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From In-Out Duality to the Foundation of Social Quantum Mechanics

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Abstract

This paper introduces a framework of in-out duality, merging insights from quantum mechanics with social sciences to illuminate the complex interplay between internal potentialities and external manifestations. It articulates foundational, mathematical axioms (Entanglement, Homogeneity, Emergence, and Measurement) that underpin the dynamics of systems, emphasizing the interconnectedness and emergent behaviors resulting from internal and external interactions. By exploring quantum concepts like coherence, entanglement, and superposition, the paper proposes an interdisciplinary approach termed Quantum Social Mechanics. This approach challenges classical paradigms, advocating for a reevaluation of conventional notions through the lens of quantum principles. The paper argues that understanding the universe's complexities requires a synthesis of motion states and potential states, suggesting a paradigm shift towards integrating quantum mechanics into the philosophical foundation of social theory. Through this comprehensive framework, the paper aims to foster a deeper understanding of the universe's interconnected nature and the dynamic processes that govern the emergence of complex systems and behaviors.

Keywords

Ontology, Meta-Theory, Quantum Social Science, Structure, Duality, Entanglement

1. Introduction

Is something that lacks a distinction between inside and outside can be measured, or even can be considered as existing? Probably not. For example, the reason why a dot can be considered an undefined term is because it should be conceptually without its interior—without such an inside, it is difficult for us to accept such things as existing. Therefore, the proposition is that for something to exist, there must be a differentiation between in and out, as well as the presence of something external to the object in question, becoming the external environment of each other and enabling interaction. This can be said to be in-out relations. Based on this proposition, the paper defines structure as a thing that arise from in-out duality, where the coordinate in-out pairs of our experience emerge. In other words, the notion of inside and outside can be the most basic one that we can understand in ontology. Indeed, nature of the actual world conforms to in-out relations since every in-out experience is relative and multi-layered in the sense the inside becomes the outside, and *vice-versa*: When you are, for instance, *in* a room, the room becomes the fact of your *outside*. Everything potentially lies in a field in which they are external to each other—I can, for instance, say that I am your outside and, in turn, you are my outside such that we exist, a potential to share the outside of each other, making up our inner structure.

In-out ontology, based on the notion of in-out duality, can serve as the meta-theoretical foundation for some middle ground between realism and empiricism in philosophy of science. Realists argue that the successful predictions of scientific theories indicate that we are getting closer to the truth and that theoretical objects (such as the electron, the quark, etc.) should be given an ontic status. For example, critical realism examines the underlying assumptions and ontologies used in the social sciences. It looks at the terms like causation, agency, and structure, and questions the existence of social entities such as capitalism, classes, and the state. Given a commitment to realism, some critical realists are also concerned with understanding the relationship between facts and values, rejecting the idea of value neutrality and recognizing that facts and values are not separate from one another [1]. On the other hand, empiricists claim that the history of science justifies that theories and theoretical entities might continue to be replaced by new ones and then such objects are of importance to the extent that they describe visible phenomena [2]. In the realist view, there is a way things really are and science is to find out what it is. Constructive empiricists, however, argue that abstract theoretical entities such as subatomic particles and any invisible entity are designed to help predict the behavior of things as if these abstract entities existed. Therefore, according to constructive empiricism, statements which scientists make about things not directly observed need not be considered true, but only valuable insofar as they are empirically adequate. In the course of the debate, advocates of existing realism failed to reach a consensus on theory change, and then considering both sides' arguments seriously, John Worrall introduced structural realism [3]:

> There was an important element of continuity in the shift from Fresnel to Maxwell—and this was much more than a simple question of carrying over the successful empirical content into the new theory. At the same time it was rather less than a carrying over of the full theoretical content or full theoretical mechanisms (even in "approximate" form)…There was conti-

> nuity or accumulation in the shift, but the continuity is one of form or structure, not of content.

Structural realism primarily focuses on the formal or structural aspects of scientific theories, which are mainly represented through mathematical equations. This approach emphasizes the understanding of the structures underlying phenomena, while deliberately sidestepping efforts to comprehend the true essence of metaphysical or physical entities. The structural solution proposed by this approach is to merge the best aspects of two worlds: It allows for the acknowledgment of theoretical entities and simultaneously addresses the challenge posed by the pessimistic meta-induction, a problem in the philosophy of science related to the reliability of scientific theories over time. The crux of structuralism is that, although scientific theories may vary greatly, they often share a multitude of structural similarities. Worrall's seminal work in this area has garnered significant attention and has led to a proliferation of literature, further expanding the varieties of structural realism.

As such, the various kinds of realism and empiricism together lays a comprehensive groundwork for what is conventionally recognized as scientific knowledge. These foundational frameworks endeavor to respond to the core questions posed by scientific inquiry. Building on these, the in-out mechanics (IOM), rooted in the principle of in-out duality, aims to augment and refine our current scientific perspectives, offering a more holistic comprehension of the universe. This framework specifically focuses on the interplay between the external and internal realms, exploring how these dimensions interact and influence our perception and experiential reality.

2. In-Out Axioms

The in-out axioms serve as the logical foundation for the notion of in-out duality. These axioms (Entanglement, Emergence, Homogeneity and Measurement) constitute the core principles that underpin IOM, providing a structured approach to understanding the dynamics between internal potentials and external motions.

2.1. Entanglement Axiom: $Ain = Bout$; $Aout = Bin$

Imagine a primordial void where one condition exists: ($in + out$). The inside and outside are entangled, meaning that the state of inside influences the state of outside and vice versa, creating a complex web of interdependence despite the simplicity of its condition: the condition described as ($in + out$), combined with an outside-working wave property and an inside-working particle property, can be made up with the equation like $(A)(in+out)=(B)(in+out)=(c)(in+out),\cdots$. The (initial) in-out condition and its equation allow for every in-out state, mirroring the outside-working inductive (wave-like) and inside-working deductive (particle-like) properties. The wave property can be seen as a coherent analogy to how quantum theory describes the dynamic, interconnected fabric of spacetime and matter, evolving from a fundamental *in* + *out* state.

By considering the case of *A* and *B*,

$$Ain + Aout = Bin + Bout;\ \text{when,}\ Ain = Bout,\ Aout = Bin \tag{1}$$

Here, the Entanglement Axiom came up. This entanglement axiom dictates the equal summation of every "in and out" state. In physics, conservation laws, such as the conservation of energy, momentum, and charge, ensure that certain physical properties of a closed system remain constant over time. These laws could reinforce the Entanglement Axiom, suggesting that the "in" and "out" states' transfer between *A* and *B* preserves certain quantities, mirroring conservation principles. Noether's Theorem, a fundamental principle in theoretical physics, provides a profound connection between symmetries in physical systems and conservation laws. When we apply this theorem to the relationship between entities *A* and *B*, as described by the equations $Ain = Bout$ and $Aout = Bin$, we can delve into the realm of physical principles and their theoretical, philosophical implications.

Symmetry in physical systems, as described by Noether's Theorem, implies that if a system exhibits invariance under a certain transformation (e.g., shifting in time or space), there is a corresponding quantity conserved within the system. For time symmetry, this conserved quantity is energy, reflecting the principle that the laws of physics do not change over time. For spatial symmetry, the conserved quantity is momentum, indicating that the laws of physics are the same in all directions in space. Applying this notion to the in-out relationship between *A* and *B*, we can infer a kind of "symmetry" in the exchange of "in" and "out" states. In the context of the in-out framework, the symmetry between "$Ain = Bout$" and "$Aout = Bin$", implies a conservation of information or quantum entanglement across these transitions. This would mean that as the internal state of one entity becomes the external state of another, the overall "information" or "entanglement" within the system remains constant, reflecting a deep interconnectedness and balance. The described symmetry also suggests a relational balance between entities *A* and *B*. This balance might be seen as a conservation of relational dynamics, where the interaction between internal and external states is governed by a conserved "relational energy" or "momentum," ensuring that the total relational dynamics within the system remain unchanged. Philosophically, this interpretation reinforces the idea of an interconnected universe where the boundaries between internal and external states are fluid and governed by underlying symmetries. It suggests a cosmos where the fabric of reality is woven through continuous transformations that adhere to conservation principles, reflecting a universal balance and harmony.

The quantum entanglement is a physical phenomenon that occurs when pairs of particles interact in a way such that, even when they are separated by a large distance, the quantum state of each particle cannot be described independently of the others. That is, they are not individual particles but are an inseparable whole. To better understand the property of entanglement we can assume the two particles are located in two distant countries. If we want to measure a particular characteristic of one of these particles and obtain a result, then measure the other particle using the same criterion, we find that the measurement result of the second particle matches (in a complementary sense) that of the first particle. This quantum entanglement indicates a mutual dependence between entities. It provides a concrete foundation of how entities can be fundamentally linked in ways that challenge conventional notions of independence and separability.

