Substrate Stability Under Persistent Disagreement: Structural Constraints for Neutral Ontological Substrates

Denise M. Case

Northwest Missouri State University, Computer Science and
Information Systems, Maryville, MO, USA

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Abstract

Modern data systems increasingly operate under conditions of persistent legal, political, and analytic disagreement. In such settings, interoperability cannot rely on shared interpretation, negotiated semantics, or centralized authority. Instead, representations must function as neutral substrates that preserve stable reference across incompatible extensions.

This paper investigates the structural constraints imposed on ontological design by this requirement. Building on a neutrality framework that treats interpretive non-commitment and stability under extension as explicit design constraints, we ask what minimal ontological structure is forced if accountability relationships are to remain referable and comparable under disagreement. Minimality here is not mere parsimony: a

reduction is admissible only if it does not reintroduce stability-critical distinctions as hidden roles, flags, or contextual predicates.

We establish a conditional lower-bound result: any ontology capable of supporting accountability under persistent disagreement must realize at least six distinct identity-and-persistence regimes. We further show that a construction with exactly six such regimes is sufficient to satisfy the stated requirements without embedding causal or normative commitments in the substrate. The result is not a proposal for a universal ontology, but a constraint on what is possible when neutrality and stable reference are treated as non-negotiable design goals.

Statement of Result (Preview). *Under explicit neutrality and stability constraints, we show that attempts to simplify ontological structure by collapsing distinctions inevitably reintroduce those distinctions as hidden interpretive mechanisms. When such hidden regimes are excluded, accountability under persistent disagreement requires a minimal set of six distinct identity-and-persistence regimes: fewer do not satisfy the stated neutrality and stability requirements, and more are unnecessary.*

Informally: Neutrality is achieved by externalizing explanatory and evaluative structure. To function as a substrate for disagreement, an ontology must remain agnostic with respect to causal and normative interpretation.

The formal statement and proof appear in Section 6.

Keywords: formal ontology; ontological neutrality; accountability; neutral substrates; extension stability; causal and normative commitment

1   Introduction: Structure Under Disagreement

Modern data systems increasingly operate in environments characterized by persistent legal, political, and analytic disagreement. In such settings, no single interpretive authority can be assumed, and semantic convergence

cannot be enforced without excluding legitimate participants or perspectives. Nevertheless, shared use of data remains necessary: entities must be referable, actions traceable, and records comparable across frameworks that may diverge in assumptions, methods, or evaluative standards.

This paper addresses a structural question that arises in this context: *what ontological structure is required if a representation is to remain usable as a shared substrate across incompatible interpretations?* The focus is not on domain modeling, explanatory adequacy, or normative correctness. Rather, it concerns the structural conditions required for stable reference and accountability under persistent disagreement.

We adopt a neutrality framework developed in prior work Case [2025], treating ontological neutrality as a design constraint rather than an aspirational ideal. Neutrality is understood here as interpretive non-commitment combined with stability under incompatible extension. Under this view, a substrate must permit independent extensions to introduce causal, normative, or analytic structure without requiring revision of the underlying representation. Accordingly, explanatory and evaluative structure is externalized, and the substrate is constrained to remain pre-causal and pre-normative at the substrate level.

Within this setting, ontological minimality cannot be understood solely as a reduction in the number of primitives. Many apparent simplifications achieve parsimony by reintroducing essential distinctions indirectly, through roles, flags, contextual typing, or other internal discriminators whose interpretation is supplied by extension layers (e.g., a single undifferentiated entity type distinguished only by role predicates such as *isAgent*, *isOccurrence*, or *isAuthority*). Such encodings rely on shared interpretive assumptions, which may not be available in settings characterized by persistent disagreement. For this reason, the present analysis excludes reductions that preserve stability only by deferring essential distinctions to interpretive mechanisms not represented at the substrate level.

