From Action to Inscription: A Structural–Contextual Analysis of Physical Information

Abstract

This article develops a structural–contextual account of how physical information is generated, stabilized, and rendered objectively determinate. Rather than treating information as ontologically primitive, the paper develops a framework in which quantized action provides a lower physical scale for the discrimination of alternatives, while contextual constraints determine when and how a specific informational value may be objectively attributed.

First, the quantum of action $\hbar$ is not itself a bit, but sets a characteristic lower action scale for the registration of physically significant distinctions in phase-sensitive physical settings. Second, drawing on the Kochen–Specker theorem, the paper argues that informational values cannot be straightforwardly treated as globally pre-assigned across all contexts; rather, their determinate attribution is context-relative. Third, it introduces the notion of *inscription*, understood as the stabilization of a contextually generated distinction through a stabilizing structural condition, such as topological protection or metastable energetic separation. Such stabilization turns an otherwise transient distinction into objective, physically stored information.

Taken together, these claims support a physically grounded account on which objective physical information is not fundamental but emerges from the interplay of quantized action, structural context, and structural stabilization, in a sense that does not depend on any particular observer's knowledge or interpretation. The resulting framework complements rather than replaces existing approaches, offering a synthetic reinterpretation of the relationship between dynamics, context, and informational content.

Keywords: action principle; contextuality; physical information; topological invariants; Kochen–Specker; inscription

1 Introduction

Informational concepts have acquired an increasingly prominent role in contemporary physics. Across quantum foundations, quantum information theory, statistical mechanics, and certain approaches to quantum gravity and thermodynamics, information has been invoked in various ways: as a mathematical resource, as an epistemic constraint, and, in some interpretations, as explanatorily or ontologically prior within physical theory [1–4]. In some influential settings, this development has encouraged the view that informational notions may be explanatorily prior to traditional dynamical quantities such as energy, momentum, or action.

Several influential programs have contributed to this shift. Wheeler's slogan "It from Bit" [1] suggested that physical entities might ultimately be grounded in elementary informational propositions rather than in material primitives. Landauer's principle [5] that "information is physical" tied informational manipulation to thermodynamic irreversibility, embedding it directly into the laws of physics. Some influential programs and interpretations have assigned a central explanatory role to information in physical theory, though they differ substantially in whether information is treated as ontologically primitive, epistemically central, or structurally indispensable [3, 6, 7].

However, despite its conceptual appeal, this development raises a significant conceptual challenge. The term "information" is used in at least three distinct and often insufficiently distinguished senses [8, 9]: (i) Shannon-theoretic information [10] as a measure of uncertainty or probabilistic correlation, (ii) quantum information as a structural notion associated with states, channels, and transformations, and (iii) ontological information, in the stronger sense found in some philosophical programs, as a purported constituent of physical reality. The absence of a principled distinction between these senses has led to a blurring of epistemic and ontic roles [8, 9]. Furthermore, some accounts remain measurement-centered in the sense that informational values are articulated primarily through measurement settings or observationally defined contexts. What is needed, we suggest, is a more explicit account of when a physically realized distinction qualifies as objective information in a sense grounded in physically identifiable conditions rather than in any particular observer's knowledge.

This paper addresses this gap by developing a structural–contextual analysis of the physical generation of information. We advance an action-first framework in which information is not fundamental but emerges from the interaction between quantized action, structural context, and stabilizing invariants. Our proposal advances three connected claims. First, the quantum of action ($\hbar$) provides a characteristic lower action scale for physical discrimination but is not itself a bit of information. Second, informational values are not straightforwardly treated as globally pre-assigned independently of context; rather, their determinate attribution is context-relative, a conclusion motivated by the Kochen–Specker theorem [11]. Third, on the present account, informational distinctions qualify as objective only when they are fixed by sector-preserving structural conditions—a process we term "inscription," understood here as the fixation of a contextually generated distinction in a persistent and re-identifiable physical state. These claims jointly support a physically grounded account of informational generation that is not tied to any particular observer's knowledge or interpretation.

1.1 Novelty and Relation to Existing Work

The present framework differs from existing informational and structural approaches in several respects, though it is best understood as offering a synthesis and reinterpretation rather than a wholesale replacement of them.

Floridi's informational structural realism [12] treats information as ontologically primary, taking informational structure to have explanatory priority and, in an important sense, ontological priority. Our framework offers a contrasting perspective by grounding informational content in dynamical and structural processes: on the present view, information is derivative of action, context, and stabilization rather than constitutive of them. *Timpson's critique* [8] argues that information should not be treated as a foundational ontological category. The present paper does not attribute to Timpson the positive project pursued here; rather, it takes his critique as motivating the further question of whether a non-primitive but physically grounded account of objective informational status can nonetheless be given. *Wharton's action-based approaches* [13] emphasize global action constraints in quantum mechanics but do not address the contextual generation or structural stabilization of information. Against this background, our proposal brings together three elements often discussed separately: (i) quantized action as a lower scale for physical discrimination, (ii) Kochen–Specker contextuality as a constraint on non-contextual value assignment, and (iii) structural inscription as a condition of objectivity.

In what follows, "objective physical information" does not mean information in every possible sense, but specifically a physically realized distinction that is both contextually determinate and sufficiently stabilized to permit persistence and re-identification.

The structure of the paper is as follows. Section 2 introduces the theoretical background, including the role of action, the distinction between the quantum of action and the bit, and the notion of contextuality. Section 3 engages with contemporary philosophy of information, examining the positions of Floridi, Timpson, and Anta. Section 4 develops the core generative mechanism by analyzing how contextual constraints produce informational distinctions. Section 5 examines the conditions under which such distinctions are stabilized through inscription. Section 6 synthesizes these elements into a unified action-first ontology of physical information. Section 7 clarifies the ontological status of this framework. Section 8 addresses potential objections. Section 9 discusses broader philosophical implications, including the quantum–classical transition, and identifies limitations. Section 10 concludes.

2 Background and Preliminaries

This section introduces the theoretical foundations required for the argument developed in the remainder of the paper. We review the physical role of action, clarify the distinction between the quantum of action and informational units, and summarize the formal notion of contextuality as it appears in the foundations of quantum mechanics.

2.1 Action as a Structural Basis of Physical Possibility

Action (S) plays a central role in both classical and quantum physics. In classical mechanics, the Principle of Least Action [14] determines the realized trajectory by extremizing the functional

$$S[\gamma] = \int_\gamma L(q, \dot{q}, t)\, dt,$$

where L is the Lagrangian. In quantum mechanics, through the path integral formulation [15], action governs the phase weighting of possible histories: each trajectory contributes with a phase factor $e^{iS/\hbar}$. This dual appearance reflects the generality of action as a quantity that encodes constraints on full histories rather than on instantaneous states. While state variables such as energy or position characterize a system at a moment, action characterizes relations among possible histories. For the purposes of this paper, action will be treated as expressing a structured space of physical possibilities [16].