The Entanglement Axiom can be articulated in a form that captures the essence of quantum entanglement and translates it into a broader context of interconnected systems. In quantum mechanics, entanglement is represented by a composite wave function that cannot be separated into individual wave functions for each component. To represent Entanglement Axiom as a formula that aligns with the in-out duality framework, let's denote the internal state of entity A as Ain and the external state as $Aout$, and similarly for entity B as Bin and $Bout$. The Entanglement Axiom then posits that the internal state of entity A is influenced by the external state of entity B, and vice versa. In mathematical terms, we could express this relationship using the following equation:

$$\Psi\left(Ain, Bout\right) = \Psi\left(Aout, Bin\right) \tag{2}$$

This equation asserts that the entangled state Ψ is a product of both the internal state of entity A and the external state of entity B, and it is equally a product of the internal state of entity B and the external state of entity A. The equation $\Psi(Ain, Bout) = \Psi(Aout, Bin)$ is mathematically consistent with the principles of quantum entanglement. This equation reflects the entangled nature of the system, where the variables Ain and $Bout$ (internal and external states of A and B, respectively) are intertwined. Similarly, the variables $Aout$ and Bin represent the internal and external states of A and B after a transition, maintaining the entangled relationship. This equation illustrates the inseparable connection between the internal and external states of interconnected entities, encapsulating the essence of the in-out Entanglement Axiom within the framework of quantum mechanics. Here, imagine that we explore the impact of social media influencers on the buying behavior of their audience. The influencers (Entity A) are linked with their followers (Entity B) via the social media network, illustrating a case of entanglement within the digital ecosystem. The state of Ain can be defined as the influencer's preference or promotion of a product. The state of $Aout$ can be the influencer's public posts and communications about the product. The state of Bin is defined as the follower's perception or opinion about the product. The state of $Bout$ can be the follower's decision to purchase the product. The state of the system Ψ then considers both the influencer's posts ($Aout$) as an external action and the resulting perception of the followers (Bin). Conversely, the internal preferences of the influencer (Ain) are related to the external actions of the followers ($Bout$), indicative of entanglement. The influence is mutual; the follower's feedback and purchasing decisions ($Bout$) could, in turn, affect the influencers' future preferences and promotions (*Ain*). This simple case study exemplifies how the entanglement axiom can be applied to understand and analyze the interconnectedness of actions and reactions within a social network, reflecting the reciprocal influence between entities.

2.2. Homogeneity Axiom: $Ain = Bin$; $Aout = Bout$

The equation $Ain + Aout = Bin + Bout$, with the specific condition that $Ain = Bin$ and $Aout = Bout$, establishes direct equality between the respective *in* and *out* states of entities *A* and *B*. This case implies a perfect symmetry or balance between these entities in both their internal and external states.

The Homogeneity Axiom provides a compelling basis for analyzing the category concept across different domains, including quantum mechanics, biology, and sociology. This axiom signifies that entities regardless of their scale or complexity, exhibit a fundamental symmetry in their internal and external states, suggesting a universal principle of interconnectedness and homogeneity. In quantum mechanics, particles of the same type, such as electrons, are indistinguishable in terms of their quantum properties. This indistinguishability is a form of homogeneity, where particles exhibit the same *in* states (quantum properties like spin, charge) and *out* states (interaction with fields and forces). This indistinguishability reflects the axiom's essence, where the internal (quantum state) and external (observable properties) aspects of particles are uniform across a category of particles. This quantum homogeneity supports the axiom's implication that at a fundamental level, entities exhibit a symmetrical relationship between their *in* and *out* states. In biology, the axiom can also be applied to understand the homogeneity within categories such as cells. Cells, despite their vast diversity, share core processes (e.g., cellular respiration, DNA replication) that define their internal state ($Ain = Bin$) and how they interact with their environment ($Aout = Bout$). Similarly, humans, despite individual differences, share fundamental biological and psychological processes that dictate their interactions with the external world ($Aout = Bout$) and are influenced by internal states ($Ain = Bin$). This biological and psychological uniformity across the category of humans exemplifies the axiom's suggestion of an underlying symmetry and interconnectedness in the *in* and *out* states of entities within a category. In sociology, the axiom can illuminate the dynamics of social entities, where the internal states ($Ain = Bin$) of social groups (values, norms, and beliefs) are mirrored by their external manifestations ($Aout = Bout$) such as cultural expressions, social practices, and collective actions.

The in-out axioms, focusing on the dynamic interplay between internal states and external manifestations, can also analyze the fundamental differences between bosons and fermions, two distinct classes of particles in quantum physics. In quantum physics, bosons are particles that follow Bose-Einstein statistics and are characterized by integer spin values (0, 1, 2, …). They include force carrier particles like photons, gluons, W and Z bosons, and the Higgs boson. A key property of bosons is their ability to occupy the same quantum state, even in large numbers. This is what allows phenomena such as superconductivity and superfluidity, where particles move en masse without resistance. This property is crucial for phenomena like Bose-Einstein condensates, where particles coalesce into a single quantum state, demonstrating macroscopic quantum phenomena that highlight the collective behavior and unity among particles. Then, from the perspective of IOM, bosons serve as the essential connectors in the universe, *bridging the in states of different entities with the outside-working inductive wave property*:

$$\forall X \in A, B, C, \cdots Xin = constant \tag{3}$$

This formulation signifies that for every entity *X* within the set {*A*, *B*, *C*, …}, the internal state (*Xin*) is equal to a constant value, indicating a universal condition shared across all entities. Bosons, by mediating interactions like electromagnetic forces and gravitational pull, craft the fabric of the observable cosmos. Their inductive wave property allows them to occupy the same state simultaneously, facilitating phenomena where particles behave as coherent units. This capability underscores boson's role in establishing a unified field, knitting together the universe's diverse components into a cohesive whole. Fermions, on the other hand, follow Fermi-Dirac statistics and have half-integer spins (1/2, 3/2, …). This category includes quarks and leptons, the building blocks of matter. A defining characteristic of fermions is the Pauli exclusion principle, which prevents two identical fermions from occupying the same quantum state within the same quantum system. This principle is foundational for the structure of atoms and the diversity of matter in the universe. Fermions include particles like electrons, protons, and neutrons, which are the building blocks of atoms. They are integral to defining the identity and diversity of matter, as their arrangements and interactions result in the vast array of chemical elements and compounds observed in the universe. Then, in the context of IOM, these fermions are interpreted as *representing the in aspect of physical systems with the inside-working deductive particle property*:

$$\forall Ain, \sum Ain = k \tag{4}$$

where *Ain* represents the internal state of every entity, and *k* is the constant that signifies the unified property shared among all internal states. This reflects the notion that despite the diversity of fermions and their configurations, there's a fundamental principle or constant that underpins their interactions and contributions to the universe's structure. Their unique, individual quantum states and the principle of exclusion highlight the internal complexity and diversity of systems. Fermions are the carriers of the internal states that differentiate and define the identity of matter, ensuring the complexity and variety of the material world through their distinct *in* states. As such, within IOM, fermions represent the inside-working deductive particle property, contrasting with bosons' outside-working inductive wave property. Then, the following can be expressed:

$$Fermions : Fin \rightarrow Inward\ Deductive\ Identity \tag{5}$$

$$Bosons : Bout \rightarrow Outward\ Inductive\ Field \tag{6}$$

This captures the dual nature of physical systems within IOM. Fermions, through a deductive process, contribute to the structural identity and diversity of matter, embodying the *in* aspect. Conversely, bosons, through an inductive process, facilitate interactions and coherence in the *out* domain. Interpreting bosons and fermions through IOM reveals a profound symmetry and balance in the universe. Bosons, with their collective behavior and role as force mediators, reflect the cohesive *out* aspect that binds and unifies the universe. Fermions, with their individuality and the principle of exclusion, exemplify the diverse and differentiated *in* aspect that gives rise to the multiplicity of matter and forms. This understanding underscores a deeper philosophical interpretation of the universe as a balance between unity and diversity, cohesion and differentiation—mirroring the foundational principles of IOM. Bosons and fermions, in their respective roles, exemplify the essential dualities of existence, from the quantum scale to the cosmological, highlighting the interconnectedness and mutual dependence of the *in* and *out* aspects of reality, or the in-out universe.

2.3. Emergence Axiom: $(A + B)out = Cin$

The Emergence Axiom describes how the combined output of two entities leads to the creation of a new entity or system. Let me consider, again, A and B as entangled entities. Although they can have each harboring unique attributes or states (Ain and Bin) that signify their internal potentialities, upon interaction they do not merely influence each other in a linear or additive manner; they can become entangled ($Ain = Bout; Aout = Bin$). This entanglement signifies an interconnectedness that transcends simple interaction, leading to a state where the properties of A and B cannot be described independently of each other. The outcome of this entanglement is a combined state $(A + B)out$ that encapsulates the entanglement of both entities. Then, the entanglement of A and B necessitates the notion of an *external* realm relative to them—denoted as Cin. This realm represents the observable, potential consequences of their entanglement, encompassing the combined effects, behaviors, or phenomena that arise from $(A + B)out$ viewed as a unified system. They are no longer predictable from the individual states of A and B alone. Cin thus has its own set of potentialities that are fundamental to the nature of Cin and the future manifestations ($Cout$).

As a logical deduction of in-out duality, the Emergence Axiom provides an insight into the nature of complex systems and the emergent properties that arise from the interaction and entanglement of simpler entities. From the *in-out dance* of mutual observation and entanglement, a new entity can begin to take shape: Cin, the environment or the complex system to which A and B belong. This emergent entity is not merely the sum of A and B but a new phenomenon that transcends its constituents. For example, in an ecological context, the interaction between different specifies (A and B) and their environment can lead to the emergence of new ecosystems (*Cin*). These ecosystems exhibit unique characteristics and dynamics that cannot be predicted merely by studying the individual species. The emergent properties, such as biodiversity levels and ecosystem productivity (*Cout*), are outcomes of complex interactions and entanglements among the species and their physical environment.

