the observer's beliefs, knowledge, or subjective experience. Rather, it is a practical decision that shapes the experimental conditions, allowing one relational property (e.g. , position or spin) to manifest over another based on the selected experimental context. This soft perspectivism is fundamentally different from the robust perspectivism found in interpretations like QBism, where the observer's beliefs or informational state directly influence the definition of quantum properties. In RQM, the relational property is entirely independent of the observer's informational stance or subjective experience. Once the experimental interaction has been set up, the resulting property, such as the electron's spin or position, emerges as a real, objective feature of the relational context between the systems involved. The observer's choice of measurement thus plays no role in defining the property itself but merely in selecting which interaction will manifest that property.

This subtle distinction in RQM avoids the epistemic dependence that would tie the property to the observer in any intrinsic sense. The observer's role is akin to a "gatekeeper" of the experimental conditions, determining the pathway through which specific relational properties are realized, but this does not impart any special ontological status to the observer. In other words, while the observer has agency in shaping the experimental setup, this agency does not render the relational properties subjective or dependent on the observer's perspective. The properties themselves are real, objective, and rooted in the physical interactions of the systems involved.

4 A Historical Root of RQM and (soft) Perspectivism

It is well known that shortly after the definitive formulation of non-relativistic quantum mechanics the key figures of the time were divided on the true ontological implications of the theory. Without aiming for exhaustive historical completeness, and acknowledging that many of these thinkers expressed differing views in different contexts, we can outline a few characteristic positions. The purpose here is to trace the historical roots of the relational interpretation of quantum mechanics and to further support our thesis on (soft) perspectivism from this historical standpoint.

Consider, for example, Heisenberg's *Chicago Lectures*, delivered in 1929 and published in 1931 (Heisenberg, 1949). On page 3, Heisenberg explicitly asserts that a defining feature of the new theory is the uncontrollable interaction between the observer and the object. If we interpret the term "observer" charitably, understanding it as referring to the measuring apparatus, the meaning of Heisenberg's statement becomes clear: at the microscopic level, there exists an interaction between the measuring instrument and the physical system that cannot be reconstructed or precisely calculated. Indeed, Heisenberg's text introduces the classic thought experiments that operationally should demonstrate the principle of uncertainty, illustrating the impossibility of simultaneously measuring with absolute precision the position and momentum of a microscopic object (Section I.2). These thought experiments have since become a staple in standard quantum mechanics textbooks, cementing their place as foundational examples in the interpretation of the theory.[3] and §§ 21-22 Persico (1939) On the other hand, as early as 1957, Grünbaum (1957) highlighted the limited plausibility of this view in his paper. Let us take a step back and examine Bohr (1928), which builds on his renowned Como lecture from 1927. In this work, Bohr introduced the concept of *complementarity* for the first time. Starting from the uncertainty relations between position and time on one hand, and momentum and energy on the other, Bohr emphasizes that these relations lead to the conclusion that the spatiotemporal and causal descriptions of the microscopic world are mutually exclusive yet complementary. The ontological message conveyed in these pages can be summarized as follows: the quantum object remains fundamentally unknown in its essence. However, we can provide two alternative descriptions of it, each offering crucial insights in its own way—namely, the causal description and the spatiotemporal description. These two perspectives, while irreconcilable, together capture different aspects of the quantum object's behavior. In response to this ontological conclusion, several attitudes can be adopted:

(i) One might argue that this represents a fundamental and unacceptable abandonment of objectivity, as proposed by those who have sought to reinterpret quantum mechanics along the lines suggested by David Bohm. Bohm's approach attempts to restore a form of objectivity by introducing hidden variables that underpin quantum phenomena, aiming to reconcile the apparent indeterminacy with a more classical framework of reality.

(ii) Another response is to accept this peculiar situation as an inherent limitation of human knowledge. This has often been the predominant stance among orthodox physicists, who view the complementarity principle and the associated limits of measurement as reflective of the intrinsic constraints on our ability to fully describe the quantum world. From this perspective, quantum mechanics does not so much describe reality as it reveals the boundaries of our interaction with it.