The specific focus of this paper is accountability. Accountability analysis

3

requires stable reference to participants, authority structures, regulated occurrences, applicability contexts, and descriptive records, without embedding causal claims or normative judgments in the substrate itself. These categories are not introduced as an ontological partition, but as representational capacities whose simultaneous support places structural constraints on any neutral substrate. The question addressed here is not how these elements should be interpreted, but whether a neutral substrate can support them at all, and if so, with what irreducible structural commitments.

The central contribution of this paper is a conditional bound on ontological structure given the design goals outlined above. Under explicit neutrality and stability constraints, we show that any ontology capable of supporting accountability under persistent disagreement must realize at least six distinct identity-and-persistence regimes. We further show that a construction with a minimal set of six such regimes is sufficient to satisfy the stated requirements without introducing hidden or implicit structure. The result is not a proposal for a universal ontology, but a constraint on what is possible under a specific optimization objective.

Alternative optimization objectives prioritize different tradeoffs, such as interpretive convergence, domain-specific efficiency, or context-dependent classification at the substrate level. The results presented here apply only under the stated constraints, within which a minimal, domain-independent bound on ontological structure is established for stable reference and accountability.

The remainder of the paper proceeds as follows. Section 2 states the assumptions, neutrality constraints, and optimization criterion. Section 3 formalizes the structural requirements imposed by accountability analysis. Section 4 derives a lower bound on the number of required identity-and-persistence regimes. Section 5 presents a construction achieving this bound. Section 6 discusses the scope and implications of the result. Section 7 situates the work relative to existing ontology frameworks. Section 8 concludes.

2 Assumptions, Neutrality, and Optimization Criterion

This section fixes the problem setting for the remainder of the paper. All results that follow are conditional on the assumptions stated here. The purpose is not to argue that these assumptions are universally correct, but to make explicit the constraints under which a neutral substrate for accountability is possible.

2.1 Persistent Disagreement and Uncoordinated Extension

We assume environments in which disagreement is not an anomaly to be resolved, but a persistent condition. Legal interpretation, policy evaluation, and analytic methodology may remain incompatible across communities and over time. Accordingly, no single interpretive authority or shared semantic framework can be assumed at the substrate level.

We further assume that extensions to the substrate may occur without coordination. Independent actors may add explanatory, normative, or analytic structure, and such extensions must not require revision of the substrate itself. This assumption does not rely on global semantic agreement, centralized governance, or negotiated meaning as preconditions for interoperability.

2.2 Neutrality Constraint

This work assumes substrate neutrality and stability as a design constraint rather than as a philosophical claim. A neutral substrate does not assert why events occur, whether outcomes are desirable, or how actions ought to be evaluated. Instead, it provides stable referents and structural relations upon which external interpretive layers may operate.

Neutrality further requires stability under incompatible extension. If two extensions disagree in interpretation, evaluation, or explanation, their dis-

agreement must not force reclassification of entities, alteration of identity conditions, or revision of the substrate. Any representation whose admissibility conditions depend on interpretive agreement does not satisfy this constraint.

2.3 Stable Reference Requirement

For a substrate to support accountability, entities must remain referable over time and across extensions. Identity conditions and admissible relationships must be invariant under changes in interpretation. An entity may participate in new relationships or acquire additional annotations, but it must not change its ontological status (i.e., its identity conditions or persistence regime) in order to remain usable as a shared referent.

This requirement excludes representations in which stability-critical distinctions are encoded only as roles, flags, or contextual predicates. Such mechanisms rely on interpretive conventions supplied by extension layers and therefore permit divergent admissibility judgments under persistent disagreement.

2.4 Optimization Criterion

The optimization objective of this paper is to minimize explicit ontological structure subject to the constraints above. Minimality is not defined as the smallest possible number of primitives in the abstract, but as the smallest number of explicit identity-and-persistence regimes required to preserve neutrality and stable reference.

A proposed reduction is counted as a simplification only if it does not reintroduce the same distinctions through hidden or interpretive mechanisms. Collapsing regimes while reintroducing their distinctions via internal discriminators, contextual typing, or role predicates does not reduce total structural complexity and is therefore excluded by the optimization criterion adopted

here.