2.4. Measurement Axiom: *Cin* = *Aout* + *Bout*

The Measurement Axiom articulates the transformative role of observation. It posits that the act of measurement doesn't just reveal, but actively participates in defining the emergent properties of a system. Through measurement, we access a level of systemic integration where individual components' behaviors (*Aout* and *Bout*) reflect back on the system as a whole (*Cin*), thus illustrating a dynamic feedback loop. The observer's role is integral to the observed reality, suggesting that our understanding of complex systems is inherently shaped by how we choose to engage with and measure them. For example, when you measure the heights (*Cin*) out of *A* and *B*, you can get *A*'s height (*Aout*) and *B*'s height (*Bout*) respectively. The Measurement Axiom, with its emphasis on the role of observation and quantification in understanding systems, can be applied across various examples: Measuring economic growth (*Cin*) through GDP involves aggregating individual outputs (*Aout* and *bout*) of sectors, showing how macroeconomic indicators emerge from microeconomic activities. In an ecosystem, measuring biodiversity (*Cin*) involves assessing the presence and abundance of species (*Aout* and *Bout*), highlighting how complex ecological characteristics arise from simpler biological interactions. Measuring public opinion (*Cin*) through surveys reflects collective attitudes and beliefs (*Aout* and *Bout*), demonstrating how individual perspectives contribute to societal norms. These examples illustrate how the Measurement Axiom applies across disciplines, emphasizing the significance of observation.

The measurement problem in physic deals with how and why the process of measurement causes a quantum system to collapse from a superposition of states into a single, definite state. It questions how quantum probabilities (inherent in the wave function) convert to the certainties observed in the classical world upon measurement. Central to the measurement problem is the role of the observer or measurement apparatus in determining the outcome. The act of measurement seems to break the linear, deterministic evolution of quantum systems described by the Schrödinger equation, leading to debates on whether the wave function collapse is a real physical process or an artifact of incomplete understanding. In physics, Carlo Rovelli's Relational Quantum Mechanics (RQM) argues that phenomena like quantum leaps, superposition, and entanglement—all crucial attributes of quantum mechanics—result solely from interactions or observations [4]. Observation is not merely a measurement of a particle's state but is considered a decisive act that determines the state of the particle. This suggests a profound connection between the universe as we perceive it and our observations. Without such interactions, all particles would exist in a state of superposition, implying no particle existence and no quantum leaps, thus no energy changes. RQM suggests that without interaction, the universe as we know it could not exist, highlighting the foundational role of observation in the reality's fabric, as posited by the Measurement Axiom.

The Measurement Axiom represents the transition from potential states to actualized outcomes through interaction or observation. *Cin* symbolizes the internal potential states before measurement, while *Aout* and *Bout* represent the actualized, observable outcomes after measurement or interaction. It highlights how the outcome of a measurement (or observation) is not merely a revelation of a pre-existing state but involves the actualization of potentialities based on the interaction between the system and the measurement apparatus or environment. While the measurement problem seeks to understand the underlying physical mechanisms, the Measurement Axiom just encapsulates this transition. However, the axiom's representation of outcomes as a combination of potentials aligns with the measurement problem's inquiry into how superposed potentialities collapse to a single reality.

To interpret this problem, RQM offers a framework for understanding quantum mechanics where the key idea is that the properties of quantum systems are not absolute but relative to other systems. According to this interpretation, different observers may give different accounts of the same sequence of events because the state of a quantum system and the outcome of its measurements are relative to the observing system. In essence, there is no single, observer-independent state of a system; instead, states and the outcomes of measurements are relative to the observer. This means that what one observer perceives as a result of a measurement can be different from what another observer perceives, without a privileged perspective. The Relational Interpretation posits that this indefinite state is not merely a placeholder for ignorance but is indicative of how properties truly exist in a relational context. Traditional interpretations often grapple with the implications for objective reality, leading to various paradoxes and philosophical quandaries. The Relational Interpretation offers a resolution by denying the existence of an observer-independent state of the system. Instead, it suggests that what is *real* is the network of relations among interacting quantum systems, including observers. Rovelli's relational interpretation offers a compelling way to reconcile some of the paradoxes and conceptual challenges of quantum mechanics, such as the measurement problem and the notion of superposition, by framing them within a relational context where the observer's role is fundamental. This perspective underscores the idea that the description of the world is inherently dependent on the interaction between its constituents, challenging traditional notions of objective reality in quantum physics.

When we consider the Measurement Axiom in the context of RQM, we can interpret it as highlighting the relational aspect of measurements. Just as RQM emphasizes that the outcome of a measurement (or the state of a system) is meaningful only in relation to the observer, the Measurement Axiom can be seen as expressing that the internal state of a system (or the outcome of a measurement in quantum mechanics) can be influenced or determined by multiple external factors or observers. This resonates with RQM's idea. In RQM, the reality of a quantum state is always in relation to the observer's perspective. Similarly, the axiom implies a form of contextuality, where the relative in-out relations make up together the outwardly inductive motions (*Aout* and *Bout*), constituting *Cin*, or the potential. Both frameworks emphasize the context-dependent nature of reality and the importance of interactions between systems (or observers) in determining the state of a system.

3. The World View: The In-Out Universe

Karen Barad emphasizes the integration of quantum mechanics into social theory, suggesting that contemporary physical theories offer a more accurate foundation for understanding the world than classical mechanics [5]. Barad, along with Alexander Wendt, posits that quantum mechanics unveils the need for reevaluation of traditional concepts across disciplines, urging a reconsideration of outdated worldviews [6]. They advocate for a symbiotic relationship between physics and social theory, where quantum mechanics not only informs but also necessitates a rethinking of social theorizing to reflect the complexities and interconnectedness revealed by quantum physics. This perspective champions a paradigm shift towards embracing quantum mechanics' implications across all domains of inquiry, highlighting its significance in reshaping our understanding of social dynamics and theoretical frameworks. This shift involves more than using physics as a source of inspirations; it requires a foundational understanding of quantum mechanics as a lens through which to view social phenomena. Wendt's view of humans as walking quantum wave functions and Barad's focus on the epistemological and ontological challenges posed by quantum physics highlight their belief in the relevance of quantum mechanics to social theory. The integration of quantum mechanics into social theory, as advocated by Bard and Wendt among others, demands a sophisticated recalibration of social sciences' epistemological and ontological foundations.

In response to this discourse, the worldview based on IOM can be articulated as follows: The world is the interplay of potentialities and their actualization on the in-out matrix, or in-out universe. It is a synthesis of motions states that externalize as parts, and potential states that internalize as wholes. This duality echoes the fundamental principles of quantum mechanics, as exemplified by Schrödinger's wave mechanics and Heisenberg's matrix mechanics, which, despite their distinct mathematical formulations, converge on an equivalent description of quantum phenomena. Wave mechanics utilizes wave functions to describe the probabilistic nature of particle positions and momenta, highlighting the wave-like behavior of particles. The state of a quantum system is described by a wave function, Ψ, which encapsulates the probabilities of finding the system in various configurations. This wave function evolves according to the Schrödinger equation, a differential equation that governs the dynamics of the system over time. The wave function's evolution reflects the external, motion-related aspects of the system, aligning with the outward inductivity of in-out ontology. Moreover, the wave function also embodies the system's potential states, *in* aspect, by encoding all possible outcomes of measurements before they are observed. Heisenberg's matrix mechanics, on the other hand, employs matrices to quantify the states and observable properties of quantum systems, focusing on the discrete, quantized nature of these properties. Both theories, despite their distinct mathematical formulations, converge on the same physical predictions, demonstrating quantum mechanics' core principle of duality—the notion that quantum entities exhibit both particle and wave characteristics. This duality mirrors the in-out worldview's emphasis on the interaction between potential (internal) states and their actualizations (external) on the in-out world, illustrating the interconnectedness and fluidity between the seen and unseen aspects of the universe.

Fundamental physical constants like the speed of light and Planck constant can also encourage this view. The speed of light, a limit on how fast information can travel, can be interpreted as implying the boundary between potential and actualized states. Planck constant, central to quantum mechanics, underscores the discrete nature of energy exchanges and the inherent uncertainties in measuring states, reflecting the interplay between entities' internal potentialities and their external manifestations. This ontological view enriches our understanding of quantum mechanics and the universe by framing it as a manifestation of the in-out principle, where the dynamics of entities and their inherent potentialities are inseparably linked, offering a more cohesive understanding of the universe's fabric. The in-out ontology's worldview, centered on the in-out matrix and its interpretation of quantum mechanics, offers a distinct perspective when compared to other interpretations of quantum mechanics. This perspective aligns with fundamental notions like wave-particle duality, quantum entanglement, and the role of observer, presenting a unified view of reality as a dynamic interplay of *outward becoming as parts and inward being as a whole.*

4. Construction of Social Quantum Mechanics

Quantum physics, since its groundbreaking inception in the early 20th century, has been a monumental achievement, revolutionizing our understanding of the microscopic aspects of the universe. Its precise delineation of the structure and interactions at the quantum level has paved the way for numerous discoveries that are the cornerstones of contemporary scientific and technological advancements. These contributions have profoundly shaped our modern experiences and understanding of reality. Moreover, in the quest to broaden our comprehension of the nature of reality and tackle complex issues transcending the boundaries of traditional disciplines, the interdisciplinary field of quantum social science has emerged. This novel domain synergizes insights from quantum physics with methodologies and theories from the social sciences. Although there is not a definitive consensus on what constitutes it, a unifying theme is that the classical physics principles, which have historically underpinned socials science theories, are increasingly seen as inadequate for interpreting the complexities of contemporary social phenomena [7]. Quantum social science posits that quantum ideas, initially developed to explain the physical world at its most fundamental level, can also provide valuable framework for understanding complex social systems and behaviors. Then, this paper endeavors to demonstrate how the wave function in quantum mechanics can be paralleled with the structure of in-out duality, leading to construction of social quantum mechanics.