(iii) Finally, one can acknowledge that quantum objects are fundamentally different from classical ones, rendering classical concepts such as spatiotemporal representation and causality inapplicable. This third path appears to be the most intriguing. Much of modern physics over recent decades has diminished the centrality of space and time as primary variables in the physical representation of the world, suggesting that their classical roles are less fundamental than previously thought.[4] Moreover, the concept of causality itself, even before Bohr, had shown

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[3] See for example § 53 Pauling and Wilson (1935), chapter 4 section 3.12 Messiah (1995)

[4] This observation finds support in various modern physical theories, where the roles of space and

signs of being problematic, to the point of being nearly dispensable in certain contexts (Waismann, 1968)[5].

This third route invites a more profound rethinking of the nature of physical reality, one that moves beyond the constraints of classical intuition and engages with the novel ontological framework that quantum mechanics presents. It challenges us to reconceptualize foundational notions, embracing the radical departure from classical paradigms that quantum phenomena demand.

Note that, in his seminal 1927 lecture, Bohr also emphasizes from the very beginning what he later refers to on page 586 as *the complementarity between wave and particle*. Indeed, the complementarity between spatiotemporal and causal descriptions arises directly from this fundamental duality of wave and particle behavior. Bohr also points out that while this complementarity has been somewhat overshadowed by the introduction of a new mathematical formalism, it should not be overlooked. Here, Bohr is referring to the matrix algebra developed by Heisenberg, Born, and Jordan, which had become a cornerstone of quantum mechanics.

It is worth recalling Pascual Jordan's perspective, as recounted by (Jammer, 1974, p. 161). According to the German physicist, the state of a system before measurement is indeterminate, and the interaction with the measuring apparatus generates the observed value. As we noted earlier with Heisenberg, it is not always clear in these discussions whether terms like "observer" and "observation" refer to the actual intervention of a conscious subject or merely to the role of the measuring instrument. However, here, it is important to highlight an epistemologically significant distinction: that between a *manipulating subject* and an *intervening subject*. The epistemological importance of the manipulating subject is central to all of modern physics. Unlike ancient astronomy, which was primarily based on observation, modern physics actively manipulates reality to extract knowledge.[6] In this sense, quantum mechanics aligns with an established tradition of experimental physics. However, in the context of quantum mechanics, certain observations by von Neumann, later expanded upon by London and Bauer, and Wigner, sparked discussions about a more direct and active role for the observer as

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time are significantly redefined or diminished. In Loop Quantum Gravity (LQG), for instance, space and time can be thought as emergent properties arising from more fundamental, discrete structures of quantum geometry, rather than being fundamental continua. Similarly, in String Theory, the classical notion of spacetime is supplanted by a higher-dimensional framework, where spacetime itself emerges from the dynamics of strings and branes in a more fundamental background. These approaches highlight a shift in contemporary physics, moving away from the classical understanding of space and time as primary entities towards viewing them as derivative or emergent concepts.

[5] Originally published in 1927, this version is a later reprint.

[6] This shift from mere observation to active intervention is a hallmark of modern science. Hacking (1983) emphasizes the role of experimentation as not merely a way of testing theories but as a means of actively engaging with and reshaping the natural world to produce knowledge. This marks a profound epistemological departure from classical approaches like ancient astronomy, where understanding was derived solely from passive observation.

an intervening subject.[7] In Jordan's case, we interpret the term "observer" in the first sense—as a manipulator, not as a conscious intervening subject.[8] It is also worth noting that these two senses—manipulating and intervening—should not be confused with a third sense, the epistemological role of the observer in QBism. In QBism, the observer is neither a passive manipulator nor a mere intervening subject but a central epistemic agent. The quantum state is not just influenced by manipulation or intervention but is fundamentally tied to the personal, subjective experiences and beliefs of the agent. This highlights a distinctive epistemological framework that diverges significantly from both traditional manipulation and interventionist views in quantum mechanics.

