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—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 extend quantum formalism into cognition, but to use this analogy to rethink the structural limits of representation, and to illuminate why precision may sometimes destabilize, rather than clarify, meaning.

This critique aligns with concerns raised in cognitive science and philosophy of logic. Chater and Oaksford (2000), for instance, argue that human reasoning is more accurately modeled by probabilistic inference (as we find it in quantum mechanics), rather than by classical logic, highlighting a structural mismatch between normative logical systems and everyday cognition. Their work reinforces our claim that context-insensitive formal models fail to account for the dynamic and integrative character of real-world representation—an issue we address not through probabilistic formalism but by developing a structural analogy based on representational interference and diffraction.

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.

The current approach follows a structural line of reasoning that has also inspired a body of work in quantum cognition. 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 cognitive phenomena that systematically deviate from predictions based on classical logic and probability theory, such as concept combination, decision making, and order effects (Aerts, 2009; Busemeyer, Wang, & Pothos, 2015; Fernández Cuesta, Piazzai, & Rivieccio, 2025; Wang & Busemeyer, 2013). These models adopt the formalism of quantum mechanics to explain how meaning and behavior emerge from non-classical information integration. Our approach, by contrast, leaves the mathematical perspective aside but shares the same structural insight: that representation involves a dynamic and context-sensitive integration of cues, where interference between representational components plays a central role. While quantum cognition provides formal tools for modeling such interference effects, we offer a complementary philosophical framework that explains how representational vehicles constrain integration and how diffraction results from this constraint.

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 L. 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 paper proceeds in five parts. Section 2 defines core concepts (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 the contributions of Polanyi, Ruben, and Stegmaier to describe how representational meaning emerges from oscillation between abstraction and context. Section 4 introduces a wave-based analogy using a thought experiment to model 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 evaluates broader implications for philosophical methodology, cognitive science, and artificial intelligence, and discusses the limits of the quantum analogy itself.

2 Foundational Concepts: Percept, 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 orients 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 do not reject the idea that cognition involves processing. 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. 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 interference, fit, and situational relevance.

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

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, independent of any perceptual or representational act. This manifold 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 series 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 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 langauge. 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 is not based on necessary and sufficient features, but on overlapping patterns that resonate differently across contexts. Moreover, Wittgenstein's idea of language-games shows that the same expression can function differently depending on the activity it's embedded in, as aspects of the activity interfere with it. This supports the claim that meaning depends on integration within a broader situational context.

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 dynamically evolving content through the ongoing integration of multiple overlapping cues. This process enables context-sensitive interpretation by allowing certain meanings to become dominant while others are attenuated, depending on how well they fit the current situational manifold.

Representational interference, more specifically, describes the interaction 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 flexible interpretation that supports flexible, 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. Both 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 describes a general structural phenomenon in which meaning arises through the coordination of overlapping cues. Wittgenstein's *family resemblance* can be understood as a dynamic modulation of similarities rather than merely as shared features. A similar process occurs in *co-compositional semantics* (Pustejovsky, 1995), where meanings are not composed in isolation but mutually influence one another. *Affordance theory* (Gibson, 1979), too, reveals how perceptual features gain functional significance through their combined contribution to a coherent percept. Across these views, interference captures how the integration of distributed cues (constructively or competitively) shapes meaning.

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 semantic co-compositionality (Pustejovsky, 1995), 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.[2]

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.[3] 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

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[2] 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.

[3] 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).

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 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 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 quantum theory from which the Representational Uncertainty Principle (RUP) draws its name.

The tension between structure and flexibility, which we can trace in cognitive and perceptual terms, has a striking analogue in quantum theory where a measurable properties of a physical system depends 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). 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.[4]

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 contextual cues that would otherwise support coherent integration are suppressed. This often occurs 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

[4] 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.

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 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 description 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.[5]

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.

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) aligns with our account of content as both recognition-guiding and action-oriented. 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

[5] 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.

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 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.

6 Discussion

6.1 Status and Limits of the Representational Uncertainty Principle

The 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.

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 vs. particle, interference vs. diffraction, and openness vs. fixation. In quantum theory, diffraction is always structurally present but becomes prominent when interference is suppressed. The same logic holds in representations: diffraction is structurally present but becomes perceptually significant when interference is lacking.

The analogy remains metaphysically neutral, as we do not assume a literal collapse of the wavefunction or claim ontological parallels. Moreover, quantum mechanics is a quantitative theory; our use of it is conceptual, offering a structural framework for representational dynamics.

6.2 Practical and Epistemic Trade-Offs

Representational precision is desirable in scientific and technical contexts—provided that contextual factors can be largely excluded. In experimental design, for example, the aim is to isolate relevant variables and control disturbances in order to enable precise and robust vehicles. But this condition does not generalize: social life, legal reasoning, and interpretation rely on flexible adaptation.

Here, Stegmaier's model of temporary stability becomes relevant. We need footholds and representations for constructing plans, goals, and tools as means of orientation. But when context becomes highly contingent, we must return to situational openness, allowing interference to realign meaning.

Interference should not be seen as noise but as a constructive mechanism that stabilizes meaning through the integration of diverse, sometimes competing cues. It is through interference that cognition transitions from the fluid, stream-like perception to the stabilized structures of concept-based reasoning. This addresses an enduring problem in the philosophy of mind: how implicit processes become explicit without assuming a clean boundary or representational code.