Alternative optimization objectives prioritize different tradeoffs, such as interpretive coordination, domain-specific efficiency, or context-dependent classification at the substrate level. The results presented here apply only to substrates optimized for interoperability under persistent disagreement.

3 Structural Requirements for Accountability Substrates

Given the assumptions and optimization criterion fixed in Section 2, the central question is not which ontology is most expressive or convenient, but which structural distinctions are unavoidable. We therefore state the representational requirements that an ontological substrate must satisfy in order to support accountability analysis under persistent disagreement.

These requirements are structural rather than interpretive. They do not prescribe how accountability should be understood, evaluated, or enforced; instead, they specify what must be representable in a stable and neutral manner.

The requirements are framed as necessary capacities. They are not derived from any particular domain, policy area, or theory of governance, but from the minimal conditions under which accountability claims can be stated, inspected, and compared without embedding causal or normative commitments in the substrate.

3.1 R1: Stable Identity and Persistence

The substrate must support stable reference to entities over time. Each entity must have identity and persistence conditions that are invariant under incompatible extensions, independent of how the entity is later classified, interpreted, or evaluated. Changes in interpretation, role, status, or evaluation

7

must not require reclassification of entities or modification of their identity criteria.

This requirement does not apply to representations in which identity is determined contextually or retroactively by interpretive layers. If an entity must change its ontological status in order to participate in new relationships or analyses, stable reference is not preserved.

3.2   R2: Obligation-Bearing Capacity

The substrate must support representation of entities that can bear obligations or responsibilities. Such entities must be referable independently of the particular occurrences in which obligations are fulfilled, violated, or discharged.

This requirement does not presuppose any substantive theory of normativity. It requires only that obligation-bearing entities be representable as enduring referents whose identity does not depend on specific events.

3.3   R3: Normative Reference Without Execution

The substrate must distinguish between the existence of authority or obligation and its execution. Normative or regulatory structures must therefore be representable independently of the occurrences that enact, comply with, or violate them.

This distinction is necessary to support accountability over time, including cases of delayed enforcement, partial compliance, amendment, or contested application. Encoding normative reference solely through occurrences collapses authority into execution and undermines stable reference to governing structures.

3.4 R4: Time-Indexed Occurrence

The substrate must support representation of time-indexed occurrences. Occurrences must be individuated by their temporal realization and provenance, and must be distinguishable from enduring entities.

This requirement applies to actions as well as to other discrete occurrences relevant to accountability, such as filings, inspections, or transactions. Occurrences are not required to carry interpretive or evaluative meaning; they must only assert that something occurred at a particular time and place.

3.5 R5: Applicability and Scope

The substrate must support representation of applicability contexts. It must be possible to state where, to whom, or under what conditions a normative or regulatory structure applies, without collapsing such contexts into either obligation-bearing entities or physical loci.

Applicability contexts may be nested, overlapping, or partially coincident. They must therefore be representable as stable referents in their own right, rather than as incidental attributes whose interpretation may vary across extensions.

3.6 R6: Descriptive Indicators Without Causal Commitment

The substrate must support representation of descriptive indicators or records that characterize states, performance, or outcomes associated with entities or occurrences. Such indicators must be representable without asserting causal relations, evaluative judgments, or explanatory claims.

This requirement is necessary to support longitudinal comparison and outcome inspection while preserving neutrality. Collapsing indicators into occurrences or into interpretive annotations eliminates stable reference to descriptive records over time and across analytic frameworks.

3.7 Summary

Together, R1–R6 specify the minimal representational capacities required for an accountability substrate optimized for interoperability under persistent disagreement. They do not yet impose a particular ontological partition. Rather, they define the constraints under which any such partition must operate.

In the following section, these requirements are used to derive a lower bound on the number of distinct identity-and-persistence regimes that a substrate must realize in order to satisfy them simultaneously.