According to Jammer, Jordan's interpretation gained significant traction in the 1930s. However, this view is ultimately unsatisfactory because it overlooks the critical concept of "preparation". Before a system undergoes measurement, it is prepared in the eigenstate of a particular observable. As a result, the system is, in fact, perfectly determined relative to that observable and any compatible measurements. It is true that the system does not possess a definite property relative to the new measurement to be performed, but this does not mean that the system is indeterminate. Rather, it indicates that properties must always be ascribed in a relational manner. This relational understanding aligns more closely with the fundamental principles of quantum mechanics and avoids the oversimplification inherent in Jordan's original interpretation.

We must also consider the position of thinkers aligned with neopositivism, such as Philipp Frank, who articulates this perspective in his contribution to the *International Encyclopedia of Unified Sciences* (Frank, 1946). According to this approach, physics concerns itself solely with experimental data, while everything else is regarded as a theoretical framework for predicting further experimental results, with no claim to represent reality. A similar perspective can be found in Reichenbach (1944), where he distinguishes between phenomena—the results of measurements—and interphenomena, the quantum state prior to measurement, about which the theory cannot make any definitive statements. However, Reichenbach's viewpoint is somewhat closer to a relational perspective, as his introduction of these notions highlights the ontological importance of the preparation state of the physical system. Among physicists, this neopositivist perspective is most prominently echoed by Persico (1939), where he gives a detailed account of this view, emphasizing the predictive function of physical theories without asserting any direct correspondence to an objective reality.

As underlined by (Jammer, 1974, p. 166), those who attempted to formulate an ontology for the new theory were compelled, in one way or another, to emphasize the disturbance caused by the measuring apparatus on the physical system being measured. However, this emphasis was less a result of an operational analysis of the theory and more a

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[7] For a broader exploration of these ideas and their implications, see the essays collected in Wheeler and Zurek (1986), which provide key perspectives on the observer's role in quantum mechanics.

[8] Jordan's perspective aligns more closely with the experimentalist tradition, viewing the observer as an agent who sets up and manipulates experimental conditions without attributing a unique epistemic role to consciousness.

consequence of the use of specific operators to define the physically relevant variables (observables). As we will see, this approach underwent a subtle evolution over time, moving towards a more relational perspective.

Fine (1996) and Howard (2015) have convincingly shown that Jammer (1974)'s historical reconstruction of the EPR argument contains two significant inaccuracies. First, Einstein's argument did not rely on the so-called *reality principle* explicitly stated in the EPR paper; instead, it was simpler and more direct than the version published by Einstein, Podolsky, and Rosen. Second, Einstein's main objection to quantum mechanics was not its indeterminism but rather its non-locality. However, these corrections to Jammer's historical analysis do not undermine his broader observation that the introduction of the EPR argument significantly pushed major interpreters of quantum mechanics toward a relational interpretation. Let us delve into some details.

To briefly present the EPR argument, we follow Fine (2020). EPR start from the premise of an exclusive disjunction: either quantum mechanics is incomplete, or it is impossible to simultaneously determine the values of two incompatible observables, such as position and momentum. One of these must hold. They then construct a physical scenario involving two distant systems, which we will call Albert and Niels, whose positions and momenta along the x-axis are correlated. EPR assume *locality* (a measurement on one system cannot influence the other) and implicitly assume *separability* (the two systems can be treated as distinct, individual entities). When measuring x on Albert, the x-value for Niels is also determined due to the correlation. However, because of locality, this determination cannot be caused by the measurement performed on Albert. EPR then apply their criterion of *reality*, which asserts that if the value of a variable can be predicted with certainty without disturbing the system, that variable must correspond to an element of reality. Thus, x for Niels must already be determined. EPR extend this argument by considering an alternative measurement. Had we instead measured p_x on Albert, we could also predict p_x for Niels with certainty. This controversial step suggests that both x and p_x for Niels are simultaneously determined, which quantum mechanics prohibits. Returning to their initial disjunction, EPR conclude that quantum mechanics must be incomplete. While the argument itself is well-known, its historical and interpretative impact is equally important. As Jammer (1974) observed, and as Fine (1996) and Howard (2015) refine, the EPR paradox forced many quantum theorists to grapple with the relational aspects of quantum mechanics. Here, we do not delve into the complex debates and reformulations surrounding the EPR argument. Instead, our focus is on the impact it had on the community of the most orthodox pioneers of the new quantum theory.

