Representational Interference and the Limits of Abstract Representation

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Abstract

This paper introduces the Representational Uncertainty Principle (RUP) as a structural account of the limits of representational precision. We argue that as representations become more narrowly defined—by fixing more internal structure—they constrain the integration of perceptual and contextual cues. This often suppresses representational flexibility: the capacity to draw on multiple situational cues to stabilize meaning. When this flexibility is reduced, representational diffraction becomes more prominent: a structural phenomenon in which aspects of a situation are subsumed under a representation that deviates from the expected or standard framing, resulting in ambiguity or tension. Drawing on a structural analogy with quantum mechanics, we treat interference and diffraction as complementary manifestations of how representational content is formed. This framework explains why overly precise representations often fail in contexts that demand sensitivity to subtle variations. We support this account through examples of conceptual ambiguity and apparent contradiction, and by developing a framework that distinguishes between the structuring role of the representational vehicle and the dynamic process of integration that gives rise to content. The RUP thus highlights a structural tension between abstraction, context sensitivity, and the need for orientation within experience.

Keywords: Representation, Interference, Perceptual Integration, Representational Uncertainty Principle, Contextual Meaning, Abstraction, Quantum Analogy

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1 Introduction

Contemporary philosophy of mind and cognition faces a persistent tension between the stability of representation and the stream of experience. Formal semantics, epistemology, and concept theory often seek precision through increasingly articulated representational vehicles (e.g., definitions, rules, logical forms). Yet as these representations become more precise, they frequently lose applicability across the nuanced variability of actual contexts. This paper introduces the **Representational Uncertainty Principle (RUP)** as a structural account of the trade-off between representational precision and situational adaptability. The core idea is that when we define a representation more precisely (e.g., by adding more specific elements or structure) we gain clarity but lose flexibility. Representational precision helps to stabilize meaning in some contexts, but it can backfire in others by limiting how well we can integrate unexpected details or contextual variation. This can create a structural tension between a representation's fixed form and the fluid demands of the situation. We argue that this tension becomes especially visible when the representation used diverges from what is expected in context—a phenomenon we later describe as representational diffraction.

This principle sheds light on the fragility of overly narrow descriptions in everyday reasoning and concept formation, as these are domains in which fixed definitions (unlike in scientific classification) often fail to accommodate contextual nuance. The aim of our analysis is not to introduce a formal model of cognition, but to develop a structural analogy—later compared to principles from quantum theory—to rethink the limits of representation and to illuminate why precision may sometimes destabilize, rather than clarify, meaning.

Efforts to capture meaning through formal definitions, necessary conditions, or rule-based systems repeatedly encounter contextual exceptions, ambiguous cases, or interpretive gaps (Casasanto & Lupyan, 2015; Machery, 2009; Wittgenstein, 1953; Zagzebski, 1994). Yet despite growing recognition of this tension, its underlying structural dynamics (i.e., linking representational form to contextual adaptability) remain undertheorized. Philosophical theories of representation increasingly confront a structural dilemma: the more precisely a representation is defined, the less flexibly it applies across the rich variability of experience, since stricter definitions tend to exclude contextual cues that support adaptive use (Boghossian, 2008; Travis, 1994). This dilemma—whether in epistemology, philosophy of language, or cognitive science—reflects an unresolved tension between formal abstraction and situational adaptability. From reflections on rule-following and language-games (Wittgenstein, 1953) to theories of situated cognition (Clark, 1997; Gallagher, 2005) and contextualism (Barsalou, 1987; Casasanto & Lupyan, 2015), a common thread emerges: abstract representations tend to fail when divorced from the context-sensitive processes that support their integration and application.

This critique aligns with developments in quantum cognition—a research program in psychology and cognitive modeling that relies on quantum probability theory to better capture the structural patterns of human rationality. As Chater and Oaksford (2000) emphasize, traditional models based on probability and logic cannot fully capture the contextual and dynamic character of human reasoning. Quantum cognition builds on this insight, highlighting systematic deviations such as context dependence, interference, and order effects. Researchers such as Diederik Aerts, Jerome Busemeyer, and Peter Bruza have drawn on quantum-theoretical principles—such as superposition and interference—and structural features like contextuality to model phenomena including concept combination, decision making, and ambiguity resolution under the term *quantum cognition* (Aerts, 2009; Aerts, Sozzo, & Veloz, 2015; Busemeyer & Bruza, 2012; Pothos & Busemeyer, 2022). While many of these models adopt the formalism of quantum mechanics, our approach reframes the same structural insight through philosophical analysis: representation is a dynamic, context-sensitive process, and interference among representational cues plays a central role. Rather than extending quantum probability directly, we offer a complementary philosophical framework that explains how representational vehicles constrain integration and how diffraction results from this constraint.

Recently, Fernández Cuesta, Piazzai, and Rivieccio (2025) have argued findings from cognitive science suggest that quantum logics are apt to characterize human reasoning. Additionally, *wave-functionalism* (Allori, 2021) defends an interpretation of the wavefunction in terms of functional role—resonating with our structural analogies in representation. These views have encouraged us to employ the quantum formalism as a tool for modeling structural constraints on cognition through representation, without appeal to quantum ontology or physical instantiation.

We focus on the structural insight that representation involves an ambivalence between fixation through abstraction and openness through situated embedding. This duality becomes particularly clear when viewed through a structural analogy with quantum mechanics. Just as wave–particle duality in quantum systems entails mutually exclusive yet complementary modes of description—preventing simultaneous precision in both position and momentum (Dirac, 1958)—we argue that a representational duality exists between the explicit form of a vehicle and the integrative flexibility of its content. This analogy is not metaphysical but structural: interference and diffraction emerge as intrinsic features of meaning under representational constraints, shaped by the inherent uncertainty of situated experience. The view resonates with complementarity-based approaches in other epistemic domains that attribute an essential role to context.[1]