Identity-and-Persistence Regimes

Before deriving the lower bound, we make explicit what is meant by an *identity-and-persistence regime.* An identity-and-persistence regime specifies the conditions under which entities remain the same entities over time and across incompatible extensions, together with the relations they may admit without reclassification. Two entities belong to the same regime if and only if they share the same stability-critical identity criteria, persistence conditions, and admissible relations under the neutrality and stability constraints adopted here. Informally, a regime captures a distinct way of being an entity: regimes differ in what it means for an entity to persist and in which relations it can structurally admit without reclassification.

Regimes are not introduced as ontological kinds or domain categories. They are structural distinctions forced by the requirement that identity and admissibility remain invariant under persistent disagreement.

4   Necessity: A Lower Bound on Ontological Structure

This section establishes a lower bound on ontological structure under the assumptions and optimization criterion fixed in Section 2. The result is a necessity claim: if a substrate is to support accountability under persistent disagreement while maintaining neutrality and stable reference, then a minimum number of distinct identity-and-persistence regimes is unavoidable.

The argument proceeds in two steps. First, we identify the representational capacities that an accountability substrate must support, independent of any particular ontology. Second, we show that collapsing any two of the resulting identity regimes either violates stable reference or reintroduces hidden distinctions that are inadmissible under the stated optimization.

4.1   Identity-and-Persistence Regimes

Under the neutrality constraint, ontological distinctions cannot be grounded in function, role, or interpretation. They must instead be grounded in differences in identity, persistence, and admissible relations. An *identity-and-persistence regime* specifies what it means for an entity to remain the same entity over time and across incompatible extensions, and which relations it may admit without reclassification.

R1 is a global constraint on any admissible substrate: all entities admitted by the substrate must have extension-invariant identity and persistence conditions. The items below are the distinct identity-and-persistence regimes forced when the capacities R2–R6 are required subject to R1. In particular, beyond obligation-bearing and authority-bearing entities, accountability requires stable reference to enduring non-normative referents that may be acted upon or regulated; this yields the acted-upon regime as a distinct case.

Accountability analysis requires support for at least the following distinct

regimes:

1. **Obligation-bearing entities:** enduring referents that may bear obligations or responsibilities and remain identifiable as parties across time.

2. **Authority-bearing structures:** enduring referents that ground obligations or permissions without being tied to any single occurrence.

3. **Acted-upon referents:** enduring non-obligation-bearing entities that may be regulated, operated on, or affected by occurrences.

4. **Time-indexed occurrences:** entities individuated by their temporal realization and provenance, recording that something happened.

5. **Applicability contexts:** referents that scope where, to whom, or under what conditions authority applies, and which may be nested or overlapping.

6. **Descriptive records or indicators:** referents that report measured or derived properties without asserting causal or normative conclusions.

Each regime differs in its identity conditions, persistence behavior, and admissible relations. Treating these differences as merely contextual or role-based distinctions would make admissibility depend on interpretation, violating the requirement of stable reference.

4.2   Collapse Strategy and Admissibility

To establish a lower bound, we consider whether any two of the regimes above can be collapsed into a single identity regime without violating the assumptions of Section 2. A collapse is admissible only if the resulting representation admits a single, extension-stable identity regime and does not require hidden discriminators to recover the original distinction. (For example, collapsing obligation-bearing entities into authority-bearing structures would

require distinguishing parties from authorities using a role predicate such as *isParty*, reintroducing the distinction as an interpretive discriminator.)

For each possible collapse, at least one of the following outcomes arises:

- **Identity instability:** the collapsed regime requires incompatible persistence criteria, so that identity varies across extensions.
- **Category error:** the collapsed regime admits relations that are structurally inappropriate, requiring interpretive rules to block them.
- **Hidden regime reintroduction:** the distinction is reintroduced via roles, flags, or contextual predicates, violating the optimization criterion excluding hidden discriminators.

Because such mechanisms rely on interpretive agreement supplied by extension layers, they are excluded by the stated optimization objective.