Of particular interest to us is Bohr's dual response to the EPR argument, i.e. Bohr (1935b) and Bohr (1935a).[9] In these two brief contributions, Bohr upholds his position on the unavoidable disturbance of the measuring apparatus on the measured system—a

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[9] Notably under the same title as the EPR paper.

point, as we have seen, that arises directly from the mathematical structure of the theory. However, Bohr also introduces a new aspect in his critique, one that foreshadows a relational interpretation. Bohr challenges the EPR criterion of reality, specifically the assignment of an element of reality to an observable independently of the measurement apparatus used. According to Bohr, the fundamental flaw in the EPR argument is the attribution of x to Niels after the measurement of x on Albert, without including the measurement on Albert as an integral part of that element of reality. The same critique applies to the attribution of p_x to Niels. In Bohr's perspective, this does not mean that there are two independent elements of reality, x and p_x for Niels, as EPR claim. Instead, the two elements of reality are the two mutually incompatible situations that include the measurement on Albert as an inseparable component. This perspective reframes the EPR argument and points toward an inherently relational view of quantum properties, where the context of measurement plays an essential role in defining reality. One of the first to embrace Bohr's relational interpretation was Frank (1936). However, Frank appears to overlook the subtle distinction between this perspective—which carries an ontological dimension—and the neopositivist interpretation. According to Bohr, it is not that we cannot speak of a physical object prior to measurement, but rather that any such description must always be framed in relation to a specific measuring apparatus. This relational aspect is crucial to Bohr's interpretation, marking a departure from the purely epistemic stance often associated with neopositivism.

That said, we cannot fully follow Jammer (1974)'s analogy between the relational character of quantum mechanics and that of special relativity. While it is true, for instance, that the time measured on system Albert by two other reference frames—let us call them Werner and Niels—moving at different velocities relative to Albert is different, the analogy breaks down upon closer examination. In special relativity, time intervals are indeed relative to the reference frame, but the quantity $\Delta r^2 - c^2 \Delta t^2$ (where r represents spatial displacement) remains invariant across all reference frames. This quantity is not relational but absolute within the framework of special relativity. By contrast, no comparable invariant exists at the level of microphysics. Quantum mechanics lacks an analogous absolute quantity that transcends the relational framework. It should also be noted that Jammer (1974) himself partially revises this view on p. 202 of his analysis, acknowledging the limitations of the analogy.

As noted by (Jammer, 1974, p. 202), V. A. Fock enthusiastically embraced Bohr's new relational perspective (Fock, 1962). However, it is important to note that the relationalism of both Bohr and Fock is inherently probabilistic. Jammer (1974) is explicit about this on p. 197: from this point onward, we should no longer speak of the properties of a physical system but rather of the probability P that the observable A has the value a relative to the measuring apparatus α. This probabilistic ontology is distinct from a genuinely relational one, where the eigenvalue a is ascribed to the observable A of system S in relation to the value o of the observable O of the measuring apparatus (see section §3.1 of the present paper). Furthermore, it raises significant conceptual challenges. The very notion of a probabilistic property remains enigmatic, despite Popper's concept of propensity (Popper, 1956) and more recent attempts to introduce indeterminate properties into quantum ontology, such as (Lewis, 2016). Additionally, Fock recounts a 1957 meeting with Bohr in Copenhagen (Fock, 1972). During this meeting, Fock expressed doubts about Bohr's interpretation, which he claimed Bohr himself had partially adopted. According to Fock, it is essential to affirm that the unity between the microphysical system and the measuring apparatus is a full-fledged reality, not merely a relational construct, and that the "uncontrollable interaction" between the measured system and the apparatus is merely a manner of speaking. In Fock's point of view, the key point is that the properties of the micro-object must be ascribed in a way that includes the measuring apparatus. This highlights an important nuance in Fock's materialist interpretation: it brings out the ontological dimensions of the relational approach with greater clarity. Unlike Bohr's probabilistic framing, Fock's perspective emphasizes the concrete integration of the measured system and the apparatus, proposing a more robust and explicitly ontological foundation for understanding quantum properties.