To make sense of this phenomenon, we draw on a set of philosophical approaches that may seem atypical within mainstream analytic discourse—those of Michael Polanyi, Peter Ruben, and Werner Stegmaier. Their work centers on tacit integration, the dynamics of contradiction, and orientation within contingent situations. While these authors are mostly neglected in current analytic literature, their insights offer indispensable tools for articulating aspects of meaning and representation that remain underdeveloped in formal models. It especially concerns the pre-reflective, situational, and oscillatory processes that govern how meaning is stabilized in practice. Importantly, our appeal to these approaches is not intended as an opposition to analytic

[1]The principle of complementarity formulated by Bohr (1937)—that wave and particle descriptions are valid only in distinct experimental contexts—has been extended beyond physics to resolve context-dependent interpretive tensions. Lindenberg and Oppenheim (1974) and Zhou (2018) apply this idea to epistemology and information theory, respectively, showing that conflicting descriptions can be structurally coherent when treated as contextually bound. This complements our account of representational interference and diffraction as arising from context-sensitive meaning, not logical contradiction.

philosophy, but as a complement to it. Where analytic frameworks reach their structural limits, these non-analytic approaches offer conceptual scaffolding to bridge the gap between abstraction and situated meaning.

The remainder of the paper is organized into six parts. Section 2 defines the core concepts of percept, vehicle, content, and integration, and frames them in relation to recent work on mental representation while adopting a functional approach. Section 3 lays the philosophical foundations, synthesizing contributions from Polanyi, Ruben, and Stegmaier to describe how representational meaning emerges from oscillation between abstraction and context. Section 4 introduces a wave-based analogy through a thought experiment that models integration and subsumption. Section 5 develops the analogy to quantum theory and formulates the Representational Uncertainty Principle, showing how diffraction arises from the exclusion of interference. Section 6 discusses the status and limits of the RUP, clarifying its conceptual scope and distinguishing it from agent-centered interpretations. Section 7 offers an outlook, outlining open questions concerning formal modeling, the historical scope of the framework, and possible connections to artificial intelligence.

2 Foundational Concepts: Percept, Representation, Vehicle, Content, and Integration

The debate between Shea (2018) and Egan (2020) highlights a critical tension in naturalistic theories of representation: whether representational content can be explained solely in terms of internal functional roles and environmental correlations, or whether it inevitably relies on pragmatic, interpretive, or teleological assumptions. While we do not fully endorse either position, the debate foregrounds the difficulty of grounding representational meaning in purely informational terms. Our own account sides with Egan's concern about the insufficiency of decoding models but departs from both authors by following a structurally grounded alternative: meaning arises not from informational transmission, but from the dynamic integration of perceptual cues within a representational structure. Thus, we propose a structurally grounded view: representations should not be primarily understood as signals that carry predefined content to be decoded. In our framework, we treat them as structural constraints that guide the integration of perceptual cues, enabling content to emerge from this process within the situation. Where Shea's model treats the environment as a source of information-bearing signals to be decoded, our view acknowledges the environment as a source of sensory input, but frames it primarily as a field of affordances. Representations, in this view, act not as messages but as selective structural anchoring points (footholds, in the sense developed later) that constrain how sensory input is integrated.

Recent empirical work by Parise and Ernst (2025) supports a dynamic view of integration in perception. In multisensory settings, they show that the combination of sensory cues depends on context-sensitive weighting rather than simple addition. The perceptual system prioritizes cues based on their situational reliability, leading to percepts that are shaped by how different sensory modalities are brought together in context. This supports our premise that integration is not the extraction of fixed information but a constructive process that shapes content through selective combination.

From this point of view, we clarify four foundational concepts as they are used in the present framework: percept, vehicle, content, and integration:

- **Percept** refers to a structurally organized field of sensory cues made available for potential integration. It is not a static snapshot or a labeled entity but a distributed pattern of inputs that forms a partial projection of the situation. The percept provides the raw material that can be subsumed under a representation but is only partially determined in terms of meaning.
- **Representation** is the assignment of a vehicle (simple or structured) to a percept, selectively constraining how that percept is integrated and interpreted within a given context. Representations do not passively mirror sensory input; they select a specific meaning that guides orientation towards suitable action.
- The **vehicle** is the material or structural carrier of a representation. It may be linguistic (a word or sentence), symbolic (a sign or formula), or mental (such as a structured experiential configuration or imagistic form). A vehicle is composed of elements, relations, and syntactic constraints, and enables integration by anchoring attention and categorization. It does not determine content directly but constrains how integration proceeds.
- **Content** is the functional aspect of a representation that directs a subject by jointly enabling recognition (descriptive function) and action-guiding orientation (directive function) (Millikan, 1984; Thomson & Piccinini, 2018). It emerges from the subsumption of the percept under the selected vehicle—that is, the percept is brought under the structural constraint of the representation, which brings certain cues to the fore while downplaying others, allowing a coherent orientation to take shape. Content is not stored or transmitted; it is achieved through the coordination of percept and vehicle in a particular situation.

Integration, in this view, is the process by which perceptual cues are combined, prioritized, and fitted together to produce a coherent orientation towards action. While we will later develop a model in which integration displays wave-like and interference-sensitive properties, at this stage it can be understood more generally as a dynamic, context-sensitive coordination of cues. Representational success depends on the extent to which a representation facilitates coherent integration of cues into meaning within a situational manifold.

This structural model departs from informational or encoding-based theories by locating the source of meaning not in the vehicle alone, nor in external correlations, but in the successful integration of the perceptual field for situated orientation. In contrast to Hipólito (2022) who criticizes the dominance of machine-based analogies in cognitive science—where cognition is modeled as the computation of intelligible, information-bearing representations—we understand cognition as the integration of experiential data rather than the computation over symbolic representations. We are interested in the question of what structure representations have and what role they play. Rather than treating representations as computational tokens that carry information to be decoded, our approach conceptualizes them as structural constraints on perceptual integration.[2] The process may still be computational in a broad sense (as a dynamic, rule-sensitive transformation of states), but representations themselves do not function as messages or symbolic encodings. They serve as *footholds* that stabilize orientation within a complex manifold of perceptual and contextual cues. In this sense, we align with the concern of Egan (2020): the persistence of representational language in computational models often lacks a secure naturalistic grounding. Our proposal offers an alternative structural grounding—based not on syntactic tokens, but on the capacity of representations to guide integration through contextual constraints.