6.3 Abstract Descriptions of Situations

Philosophy, law, and narrative rely on abstract descriptions of situations—but these must be understood as simulations of concrete experience. Just as perception proceeds view by view, narratives unfold sentence by sentence. They simulate perceptual flow and convey the richness and contingency of real-world situations. Their meaning depends on the reader's imaginative reconstruction. A text cannot specify every affordance or background condition; instead, it relies on shared knowledge and the ability to integrate underdetermined details. Yet this process is limited by the explicitness of the text and the subjectivity of the reader's imagination.

Wittgenstein (1953) addressed these limitations when discussing the problem of rule-following, questioning whether explicit rules alone can determine their application. Our results are consistent with his conclusion that "obeying a rule" is a practice rather than a logically determined outcome.

6.4 The Analytical–Continental Divide in Philosophy

Against this background, we can reflect on the structural divide that runs through contemporary philosophy. Its most well-known expression is the Analytic–Continental divide, which continues to shape curricula, disciplinary boundaries, and interpretive frameworks—for an overview see Bell et al. (2016). Although often framed in historical or geographical terms, the divide reflects deeper methodological tensions. On one side stand traditions rooted in formal clarity, logical analysis, and stable reference—hallmarks of Analytic Philosophy. On the other are Phenomenology, Hermeneutics, and Pragmatism, which emphasize lived experience, historical embeddedness, and the dynamic unfolding of meaning. For a genral overview see Critchley (1997) , Moran (2014), and Rinofner-Kreidl and Wiltsche (2016).

This divide is not accidental. The trade-off, as described by the RUP, becomes particularly salient in complex situations. The Gettier problem Gettier (1963) exemplifies this: attempts to define knowledge in terms of necessary, sufficient, and logically independent conditions (as in the JTB model) exclude the very contextual cues that allow us to recognize knowledge in practice. Narrowing the representational vehicle leads to conceptual diffraction—the dissonance between definition and intuition—because the stabilizing interference of context is lost.

In his later work, Wittgenstein (1953) anticipates this insight. His notions of language-games and family resemblance reject rigid definitions in favor of overlapping patterns of use. Meaning arises not from logical form alone, but from the integration of contextual cues—what we call representational interference. Hermeneutics and dialectical philosophy recover what formalism omits: the contradiction, tension, and ambiguity that arise from lived interpretation.

The RUP does not refute Analytic Philosophy but defines its scope: abstraction is necessary but insufficient. Just as we use fixed representations to build tools and scientific theories, we also need openness and dialectical flexibility to engage with meaning in practice. Recovering interference is not an abandonment of clarity, but a recognition that clarity alone cannot capture meaning.

6.5 Connection to Artifical Intelligence

The connection between representational interference and deep learning is not merely metaphorical. Pulvermüller (2023) argues that deep neural networks constrained by neurobiological principles can model key features of human conceptual integration. In these models, meaning arises from distributed patterns of activation—where overlapping signals compete and cooperate in ways that reflect contextual relevance. This resonates with our notion of interference as a functional condition for flexible representation. Pulvermüller's findings suggest that what we describe structurally through representational diffraction and interference may correspond to mechanistic features in both human cognition and artificial systems. This continuity strengthens the broader claim that representational structure involves inherently wave-like, interference-sensitive integration, whether realized in biological or synthetic substrates.

Other recent interdisciplinary work supports a growing convergence between representational dynamics and artificial intelligence. Neural networks emulate interference-like integration through parallel processing, aligning with our view of perceptual integration as wave-like. Filk (2022) demonstrates that neural networks can exhibit behavior structurally analogous to quantum systems, including superposition and interference effects. Similarly, Busemeyer and Bruza (2012) model decision-making as a wave-based interference process.

S. Zhou, Chen, An, Zhang, and Hou (2025) show that large language models can simulate quantum state propagation, reinforcing the structural relevance of our analogy between representational diffraction and quantum diffraction. Agostino et al. (2025) propose a quantum semantic framework for natural language processing, in which meaning construction emerges from interference-like linguistic operations.

These developments suggest that explainable artificial intelligence (XAI) could benefit from the framework developed here. The shift from high-dimensional parallel processing to explicit representational explanation is precisely the kind of transition this framework is designed to clarify. At the same time, the RUP highlights the limits of representational precision in this shift. Rather than challenging the value of representations in AI, the RUP helps define their proper scope. It shows how representational explanation, if informed by interference-based integration, could preserve the nuance of high-dimensional processing without reverting to reductive abstraction.

6.6 Open Questions and Future Research

Can interference be formally modeled? Emerging work in Machine Learning and neural nets suggests it can. But empirical testing of representational narrowing—how precision affects integration and orientation—remains an open area for cognitive science. More work is also needed to understand the dynamics of oscillation between abstraction and situated engagement.

Another open question concerns the theories integrated here: Polanyi's tacit integration, Ruben's dialectics, Stegmaier's orientation that have remained outside mainstream analytic philosophy. But precisely because they emphasize oscillation, context, and fit, they offer insights into problems that analytic philosophy struggles to formalize. Millikan's descriptive/directive distinction aligns with our model but does not address how interference arises or how content dynamically adjusts. Wittgenstein's family resemblance can now be seen as a form of structural interference—where patterns gain meaning not from strict identity but from shared relations. Thus, it appears promising to investigate how these theories can be brought into accord with traditional analytical philosophy.

The RUP reframes how representation, precision, and perception relate. It challenges us to think beyond clarity toward resonance, alignment, and the oscillating interplay between structure and situation.

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