Following this shift in Bohr's interpretation of quantum mechanics, Pascual Jordan, who had previously emphasized the indeterministic aspect of the early notion of complementarity, adopted a far more neopositivist stance. He argued that quantum theory should not extend beyond experience (Jordan, 1936, p. 277). This position reflects a retreat from ontological considerations, aligning instead with a more empiricist perspective that restricts the scope of the theory to the description and prediction of experimental phenomena.

In the correspondence between Born and Einstein, curated by Max Born, there is a fascinating letter from Wolfgang Pauli dated March 3, 1954. Writing shortly after meeting Einstein in Princeton, Pauli sides with the orthodox interpreters of quantum mechanics, emphasizing that Einstein refuses to accept that, in quantum mechanics, the states of a system are defined only in relation to an experimental apparatus. Interestingly, while Pauli accuses Einstein of interpreting this relationality in a subjective manner—thereby reducing it to absurdity—he himself uses ambiguous language immediately afterward, referring to an "ideal observer" (Einstein et al., 1971). Nevertheless, the fact remains that Pauli, too, had embraced a relational conception of quantum mechanics. This relational perspective situates the definition of quantum states within the context of their interaction with specific experimental configurations, aligning with the broader framework of relational interpretations that emerged during this period.[10]

In conclusion, this historical survey has highlighted the roots of the relational approach in quantum mechanics, exploring its development through the perspectives of key figures such as Bohr, Heisenberg, and others, with particular emphasis on V. A.

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[10] Jammer concludes his survey of relational interpretations by mentioning, on p. 208, the perspective of Grete Hermann, which precedes even Bohr's relational approach Hermann (1935). For an authoritative analysis on this point see Crull (2016).

Fock's contributions. Fock's materialist interpretation brought greater clarity to the ontological dimensions of the relational framework, emphasizing the integration of the measured system and the apparatus as a full-fledged reality rather than a purely relational construct. From this historical context, it becomes evident that the relational framework, even in its early formulations, did not embody the kind of perspectivism discussed in §2, where the observer's subjective stance plays a central role in defining quantum states or properties. Instead, scholars like Fock underscored the ontological significance of relationality, framing quantum properties as arising from interactions that include the measuring apparatus rather than being tied to an observer's epistemic perspective. However, as we argued at the end of §3.3, a form of "soft" perspectivism may still be preserved. This refers to the observer's role in selecting the experimental setup or determining which relational property to measure, without implying that the property itself depends on the observer's subjective viewpoint. Fock's work helps to clarify this distinction, aligning the relational ontology with a minimal, structural role for the observer while avoiding the epistemic implications of stronger perspectivist interpretations.

5 Conclusions

This paper has examined a central question: how much perspectivism is embedded in RQM? Addressing this issue is critical for understanding RQM's place among quantum interpretations and for clarifying its ontological and epistemological foundations. Furthermore, it has broader implications for the scientific realism debate, as perspectivism challenges the notion of a fully objective, observer-independent reality in quantum mechanics.

Our investigation reveals that RQM departs from the strong perspectivism seen in interpretations like QBism. While RQM acknowledges the role of the observer in determining experimental setups and selecting relational properties to measure, this results in only a "soft" perspectivism. Unlike QBism, where the observer's epistemic state defines the quantum state, RQM's relational framework remains realist and minimal, tying properties strictly to interactions between systems rather than to the observer's perspective.

Additionally, we explored the historical underpinnings of relational interpretations in the works of Bohr and other pioneers of quantum mechanics. This analysis showed that, from its inception, relational thinking did not imply strong perspectivism. Instead, it focused on the relational emergence of properties without invoking observer dependence as a fundamental principle. This historical perspective further supports the conclusion that RQM embodies only a "soft" perspectivism, both in its modern articulation and in its historical lineage.

By situating RQM within these philosophical and historical contexts, we have highlighted its unique position as a realist yet relational interpretation of quantum mechanics, offering a distinct alternative to more strongly perspectivist approaches.

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