Neurocognitive research supports this view of integration as a dynamic and context-sensitive process. Pulvermüller (2023) shows that conceptual content in the brain arises from the distributed activation of multimodal neural assemblies, which encode perceptual, motor, and contextual features. These assemblies interact in a manner that resembles interference: overlapping activations can amplify or attenuate each other, depending on situational demands and prior associations. This parallels our structural claim that perceptual content is not determined by intrinsic features alone, but emerges from the contextual modulation of cues. Pulvermüller's use of brain-constrained deep neural networks further demonstrates that such wave-like patterns of integration can be replicated in computational architectures, reinforcing the plausibility of our account.

3 From Situation to Orientation: Philosophical Background

The recent advances in deep learning and neural architectures—especially within applied AI—have renewed interest in foundational questions about how cognition integrates context, structure, and experience. Many traditional philosophical approaches to representation, shaped by symbolic or propositional models, struggle to accommodate the distributed, context-sensitive, and interferential nature of cognition suggested by these systems. As a result, previously marginal frameworks that emphasize orientation, situational responsiveness, and structural constraint become increasingly relevant. In what follows, we draw on three thinkers—Ruben, Polanyi, and Stegmaier—who, though working outside the analytic mainstream, offer conceptual resources particularly well suited to the questions we are interested in. Their focus on concrete practice, situated perception, and orientation helps articulate a view of representation not as internal encoding, but as a selective structuring of potential integration within evolving situations.

3.1 Situational Perception: Grounding Representation

Following Stegmaier's concept of orientation (Stegmaier, 2008, 2019), we can more precisely structure the relation between *situation*, *view*, *percept*, and *representation* as follows:

The **situation** represents the full manifold of environmental affordances—the total field of possible actions, resistances, and opportunities presented by the environment,

[2] We do not generally exclude the use of representations for computations, but rather consider such use to be secondary; representations do not primarily function as messages.

independent of any perceptual or representational act. This manifold understood as a space exists prior to any given perception or representation, but it is not static, as it continuously evolves and is reshaped through the subject's engagement, forming the dynamic horizon within which meaningful orientation becomes possible.

The subject gains an overview of the situation through a sequence of views (Stegmaier, 2008, Sec. 5). A **view** can be formally understood as a subspace of the situational space—a structured restriction that determines which aspects of the situation are available for perceptual integration. This view limits what becomes perceptually salient, selecting a portion of the environment relative to the subject's *standpoint* and *perspective*. The view does not yet specify particular objects or meanings; rather, it constrains the space of potential focus.

The **percept** can then be understood as the projection of the situation onto this subspace—a specific structuring of environmental features within the view that remains open to multiple possible representations. Importantly, while we often imagine percepts as entities—discrete, object-like elements—understanding them as structured process of wave-like integration of cues aligns with Polanyi's integration of subsidiaries and Stegmaier's evolving orientation: percepts emerge through interaction, not isolation. They are pre-representational fields from which various interpretive acts (as subsumptions) are possible. Only when the subject—or the cognitive system—commits to a particular subsumption under a representational vehicle does the content take on a definite meaning. This act of **representation** abstracts from the openness of the percept, rigidifying it under a specific conceptual form suitable for further orientation or communication.

This layered account of situation, view, and percept sets the stage for understanding how representation emerges from the process of orientation. To fully grasp the dynamics of this emergence, we now turn to the philosophical frameworks that clarify the tensions between fixation, openness, and integration.

3.2 Philosophical Background: Integration, Dialectical Tension, and Orientation

Stegmaier (2008, 2019) introduced the concept of the **foothold** (*Anhaltspunkt*) to describe how perception stabilizes or holds onto certain aspects of an evolving situation to enable orientation. Crucially, a foothold is not isolated; it only gains significance through the subject selecting it to stabilize the understanding of the situation, and through the **fits** (*Passungen*) that connect it to other footholds.

Not every foothold constitutes a representation. As (Stegmaier, 2008, Sec. 10.4) notes, footholds can manifest themselves in images, symbols, or names (i.e., forms that correspond to representational vehicles), but they may not necessarily do so. Representations can thus be seen as a subset of footholds: those that stabilize meaning through symbolic or structural encoding.

This temporary stabilization resonates with a distinction between the concrete and the abstract discussed by Ruben (1966/2022). For Ruben, the concrete is the ongoing process of the situation itself—not captured by any privileged fixed representation, but open to multiple, context-sensitive descriptions that resonate with the situation. In such concrete situations, the same percept can bear different meanings depending on context; these differences come to light as contradictions when the situation is translated into language, where representations fix meanings that might otherwise overlap or remain fluid in practice. This is the source of Ruben's distinction between dialectical contradiction (actual contradictions resolved in context) and logical contradiction (contradictions exposed in formal abstraction).

Ruben's notion of organizing activity (*organisierende Tätigkeit*) involves abstraction from the concrete process: selecting, establishing, and connecting features into concepts and relations for distinction-making and stable description. This organizing activity halts the flow of the concrete to form abstract structures—what we here call representational vehicles—that can be transferred between contexts. Conversely, processing activity (*verarbeitende Tätigkeit*) returns to the flow of the situation, where these abstracted entities lose their isolation and become moments of the unfolding process, no longer separable but integrated into the flux of experience.

This process mirrors the dynamic at work in representational narrowing: a singular structure is fixed from an open field of possibilities, and in doing so, potential contradictions or alternative representational subsumptions are excluded for as long as the subject remains within the organizing mode of activity. The apparent stability is achieved by suspending the multiplicity and openness of the situation, not by eliminating them altogether.

For instance, when a person lays bricks to build a wall, the brick becomes focal only when it is distinguished from other objects. As soon as the brick has been grasped, attention shifts toward the construction activity itself. As the wall takes form, the structure becomes the perceptual focus, while the individual brick is no longer apprehended in isolation.

Ruben (1966/2022) uses this example to illustrate how a perceived object becomes a moment of a larger activity: no longer discrete or explicitly represented but functionally integrated into the unfolding process. Polanyi, in a similar vein, describes this as a shift from focal to subsidiary awareness, when the part starts to contribute to the whole. These complementary formulations converge on the same structural insight: integration transforms elements into backgrounded contributors to meaning and action.