4.1. In-Out Formula

IOM can be represented by the formula of in-out duality, which serves as a mathematical expression of the interaction between the internal working of a system and the external interactions of its parts. This formula is articulated as:

$$S = I + O \tag{7}$$

In this equation, S symbolizes the entirety of the structure, O denotes the outwardly inductive motion of parts, and I represents the inwardly deductive potential system. This formulation illustrates that a complete system comprises both its internal mechanisms and the external movements of its components. Accordingly, the in-out formula corresponds to the Hamiltonian, a fundamental concept in physics that describes the total energy of a system, encompassing both kinetic and potential energy. The in-out formula thus can be interpreted as a combination of these energy types: the kinetic energy term symbolizes the energy exerted by the parts on the outside of them (O), while the potential energy term reflects the energy within the system as a whole (I). This unintended similarity positions IOM as an interpretative model to the Hamiltonian in its ability to capture the interplay between the constituent parts and the overall system. It provides a framework for understanding the energy exchange occurring between the internal potential of a system and the external motion of its constituent parts.

In the social sciences, the in-out formula can be a method for examining social system dynamics. For instance, the structure of a social group can be represented by a composite of the group's collective internal potential energy (I) and the kinetic energy of its individual members (O). Here, each member of the group acts as an active component, while the group itself embodies potential energy, manifesting as shared norms, values, or structural roles among its members. This potential energy is not static; it transforms into kinetic energy through the activities of its members. In this way, the collective norms and values provide a meaningful context for the individual actions, conferring purpose and direction to their movements. Therefore, in IOM, the meanings that emerge within social systems are fundamentally anchored in their potential energy, signifying the latent capacity for action or transformation. While the specific application of this formula may vary depending on the particularities of the system under analysis, it universally illustrates that a social system is an interplay of the internal potentialities and external actions.

4.2. The Creation of Meaning

Let me first introduce the principle of potential energy. In physic, it represents the energy stored within a system due to its position in a force field or its configuration. For example, in the context of gravity, an object held at a height has gravitational potential energy due to its potential to fall. This form of energy is dependent on the relative position of different parts of a system and can manifest in various forms such as gravitational, elastic, chemical, and electrical potential energy. The concept is fundamental in physics because it highlights how energy can be stored and later converted into kinetic energy (energy of motion) when the object's position changes, such as when it begins to move. This principle is widely applicable across different fields of science, illustrating the potential for stored energy to cause changes within a system when conditions allow for its conversion into other forms of energy. Indeed, it finds similar applications across various disciplines, albeit under different terminologies or conceptual frameworks. These applications leverage the idea of latent capabilities or energies within systems that can be transformed or actualized under certain conditions.

Here are a few examples. In economics, the concept of potential output or potential growth can be seen as a form of potential energy. It represents the maximum level of output an economy can achieve when operating at full capacity, without accelerating inflation. In business, the potential market for a product or service reflects its potential energy, indicating the total possible sales if fully actualized in a market environment. Similarly, in developmental psychology, the idea of potential development reflects what an individual can achieve with guidance, representing a form of potential energy within the learning process. In ecological systems, the concept of ecological potential refers to the capacity of an ecosystem to develop a certain structure, productivity, or set of functions under given environmental conditions. The idea of political capital can also be paralleled with potential energy. It represents the influence, authority, and power a political actor has, which can be mobilized to achieve certain goals or implement policies. The notion of cognitive reserve in neuroscience and psychology refers to the brain's ability to improvise and find alternate ways of completing a task in response to brain aging or damage. This reserve can be thought of as the potential energy of the brain, highlighting its capacity to adapt and maintain function despite challenges. In the field of information technology, the concept of data potential refers to the value that can be extracted from data through analysis. Each of these examples illustrates how the applicability of potential energy finds resonance in diverse fields beyond physics.

IOM offers a perspective that social systems are deeply interlinked with the potential energy embedded in collective norms and values. By embracing the principle of potential energy, IOM presents a viewpoint on how meaning is produced within social contexts. The meaning is not an inherent property of objects or actions but emerge from their integrations into a broader assemblage of relationships and contexts. Take, for instance, the mundane object of a chair. Its significance transcends its mere physicality, emerging instead from its contextual assemblage, which includes not only its interaction with the individual who uses it but also gravitational forces and its material condition. The chair's design, materials, and construction also embody its potential energy. This includes not just its physical properties, but also the cultural, historical, and personal significances attached to it. These aspects are not immediately visible or kinetic but have the potential to influence actions, interpretations, and meanings. When someone sits on the chair, its potential energy is actualized into kinetic energy. The act of sitting transforms the chair from a mere object with potential uses and meanings into an actively engaged item fulfilling its function. This transformation also includes the realization of the chair's cultural and personal significance in the act of using it, such as comfort, status, or aesthetic appreciation. By applying the potential-kinetic energy process, IOM articulates how objects, concepts, and systems transition from a state of potentiality to actuality, generating meaning and action in the process. In other words, this process imbues outwardly inductive each component with inwardly deductive, meaning-maintaining, potential energy. This IOM's perspective echoes Martin Heidegger's philosophy, particularly his exploration of the essence of objects and their integration into the world of human concerns, as articulated in his seminal work on the question of being [8]. Heidegger's analysis of the tool-being offers a compelling parallel to the IOM's viewpoint on the chair's significance. For Heidegger, the essence of a tool (or any object) becomes apparent not in isolation but through its use—when it becomes ready-to-hand (Zuhandenheit), integrated into the flow of human activity. This transition from potential to actual use, where the tool's significance emerges from its contextual integration, is coherent with IOM's notion of potential energy being actualized into kinetic energy. Moreover, Heidegger's emphasis on the relationality of objects—how their meaning is co-constituted by their materiality, the historical and cultural significances attached within them, and their use by individuals—aligns with IOM's assertion that meaning is not an inherent property but emerges from the object's integration into a broader assemblage of relationships and contexts. In applying the process of the meaning-maintaining potential with its components to Heidegger's philosophy, one could argue that IOM provides a metaphysical framework that complements Heidegger's existential ontology. It suggests a dynamic process of becoming, where objects transition from being merely present-at-hand (Vorhandenheit) as isolated, potential entities, to being meaningfully engaged within the fabric of human existence. This conceptual bridge highlights the fluidity between potentiality and actuality in the creation of meaning, underscoring the inseparability of objects, their uses, and the human experience in the phenomenological unfolding of the world.

IOM thus provides understanding how interactions within/across systems generate meaning, information or significance. In the quantum realm, particles exist in a state of potentiality, represented by the wave function (in, or potential energy). The act of measurement collapses this wave function into a definite state (out, or kinetic energy), a process that is fundamental to quantum mechanics. This collapse isn't just a physical transformation; it signifies the creation of meaning within the quantum text—the particle's position or momentum acquires a definitive value from a range of possibilities. Thus, meaning in the quantum world also emerges from the interaction between the potential states of particles and the act of observation, highlighting how external interventions (measurements) convert potential into observable reality. At the cellular level, the potential energy and genetic information encoded within a cell guides its development and function, manifesting in specific cellular activities. For example, a stem cell's differentiation into a specialized cell type is not just a biological process but also a meaningful transition, where the cell's potential translates into functional contributions to an organism's health and development. Here, meaning emerges from the cellular potential being actualized through interactions with biochemical signals and environmental conditions, illustrating the cell's role within the broader biological system. A family meal is not merely an act of eating together; it can be a manifestation of the family's values around togetherness and communication. At the national level, the concept of identity can represent a potential energy mainly formed by history, culture, and shared aspirations. This inward collective identity can be actualized through national symbols, rituals, and policies, which in turn reinforce and reshape the national identity. On a global scale, potential energy resides in the shared challenges and aspirations of humanity, such as peace, environmental sustainability, and global health. The act of addressing these challenges through international cooperation, treaties, and global movements represents the actualization of this potential energy into meaningful global actions. For example, international climate agreements are not just legal documents; they are manifestations of the global community's commitment to addressing environmental challenges. The meaning of these agreements as well as the notion of global citizenship emerges from the interplay between shared global values (the potential) and concerted actions (the observable). Across these scales—particle, cell, family, nation, and global—illustrates how meaning is dynamically created through the interaction between internal potentials and external manifestations.

The meaning-making process of IOM is especially fitting when analyzing objects, social practices, or even broader societal phenomena, where the potentialities (cultural values, social norms, or historical contexts) are actualized in specific actions or events, revealing the deeply interconnected nature of potential and kinetic energies in the creation of meaning and the enactment of social realities. In IOM, potential energy symbolizes the stored capacities within any social entity or construct. This includes the traditions, values, collective identities and global aspirations for peace and sustainability, etc. These capacities, though initially latent or unexpressed, hold the possibility of being actualized into meaningful actions, practices, or outcomes through the dynamics of social interaction and the influence of external conditions. It can also be operationalized to study the mechanism of how these tangible outcomes, in turn, contribute to the transformation of those potentials.