4.3 Lower-Bound Result

Lemma 4.1 (Necessity of distinct regimes)**.** *Under the assumptions of Section 2, no ontology whose stable partition contains fewer than six distinct identity-and-persistence regimes can satisfy the representational requirements of accountability while remaining neutral and stable under incompatible extension.*

Proof sketch. Suppose an ontology realizes fewer than six identity-and-persistence regimes. Then at least two of the regimes required for accountability are collapsed into a single identity regime. By the collapse analysis above, any such collapse forces either incompatible identity criteria, structurally invalid relations, or internal discriminators whose interpretation is supplied by extension layers. Each case violates either stable reference or the neutrality constraint. Therefore no ontology with fewer than six regimes can satisfy all stated requirements simultaneously. A complete pairwise collapse analysis is finite and routine; representative failures are discussed

in Section 4.2 above, and the remaining cases follow the same three failure modes under the stated admissibility criterion. □

4.4   Interpretation of the Necessity Result

The necessity result is conditional and structural. It does not claim that fewer regimes are impossible in general, but that they are incompatible with the optimization objective fixed in Section 2. Ontologies optimized for local agreement, negotiated semantics, or expressive flexibility may legitimately employ fewer explicit distinctions by relying on hidden or interpretive mechanisms.

Within the stated constraints, however, the result establishes a sharp lower bound: any neutral substrate capable of supporting accountability under persistent disagreement must realize at least six distinct identity-and-persistence regimes. The following section shows that this bound is tight by exhibiting a construction that satisfies all requirements with a minimal set of six regimes.

5   Sufficiency: A Six-Regime Construction

This section shows that the lower bound established in Section 4 is tight. We exhibit a construction with a minimal set of six distinct identity-and-persistence regimes that satisfies all structural requirements stated in Section 3, while respecting the neutrality and stability constraints fixed in Section 2. No additional regimes or hidden interpretive mechanisms are required.

5.1   The Six Identity-and-Persistence Regimes

We realize six pairwise-disjoint identity-and-persistence regimes. For concreteness, each regime is defined solely by its identity conditions, persistence behavior, and admissible relations:

- **K1:** enduring entities capable of bearing obligations or responsibilities.
- **K2:** enduring physical or operational entities that may be acted upon but do not bear obligations.
- **K3:** enduring authority-bearing structures that ground obligations or permissions independently of any particular occurrence.
- **K4:** time-indexed actions or events whose identity is inseparable from temporal realization and provenance.
- **K5:** enduring applicability contexts that delimit where, to whom, or under what conditions instruments apply.
- **K6:** descriptive records or measurements that assert observed or derived facts without asserting causal or normative claims.

These six regimes correspond directly to the six capacities derived in Section 3: obligation-bearing capacity (K1), acted-upon reference (K2), normative grounding without execution (K3), time-indexed occurrence (K4), applicability and scope (K5), and descriptive indication without causal commitment (K6).

Each regime fixes a distinct identity criterion that is invariant under incompatible extension. No entity changes regime over time, and no regime's identity conditions depend on interpretation supplied by analytic or application layers.

5.2   Admissible Relations

A minimal set of typed, directional relations suffices to connect the six regimes and to satisfy all stated requirements. Representative relations include:

- authority grounding and delegation: $enacts, issues : \text{K1} \rightarrow \text{K3}$
- participation: $party\text{-}to : \text{K1} \rightarrow \text{K3}$
- execution under authority: $occurs\text{-}under : \text{K4} \rightarrow \text{K3}$
- involvement and action: $involves : \text{K4} \rightarrow \text{K1}$, $acts\text{-}on : \text{K4} \rightarrow \text{K2}$

- applicability: *applies-in* : K3 → K5
- description: *measures* : K6 → (K1 | K2 | K5)

Indicators are not taken to measure occurrences directly in the substrate. Occurrences serve as temporal and provenance anchors for indicators, while measurements target enduring referents whose identity persists across incompatible extensions.

This relation set is not exhaustive, but illustrates that no additional identity regimes are required to satisfy the structural constraints. Temporal and provenance information attach only to K4 and K6 via attribute schemas; no separate entities for time, provenance, or explanation are introduced.