Stegmaier (2008) describes the notion of aspect (*Hinsicht*) that can also be read as part of this continuum. A moment, once selected for attention, becomes an aspect when not in focus as part of the situational context. As Stegmaier notes, "Insights into the inner workings of things make all perspectives appear as superficial aspects of a 'depth' that, as long as perspectives can still be distinguished, must be further 'deepened.'" (ibid, p. 189) This suggests that moments, subsidiaries, and aspects all share a transitional role in the dynamic structure of orientation.

Taken together, these examples illustrate what we mean by integration: the dynamic process by which discrete cues or elements are drawn into a larger orientation structure, where their individual status shifts depending on the situational focus.

Stegmaier's fits serve here as the mechanism of sense making: the wall becomes meaningful because the bricks fit together in the right way, just as (Ruben, 1966/2022, p.48) emphasizes that every interpretation of reality presupposes an organized connection between circumstances. The result of this integration process—the whole—determines the meaning of its parts: in Polanyi's terms, the subsidiaries gain significance through their contribution to the focal whole.

Thus, in all three frameworks, representation entails a necessary oscillation. The situation must be momentarily halted—grasped via footholds and through organizing activity—to yield clarity and structure. Yet these abstractions must dissolve into the flow of concrete experience, where the formerly focal elements revert to subsidiaries (in Polanyi's terminology) or moments (in Ruben's dialectical terminology) as integrated parts of the activity (Polanyi, 1962; Ruben, 1966/2022). Representation is never complete or total; it moves between fixation and openness, part and whole.

This context-dependence is not uniform across domains. As (Ruben, 1966/2022, pp. 51-52) emphasizes, scientific practice deliberately minimizes contextual variability by stabilizing experimental conditions, which enables abstract representations to function more effectively in scientific settings, where meanings can be fixed across repeated instances through the use of technical language. In contrast, everyday reasoning, legal interpretation, or social categorization often operate under shifting, unbounded contexts. This distinction underscores that the susceptibility to contextual deviation is not a flaw of abstraction *per se*, but a consequence of its application in environments where contextual stability cannot be assumed.

While none of the three thinkers explicitly formulate the notion of interference, their ideas converge on it. Stegmaier's *fits* show how footholds support or inhibit each other, anticipating the way cues reinforce or weaken one another in interference. Ruben emphasizes that in colloquial language, it is the context of concrete experience that enables the subject to narrow down the meaning from a multitude of possible interpretations. While he does not describe the interaction of features in detail, this dependence on situational alignment suggests a process akin to interference. Finally, with his account of tacit inference, Polanyi (1968) describes how perceptual integration forms a coherent whole overriding contradictory details; cues gain or lose salience depending on how they fit into a larger representational field.

Wittgenstein (1953) prefigures our notion of interference in his concept of family resemblance, which rejects the idea that concepts are defined by necessary and sufficient conditions. Instead, meaning arises from overlapping patterns of use that vary across contexts. Just as in our account, these patterns do not yield a stable, centralized representation, but remain open to situational modulation—what we describe as interference. Recent neurocomputational work by Henningsen-Schomers and Pulvermüller (2021) supports this interpretation. Their simulations show that concepts grounded in family resemblances fail to form robust neuronal assemblies in central integrative areas of the brain, in contrast to concepts based on consistently shared features. This suggests that representations based on partial overlap are inherently diffuse and resist fixation—much like our notion of diffraction, where multiple overlapping cues destabilize unitary content. While concrete concepts in their model behave like stable, strongly integrated assemblies, abstract (family-resemblance-based) concepts are functionally weaker, more dispersed, and more context-dependent. This convergence reinforces our structural claim: that interference emerges not from noise, but from the probabilistic structure of conceptual similarity itself, which resists sharp delineation even in neural architectures.

This integrated view lays the groundwork for understanding the structural limits of representation as a trade-off between stability and situational adaptability, which becomes a fundamental limitation for representational acts.

4 Explicit Representation and the Expansion of Cognitive Capacities

We now introduce two structural concepts that emphasize the wave nature of perception in relation to representation: interference and diffraction.

Interference refers to the evolving content that emerges through the continuous integration of situated cues. This process enables context-sensitivity by allowing certain meanings to gain prominence while others are attenuated or suppressed. In some cases, even salient features can be overridden when a multitude of subtle, non-salient cues collectively suggest a different interpretation. For example, in a job interview, a panelist's explicit statement of strong interest may be undermined by other panelists who check their watches, avoid eye contact, or appear distracted. Despite the verbal statement's salience, these overlapping contextual cues interfere with it, prompting the candidate to question the sincerity of the expressed interest.

Representational interference, more specifically, describes the interference among the contents associated with the components of a representational vehicle—how perceptual, semantic, or contextual elements reinforce or weaken one another depending on the situation, while the vehicle itself remains structurally fixed. Interference is a functional necessity for interpretation that supports context-sensitive integration. When interference is excluded (for the sake of analytic clarity) the process loses the stabilizing effect that contextual cues exert on one another.

It plays a central role in managing *ambiguity*, where perceptual or conceptual cues may support more than one possible interpretation. In such cases, interference enables the system to converge on a coherent meaning by amplifying some cues while downplaying others. For example, in the phrase "red rose", both "red" and "rose" independently convey aspects of affection, but in combination, their shared associations reinforce that meaning more strongly than either term alone.

Representational interference can even occur between statements that appear logically contradictory. For example, saying "She is helpful because I can always talk to her" and "She is not helpful because she does not come to help me move" introduces a formal contradiction in the abstract representation of 'helpfulness'. From a purely logical standpoint, these statements are mutually exclusive. Yet when the contextual details of each are considered, interference between them allows the subject to form a richer, more situated understanding of what 'helpful' might mean. While the abstract vehicle struggles to resolve the contradiction, contextual integration supports an interpretation that reflects the experiential texture of the situation. Here, interference does not obscure meaning—it enables it, by reconciling incompatible representations into a context-sensitive synthesis.