2.2 The Quantum of Action vs. the Bit

In the semiclassical and phase-sensitive settings relevant here, the quantum of action $\hbar$ may be interpreted as setting a characteristic lower scale for phase-space resolution [17]. In this sense, it provides a characteristic lower action scale for physical discrimination and thereby establishes a lower bound on distinguishability in the cases considered in this paper. It is important to distinguish this capacity for distinction from an actual informational value. A bit is a dimensionless binary unit representing a specific choice between alternatives, whereas $\hbar$ is a dimensionful constant $(\mathrm{J \cdot s})$ that constrains the effective granularity of phase space. Thus, the quantum of action provides a lower physical scale for discrimination, but does not, by itself, determine a realized informational value.

Table 1 summarizes the key distinctions between the quantum of action and the informational bit.

Table 1 Comparison of the quantum of action and the informational bit

Property	**Quantum of Action ($\hbar$)**	**Informational Bit**
Dimensionality	Dimensionful $(\mathrm{J \cdot s})$	Dimensionless
Physical role	Capacity for distinguishability	Realized distinction
Ontological status	Fundamental constant	Derivative structure
Context dependence	Context-independent scale	Context-dependent value
Measurement	Sets resolution limit	Outcome of measurement

2.3 Contextuality in Quantum Theory

The notion of contextuality plays a significant role in the mathematical structure of quantum mechanics. Measurement outcomes depend on the set of jointly measurable observables that define the measurement context [18]. The Kochen–Specker theorem [11] formalizes this dependence: for Hilbert spaces of dimension $d \geq 3$, no global valuation function $v(\hat{A})$ assigning non-contextual pre-existing values to all observables can preserve the functional relationships among operators across all contexts. Formally, it is impossible to assign values to all projectors in a way that is simultaneously non-contextual and consistent with the algebraic structure of the theory. This result implies that quantum observables cannot, without the introduction of additional variables, be regarded as bearing measurement-independent values, and that the determination of an outcome is, in that sense, inseparable from the context in which it is measured [19, 20].

The theorem itself establishes a negative constraint on global non-contextual value assignments. The present framework, by contrast, develops a positive interpretive proposal concerning context-relative informational determination.

Example 1: Spin measurements. Consider a spin-1 particle. One can measure spin along the x-, y-, or z-axis. The Kochen–Specker theorem implies that no global non-contextual valuation for the relevant family of spin-1 observables can preserve the functional relations among them across all admissible measurement contexts [21]. In particular, quantum mechanics requires that the squared spin components along any three mutually orthogonal directions $\mathbf{n}_1, \mathbf{n}_2, \mathbf{n}_3$ satisfy

$$\hat{S}^2_{\mathbf{n}_1} + \hat{S}^2_{\mathbf{n}_2} + \hat{S}^2_{\mathbf{n}_3} = 2\hbar^2,$$

so that the corresponding outcomes for $(\hat{S}^2_{\mathbf{n}_1}, \hat{S}^2_{\mathbf{n}_2}, \hat{S}^2_{\mathbf{n}_3})$ are constrained to take the form $(\hbar^2, \hbar^2, 0)$, up to permutation. What the theorem rules out is any single context-independent assignment of such values that remains consistent across all these contexts.

3 Physical Information in Contemporary Philosophy

Before developing our positive account, we engage critically with three influential positions in the contemporary philosophy of information: Floridi's informational structural realism, Timpson's critique of information as a fundamental physical quantity, and Anta's analysis of epistemic and ontological difficulties in physical information. This engagement clarifies what our framework accepts, rejects, and seeks to complement.

3.1 Floridi: Informational Structural Realism

Luciano Floridi's *informational structural realism* [12] proposes that reality is fundamentally informational in character. On this view, the basic furniture of the world is not best understood in terms of material substances with intrinsic properties, but in terms of informational structures and relations. Floridi's position is more nuanced than a simple "information as bits" picture: what matters for present purposes is not the reduction of reality to discrete informational units, but the stronger claim that informational structure has explanatory and ontological priority over material or dynamical constituents.

This position has the virtue of taking structural relations seriously and of aligning naturally with the abstract and relational character of much contemporary physics. At the same time, however, it leaves open a question that is central for the present paper: if information is treated as ontologically basic, what explains the physical conditions under which informational distinctions become available, determinate, and stable? The action-first framework departs from Floridi primarily at this point. Rather than treating information as the basis of structure, it treats informational content as a derivative outcome of structural and dynamical processes. On this view, information does not ground structure; rather, informational content emerges when quantized action, contextual determination, and structural stabilization jointly obtain.

In this sense, the present account is compatible with Floridi's emphasis on the importance of structure, but it reverses the direction of explanatory priority. The relevant disagreement is therefore not with a caricature of "information as bits," but with the stronger thesis that informational structure is ontologically prior. The alternative proposed here is that structures and dynamics are prior, while information arises from their interplay under physically specified conditions.

3.2 Timpson: The Category Mistake Critique

Christopher Timpson [8] advances a powerful critique of attempts to treat information as a fundamental physical quantity. Drawing on Ryle's notion of a category mistake, Timpson argues that information is not the kind of thing that can be a physical constituent or property. Information is a relational, context-dependent notion tied to the use of physical systems for communication or representation. To treat it as a physical primitive is to confuse an *epistemic* or *semantic* category with an *ontological* one.

Timpson's critique is compelling, but it is primarily negative: it shows what information *is not* (a fundamental physical quantity) without proposing a positive account of how informational content relates to physical processes. We do not attribute this positive project to Timpson himself. Rather, we take his critique as opening a space for asking under what physical conditions informational attributions become objectively warranted. Our framework is intended to address part of this gap. We accept Timpson's conclusion that information cannot be ontologically primitive, but we go further by specifying the physical conditions under which informational distinctions are generated and stabilized. By treating information as derivative of quantized action, contextual determination, and structural stabilization, the present framework is intended to avoid reifying information as a primitive physical constituent while preserving the explanatory role of informational concepts in physics.

3.3 Anta: Epistemic Accessibility and Physical Content

Javier Anta [22–24] has argued, across several related works, that the notion of "physical information" faces serious epistemic and ontological difficulties. In his 2021 paper, he shows that informational approaches to thermal physics risk explaining the approach to equilibrium only by reintroducing epistemic or observer-relative elements. In his 2023 paper, he generalizes this concern by arguing that information concepts often lack determinate physical content, since they remain ambiguous between epistemic interpretations (what an agent knows) and physical interpretations (what the system is), and attempts to collapse this distinction can generate conceptual incoherence.

Anta's critique identifies a genuine difficulty for any account that seeks to speak of "physical information." Many uses of the term in physics slide too quickly between what is knowable and what is physically the case. The present framework responds by distinguishing *epistemic access* to information from the *physical conditions under which a distinction qualifies as objective information*. On our view, informational content is not primitive and is not introduced as an additional physical magnitude or substance. Rather, it is the status of a physically realized distinction once three conditions are jointly satisfied: a quantized action threshold, a context that defines mutually exclusive alternatives, and a stabilizing structural condition that preserves the distinction over relevant timescales.