5.3 Satisfaction of Structural Requirements

We briefly verify that the construction satisfies the requirements of Section 3:

- **R1 (Stable identity):** each regime fixes a distinct, invariant identity criterion under extension.
- **R2 (Obligation-bearing):** obligations attach only to K1 via K3, preserving role stability.
- **R3 (Normative reference):** K3 grounds authority independently of execution, without causal or evaluative claims.
- **R4 (Time-indexed occurrence):** K4 captures temporal action without persistence ambiguity.
- **R5 (Applicability):** K5 provides first-class scope referents that support nesting and overlap without reclassification.
- **R6 (Descriptive records):** K6 represents indicators as stable referents distinct from occurrences, enabling longitudinal comparison without causal commitment.

All requirements are satisfied without introducing hidden regimes, role-based typing, or interpretive predicates at the substrate level.

5.4 Sufficiency Proposition

Proposition 5.1 (Sufficiency of six regimes)**.** *The six-regime construction defined above satisfies the neutrality, stability, and accountability requirements fixed in Sections 2 and 3.*

Proof. Each requirement is satisfied by a distinct identity-and-persistence regime with explicitly constrained admissible relations. No requirement demands an additional regime, and no regime is redundant under the stated optimization criterion. Because the construction preserves stable reference under incompatible extension and introduces no hidden distinctions, it is sufficient. Non-redundancy follows from the necessity argument: each regime is required by at least one of R2–R6, so omitting any regime would violate a stated requirement. □

5.5 Tightness of the Bound

Together with the necessity result of Section 4, the sufficiency proposition establishes that six identity-and-persistence regimes are both necessary and sufficient for a neutral accountability substrate under the stated assumptions. The bound is therefore tight with respect to the optimization objective of interoperability under persistent disagreement.

6 Interpretation of the Result

This section clarifies how the lower- and upper-bound results should be understood, and how they should not be understood. The aim is not to defend the result against alternative modeling goals, but to situate it relative to the explicit optimization criterion fixed earlier in the paper.

6.1 What the Result Establishes

Taken together, the necessity and sufficiency results establish a conditional optimality claim. Under the assumptions of Section 2, any ontology intended to function as a neutral substrate for accountability under persistent disagreement must realize at least six distinct identity-and-persistence regimes. Conversely, a construction with a minimal set of six such regimes suffices to meet all stated representational requirements without introducing hidden structure or interpretive commitments.

The result is therefore tight. The result does not merely show adequacy or inadequacy under particular conditions; it establishes that six regimes are both necessary and sufficient under the stated optimization objective.

Theorem 6.1 (Tightness of the six-regime bound)**.** *Under the assumptions of Sections 2–3, exactly six identity-and-persistence regimes are necessary and sufficient for a neutral accountability substrate under persistent disagreement.*

Proof. Immediate from Lemma 4.1 and Proposition 5.1. □

6.2 Minimality Relative to Stability

The result should not be read as a claim about simplicity in an intuitive or engineering sense. Ontologies with fewer explicit entity kinds may be easier to describe or extend within a coordinated interpretive community. However, when such reductions are achieved by encoding stability-critical distinctions as roles, flags, or contextual predicates, total structural complexity is not reduced. Instead, it is displaced into extension layers whose interpretation cannot be held fixed under disagreement.

In this paper, minimality is defined relative to stability. *A representation is minimal only if removing explicit structure does not require reintroducing the same distinctions implicitly.* From this perspective, an ontology with fewer explicit kinds but greater interpretive burden is not simpler, but less explicit.

18

6.3 Why Hidden Regimes Are Excluded

Hidden regimes are often effective where interpretation is shared, enforced, or low-cost to renegotiate. They support flexibility and expressive economy within a single governance framework.

The present analysis excludes such regimes not because they are incorrect, but because they are incompatible with the stated objective. When disagreement is persistent and uncoordinated, distinctions that are not fixed at the substrate level cannot be relied upon to preserve identity or admissible relations. Stability then depends on interpretive convergence, which the substrate is explicitly designed not to assume.