A similar case arises with the apparent opposition between *discovery* and *invention*. Abstractly defined, these are exclusive categories: something is *discovered* if it existed prior to its representation; something is *invented* if it is represented prior to its existence. Yet in practice, this dichotomy often breaks down. For an invention to be viable, the conditions for it must already exist—latent features of the world that are, in a sense, *discovered* as suitable for an *invention.* Conversely, *discovery* often requires a pre-existing conceptual lens—an *invented* framework—that renders certain phenomena intelligible. While the abstract concepts exclude each other, interference reveals a meaningful synthesis of the two concepts, as *discovery* includes an aspect of *invention* and vice versa. The examples show how representational tension can yield a coherent and pragmatically useful orientation, even in the face of formal contradiction or mutual exclusion.

The concept of interference, as used here, does not presuppose literal wave physics but refers to its general structure. Wittgenstein's family resemblance can be understood as an interferential structure based on dynamic modulation of similarities rather than merely as shared features. Likewise, in his early formulation of resonance, Gibson (1966) already hints at a wave-like conception of perception (described as "*richness of stimulus*"): rather than treating perception as the result of internal construction from disordered stimuli, he proposes that the perceptual system resonates with structured environmental information through coordinated input–output coupling (Raja, 2017, 2020). This anticipates a dynamic model in which perception arises not from passive reception but from interactional structure—though in our case, the emphasis shifts to internal interference among cues, where interference serves as the structural basis for resonance within the cognitive system.

The phenomenon of (representational) interference has been explored in various research traditions using different terminologies. For example, in psycholinguistics, MacDonald, Pearlmutter, and Seidenberg (1994) have shown how multiple syntactic and semantic cues compete during ambiguity resolution in real-time language processing, a process that reflects dynamic contextual integration rather than rule-based disambiguation. The integration of perceived content components—when features are combined into unified perceptual structures—has been explored in various research traditions using different terminologies. In linguistics, it appears as *co-compositional semantics* (Pustejovsky, 1995, 2017), where the meaning of a compound expression cannot be reduced to its parts, and in conceptual blending theory (Fauconnier & Turner, 2002), which models how disparate conceptual domains interact to generate emergent meanings. In cognitive psychology, this dynamic aligns not with attentional or cross-modal interference, but with predictive, context-driven feature integration—what Treisman and Gelade (1980) describe as feature binding and Clark (2013) situates within predictive processing models. Across these domains, the key insight is that meaning formation depends on contextual fits between features—what we describe as interference—rather than on linear compositionality.

As shown by Parise and Ernst (2025), perceptual integration involves the contextual weighting of cues across modalities—reinforcing some while downplaying others. Although their study concerns multisensory integration, the underlying mechanism reflects the structural dynamic we describe as interference: the mutual adjustment of cues in the direction of a coherent percept. This illustrates how cue interaction, even at the perceptual level, can produce emergent meaning that is not traceable to any single input in isolation.

A similar structure appears in computational models of language, where ambiguity is not treated as a flaw but as part of the system's dynamic processing. Park and Kim (2025) show that large language models encode ambiguous inputs more strongly in intermediate layers than in final outputs. This suggests that ambiguity is a structural feature of the system's internal coordination—arising from multiple interpretive paths that coexist and interact before a resolution is reached. Their findings reinforce the idea that meaning construction involves a graded process of coordination across representational layers, consistent with our notion of interference. The fact that ambiguity peaks mid-process implies that flexible interpretation relies on the temporary coexistence of competing cues before stabilization occurs.[3]

Representational diffraction arises from representational interference. Percepts can be associated with various representations, but the probability of each is different. This probability does not reflect intrinsic properties of the percept, but the statistical regularities of past associations learned through repeated exposure, contextual co-occurrence, and socially reinforced conventions.[4] The most probable assignment typically dominates as the "leading representation" or the expected categorization formed by habit. However, this dominance is probabilistic, not absolute. The manifold of the situational circumstances can activate contextual cues that favor an alternative representation, suppressing aspects of the dominant one and amplifying others. In this way, a typically dominant representation may be overridden when alternative pathways of integration become more salient in a particular context. Thus, representational diffraction mostly occurs in the form of a subject's unusual use of an object, whereby a neutral observer would assign a different use to this object.

Suppose a visitor at the zoo says, "That's an African elephant," referring to the fact of its origin from Africa (e.g., the Cairo Zoo). A second observer replies, "No, that must be an Asian elephant—its ears are too small, and the head shape is different." The first speaker uses an abstract compositional representation: elephant + African = elephant from Africa. In contrast, the second speaker relies on interferential integration, where the label "African elephant" evokes a typical species-specific appearance that conflicts with the perceptual cues—such as smaller ears—indicating an Asian elephant. For the second speaker, the first speaker's categorization constitutes a case of representational diffraction: the representation assigned deviates from what the speaker would typically expect in terms of the animal's perceptual features, regardless of the specific context (origin from the Cairo Zoo).

Another example is the use of a metal sculpture as a hammer. In the usual view, the perception of the object (a metal sculpture) results in its representation as an art object. However, in a situation where no hammer is available and a functional tool is urgently needed, the view can shift: the same perceptual features (shape, mass, hardness) are projected differently, allowing the object to be subsumed under the representation "hammer." The subject remains aware that, in most contexts, the

[3] Park and Kim (2025) analyze how large language models respond to ambiguous prompts and find that the semantic variability is most pronounced in intermediate layers—prior to any output commitment. This supports a layered, integration-based model of meaning construction, aligning with the idea that cues interact dynamically before stabilizing into a focal orientation.

[4] Probabilistic association between percepts and representations is supported by cognitive models of categorization (Anderson, 1991; Nosofsky, 1986) and neural network simulations showing contextual reinforcement effects (Park & Kim, 2025; Pulvermüller, 2023).

sculpture would be seen as an art object, however, in this situation, the affordances call for a different use.

The resulting deviation from situational expectations marks the experience as diffraction: the situational manifold supports multiple possible representations, and the act of choosing one reveals the exclusion of the other. Diffraction does not mark an error in perception but reveals the persistent intrinsic tension between the multiplicity of the manifold and the simplifying act of representation.