In this sense, the framework seeks to respond to Anta's challenge without reifying information. It does not treat information as an autonomous ontic ingredient of physical theory. Instead, it specifies when a physically realized difference may be regarded as objective information: namely, when that difference is contextually determined and structurally stabilized in a way that is not tied to any particular observer's knowledge or interpretation. Thus, while we accept Anta's diagnosis that purely epistemic construals of information are inadequate, we argue that a properly structural account can give the notion of objective physical information a more precise and defensible role.

3.4 Summary: Complementing Existing Positions

The action-first framework developed here is compatible with several important insights from these positions, while departing from each of them in a specific respect.

- **Floridi.** The present account is consistent with the importance Floridi assigns to structural relations, but it rejects the explanatory priority of informational structure. On our view, information does not ground structure; rather, informational content emerges from dynamical and structural conditions.
- **Timpson.** The framework agrees with Timpson that information should not be treated as an ontologically primitive physical constituent. At the same time, it departs from a purely negative diagnosis by asking under what physical conditions informational attributions become objectively warranted.
- **Anta.** The framework is likewise compatible with Anta's critique of ambiguous epistemic and physical uses of information. Its departure lies in proposing that this ambiguity can be addressed, not by reifying information, but by specifying the structural conditions under which a physically realized distinction qualifies as objective information.

The resulting picture treats information as objective but derivative: a structured outcome of quantized action, contextual determination, and structural stabilization.

3.5 Bub and QBism: Structural and Agent-Relative Conceptions

Two influential approaches explicitly resist treating information as an ontological primitive, but they do so in different ways. Bub's information-theoretic approach to quantum theory emphasizes that "quantum information" is best understood as a structural constraint on physically admissible correlations (e.g. no-signaling, no-cloning), rather than as a basic entity in the ontology [7, 25]. By contrast, QBism treats quantum states as expressions of an agent's personal degrees of belief; in this sense, informational content is irreducibly agent-relative [26].

Our framework is compatible with both positions in rejecting primitivism about information. Where it differs is not by denying the structural constraints emphasized by Bub, nor by contesting the agent-relative reading within QBism, but by addressing a complementary question: under what physical conditions can a realized distinction be treated as *objective* physical information (i.e. not tied to any particular agent's credences or interpretive stance)? On the present account, this status requires (i) a quantized action scale that supports physical discriminability, (ii) a structural context that fixes mutually exclusive alternatives, and (iii) a stabilizing condition (inscription) that confers persistence and re-identifiability. In this way, Bub and QBism provide important boundary constraints on what an ontology of information should avoid, while the action-first proposal supplies a positive, physically articulated criterion for objectivity within those constraints.

4 Main Argument I: Contextual Generation of Information

This section develops the first part of the core argument. We examine how informational distinctions arise only in the presence of physically specified contexts and show that such distinctions cannot be regarded as pre-existing features of quantum systems. The argument proceeds in three steps: (i) replacing the epistemic notion of an observer with the notion of a structural context, (ii) using the Kochen–Specker theorem to rule out non-contextual value assignments, and (iii) establishing the joint conditions under which quantized action and context determine a physically distinguishable bit.

4.1 From Observer to Structural Context

Traditional presentations of quantum measurement often rely on the role of an observer, suggesting that informational values are revealed or determined through an observational act [27]. For the purposes of this paper, we adopt a structurally grounded description in which the relevant notion is not an observer but a *measurement context*. By this we mean any physically realizable set of jointly measurable observables or, more broadly, any configuration of boundary conditions, potentials, or symmetry constraints that select a maximal commuting set of operators.

Our notion of physical context shares some features with Richard Healey's pragmatist account[28] and Carlo Rovelli's relational interpretation [29, 30]. Healey argues that quantum states provide objective information relative to a physical situation, not to a subjective observer. Rovelli emphasizes that properties are relational, that is, always properties *with respect to* another system. Our framework is compatible with both views, but it emphasizes a different question: not primarily how content or properties are relativized, but under what physical conditions a distinction qualifies as objective information. More precisely, Healey focuses on the objectivity of representational content relative to pragmatically defined situations, whereas we focus on the conditions under which a stable physical distinction qualifies as objective information at all. Rovelli relativizes properties to interaction partners, whereas we analyze the specific physical mechanisms—quantized action thresholds, contextual exclusivity structures, and topological or energetic stabilization—that determine when and how informational content is generated and preserved. In short, our contribution is less to relativize content than to specify when a physically realized difference qualifies as objective information.

It is also important to clarify the scope of structural context as used here. The term functions as an umbrella notion encompassing three analytically distinguishable levels: (i) the measurement context proper, given by the choice of compatible observables and experimental arrangement; (ii) the physical implementation of that context, including boundary conditions, apparatus couplings, and environmental interactions; and (iii) the stability conditions under which a contextually generated distinction can persist. In the present framework, these levels are treated as analytically distinguishable but jointly constitutive of a single structural context, rather than as wholly independent factors.

Examples of structural contexts include:

- **Interferometric setups:** A Mach–Zehnder interferometer defines a context in which path information and interference visibility are complementary [31].
- **Polarization bases:** A polarizing beam splitter oriented at angle θ defines a context distinguishing between two orthogonal polarization states.
- **Potential wells:** A particle in a box or harmonic oscillator defines discrete energy eigenstates as the relevant context.
- **Lattice geometries:** In condensed matter systems, crystal symmetries define contexts for momentum eigenstates in Brillouin zones [32].

Under this description, context is understood primarily as a physical structure rather than as a psychological notion or a merely epistemic placeholder. It specifies which alternatives are mutually exclusive and therefore determines the space of admissible outcomes. Informational distinctions must consequently be understood relative to a physically instantiated context, rather than as straightforwardly available independently of it[33].

Definition 1 (Structural Context) A structural context C is a physically instantiated configuration

$$C = (\mathcal{H}, \{\hat{O}_i\}, \mathcal{B}),$$

where:

- $\mathcal{H}$ is the relevant Hilbert space,
- $\{\hat{O}_i\}$ is a maximal commuting set of observables ($[\hat{O}_i, \hat{O}_j] = 0$ for all i, j),
- $\mathcal{B}$ encodes the boundary conditions or physical constraints that implement this basis.

Operationally, a system instantiates C when:

1. boundary conditions select or effectively single out $\{\hat{O}_i\}$;
2. the decoherence timescale for $\{\hat{O}_i\}$–eigenstates is shorter than the measurement timescale;
3. perturbations δE satisfy $\delta E \ll E_{\text{context}}$, where E_{context} is the energy scale defining the context.

Figure 1 summarizes this notion of a structural context as a physical configuration that selects a maximal commuting set of observables via boundary conditions.

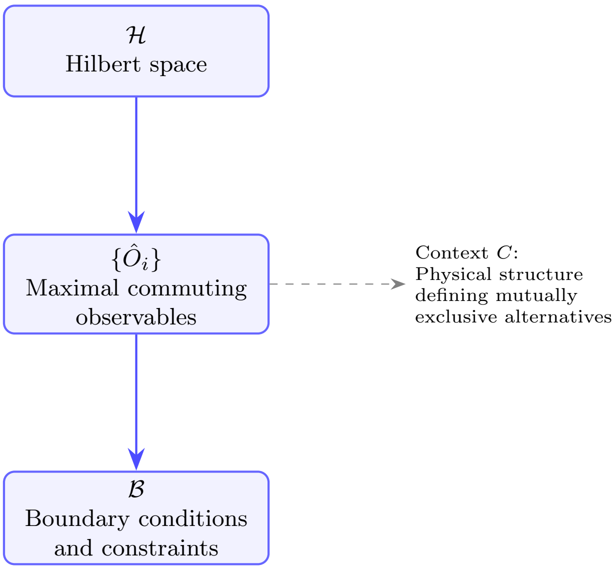

Fig. 1 Formal structure of a measurement context C. A context is not an epistemic notion but a physically instantiated configuration that selects a maximal set of commuting observables via boundary conditions.