4.3. The Wave Aspect of Structure

In quantum physics, a pivotal inquiry centers on reconciling the dual processes of wave function evolution and its subsequent measurement [6] [9] [10]. Essentially, quantum mechanics primarily addresses the former, conceptualizing it as pre-existing in a classical sense before the latter process actualizes or localizes it into the observable world. The crux of the challenge lies in reconciling the observable, classical phenomena with the underlying quantum reality.

In quantum mechanics, the Copenhagen interpretation posits that the wave function represents not a concrete physical reality but a pure potentiality, encapsulating every conceivable trajectory that quantum waves could take. This interpretation suggests that while the wave function itself is an abstract concept, the interference patterns observed on a screen, which are result of these potential paths, are indeed real manifestations. Accordingly, the Copenhagen interpretation stops short of providing definitive answers to essential ontological and epistemological questions. In other words, it leaves unresolved the deeper understanding of how these possibilities translate into actualities. The Copenhagen interpretation acknowledges the wave-particle duality, a cornerstone of quantum mechanics, but does not offer a theoretical model that can unify these dual characteristics into our cohesive understanding of quantum phenomena. Although advocates of instrumentalism would say that certain questions, particularly those concerning the fundamental nature of quantum phenomena, are inherently unanswerable, suggesting that any attempt to resolve them falls into the realm of unscientific conjecture, this position faces criticism from those who argue that declaring these questions off-limits is a premature capitulation that potentially hampers the progress of scientific knowledge. The paradoxes that arise in describing quantum systems, such as the breakdown of classical concepts like causality, space and time, underscore the inadequacy of traditional frameworks in comprehensively explaining quantum mechanics, and signals the need for a novel, higher-order framework of knowledge [6]. Such a framework would not only accommodate the unique characteristics of quantum phenomena but also provide a coherent understanding that transcends classical limitations.

To approach this conundrum, IOM posits that all structures on the universe are intrinsically functions, or the in-out matrix, echoing the quantum-mechanical perspective where the world is described in terms of wave functions. Erwin Schrödinger established that wave functions are fundamentally functions involving complex numbers. By aligning with this viewpoint, IOM can effectively encapsulate core quantum physics concepts such as entanglement, superposition, and coherence. This alignment allows IOM to transcend traditional boundaries, offering a comprehensive base for what could be termed *social quantum mechanics*. In this expanded scope, IOM not only addresses the structural aspects of social systems but also integrates the principles of quantum theory. This synthesis provides a platform for exploring and understanding social phenomena through a quantum lens, potentially revolutionizing our approach to social dynamics by incorporating quantum theory's insights into the fabric of social analysis.

In the context of quantum physics, coherence is a fundamental aspect of quantum mechanics that captures the ability of quantum states to exhibit interference effects due to the superposition principle. Quantum coherence refers to the condition where these states can add up or cancel each other out in a predictable manner, leading to observable interference patterns. The coherence of a quantum system is maintained as long as the phase relationship between different states are preserved. This coherence is essential for the unique behavior observed in quantum systems, such as quantum entanglement and quantum tunneling, where particles can instantaneously affect each other's states regardless of distance or overcome barriers without sufficient energy, respectively. However, quantum coherence is fragile and can be easily disrupted by interactions with the environment in a process called decoherence. Decoherence describes the transition of a system from a quantum to a classical state, where the system loses its quantum properties due to the loss of phase information. Quantum coherence thus represents a delicate balance that quantum systems must maintain to exhibit their unique properties, serving as a bridge between the quantum and classical worlds.

Coherence, when viewed through IOM, is interpreted as a process predominantly driven by outward wave properties. In this context, coherence emerges from the collective behavior of these waves, where the *whole* of one system becomes a *part* on its outside, exemplifying inductivity at work. The notion of inductivity, central to this interpretation, posits that quantum systems, through their inherent wave-like nature, extend beyond their isolated boundaries to interact with the environment and other systems. This extension and interaction facilitate the emergence of a larger, coherent structure, where the boundaries between individual systems become less defined. The wave properties of quantum particles thus serve as bridges that enable the integration of discrete systems into a unified whole. This understanding of quantum coherence as a process driven by the external workings of wave properties introduces a novel way of looking at the quantum-classical interface. It suggests that quantum systems, through their wave-like behavior, actively reach out to and intertwine with their surroundings, leading to the manifestation of coherence. The challenge of maintaining coherence on a macroscale, where interaction is inevitable, can be addressed through the notion of *in-out relativity*, suggesting that interactions operate between relative inside and outside, enabling entities or systems across scales to have potential abilities and become actualized through interaction. The experimental results about coherence tell us that the inside, potential, and outside, actualized realm by interaction, are *relative*. These experiments underscore the principle that the boundaries between the quantum (potential) and classical (actualized) realms are not fixed but are influenced by the nature of interactions a system undergoes with its environment. As such, interaction operates between the relative inside and outside, which can be called in-out relativity. Entities can become actualized when interaction occurs with their relative outside like social groups do. They can make up the relative inside in relation with environment, thus making coherent structures they can belong to, and can interact with each other within that relative inside. In the realm of molecular quantum mechanics, experiments have vividly demonstrated this relativity. For instance, research invoking molecules such as fullerenes or photosynthetic complexes has shown how quantum coherence can be maintained within these systems over surprisingly long timescales, even in complex, warm biological environments. These experiments reveal that coherence is not merely a microscopic quantum effect but can also manifest and play a functional role at the molecular scale, bridging the quantum and classical worlds. These findings support the notion of in-out relativity by demonstrating that the potential states of quantum systems (*their inside*) are deeply influenced by their interactions with *their external environments*. When a quantum system interacts with its environment, this interaction leads to the collapse of the wave functions—a transition from the superposition of states to a single, definite state. However, before this collapse, the system exhibits coherence, a testament to its quantum nature and the relative influence of its interactions with the external world (*in-out dance*). Furthermore, the persistence of quantum coherence in molecules highlights how the classical world emerges from quantum foundations through the process of decoherence. Decoherence, driven by interactions with the environment, delineates the boundary between the quantum and classical realms, emphasizing the context-dependent natures of this in-out boundary. Consider, for example, the global climate system, where the emissions of greenhouse gases in one part of the world can lead to climate effects (such as melting ice caps or extreme weather events) in another, distant part of the world. Local actions (external emissions) trigger global reactions (internal systemic changes in climate patterns (in-out dance). The coherence of the climate system on a macroscopic scale is maintained through the complex interplay of these local and global interactions. The inside and outside are relative, illustrating the fluid boundary between the potential and actualized realms.

Diving into the complexities of the quantum realm with the lens of IOM, we can explore the dance between coherence and decoherence. Within IOM, "in" signifies a quantum system's coherent phase, marked by uniformity and the presence of quantum characteristics such as entanglement and superposition. This phase represents a state of synchrony among the system's components. Conversely, the "out" phase denotes decoherence, characterized by the system's loss of quantum coherence due to environmental interactions, leading to a shift towards classical, external behavior where potential attributes fade. This cycle of transitioning from coherence, through decoherence, and back to coherence exemplifies not just a simple reversal but showcases the inherent resilience and adaptability of quantum systems. This dynamic process reflects a quantum system's journey through potential states (coherence), interaction with the external environment leading to decoherence, and the subsequent restoration of coherence. This phenomenon, known as recoherence, demonstrates the system's ability to regain its quantum coherence despite disturbances from its surroundings. Drawing parallels from the quantum to the social, this process can be likened to an individual or a community facing external challenges or opportunities. Initially in a state of harmony or coherence ("in"), they encounter external stresses or changes ("out"), which might disrupt their established state. However, through resilience and adaptability, they can recover or re-establish their original harmony, or even emerging broader ("in"). Just as a quantum system navigates through and recovers from decoherence, complex systems, whether in physics, biology, or social sciences, demonstrate a similar capacity to adapt and reorganize in response to external challenges or opportunities. Thus, analyzing recoherence through IOM illuminates the underlying principles governing transitions between coherence and decoherence, highlighting the universal nature of dynamic systems' interactions with their environments and their ability to maintain or restore order from disorder.

In IOM, the internal state of a particle is shaped by its relationship with the external state of its entangled partner. This interaction is a reciprocal process, where the inside of one particle is directly connected to the outside of the other, creating a unique state of interconnectedness. This perspective on entanglement, as is informed by previous Entanglement Axiom, can deepen our understanding of the phenomenon. It portrays entanglement not just as a static link between particles but as an ongoing, dynamic exchange where each particle's state is co-defined in relation to its entangled partner. The mysterious and instantaneous connections observed in entangled particles thus emerge from this in-out dance, where their relative internal and external aspects are linked, exemplifying the core principle of in-out duality. In this view, quantum entanglement is not only a fundamental aspect of quantum mechanics but also a vivid demonstration of the interconnected nature of the universe.