In contrast, if the subject encounters a novel object (e.g., an unknown animal) with no dominant or familiar representation, they may be puzzled about what it is or how to interpret it. In such cases, there is no deviation from an established representation, and thus no diffraction in the proper sense but only representational uncertainty.

In this way, the view (as subspace), the percept (as projection), and the representation (as subsumption) form a layered process of reduction and selection from the manifold of the situation. Diffraction reflects the deviation of a chosen representation from the meaning afforded by the current situation when the integration of contextual cues is suppressed or misaligned due to representational narrowing.

This account clarifies why representational diffraction is a fundamental structural feature of representations: it does not arise from the instability of perception itself but from the openness of the manifold and the constraint imposed by any representational vehicle.

5 The Representational Uncertainty Principle

To better understand this structural trade-off, it is helpful to consider the analogy to Heisenberg's Uncertainty Principle (Heisenberg, 1930) in quantum theory from which the Representational Uncertainty Principle (RUP) draws its name.

The tension between structure and flexibility—evident in both cognitive and perceptual processes—has a striking analogue in quantum theory, where the measurable properties of a physical system depend on how it is probed, and interference plays a decisive role in shaping observable outcomes. This analogy will be further developed in the following section, which shows how the RUP echoes core features of quantum indeterminacy and diffraction.

5.1 Quantum Mechanics and the Uncertainty Principle

Quantum systems exhibit a fundamental duality between particle-like and wave-like behaviors—a duality that becomes manifest through the experimental conditions under which the system is probed (Falkenburg, 2007, Sec. 7). Experimental arrangements designed to detect discrete, localized events—such as particle impacts on a screen—bring to the fore the system's particle aspect, disclosing features characteristic of individual, countable entities. Conversely, configurations that enable interference phenomena—such as the paradigmatic double-slit experiment—elicit the system's wave-like aspect, revealing its capacity for coherent propagation and spatial extension. This duality is not merely a byproduct of epistemic limitations or measurement-induced disturbance but expresses a structural feature of quantum systems themselves: particle and wave descriptions constitute mutually exclusive, yet jointly indispensable, modes of representing quantum reality. Which aspect appears is determined not by the system in isolation, but by the holistic relation between system, measuring apparatus, and experimental context.

While the deeper metaphysical implications of this duality—regarding the ontology of quantum objects—remain debated, our present concern does not lie with these interpretive disputes. Rather, our interest is in the consequences that arise directly from the structural similarity to quantum theory, in which a wavefunction determines a probabilistic distribution for the probability of measuring particular values for a particle's position and momentum. The wavefunction can be described in a position or a momentum representation, which are equivalent. The two representations are related by a Fourier transform (Dirac, 1958). Without going into mathematical details, Heisenberg's Uncertainty Principle is a consequence of this Fourier duality and states: In the limit, the more precisely the position of a particle is determined, the less precisely the momentum of this particle can be simultaneously measured, and vice versa.

According to (Falkenburg, 2007, p. 283), the "particle-like properties of quantum phenomena are measured by a particle detector or screen which detects single [particles]. The wave-like properties become obvious from the diffraction of [particle] beam at a crystal or double slit which gives rise to an observable interference pattern." It depends on the measurement that determines particle-like observables (configurational aspects) or wave-like observables of particle beams (propagational aspects), which of the two natures comes to the fore.

In this description, we have deliberately retained a high level of generality in order to emphasize the essential contrast: the particle-like aspect corresponds to the static, configurational description—akin to a representation with fixed components—while the wave-like aspect corresponds to the unfolding, dynamic behavior—akin to the context-sensitive integration of content that includes phenomena such as interference. This contrast—between particle-like localization and wave-like propagation—is a consequence of the contingent nature of the wave-particle state, which corresponds to the fundamental condition of contingency in situations, as we will explain later.

While our use of quantum theory is purely structural, the analogy is not arbitrary. Interference and diffraction are general features of systems in which distributed input patterns undergo integrative processing under structural constraints. This applies not only to quantum systems—where interference emerges from the propagation of wavefunctions through experimental apparatus—but also to models of cognition and learning, where representational constraints (like categories, concepts, or linguistic forms) shape the integration of perceptual cues. Recent developments in Quantum Neural Networks and Quantum Machine Learning (Marcianò et al., 2022; Pira & Ferrie, 2024; Zhang, Li, Song, & Tiwari, 2025) offer further support for this structural analogy: wave-like processing and interference effects have been shown to enable powerful forms of pattern recognition and adaptive generalization. These insights suggest that interference is not a quirk of physics but a general principle of integrative dynamics in systems which depend on the parallel integration and modulation of overlapping cues. In this light, representations function analogously to physical constraints like slits or measurement configurations: they stabilize a particular mode of integration at the cost of suppressing others. This makes visible the trade-off central to our account: eliminating interference to gain representational clarity increases the risk of representational diffraction, a misfit between structural fixation and situational complexity.[5]

5.2 Analogy of Behavior of Quantum Systems and Representation

This structural setup bears striking similarities to the dynamics of representation. In both domains—quantum mechanics and representational cognition—the system to be described is contingent, and the mode of experiential access—whether through measurement or representation—determines which aspects of the system become available to perception or cognition. The interplay between static and dynamic descriptions is crucial: in quantum mechanics, particle-like localization contrasts with wave-like propagation, just as in representation, fixed vehicles contrast with the integration process that unfolds meaning of content across contexts. Both frameworks feature interference—quantum interference in wave propagation, and representational interference in how features reinforce or suppress one another in meaning formation. Likewise, diffraction emerges when this interference is suppressed, making diffraction more prominent. In quantum mechanics, diffraction is always present as a structural feature of wave propagation, but it becomes especially visible when interference is reduced—such as with a narrower slit that disrupts coherent wavefronts. Similarly, in representational systems, diffraction becomes more salient when cues are modulated in a way that shifts meaning towards an unexpected alternative. This can occur when the representational vehicle fixes interpretation too narrowly, reducing flexibility. For instance, labeling a desert as 'lifeless' may preclude the recognition of adaptive ecosystems that thrive under extreme conditions. When signs of life (e.g., a blooming cactus or insect activity) appear, they clash with the expectations set by the term 'lifeless.' This clash constitutes representational diffraction: the situational manifold affords a richer interpretation, but the fixed representation fails to accommodate it, making the mismatch salient. As a result, the system's ability to remain aligned with situational complexity in borderline cases is diminished—a point we return to below in discussing representational diffraction. Finally, just as a slit restricts wave propagation in quantum systems, a representational vehicle constrains integration. Whether or not we speak of 'collapse' is a metaphysical question, but structurally, both frameworks describe a selective narrowing of possibility conditioned by the act of representation or measurement.