4.2 The Kochen–Specker Theorem and the Context-Dependence of Value Attribution

The structural role of context is supported by the Kochen–Specker theorem. For Hilbert spaces of dimension $d \geq 3$, the theorem demonstrates that no global valuation function

$$v : \hat{A} \mapsto \lambda_A$$

exists that assigns definite values to all observables $\hat{A}$ while preserving the functional relationships among operators across all contexts. In other words, no assignment can simultaneously satisfy (i) non-contextuality and (ii) consistency with the algebraic structure of quantum projectors [11, 34].

The implication for present purposes is that the theorem rules out a global non-contextual assignment of determinate values across all contexts. Accordingly, informational values cannot, on any straightforwardly non-contextual picture, be treated as globally pre-existing across all contexts. In the present framework, their determinate attribution is context-relative, since a specified context determines the mutually exclusive alternatives relative to which a value can be meaningfully defined. Context selection is therefore a necessary condition for informational determination, though not a sufficient one.

Example 2: Peres–Mermin square. The Peres–Mermin proof [35, 36] provides a simple demonstration of contextuality using a 3×3 grid of observables for two qubits. Each row and column contains mutually commuting observables, yet no consistent value assignment exists that satisfies all algebraic constraints simultaneously. This shows that no single non-contextual valuation can reproduce the algebraic constraints for all commuting sets at once; admissible value-attribution is therefore context-dependent in the Kochen–Specker sense.

4.3 Action, Context, and the Emergence of a Physical Bit

We now combine these considerations with the role of quantized action. The quantum of action $\hbar$ may be taken to provide a lower physical scale at which distinct alternatives can be resolved in phase-sensitive settings. In the semiclassical and phase-sensitive sense relevant to the present discussion, action differences of order $|\Delta S| \gtrsim \hbar$ may be treated as capable of supporting physically distinguishable alternatives [37]. This establishes a *capacity* for distinction, but does not by itself determine which alternative is realized.

For a determinate bit-value in the sense relevant here to emerge, two conditions must be jointly satisfied. First, the underlying dynamics must permit distinctions whose action difference meets or exceeds the threshold $\hbar$. Second, a physically implemented context must specify which alternatives are mutually exclusive and therefore eligible for determination. Both conditions are required: quantized action provides the capacity for distinction, while context determines the admissible set of distinctions.

Let $S[\gamma]$ denote the relevant action functional and C the measurement context, and let ΔS denote the action difference between two competing histories. On the present account, a determinate bit-value in the sense relevant here corresponds to a determinate value that satisfies:

$$\text{Distinguishability: } |\Delta S| \gtrsim \hbar, \qquad \text{Contextual Determinacy: } C \text{ defines mutually exclusive outcomes.}$$

When these two criteria are jointly met, a binary informational distinction is well-defined relative to the context in question.

Example 3: Double-slit experiment. In a double-slit setup, the action difference between paths through slit 1 and slit 2 is $\Delta S = \int (p_1 - p_2) \cdot dx$. When $|\Delta S| \gtrsim \hbar$, the paths become distinguishable. However, which-path information is only determinate when a context (e.g., a detector at one slit) is introduced that makes the two paths mutually exclusive [38].

We may therefore state the first main thesis of the paper:

First Main Thesis. On the present account, a physically realized bit-value arises only when a contextually specified set of mutually exclusive alternatives is supported by an action difference ΔS of order $\hbar$. Neither quantized action nor context alone is sufficient; informational determination requires their conjunction.

Table 2 summarizes the necessary and sufficient conditions for the generation of a physical bit.

Table 2 Conditions for the generation of a physical bit

Condition	**Physical Requirement**	**Formal Expression**
Distinguishability	Action difference exceeds quantum threshold	$\lvert\Delta S\rvert \gtrsim \hbar$
Contextual determinacy	Physical context defines mutual exclusivity	$C = (\mathcal{H}, \{\hat{O}_i\}, \mathcal{B})$
Joint satisfaction	Both conditions simultaneously met	Determinate bit-value relative to (S, C)

5 Main Argument II: From Distinction to Inscription

This section develops the second part of the core argument. Even when contextual constraints and quantized action jointly produce a physical distinction, such a distinction may lack the stability required for information storage. We therefore examine the conditions under which a contextually generated difference becomes preserved over relevant timescales. The argument proceeds in three steps: (i) identifying the insufficiency of bare distinctions, (ii) introducing structural protection as a condition for objective persistence, and (iii) defining *inscription* as the structural stabilization of a distinction.

5.1 The Fleeting Bit and the Problem of Stability

A contextually determined bit, as characterized in the previous section, may remain dynamically fragile. In quantum systems, superpositions can be restored after weak measurements unless stabilizing mechanisms prevent recombination [39]. More generally, the mere adoption of one alternative does not ensure that this distinction will persist under subsequent evolution. Processes such as environment-induced decoherence [40, 41] suppress interference terms, but the resulting distinctions can be sensitive to local perturbations or thermal fluctuations. Decoherence alone therefore does not guarantee long-term robustness.

Accordingly, contextual determinacy and action-based distinguishability are necessary but not sufficient for constituting objective information. Additional structural conditions are required to ensure persistence against erasure.

5.2 Structural Protection as a Condition for Objectivity

In several areas of physics, stable distinctions are associated with stabilizing structural conditions—including topological invariants, energetic barriers, and boundary-based constraints. Examples include:

- **Quantized circulation in superfluids:** The circulation around a vortex in superfluid helium is quantized in units of h/m, where m is the mass of a helium atom. This quantization arises from the topological constraint that the phase must be single-valued [42].

- **Flux quantization in superconductors:** Magnetic flux through a superconducting loop is quantized in units of $\Phi_0 = h/(2e)$, protected by the macroscopic phase coherence of the Cooper pair condensate [43].
- **Domain walls in ferromagnets:** The orientation of magnetization in different domains is separated by energetically stable walls that cannot be removed by smooth deformations [44].
- **Topological insulators:** Edge states in topological insulators are protected by bulk topological invariants (Chern numbers) and remain robust against local perturbations [45].
- **Classical memory systems:** Magnetic domains, potential wells, and chemical bonds exhibit metastability generated by energy barriers which—when represented in configuration space—constitute effective structural protection.

In each case, the relevant stabilizing condition constrains the system's evolution to a specific sector, though the underlying mechanisms differ: topological invariants remain unchanged under continuous deformations, whereas energetic barriers suppress transitions over the relevant timescale.