The traditional interpretation of quantum superposition posits that a quantum entity, such as a particle or a system, can exist simultaneously in multiple states until an observation or measurement collapses it into a single state. This principle is a cornerstone of quantum mechanics, illustrating the intrinsic probabilistic nature of quantum systems and their departure from classical determinism. Superposition embodies the quantum uncertainty and the multiplicity of possible outcomes that can arise from a single quantum system. Expanding upon this with IOM provides a broader, more interconnected view of superposition. In this framework, superposition is not solely an internal characteristic of a quantum entity; rather, it is a manifestation of the entity's potential interactions and integrations with the larger, encompassing systems. *The inductive wave property*, *acting outwardly*, *is essential in this integration*, suggesting that a quantum entity extends its influence beyond its immediate locality, becoming interwoven with its environment. This interpretation transforms the notion of superposition from a purely probabilistic occurrence to a dynamic process of potential engagement and integration with the external world. Here are some examples illustrating this interconnected interpretation: Quantum computing utilizes the principle of superposition to perform complex calculations at speeds unattainable by classical computers. In this context, qubits (quantum bits) exist in a superposition of states, enabling the simultaneous processing of multiple possibilities. From the IOM viewpoint, each qubit's superposition represents its potential to integrate and interact with a vast computational space, extending its influence far beyond a binary 0 or 1. This exemplifies how quantum systems, through superposition, can dynamically engage with and become part of a larger computational framework, inductively making the boundaries of information processing. A more tangible example of superposition is the fullerene double-slit experiment, where C60 molecules exhibit wave-particle duality. The wave-like properties of fullerenes, demonstrated when they pass through double slits and create interference patterns, suggest that these molecules are in a superpositional state reflecting potential paths. This experiment illustrates how quantum entities like fullerenes interact with their experimental setup (environment) in a way that transcends classical physics, embodying the essence of potential engagement and *inductively part-becoming integration with the external world relative to them*. Quantum tunneling, where particles pass through barriers that would be insurmountable according to classical physics, is another example. The particles exist in a superposition of states that include being on both sides of the barrier. In IOM terms, this shows how quantum entities can extend their influence to overcome physical boundaries, integrating into and interacting with a broader system. Tunneling in semiconductors, crucial for electric devices, showcases superposition's role in facilitating interactions outwardly in an inductive manner.

Quantum field theory (QFT) is a fundamental framework in physics that unifies quantum mechanics with special relativity. It treats particles not as isolated entities but as excitations (or vibrations) of underlying fields that permeate all of space. For example, an electron is an excitation of the electron field, while a photon is an excitation of the electromagnetic field. In QFT, these fields are considered the fundamental constituents of nature. They are not just *over space* but are *of space*, implying that the fields are inherent aspects of the universe's fabric.

When these fields are distributed or *excited*, they manifest as particles, which are the quanta—the smallest discrete units—of these fields. This emergence of particles as discrete quanta is coherent with the in-out duality formula ($S = O + I$), which can be interpreted as a way to understand the dual nature of quantum phenomena. In the context of QFT, the internal potential (I) can be thought of as the inherent energy or properties of the quantum fields. The external interactions (O) refer to how these fields and their excitations (particles) interact with other fields and particles. IOM underscores that the complete picture necessitates a consideration of both internal potentials and external interactions.

According to Paul Dirac's groundbreaking theory, the vacuum of space is filled with an infinite number of negatively charged electrons, known as the Dirac sea. This framework not only reconciled the theory of quantum mechanics with the principles of relativity but also introduced a profound perspective on the nature of reality, where the vacuum isn't void but filled with infinite potentialities represented by virtual particles. Within IOM, the vacuum, or the Dirac sea, serves as a fundamental backdrop where potentiality and actuality converge, illustrating the transition between dormant negative energy states and observable, positive energy phenomena. The dormant states represent the unobservable, virtual aspect of particles, filled with the potential to be activated into higher energy levels through external interactions, leading to the actualization of particles into observable reality. Dirac's fish tank analogy, when viewed through IOM, provides a vivid illustration of how quantum mechanics challenges and expands classical notions of boundary and existence. The analogy of bubbles forming in a fish tank, similar to particle-antiparticle pair production in the vacuum, serves as a metaphor for the emergence of quantum entities from the sea of potentiality that the vacuum represents. This emergence is not just a transition from non-existence to existence but a delineation of boundaries within the quantum vacuum itself, exhibiting the lines between the internal (potential) and external (actual) realms. Pair production, in this context, becomes a quintessential example of the quantum boundary's in-out relativity. The process by which particles and their corresponding antiparticles are simultaneously created from the vacuum in response to external energy illustrates the fluidity between what is considered *inside* (the vacuum's potentiality) and *outside* (the actualized particles in observable reality). This relativity and co-emergence challenge the classical, Newtonian concepts of separateness and discreteness, suggesting that the quantum realm is characterized by *entities that exist simultaneously in both internal and external states.* By doubling down on the interconnectivity and the dualistic nature of quantum mechanics as illuminated by Dirac's theory and expanded through IOM, we can appreciate the complexity and the profound implications of quantum mechanics on our understanding of the universe. It illustrates a cosmos where the dichotomy between existence and nonexistence is replaced by a spectrum of potentialities all interconnected through the fabric of the universe. This expanded view not only enriches our understanding of quantum mechanics but also opens up new avenues for exploring the fundamental principles that govern the universe, challenging us to rethink the very nature of reality, existence, and the boundaries that define them.

Moreover, it can be suggested that internalization and externalization occur simultaneously as a paired process. The outwardly directed cyclic wave process, which determines direction and magnitude, forms an internalized field. This field, in turn, gives rise to the deductive properties of particles that characterize their internal workings or potentials, leading to their manifestation or externalization inwardly. Take, for instance, the behavior of electrons within atomic orbitals. Governed by wave functions—which are essentially cyclic wave processes—these electrons exhibit a probability distribution that defines their potential locations within an atom. It is from these wave functions, or internalized fields, that the deductive properties of electrons emerge, dictating their observable attributes like energy levels through a mechanism of internalization followed by externalization or interaction. A practical illustration of this in-out dynamic can be seen in the operation of photovoltaic cells. When photons from sunlight strike these cells, they are absorbed, leading to the creation of an electric field—an internalized field that is a direct consequence of external energy being integrated into the system. This field then prompts the movement of electrons, generating an electric current through a process of externalization. This phenomenon exemplifies how external stimuli are internalized within a system, ultimately resulting in tangible, external outcomes that are in line with the principles of in-out ontology. In this context, in-out ontology offers a departure from traditional views of external space, proposing instead a model of existence characterized by a reciprocal field that facilitates the transition from potential to actualized states. Here, it should be pointed out that this reciprocal field is not just a theoretical construct but a tangible entity that have measurable effects, objectifiable on the relative external. By framing the interaction between quantum systems and their environments as a cycle of internalization and externalization, IOM provides a more interconnected understanding of phenomena.

Quantized particles tune our conduct to situations. Our dependence of conduct on this externalized comprehensive picture from potential has shifted the focus of post-positivist thinkers toward a more subjective interpretation of actors and social norms, rather than purely materialistic forces [11]. According to George Herber Mead's theory, the self is not a static entity but is continuously reshaped through interactions with others within the social environment [12]. By the same token, social facts are dependent upon human agreement and social (or relational) ontology: without our acceptance of the socially divided value and the existence of financial institutions, money may be just a piece of papers [13] [14]. The interpretation of objects like missiles varies depending on the social and political context; for example, British missiles held a different connotation for the United States compared to Soviet missiles [15]. These examples highlight how socially constructed properties, such as the value of money or the significance of a missile, are deeply entwined with our perception and understanding of their functions. When individuals and these objects coexist in the same field, or social context, they become interlinked, each influencing and defining the other. This mutual interdependence creates a complex structure where the meaning and function of objects like money and missiles, exist in the social and relational potentialities.

According to Immanuel Kant, beyond the observable universe lies an underlying reality of things as they truly are, which remains entirely inaccessible to science and human cognition; as such, we are inherently unable to remove the mental constructs that shape and mediate our interactions with the world [16]. Kant's distinction between phenomena (the world of appearances, accessible to us through sensory experience and structured by our cognitive faculties) and noumena (things-in-themselves, which exist independently of our sensory experience but are unknowable to us) is foundational to his epistemology. Kant argues that our knowledge is limited to phenomena; we can never have direct access to noumena because our understanding and sensory perception are inherently structured by a priori concepts and intuitions (such as space and time), which do not necessarily apply to things as they exist independently of our perception. This leads to the conclusion that while we can know objects as they appear to us, we cannot know the essence of things as they are in themselves; the world is fundamentally a social construct, where the subjects of scientific investigation cannot be separated from the social framework and dialogue that identify them, such that the nature of existence (ontology) and the manner of our understanding (epistemology) are so intertwined that differentiating between them becomes irrelevant [17]. This constructivist viewpoint suggests that while parts of a whole may appear to integrate on their own, they do not necessarily impart unique characteristics to the materials that compose them [18]. As such, this perspective simply highlights that the processual aspects of things-in-themselves cannot be divorced from their quantized, particle-like properties.

However, our everyday concepts and their actual working-processes are deeply interconnected, forming a complex web. These interconnections allocate specific roles to individuals, contributing to the formation of social structures. As such, it is the in-out complementary structure that underpins existence and defines the functioning of reality. Reality is a combination of all measurable possibilities, or potentials. They allow individuals to become active participants or subsets within a network: represented as a function $f(x)=y$. The roles and identities we assume in society are not just arbitrarily assigned but emerge from the interplay of these in-out processes. This in-out synthesis challenges traditional binary oppositions such as structure versus agency, mind versus body, process versus outcome, and macro versus micro. Within IOM, the wave dimension of structure is conceptualized as measurable processes distributed across various potentialities, which themselves contribute to the formation of complex wave interference patterns. Conversely, the particle dimension of structure is characterized by quantified layers, categories, that emerge from their constituent subsets, making possible feedback loops and interactions that influence their originating sub-systems.