The RUP addresses a structural trade-off in representation: the more precisely the vehicle under which a percept is subsumed is defined, the more representational interference is intentionally suppressed—by assuming the independence of the vehicle's components—and the less flexibility remains for interferential smoothing, particularly

[5] Laine (2025) introduces the concept of a semantic wave function to model how Large Language Models represent meaning through interference effects in complex vector spaces. Drawing an explicit analogy to quantum interference phenomena, Laine suggests that words and phrases can be modeled as quantum states. This framework employs wave-based dynamics to capture semantic ambiguity and interference, offering a formal model of how context modulates meaning. His work strengthens the plausibility of viewing representational integration as wave-like. Laine's model thus complements our proposal by providing an empirical and computational illustration of how interference-like phenomena might underlie semantics.

in borderline cases when subtle contextual cues determine the appropriateness of representation. The RUP is not a natural law in the empirical sense, but a structural principle. It highlights a recurring pattern in representations: attempts to increase clarity by narrowing representations come at the cost of contextual adaptability. As in physics, where measurement constrains what can be known simultaneously, here precision restricts interference, which limits integration. The RUP captures this constraint not as an exception, but as a general condition of representational dynamics.

A more narrowly defined representational vehicle fixes more elements of the content. For instance, the expression "*red rose*" is more constrained than simply "*rose*." When both components interfere constructively, the affective meaning is amplified—*red* and *rose* jointly evoke a culturally reinforced association with romantic affection. This arises through situated integration. In contrast, a purely compositional reading—*rose* as a kind of flower, *red* as a color—reflects a logical simplification. Analytic traditions promote such simplification, aiming to minimize interference in favor of explicit decomposition. Yet interference is not noise; it enables representational content to align flexibly with contextual nuances and adapt its salience accordingly.

This flexibility becomes especially relevant in borderline perceptual cases, where small differences can shift the interpretation. For example, imagine a flower that appears to fall between *pink* and *red*, and between *dog rose* and *garden rose*. Isolated features might lead to a classification like "*pink dog rose*", which is a technically accurate, but the description is based on raw perceptual input. However, in a romantic setting, the expected representation might be "*red rose*." Interference between the perceptual cues and the situational manifold can modulate the content, aligning the borderline case with the dominant affective reading. Here, interference helps resolve ambiguity and stabilize the representation through contextual resonance.

If interference is suppressed—if the subject rigidly categorizes the flower as "*pink dog rose*" despite the romantic context—then diffraction occurs. The perceptual features remain constant, but the representation deviates from what the situation leads one to expect. Diffraction thus marks the breakdown of stabilizing interference, revealing how fixed vehicles can misalign with contextually embedded meaning. It is not ambiguity *per se* that defines diffraction, but the failure to resolve ambiguity through contextual integration.[6]

The following formulation of the RUP reiterates and sharpens the core insight introduced earlier: narrowing a representation by freezing internal characteristics may improve clarity through its more expressive vehicle; it also removes the interference that would otherwise help stabilize meaning—eliminating ambiguity and aligning it with contextually appropriate expectations. While earlier sections laid out the general trade-off between precision and flexibility, this sentence emphasizes the mechanism: without interference, meaning depends solely on isolated components, which reduces situational adaptability by excluding relevant alternatives that emerge only through integrative dynamics.

[6] A structural analogue from microscopy helps illustrate this trade-off: achieving greater resolution (i.e., detecting finer details) requires using shorter wavelengths, which increases the energy of the probing mechanism. This often disturbs or alters the observed object. Similarly, more precise representational vehicles can resolve finer distinctions but may also impose constraints that distort or exclude contextually appropriate meaning, as in the *pink dog rose* example.

Thus, the RUP underscores the role of interference: by setting specific features and removing context-sensitive modulations, a representation becomes less sensitive to context — increasing the risk that it fails to accommodate the interpretation best suited to the situation, even when alternative meanings are available.

The appeal of representations with logically independent components lies in their reductionist clarity: each element can be analyzed and manipulated separately, as in formal reasoning. But this clarity comes at a cost. It excludes the very interference that enables subtle, context-sensitive adaptation—what allows meaning to shift coherently with the demands of the situation.

5.3 Waves of Meaning: A Conceptual Analogy

To illustrate the dynamics of representation and diffraction, we imagine the integration of broad sensory input as a propagating wave that approaches a narrow slit—a metaphor drawn from the single-slit diffraction experiment in quantum physics. Before reaching the slit, the wave represents the continuous and unconscious integration of sensory data—what we might call pre-representational perception.

The first step in this integration is recognizing patterns that might fit a multitude of possible representations, which can be more or less suitable. Interference of the input wave determines which slit (as a metaphor for a potential representation) the wave passes through. If the percept aligns well with a given representational slit, it is subsumed under that representation, forming what Stegmaier would call a foothold.

Millikan's teleosemantic theory of representation is helpful for further interpreting this dynamic. Her distinction between descriptive and directive functions (Millikan, 1984, 1995) offers a useful framework for comparison with our account of content as both recognition-guiding and action-oriented. We adapt this distinction to our model,[7] emphasizing that representational function involves the mutual shaping of differentiation and directed integration. From our perspective, the descriptive function corresponds to the pre-representational propagation phase before the slit, where competing potential representations are evaluated in relation to the percept. The directive function comes into play once the wave has passed the slit—that is, once the representation has been selected—guiding further integration and orientation toward contextually appropriate action. This analogy underscores that representational success depends not only on structural fit, but also on functional adaptability within a specific context.