These examples serve a structural purpose in the present argument: they show that distinctions tied to such stabilizing conditions exhibit robustness not shared by transient dynamical fluctuations. The relevant stabilizing condition restricts admissible evolution and thereby supports the persistence of a contextually generated difference.

It is important to clarify the relationship between topological invariants in the strict homotopy-theoretic sense and energetic barriers. *Topological invariants* (such as winding numbers, Chern numbers, and homotopy classes) are discrete labels that cannot change under continuous deformations of the relevant structure and therefore provide a strong form of protection. *Energetic barriers*, by contrast, are not topological in this strict sense. Their role is different: when the barrier height satisfies $\Delta E \gg k_B T$, thermal fluctuations are unlikely to induce transitions, so the system remains confined to a discrete set of metastable states over the relevant timescale. In configuration space, such barriers generate a coarse-grained sector separation between accessible states. Therefore, strict topological invariants and energetic barriers do not play the same ontological role: the former provide topological protection in the strict sense, whereas the latter provide effective dynamical stabilization over relevant timescales. This difference is philosophically significant, even though both mechanisms can play a functionally analogous role in supporting the stabilization by which contextually generated distinctions count as objective information.

Example 4: Flux qubit. In a superconducting flux qubit, the two computational basis states correspond to opposite directions of circulating current, distinguished by flux quantization. Here topological protection, together with the superconducting gap, helps ensure that the encoded bit-value persists against thermal fluctuations[46].

5.3 Inscription as a Stabilizing Structural Condition

We now connect the contextual distinctions analyzed earlier with the stabilizing mechanisms schematically depicted in Fig. 2. Let a distinction be represented by the pair $(\Delta S, C)$, where ΔS is an action difference satisfying $|\Delta S| \gtrsim \hbar$ and C is the context

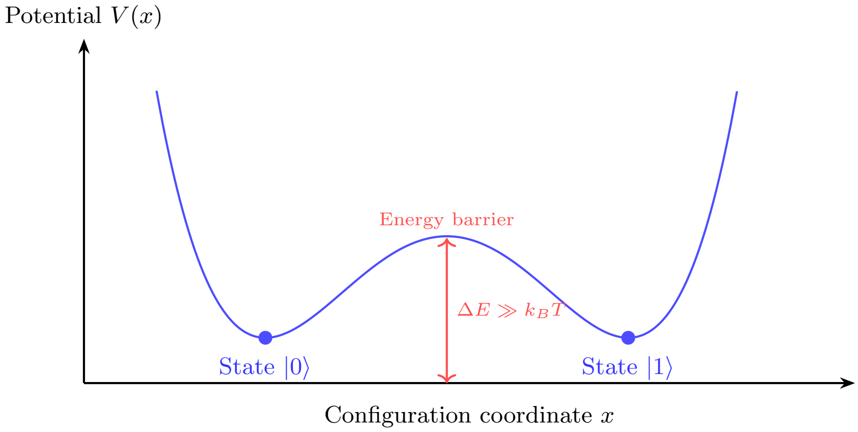

Fig. 2 Illustration of inscription mechanism: a contextually generated distinction becomes stable when protected by an energy barrier or structural invariant. The two states $|0\rangle$ and $|1\rangle$ are separated by a barrier $\Delta E \gg k_B T$, preventing thermal transitions and ensuring objective information storage.

defining mutually exclusive alternatives. Such a distinction is *inscribed* when it is preserved by a stabilizing structural condition that prevents its reversal under admissible dynamics.

Definition 2 (Inscription) A contextually generated distinction is *inscribed* if there exists a stabilizing structural condition T—for example, a topological invariant in the strict sense or an energetically metastable sector separation—such that the system's state remains confined within the corresponding stable sector, and no admissible perturbation can undo or merge the alternatives distinguished by (S, C).

A complementary stabilization mechanism, especially relevant in open quantum systems, is provided by Zurek's *quantum Darwinism* [47, 48]. In this framework, certain pointer-state distinctions become effectively objective because they are redundantly recorded across many environmental fragments. Redundant encoding functions as a concrete form of structural stabilization: the distinction is multiply inscribed in the system–environment state and thereby becomes robust with respect to the loss of any single fragment or local interaction. Quantum Darwinism can therefore be read as a specific dynamical mechanism that instantiates the broader inscription idea developed here, without reducing objectivity to the epistemic situation of any particular observer.

Stabilizing structural conditions provide a sufficient condition for a contextually generated distinction to qualify as objective information. We use this expression broadly to include:

- **Topological invariants** (in the strict homotopy-theoretic sense): winding numbers, Chern numbers, homotopy classes.
- **Energetic barriers** (functionally analogous stabilization): energy gaps $\Delta E \gg k_B T$ that partition configuration space into metastable basins.

- **Boundary constraints**: geometrical or boundary conditions that enforce sector separation.

Classical memory systems (magnetic domains, potential wells, chemical bonds) exhibit metastability generated by energy barriers which—when represented in configuration space—constitute effective structural protection. Thus, inscription is best understood as stabilization via some stabilizing structural condition (topological, energetic, or boundary-based) that prevents admissible reversal.

Inscription thus links contextual determinacy with structural persistence. On the present account, a distinction qualifies as objective physical information only when it is both (i) contextually determined and (ii) structurally stabilized. These considerations yield the second main thesis of the paper:

> **Second Main Thesis.** On the present account, a contextually generated bit qualifies as objective physical information when it is stabilized by a stabilizing structural condition that prevents its reversal under admissible evolution. Context provides determinacy; stabilization provides persistence. Such conditions include topological invariants in the strict sense as well as energetic barriers that play a functionally analogous stabilizing role in configuration space.

Clarification. Structural stabilization is here treated as a *constitutive criterion* for *objective* information—that is, for states capable of storage, persistence, and re-identification. Nothing in our framework denies that momentary physical differences may occur without such stabilization; we only claim that such fleeting distinctions do not constitute objective informational states. This distinction parallels the difference between transient quantum amplitudes and stable classical records.

Table 3 provides examples of inscription mechanisms across different physical systems.

Table 3 Examples of inscription mechanisms in physical systems

Physical System	**Distinction**	**Stabilization Type**	**Stability Mechanism**
Superfluid vortex	Circulation direction	Topological (winding)	Phase single-valuedness
Flux qubit	Current direction	Topological (flux quantum)	Superconducting gap
Ferromagnetic domain	Magnetization orientation	Energetic (barrier)	Exchange energy barrier
Topological insulator	Edge state chirality	Topological (Chern)	Bulk-boundary correspondence
Classical bit (memory)	Charge/magnetization state	Energetic (barrier)	Energy gap $\gg k_B T$

6 Main Argument III: Action-First Ontology of Physical Information

This section synthesizes the arguments developed in Sections 4 and 5 into a unified framework. We present the full generative sequence that leads from the structural role of action in physical theory to the formation of objective informational states. The resulting scheme provides an *action-first* ontological framework, or equivalently a framework of ontological dependence, in which objective physical information is structurally derivative rather than fundamental.

6.1 The Full Generative Chain

The previous analysis identified two necessary components of informational determination: (i) contextual generation of distinctions and (ii) structural stabilization through inscription. We now assemble these components into a single logical sequence describing the genesis of a physical bit.