4.4. The Particle Aspect of Structure

In everyday terms, particles refer to tiny, almost invisible objects. However, in physics, particles are idealized entities that are located at a point in space, used to study the motion of objects, regardless of their size or internal structure. For example, when studying the orbit of an electron around a nucleus, the nucleus and electron can be treated as particles, even though they have a size and structure. Similarly, the Earth is also considered a particle when studying its orbit around the sun, as its mass can be considered to be concentrated at one point. Then, within IOM, this structurally simplified model of particle is understood to be the property that can be measured from the outside while constructing the boundary of a system as a whole. Furthermore, the way in which the parts or subsets relate to each other and function as a whole determines the overall particle property of structure. Thus, any measurable process is a component of the particle aspect of structure, as Bruno Latour also notes [19]:

> Just as the division of labor created by the industries and bureaucracies helped Durkheim and Weber to trace their own definitions of social links, information technologies help us realize the work going on in actor-making…. Subjects are no more autochthonous than face-to-face interactions. They, too, depend on a flood of entities allowing them to exist.

This account of actor-network theory (ANT) presents a departure from traditional approaches in social science, particularly those rooted in reductive or eliminative materialism. ANT challenges the foundational dichotomy between subject and object prevalent in social sciences, advocating instead for an exploration of the connections that exist between and within entities. It posits that these entities, both human and non-human, form complex, heterogeneous networks. By adopting a twofold strategy, ANT aims to simultaneously analyze both the actor and the network that encompasses it, emphasizing the inseparability of the two [18]. For example, consider the case of scientific research in a laboratory setting. From an ANT perspective, the laboratory is not merely a backdrop for human activity nor are the scientific instruments; rather, scientists (actors) and their instruments (non-human actors) together form a network that produces scientific knowledge. The interactions between scientists and their equipment, the data they generate, and the interpretations they derive are all part of a larger actor-network. Another example can be found in the realm of social media. Here, individuals (actors) interact within digital platforms (networks) through interfaces and algorithms (non-human actors). The collective behavior of users, the design of the platform, and the algorithms that curate content and connections all contribute to the formation of a complex actor-network. The identity of a user (actor) is shaped by and shapes the network, illustrating the bidirectional influence between actor and network. Through this lens, phenomena are not reduced to the actions of discrete actors or the structure of networks but are understood as the outcome of the continuous (re-) composition of actor-networks.

The methodology of ANT significantly diverges from the principles outlined in classical social contract theories, such as those proposed by Thomas Hobbes. While social contract theories, including Hobbes's, seek to explain the formation of a unitary state as a mechanism for mitigating conflict among individuals, ANT focuses on the complex, interconnected relationships between both human and non-human actors within networks, without necessarily presupposing a hierarchical structure like a sovereign state. For example, Hobbes's idea of the *state of nature* posits a pre-political condition where individuals exist in a perpetual state of conflict, driven by their natural rights and desires. To escape this anarchical state, individuals collectively agree to establish a sovereign authority, the Leviathan, through a social contract. This sovereign then exercises absolute authority to maintain peace and order.

In contrast, ANT would approach this environment by examining the relationship and interactions among various actors (including ideas, beliefs, and material entities) that contribute to the formation of political and social orders. ANT might consider how non-human actors, such as written laws, physical infrastructure (e.g., walls, roads), and technologies (e.g., weapons, surveillance systems) play roles in shaping and maintaining the social contract, alongside human actors. The ANT perspective could highlight, for instance, how the physical manifestation of a border wall not only demarcates territorial boundaries but also influences human behaviors and social structures, acting within the network to enforce the social contract. Similarly, the role of written laws and legal documents can be seen as non-human actors that codify the agreements of the social contract, influencing and organizing human actions and societal norms. Furthermore, ANT would analyze how these human and non-human actors create a network that stabilizes the social order, rather than attributing peace and organization solely to the establishment of a sovereign authority.

Though the classical social contract theory based on the state of nature provides the foundation for the state and society, its contents are not sufficient enough to escape from controversy: Everyone agrees that agents generate different logics of anarchy and interaction-level anarchic structures vary [20]. While social contract theory cannot successfully describe the dynamic processes of the contemporary world, ANT effectively encompasses these dynamics by defining social as a descriptor for transient associations. ANT thereby emphasizes the fluidity and transformational potential of social interactions, highlighting the process through which entities—both human and non-human—converge to form complex, ever-changing networks. While the Hobbesian contract posits an agreement among pre-social individuals, ANT envisions the contract as a network of agreements that concerns collectives comprising both humans and non-humans [21]. While Hobbes deals with the question why social orders are accepted via his contract theory, Latour explicitly rejects this account and replaces it with notions of representation as translation [22].

This human-nonhuman hybridity of ANT has also been closely related with a wider trend toward New materialism [23] [24] [25]. New materialisms likewise depart from classical ontologies of mind/body and self/world dualism and engage in the complex human and nonhuman relations. By rejecting dualistic ways of thinking that separate the physical world from social and cultural phenomena, and emphasizing the ways in which the two are mutually constitutive, new materialisms argue that matter has agency and that non-human entities can have affective capacities and play a role in shaping social and cultural processes [26]. Matter is not passive or inert, but is always in relation to other matter, constantly in process and open to change and transformation. Its central point is that neither traditional positivist nor interpretivist approaches successfully take sufficient account of social/political events because of their lacking actual process exploration. As such, a foundational premise of this ontology involves reevaluating the essence of matter. It transitions from viewing matter as a passive entity, as traditionally seen in classical physics, to recognizing it as a dynamic and influential force within nature. In the current era, interconnected entities are anticipated to drive unprecedented levels of integration across various domains. Reflecting upon these evolving dynamics, the New Materialism framework posits a paradigm shift towards an ontology of becoming [27]. This perspective reconceptualize the processes of matter not as static and inert but as vibrant and generative. It emphasizes the importance of recognizing and analyzing the ongoing material transformations and processes, whose complexity and volatility are congruent with the principles of new materialist ontology. The new materialist initiative aims to equip scholars with the intellectual tools necessary for probing the material world without relying on language and symbolic systems, like images, that traditionally interpret its meaning [28]. Traditional approaches might focus on statistical data and predictive models, while a new materialist perspective would investigate the physical changes in the environment—such as melting glaciers or shifting weather patterns—as active participants in the climate system. This approach recognizes these environmental changes not just as outcomes but as dynamic forces contributing to the ongoing transformation of the planet, embodying the shift from viewing matter as inert to recognizing it as a vital force in its own right.

Then, I propose that IOM establishes a unifying basis for New Materialism by integrating the notion of in-out duality at its foundational level. This integration conceptualizes the world as an ensemble of potential outcomes derived from processes, contingent upon what is put (or, x) in what is measurable (or, y), thereby creating a unified in-out structure ($f{:}x = y$). IOM explicitly focuses on the dynamic interplay between the internal and external aspects of entities or systems. This explicit emphasis on duality allows for providing a structured way to understand how internal states and external context co-create reality. IOM's emphasis on in-out duality and the reciprocal nature of interactions provides a theoretical grounding that complements the existing approaches. IOM, with its axioms of Entanglement, Homogeneity, Emergence, and Measurement, provides a foundation for understanding the dynamics of systems through the lens of in-out duality. This explicit emphasis on in-out duality allows for providing a structured way to understand how internal states and external context co-create reality.

As has been frequently noted, both of inductive and deductive procedures are essential or, at least, complementary. While some scholars may prefer to concentrate on more inductive methodology, others focus their attention upon the deductive dimensions of research. They have each in their own way proved fruitful, increasing the theoretical diversity of disciplines. In general terms, induction does not strictly admit of falsification such that the deductive boundary is also necessary for theory construction, as Karl R. Popper writes that no matter how many instances of white swans we may have observed, this does not justify the conclusion that all swans are white [29]. If outside-working inductive logics with evidence are increasingly acknowledged, thus broadening their inter-subjective dimensions, they can become the collective structures of inside-working deductive logics by participants internalizing such logics. In sum, as both induction and deduction are basically used in the scientific research process, we would like to present the basis of this synthesis as follows: in-out duality makes up both motional inductivity all the outside (a wave property) and normative deductivity all the way inside (a particle property).

4.5. Interpretation of Light

An interpretation of light within IOM involves a bold exploration of how it reflects the universe. The speed of light, approximately 299,792 kilometers per second in a vacuum, is not merely a physical limit but a boundary condition that defines the universe's structure and operational parameters. Here, the role of observation brings insights into the observer-dependent effects predicted by relativity. It suggests that the speed limit of light delineates not just a physical constraint but a boundary condition for the co-creation of observable phenomena. Within IOM, the speed of light transcends its role as a physical limit and instead becomes a key player in shaping the universe's fundamental relational ontology. It acts as a crucial mediator in the ongoing process of transforming unmanifested potentials within a system into observable phenomena, highlighting the dynamic and interactive nature of reality construction.