This analogy to wave dynamics is not meant to offer a literal account of cognitive or neural processes, but to illuminate the structural interplay between representational precision and contextual adaptability. By likening perceptual integration to wave

[7]Our use of Millikan's distinction between descriptive and directive functions diverges somewhat from her original correspondence-based sense. Here, "descriptive" refers not to the identification of objects but to the identification of appropriate responses—that is, to the phase in which affordance-relevant sensory inputs are differentiated through interference. The "directive" function then refines the selected response trajectory toward contextually appropriate integration and action. In this sense, our approach is closer to the notion of "practical perceptual representations" introduced by Grush and Springle (2018); Springle and Buccella (2024), where perception is inherently action-oriented yet retains an internal structure of differentiation prior to explicit behavioral guidance. We nevertheless retain Millikan's terminology because her coupling of identification and response captures precisely the interdependence that grounds the present account of representational function.

propagation, it becomes clearer how representations can remain open to multiple possibilities while being shaped by situational constraints. This perspective highlights the non-linear, context-sensitive nature of meaning-making and suggests that core features of representational perception—particularly its openness to interference and susceptibility to diffraction—can be better understood through this dynamic, wave-based lens.

The structural constraints introduced by interference and cue integration do not merely filter input—they also shape what becomes available to experience. In this respect, our account intersects with debates on the relationship between representation and phenomenality. Following Burge (2022), we accept that phenomenal experience presupposes representational structure, though we locate this structure not in mechanisms of constancy or objective tracking, but in the interferential dynamics of cue integration. While early perception may be structurally fixed by proximal input—as Burge's Proximality Principle argues—full representations emerge only after pre-representational signals undergo context-sensitive integration shaped by interference and relevance weighting.

The view that phenomenal character presupposes representational structure has recently been defended against *Radical Enactivist* positions (Hutto & Myin, 2013, 2017) that reject internal representations altogether. Espejo-Serna (2019), for instance, argues that Radical Enactivism fails to account for the stability of phenomenal experience under conditions of sensorimotor variation, precisely because it lacks a representational layer responsive to proximal constraints. In contrast, our model affirms the need for structural mediation between input and experience, but interprets this not as internal encoding or veridical mapping, but as a process of structural filtering governed by interference-prone constraints. In this way, we sidestep the representational impasse between Radical Enactivism's rejection of internal structure and Burge's perceptual realism, offering a middle ground in which representations are not mental models, but organizational structures that constrain what can be integrated and experienced.

Other recent work in perceptual philosophy also emphasizes representation as inherently practical. Springle and Buccella (2024) used the notion of *de agendo* representations—perceptual structures defined by action readiness and contextual adequacy rather than propositional accuracy. Their approach converges with ours in supporting the broader claim that representational meaning is grounded in the dynamic integration of differentiation and directed action.

6 Discussion: Status and Limits of the Representational Uncertainty Principle

The Representational Uncertainty Principle (RUP) does not specify measurable outcomes but describes an inherent trade-off between representational precision and contextual adaptability. Unlike physical laws, which yield repeatable empirical results, the RUP outlines systemic constraints on cognition and meaning. It characterizes the limits within which representations operate: the more extensive a representation is specified, the less flexibly it can adapt to situational variation.

The analogy to quantum mechanics is not merely illustrative but offers explanatory value. It clarifies, for instance, why analytical definitions often fail to capture lived concepts, why definition by examples (or family resemblance) remains viable, and why expert human judgment remains necessary in law: the representational vehicle (legal text or formal definition) alone cannot anticipate all future situations. We do not claim any physical isomorphism but only structural similarity. The analogy highlights trade-offs such as wave versus particle, interference versus diffraction, and openness versus fixation. In quantum theory, diffraction is always structurally present but becomes prominent when interference is suppressed. The same logic holds for representations: diffraction is always possible but becomes perceptually significant when interference is constrained.

While our structural analogy draws from features of quantum formalism—such as interference and uncertainty—it fundamentally differs from agent-centered interpretations such as QBism (Pienaar, 2023), which treat quantum states as tools for modeling individual expectations. In contrast, our framework addresses structural constraints on cognitive representation, including unconscious processing, without commitment to subjective belief or physical ontology. The analogy remains metaphysically neutral, as we do not assume a literal collapse of the wavefunction or claim ontological parallels. Quantum mechanics is a quantitative theory; our use of it is conceptual, offering a structural framework for representational dynamics and the limits of orientation.

The RUP thus delineates how epistemic and practical dimensions of cognition interact. Scientific and analytical contexts rely on representational precision to secure stable differentiation, whereas everyday and applied contexts depend on adaptability and integration across shifting situations. Excessive precision can hinder practical orientation, just as excessive imprecision can erode conceptual clarity. Which pole becomes salient depends on what we are up to: whether the task demands theoretical clarity or responsive engagement.

In this way, the RUP reframes cognition as a continual negotiation between fixation and openness, between knowing and acting—a balance that defines the space of meaningful orientation and opens paths for further exploration.

7 Outlook

Can representational interference be formally modeled? Emerging work in machine learning and neural networks suggests that it can. Beyond the studies mentioned above, Filk (2022) shows that neural networks can exhibit behavior structurally analogous to quantum systems, including superposition and interference effects. Such findings may inform how contextual interference could be used to deal with computational representations.

A further challenge concerns the empirical demonstration of representational narrowing as a trade-off between precision and adaptability. The present framework already specifies how representational precision may increase through the fixation of vehicles and the reduction of interference. What remains an open technical question is how functional flexibility could be operationalized and measured in computational systems. Additional work is also needed to clarify the dynamics of oscillation between abstraction and situated engagement.

A further line of inquiry concerns the historical and methodological scope of the RUP. The framework might provide some insight into the different nature of analytic and continental approaches (Levy, 2003) since the former tend toward representational structures, whereas the latter often follow interfering or overlapping narratives. However, such an investigation requires a more extensive and independent study.

The Representational Uncertainty Principle reframes the relation between representational fixation and situational openness. It shows that attempts to increase representational precision necessarily constrain situational responsiveness. Recognizing this structural balance invites a reorientation of epistemic ideals—from evaluating representations by their precision to assessing how flexibly they sustain orientation within evolving contexts.

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