1. **Action (Substrate).** The substrate of physical possibility is given by the action functional S, which assigns dynamical values to possible histories.
2. **Quantization (Scale).** In the semiclassical and phase-sensitive sense relevant here, the quantum of action $\hbar$ establishes a characteristic lower scale for the effective granularity of phase space. Action differences of order $|\Delta S| \gtrsim \hbar$ may then be treated as capable of supporting physical distinguishability.
3. **Contextuality (Selection).** A physically instantiated context C imposes boundary conditions that select a set of mutually exclusive alternatives. Following the Kochen–Specker theorem, no non-contextual assignment of definite values is possible; determinacy is therefore context-relative.
4. **Determinate Outcome.** When the conditions of distinguishability (2) and contextual determinacy (3) are jointly satisfied, a binary alternative becomes well-defined relative to the context.
5. **Inscription (Stabilization).** If the resulting distinction is stabilized by a structural condition T (topological, energetic, or boundary-based), its reversal is prevented under admissible dynamics.
6. **Objective Information (Result).** A distinction that is both contextually determined and structurally stabilized qualifies as objective physical information.

This generative chain is physical in the sense relevant to the present discussion: it does not require the intervention of a conscious agent or subjective belief. The transition from continuous action to discrete information arises from the interplay of quantization limits, contextual constraints, and stabilizing invariants.

The structure of this chain is summarized schematically in Fig. 3.

Example 5: Classical bit in semiconductor memory. Consider a DRAM cell storing a bit:

1. **Action:** Charge dynamics governed by electromagnetic action.
2. **Quantization:** Charge quantization (e) and energy scales set by $\hbar\omega$ for relevant transitions.

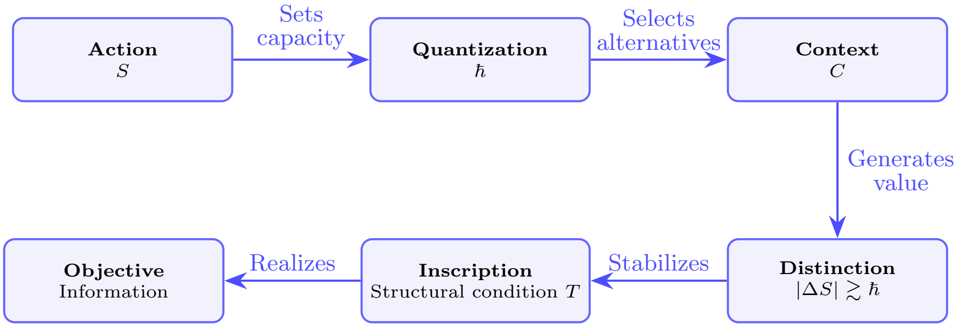

Fig. 3 Generative chain: Action sets distinguishability capacity, quantization fixes scale, context selects alternatives, distinction is generated, inscription stabilizes it, and objective information emerges.

3. **Context:** Capacitor voltage threshold defines two mutually exclusive states (charged/discharged).
4. **Outcome:** Voltage measurement yields determinate value relative to threshold.
5. **Inscription:** Potential barrier (energy gap) prevents spontaneous transitions at operating temperature.
6. **Information:** Stable bit value persists until actively erased.

6.2 Why Information Is Not Fundamental

The foregoing analysis supports a non-fundamentalist account of physical information. Information does not appear as a primitive building block of the ontology but as a derivative status dependent on the prior dynamical, contextual, and stabilizing structures analyzed above. Informational states therefore presuppose structures that are prior, in the sense of ontological dependence developed here, to the informational content itself.

Accordingly, the action-first framework treats objective physical information as a secondary status: that of a determinate and persistent distinction produced by the joint operation of quantization, contextuality, and structural stabilization. On this view, information is not a fundamental constituent of physical reality but a structured result grounded in the modal organization of action [29, 49].

Table 4 compares the action-first ontology with information-first approaches, and Fig. 4 presents the same contrast as a conceptual inversion diagram.

Fig. 4 Structural inversion: information-first ontologies treat information as primitive and derive dynamics from it, whereas the action-first ontology reverses this priority, deriving information from action, context, and structural stabilization.

Table 4 Comparison of ontological frameworks

Feature	Information-First (e.g., Floridi)	Action-First (This Work)
Fundamental entity	Information as explanatorily basic	Action (S) as structurally prior
Status of information	Primitive or ontologically basic	Derivative
Role of measurement	Often treated as revealing or articulating informational structure	Treated here as contextually determining informational values
Basis of objectivity	Informational structure	Structural stabilization
Observer dependence	Can be interpreted in observer-relative terms	Formulated here in terms not tied to any particular observer's knowledge or interpretation
Relation to dynamics	Dynamics from information	Information from dynamics

7 Clarifying the Ontological Status of the Framework

A central claim of this paper is that we advance an "action-first ontology." However, the notion of ontology in the context of action principles requires careful clarification, particularly given the subtle metaphysical issues surrounding variational formulations of physical theory.

7.1 What Kind of Ontology?

When we speak of an "action-first ontology," we do not propose that action is a *substance* in the traditional metaphysical sense. Action is not a material constituent or a spatiotemporally localized entity. Rather, action functions as a *structural principle* that encodes the space of physical possibilities and constrains the evolution of systems. In this sense, our ontology is closer to what has been called *structural* or *modal* realism: the view that reality is fundamentally characterized by structures and possibilities rather than by intrinsic properties of objects [49].

The metaphysics of action principles has been the subject of considerable debate. As discussed by Curiel [50], action principles can be interpreted in multiple ways: as mere calculational tools, as encoding dynamical laws, or as reflecting deep structural features of physical reality. Our framework is most naturally read as adopting the third interpretation: action principles are not treated here merely as heuristic but as expressing structural constraints on what is physically possible. The quantum of action $\hbar$ sets a minimal scale for distinguishability, and the action functional S determines which histories are dynamically accessible. These are intended as claims about ontological dependence and structural features of physical reality, rather than merely epistemological claims about how we represent it.

7.2 Is an Ontological Interpretation Required?

An important question is whether the conceptual framework we have developed *requires* an ontological interpretation, or whether it can be understood in purely operational or pragmatic terms. We believe the framework is valuable in either case, but the two readings have different implications.

Ontological reading: On this interpretation, the generative chain from action to inscription describes how objective physical information comes into being as a derivative feature of physical reality. Informational distinctions are objective features of physical systems, grounded in quantized action, contextual constraints, and structural invariants. This reading is realist: it claims that information exists independently of our knowledge or use of it, but is derivative of more fundamental structures.

Operational reading: On this interpretation, the framework provides a systematic way of understanding when and how informational concepts apply in physics, without committing to claims about what is ultimately real. The generative chain specifies the conditions under which it is appropriate to attribute informational content to a physical system, but remains neutral on whether information "really exists" in any ontological sense. This reading is closer to pragmatism or instrumentalism.