Through the lens of IOM, the boundary condition becomes a gateway between potential (I) and actualization (O), mediated by the systemic structure (S). This mediation underlines a universal in-out boundary that shapes the very fabric of spacetime, dictating the transition from possibilities to realities. Moreover, the constancy of light's speed, integral to the theory of special relativity, reveals the universe's dynamic balancing act. This balancing involves internal potentialities and external realizations, manifesting through phenomena such as time dilation and length contraction. These phenomena not only demonstrate adaptability of relative spacetime but also its underlying relational dynamism, which IOM can elucidate. Time dilation, a phenomenon predicted by Albert Einstein's theory of relativity, occurs when there is a difference in the elapsed time measured by two observers, either due to a velocity difference relative to each other or the difference in gravitational potential between their locations. In essence, time dilation is an observable effect of the relative nature of time and space, depending on the observer's frame of reference. Then, time dilation exemplifies how external factors (such as velocity or gravity) can influence the internal experience of time, aligning with IOM's emphasis on the interaction between internal and external realms. In this light, time dilation can be seen as a physical manifestation of in-out relativity, where the inside aspect (the observer's personal experience of time) is directly influenced by the outside conditions (relative velocity or gravitational field). Furthermore, the phenomenon of length contraction posits that an object in motion relative to an observer will appear shorter along the direction of its motion compared to when it is at rest. This effect, like time dilation, is not perceivable at everyday speeds but becomes significant as the velocity approaches the speed of light. In the context of IOM, length contraction can also be conceptualized as a manifestation of the universe's inherent adaptability and relational dynamism. This adaptability is not merely a feature of temporal experience, as highlighted by time dilation, but extends to the very geometry of spacetime, affecting spatial dimensions as well. The outside influence in this configuration is the relative motion, while the inside aspect is the object's length as experienced by the observer. The systemic structure (S) that emerges from this interaction is a spacetime in which distances and durations are not absolute but are contingent upon the relative states of motion of observers and objects. IOM illustrates that the structure of reality (S) is a product of the interplay between potentialities (I) and actualizations (O) within a relational universe.

To encapsulate the relationship between the speed of light, potentiality (I), actualization (O), and the systemic structure (S), IOM proposes a formula that symbolically represents these properties and their interactions. This formula aims to capture the essence of how the speed of light acts as a boundary condition that mediates the transition from potential to actualized states within the universe's relational structure. Let's denote: c as the speed of light, I as the internal potential or possibilities within the system, O as the external realization or actualized phenomena, S as the systemic structure that encompasses the rules, including physical laws like those of relativity and the speed of light, which mediate the transformation from I to O. Given these definitions, this paper proposes the following formula to represent IOM described:

$$S\left(c\right)=\frac{I}{O} \tag{8}$$

Here, $S(c)$ represents the systemic structure influenced by the speed of light, which acts as a mediating function. This structure is a function of c because the speed of light defines the boundary conditions for how potentialities (internal states, I) are transformed into actualized states (observable phenomena, O). The division I/O indicates the transformation process from internal potentialities to their external manifestations, mediated by the systemic structure S, which is fundamentally influenced by c, the speed of light. This formula captures the notion that the speed of light is not merely a limit but a defining parameter that shapes the universe's relational and operational dynamics, facilitating the conversion of potential into reality within the structured constraints of spacetime.

Then, we can consider the case where light's behavior is analyzed through the lens of this formula. The external aspect O could be associated with the external properties of light, such as its wave-like nature described by electromagnetic waves. The Internal aspect I, on the other hand, involves light's interaction with physical media, its observable effects like its particle-like behavior characterized by photons. Then, the formula $S(c) = I/O$ suggests that the structure at light speed is determined by the ratio of its internal potential to its external interactions. This implies a direct relationship between the characteristics of light and how these characteristics manifest in observable phenomena. For instance, the nature of light as a particle can be seen as the inward mechanism I, which, when divided by the outward wave-like interactions O (such as interactions with detectors), yields the structure $S(c)$ that encompasses the observed behavior of light at speed c. To further exemplify this formula, let's explicate a time-dependent differential equation that models light's propagation through a medium:

$$\frac{\partial^2 E(x,t)}{\partial x^2} - \frac{1}{c^2}\frac{\partial^2 E(x,t)}{\partial t^2} = \frac{I}{O}E(x,t) \tag{9}$$

Here, $E(x,t)$ represents the electric field component of an electromagnetic wave as a function of position x and time t, and c is the speed of light.

$\frac{\partial^2 E(x,t)}{\partial x^2}$: This term represents the second spatial derivative of a field (E, for electric field, in the context of electromagnetic waves) with respect to position (x). The second derivative indicates how the field changes as it moves through space, reflecting the spatial distribution of internal potentials within the system. In the context of IOM, this could symbolize the internal structuring or internal dynamics of the system that contribute to its overall state.

$\frac{1}{c^2}\frac{\partial^2 E(x,t)}{\partial t^2}$: The term features the second time derivative of the field, scaled by the inverse square of the speed of light (c). This part of the equation describes how the field changes over time, emphasizing the propagation of effects (or external actions) through the system at a rate limited by c, the ultimate speed limit for information and energy transfer in the universe. It captures the response of the system's internal potentials to external influences over time.

$\frac{I}{O}E(x,t)$: This term directly integrates IOM into the wave equation, representing the ratio of internal potentials (I) to external actions (O) as a factor influencing the field. This term could be interpreted as a measure of the system's resilience or sensitivity to external inputs, indicating how internal structures (I) buffer or amplify external disturbances (O).

Integrating the I/O term into the wave equation suggests that the propagation characteristics of electromagnetic waves can be modulated by the dynamic interplay between internal potentials and external actions. This theoretically accounts for the influence of system-specific factors on outward wave behavior. As such, the modified equation proposes that electromagnetic wave behavior can vary in media with different I/O ratios, implying that empirical observations could detect differences in wave propagation, intensity, or speed due to changes in internal potentials or external actions. The use of x^2 and ∂^2 underscores the system's dynamic nature, focusing on changes and transitions rather than static states. It signifies the importance of not just the current state but also how the system evolves and adapts spatially and temporally. The factor $1/c^2$ is crucial because it introduces the fundamental constraint of relativity into the equation, acknowledging that the system's evolution is bounded by the speed of light. This limitation is essential in systems where relativity becomes significant, ensuring that the model adheres to universal physical laws. The equation as a whole can be seen as a representation of how systems described by IOM principles might evolve under the influence of internal and external factors, constrained by the fundamental limits of physics. The formulation offers a perspective on the dynamic and reciprocal nature of systems as described by IOM, highlighting not just how internal states manifest externally but also how external realities are internalized to enrich the system's potential for future action and evolution.

The differential equation incorporating I/O suggests a direct relationship between these internal and external aspects, where the evolution or behavior of the system (S) is contingent upon the ratio of I *to* O. A method for quantifying I could involve measuring the potential energy stored in systems. Defining O as the energy a system exhibits through movement or work, and quantifying O would involve calculations based on the mass and velocity of objects or subsets in motion or the energy transferred from the system to its surroundings during work processes. Furthermore, we can explore the I/O ratio as a measure of a system's efficiency in converting potential energy into kinetic energy. This could align with thermodynamic efficiency in mechanical systems or the efficiency of energy transfer processes in biological systems. Another consideration is also possible: The ratio as a reflection of the system's ability to harness environments for its external interaction, suggesting an inquiry into how structural configurations influence its interaction with its external conditions. In this context, the integration of the speed of light (c) serves not only as a boundary condition but also as a mediator of energy and momentum in relativistic systems. A higher I/O ratio implies a medium with increased permittivity (ϵ), potentially slowing down the wave propagation as the electric field component interacts more strongly with the medium. In standard electromagnetic theory, permittivity and permeability are material-specific parameters that determine how electromagnetic fields interact with matter. Permittivity (ϵ) reflects how a material can polarize in response to an electric field, affecting the electric field within the material and the speed of light through it. Permeability (μ) indicates how a material responds to a magnetic field, influencing the magnetic field within the material and the propagation of electromagnetic waves. As such, the I/O integration marks a distinctive shift from traditional formulations in electromagnetic theory, where parameters like permittivity (ϵ) and permeability (μ) typically play a pivotal role in modifying wave equations. The I/O term in this context represents a factor that potentially alters its propagation characteristics based on the balance of internal potentials and external actions. The term theoretically quantifies the interaction between internal potentials (I) and external actions (O) within a system. It also highlights the dynamic equilibrium that systems strive to maintain between their inherent capabilities and the demands or opportunities presented by their surroundings.

5. Concluding Remarks

The paper presents an exploration of the in-out duality notion, weaving together insights from social sciences, quantum mechanics, and philosophy to offer a novel perspective on the interconnectedness of the universe. The axioms of Entanglement, Homogeneity, Emergence, and Measurement are introduced as logical foundations underpinning the notion of in-out duality. These principles frame the dynamics between internal states and external motions, offering a structured approach to understanding the interconnectedness and complex behaviors of systems. The world view of in-out duality suggests that understanding the universe requires a synthesis of motion states outward and potential states inward, highlighting the role of quantum mechanics in shaping our understanding of phenomena and philosophy. It also highlights how internal potentialities, when actualized through interactions, generate meaning, emphasizing the dynamic nature of systems. By applying the principles of in-out duality across different domains, it aims to encourage a reevaluation of how we understand the structure, behavior, and evolution of complex systems. IOM suggests that the universe operates through a fundamental interplay between entities' internal potentials and external manifestations.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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