Both readings are broadly consistent with the formal structure of the framework. However, the primary argumentative aim of the present paper is to articulate an ontological interpretation of the framework rather than to leave it at a merely operational level: the framework is offered primarily as an account of the physical conditions under which a realized distinction qualifies as objective information. The operational reading remains available as a more metaphysically modest use of the same schema.

7.3 Complementarity with Existing Interpretations

An important consequence of our framework is that it does *not* replace existing interpretations of quantum mechanics or measurement theory. Rather, it complements them by clarifying the conditions under which informational distinctions are generated and stabilized. For example:

- **Decoherence-based accounts** [37] explain how interference is suppressed and pointer states emerge. Our framework adds that inscription via structural invariants is required for these distinctions to become objective and persistent.
- **Relational interpretations** [29] emphasize that properties are always relative to a reference system. Our framework specifies the physical conditions (action, context, inscription) under which such relational properties acquire determinate values.
- **Pragmatist accounts** [28] argue that quantum states provide objective information relative to physical situations. Our framework provides a generative mechanism for how such situation-relative information arises.

The action-first framework therefore complements rather than replaces existing interpretations of measurement. It provides a meta-level analysis of the conditions for informational determination that is compatible with multiple interpretational stances.

8 Objections and Replies

In this section, we address three potential objections to the framework developed above. We consider whether the action-first account is merely a semantic reinterpretation, whether the replacement of the observer with a structural context is legitimate, and whether the appeal to structural invariants is necessary for the definition of objective information.

8.1 Is This Merely a Reinterpretation?

Objection. One might argue that the framework is empirically equivalent to standard quantum mechanics and thus offers only a change of terminology. If contextuality and quantization are already present in the formalism, does describing them in terms of “action” and “inscription” provide any additional theoretical insight?

Reply. The difference is not merely verbal. The framework proposes a reordering of ontological priority. Approaches that treat information as fundamental (such as Wheeler’s “It from Bit” [1]) take informational distinctions as primitive and seek to derive dynamics from them. By contrast, the present account treats information as a derivative outcome of dynamical and structural features that are ontologically prior in the sense developed above. On this view, the generation of information is an explicable process grounded in quantized action and contextual constraints [8]. The shift is not a restatement of quantum mechanics but a reordering of its conceptual foundations: information is not a primitive element but the result of a structured sequence of operations. This has consequences for how we understand the relationship between physics and information theory, the role of observers, and the prospects for quantum gravity approaches based on informational principles [51].

8.2 Does the Framework Address the Outcome Problem?

Objection. One may ask whether the action-first framework solves the *measurement outcome problem*—the question of why a particular value, among all contextually allowed ones, is realized in an individual measurement.

Reply. The present framework does *not* aim to solve the outcome problem and does not supply an alternative to the Born rule. We take the standard probabilistic structure of quantum theory as given. Our focus is distinct: we clarify *when* a realized difference qualifies as *objective physical information*. The framework distinguishes (i) the stochastic selection of an outcome, governed by ordinary quantum mechanics, from (ii) the ontological status of that outcome once realized. The action-first account therefore complements rather than replaces existing interpretations of measurement: it specifies the physical conditions under which a generated value achieves structural stability and becomes objectively meaningful.

8.3 Does This Illegitimately Eliminate the Observer?

Objection. By replacing the observer with a structural context, the framework may appear to neglect the role of measurement agents. One might contend that information presupposes an entity capable of interpreting the distinction [27].

Reply. The framework does not eliminate the observer; rather, it generalizes the notion of measurement beyond cases involving conscious agents. On this view, a human observer constitutes one particularly complex instance of a physical context, namely one that implements specific boundary conditions, couplings, and exclusivity relations. The determinacy of outcomes in simpler systems, such as beam splitters, polarization filters, or detectors, can be understood in terms of the same structural principles [37]. By characterizing information in terms of distinguishability and stabilization rather than epistemic access, the present account formulates informational determination in terms not tied to any particular observer's knowledge or interpretation, while remaining compatible with ordinary measurement scenarios. In this respect, it is broadly aligned with decoherence-based approaches [41] and relational interpretations [29], both of which seek to ground measurement in physical interactions rather than in conscious observation. The distinctive claim of the present framework is that contexts need not involve interpreting subjects: any physical system that implements the relevant boundary conditions and stabilizing mechanisms can serve as a context for informational determination.

8.4 Is Structural Stabilization Really Necessary?

Objection. One might question whether appealing to structural invariants is too strong a requirement. Perhaps a transient dynamical difference is sufficient to constitute physical information, even without long-term stabilization.

Reply. A transient dynamical fluctuation does not meet the criteria for objective information. Without a stabilizing structural condition, a distinction can be reversed by admissible dynamics or thermal perturbations and therefore lacks the persistence required for storage or transmission [5]. Stabilizing structural conditions (topological, energetic, or boundary-based) provide a minimal set of conditions under which a distinction remains robust against such perturbations. If information is to be understood as a stable and objective physical feature, rather than as a momentary configuration, structural stabilization is required. Inscription is therefore a constitutive condition for objective physical information rather than an optional refinement. This requirement is consistent with the thermodynamic understanding of information: Landauer's principle [5] shows that erasing information requires dissipating energy precisely because stable information is associated with metastable states separated by energy barriers—a form of effective structural protection in configuration space.

9 Discussion

This section draws out several broader implications of the action-first framework. We relate the proposal to structural realism, reconsider the status of the "It from Bit" program, address the quantum–classical transition in schematic terms, and indicate the main limits of the present account.

9.1 Implications for Ontic Structural Realism

Ontic Structural Realism (OSR) [52, 53] maintains that physical structures, rather than individual objects, constitute the fundamental ontology. The present framework is broadly compatible with this orientation, but adds a more explicitly generative dimension. Rather than treating structures as simply given, it emphasizes the roles of action, contextual differentiation, and stabilization in explaining how stable physical distinctions arise.

On this view, physically significant structures may be understood, at least in part, as stabilized distinctions grounded in the dynamics of the system. In that sense, the proposal supplements OSR by indicating how structural relations may become physically articulated and preserved, rather than merely described [54]. This does not replace structural realism, but offers a possible naturalization of one of its central intuitions: that what matters physically is not merely objecthood, but structured patterns of difference.

Furthermore, the action-first framework suggests that the relevant structures may be understood as physically grounded in quantized action and structural stabilization, rather than as merely formal abstractions.

9.2 Reinterpreting "It from Bit"

Wheeler's slogan "It from Bit" [1] suggests that informational distinctions lie at the basis of physical reality. The action-first framework reverses this order of explanatory priority. Informational distinctions do not precede physical dynamics; rather, they arise when quantized action makes differences physically available and a context selects mutually exclusive alternatives that can be stabilized.

The relevant reformulation is therefore not "It from Bit" but "Bit from Action and Structure." Information retains an important explanatory role, but it is not treated here as ontologically primitive. Instead, it is understood as a structured outcome of underlying physical conditions [8]. If this line of thought is correct, then programs that seek to derive spacetime or dynamics from informational principles [55, 56] would ultimately require a more fundamental account of the dynamical conditions under which informational structures become available and objective.

Related "reconstruction" and "law-without-law" programs pursue this strategy in a more explicitly information-theoretic idiom, for example in Müller [57] and in operational–axiomatic reconstructions due to Chiribella and collaborators [58]. The present point is not to dispute these projects, but to note a shared presupposition: such reconstructions typically operate in a regime where the relevant distinctions are already well-defined and stably accessible. The action-first framework targets this presupposition by asking what physical conditions make such distinctions objectively available in the first place.

The action-first view is more compatible with approaches that take geometry and action as fundamental, such as loop quantum gravity [59] or causal set theory [60], while suggesting that informational concepts in these theories should be understood as emergent rather than foundational.

9.3 Objectivity and Physical Semantics

The present framework also bears on a familiar question in the philosophy of information: how physical states can possess content without appeal to mental representation [12, 61]. The claim advanced here is modest. Rather than offering a full theory of semantic content, the framework identifies conditions under which a physical difference may count as objectively meaningful within a system.

A physical state acquires this status when three elements are jointly in place:

1. **Action (S):** provides the space of physically available distinctions;
2. **Context (C):** defines a set of mutually exclusive alternatives;

3. **Inscription:** stabilizes one such alternative as a persistent feature of the system.

On this view, objective informational significance is not imposed by an external interpreter, but is associated with a stable, context-defined differentiation within the system's state space. This does not by itself solve all problems of naturalized semantics, but it does suggest a way of understanding objective informational content in structural terms not tied to any particular observer's knowledge[49, 62].

9.4 Classical Information as Effective Inscription

Classical information storage appears at first to challenge the inscription framework, since many classical bits are stabilized not by topological invariants in the strict homotopy-theoretic sense but by energetic or configurational barriers. However, such barriers may still play a structurally analogous role. In configuration space, they separate metastable basins and suppress transitions between them over relevant timescales.

In this sense, classical information fits naturally into the present model:

$$S \to \hbar \to C \to \text{Distinction} \to \text{Energetic Stabilization} \to \text{Objective Bit.}$$

The mechanism of stabilization differs from strictly topological protection, but the general schema remains the same: a physically realized distinction becomes objective when it is preserved against admissible perturbations. Our treatment of this case remains intentionally coarse-grained. A fuller account would require a more explicit formalization of metastable sector separation in configuration space.

Quantum–Classical Transition. The emergence of classical information from quantum substrates involves at least three familiar ingredients:

1. **Decoherence:** environmental interactions suppress quantum coherence and select pointer states [37];
2. **Coarse-graining:** macroscopic observables average over microscopic degrees of freedom;
3. **Energetic stabilization:** macroscopic energy barriers separate effectively classical states.

The action-first framework can be applied, in schematic form, at both scales. At the quantum level, stabilization may be associated with topological or other sector-preserving constraints; at the classical level, it is more typically associated with metastable energetic separation. In both cases, objective information depends on the conjunction of contextual determination and structural persistence.

9.5 Black Holes as a Limiting Case

Black hole horizons provide a useful limiting case for the present framework, but only in a schematic sense. The Bekenstein–Hawking area–entropy relation may be read as indicating a bound on physically available distinctions at a boundary. On the present interpretation, this does not mean that horizons store primitive bits; rather, it suggests that boundary structure can constrain the capacity for inscription. A full treatment of this case would require a separate analysis and lies beyond the scope of the present paper [63, 64].

9.6 Context Dynamics and Nested Contexts

The present framework analyzes informational determination within a fixed structural context. On a genuinely physical conception of context, however, transitions between contexts and the possibility of nested contexts merit explicit discussion. We suggest that such transitions should not be treated as ordinary within-context events (i.e. updates of values under a fixed context), but rather as higher-order physical transformations of the contextual specification itself—for instance, changes in the set of admissible observables, coupling structures, or energetic boundaries.

In particular, nesting (e.g. a localized quantum system embedded within a macroscopic measuring apparatus) can be understood as a physical hierarchy of action constraints and stabilization mechanisms. A broader physical structure (the apparatus and its environment) can impose boundary conditions and decoherence timescales that stabilize the local measurement context. Correspondingly, context-transitions may be mediated by standard physical processes such as environmentally induced decoherence or sufficiently slow (adiabatic) changes in relevant constraints, insofar as these processes modify the boundaries that define contextual exclusivity.

While we sketch this physical rationale, we do not attempt to provide a formal dynamical model of context formation, modification, or nesting in the present paper. This limitation is deliberate: our primary aim is to clarify the *constitutive* conditions under which information is generated and stabilized *within* a given context. A full dynamical theory of how contexts arise, change, and compose over time remains an important task for future work, and the present proposal is intended to be compatible with such developments rather than to pre-empt them.

9.7 Limitations and Open Problems

Several questions remain open:

- **Thermodynamic considerations.** The thermodynamic cost of creating, maintaining, and erasing stabilized distinctions requires further analysis within the present framework[5, 65].
- **Extreme regimes.** The black hole case suggests possible connections with holographic descriptions, but the relation between inscription and boundary entropy in quantum gravity remains unsettled [63, 64].
- **Quantum computation.** It remains to be clarified how contextual inscription applies to quantum information processing, especially in regimes involving superposition, entanglement, and topological protection [66].
- **Biological information.** Extending the framework to biological systems would require incorporating functional context, historical selection, and other nontrivial organizational constraints [67].

10 Conclusion

The aim of this paper has been to clarify the conditions under which objective physical information may be given an ontological interpretation. We have argued that treating information as ontologically primitive can obscure the physical structures on which informational distinctions depend. Rather than adopting an information-first ontology, we have developed an action-first framework in which information is understood as a derivative outcome of quantized dynamics, contextual constraints, and structural stabilization.

The argument proceeded in three steps. First, the quantum of action was introduced as a lower physical scale for discriminability. Second, under the contextual constraints highlighted by the Kochen–Specker theorem, determinate informational attributions are available only relative to a physically instantiated context. Third, such contextually determined distinctions count as objective information only when structurally stabilized through inscription. Information is therefore not fundamental on this account, but derivative of prior dynamical, contextual, and stabilizing structures.

This framework distinguishes between the generation of distinctions and their preservation. Although the proposal is primarily ontological, it is intended to remain compatible with existing experimental practice. Contextuality experiments realize explicit structural contexts, while topologically protected qubits and classical metastable memories illustrate different forms of inscription. In this sense, the framework offers an ontological interpretation of familiar operational phenomena rather than a source of new empirical predictions. It also avoids the ambiguity between epistemic and ontic conceptions of information: informational states are neither subjective judgments nor primitive constituents of the ontology. Instead, they arise when quantized action is constrained by context and stabilized by appropriate structural conditions.

The resulting view provides a more precise characterization of objective physical information and its place within the ontology of physics. It suggests that the informational turn in physics, while valuable and often illuminating, need not be taken to show that information is ontologically fundamental. On the present account, information emerges from more basic physical structures and processes.

In summary:

> *On the present account, physical information in the objective sense is best understood as a contextually generated distinction that becomes objective through structural stabilization.*

This formulation captures the central claim of the action-first framework: information is real and objective, but not fundamental. It is a structured outcome of the interplay between action, context, and stabilizing physical conditions.

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