6.4 Relation to Other Ontological Strategies

Many upper ontologies and modeling frameworks adopt different optimization objectives, including metaphysical coverage, expressive richness, or alignment with natural language or scientific theory. Such frameworks may introduce additional kinds or tolerate contextual typing precisely in order to support richer modeling.

The result presented here neither subsumes nor contradicts those approaches. It identifies a specific point in the design space: the minimal structure required for a neutral, extension-stable substrate under persistent disagreement. Frameworks optimized for other goals may legitimately occupy different points in that space.

6.5 Conditional Scope of the Claim

The lower-bound result is explicitly conditional. If any assumption of Section 2 is rejected, such as neutrality, stability under incompatible extension, or the exclusion of hidden regimes, the optimization criterion is invalidated and the bound no longer applies. We do not claim that these assumptions

are universally correct; we claim only that the result follows when they are adopted.

Within the stated scope, however, the result is unavoidable. Any attempt to reduce the number of regimes must either sacrifice stability, reintroduce hidden distinctions, or weaken the neutrality constraint. The six-regime structure thus emerges not as a design preference, but as a structural consequence of the problem as posed.

6.6 Implications

The primary implication of this result is diagnostic rather than prescriptive. It provides a principled way to evaluate claims that an ontology supports neutral interoperability under disagreement. If such a framework relies on implicit roles or context-dependent typing for stability-critical distinctions, the present result explains why those claims cannot be sustained simultaneously under the stated constraints.

Conversely, for designers who share the stated optimization objective, the result identifies which distinctions must be made explicit, and which may safely be deferred to extension layers, in order to preserve neutrality and stable reference across incompatible interpretations. The six-regime structure thus serves both as a lower bound and as a design template for accountability substrates in contested domains.

7 Related Work

This paper is situated at the intersection of formal ontology, knowledge representation, and the study of classification under disagreement. Rather than surveying ontology engineering broadly, it situates the present result with respect to prior work on neutrality, identity, and structural stability.

7.1 Classification, Disagreement, and Neutrality

A substantial body of work has shown that classification systems embed institutional, social, and political commitments rather than functioning as neutral descriptive devices Bowker and Star [1999], Haslanger [2012]. In scientific and policy contexts, disagreement is often persistent rather than transient, reflecting incompatible evaluative frameworks rather than resolvable empirical uncertainty Longino [1990].

These observations motivate the need for representations that remain usable without assuming interpretive convergence. The present work adopts this motivation but addresses a distinct question: what minimal structural commitments are unavoidable when disagreement is treated as permanent and interpretive commitments are externalized rather than negotiated?

7.2 Identity, Roles, and Ontological Methodology

Formal ontology has long emphasized the role of identity conditions and persistence criteria in category formation. The OntoClean methodology Guarino and Welty [2002] clarifies why roles are anti-rigid and unsuitable as identity-defining categories Guarino [1998], and subsequent work on social and institutional entities has further developed these distinctions Masolo et al. [2003].

This paper builds on these insights but applies them at the substrate level. The present analysis operates at a different level than role-based modeling, deriving substrate-level identity-and-persistence regimes from neutrality requirements rather than from domain classifications.

7.3 Upper Ontologies

Upper ontologies such as BFO Smith and Ceusters [2015], DOLCE Gangemi et al. [2002], and UFO Guizzardi [2005] provide rich accounts of dependence,

endurants and perdurants, and social objects. They differ substantially in commitments and optimization objectives, and are not designed primarily as neutral substrates for interoperability under persistent disagreement.

The present work does not compare expressivity or advocate alignment with any particular upper ontology. Instead, it derives lower-bound constraints that apply independently of such frameworks, conditional on the neutrality and stability requirements adopted here. Whether the regimes derived here align with, refine, or cross-cut the category structures of existing upper ontologies is an open question beyond the scope of this paper.

7.4   Relation to Common Logic and ontology exchange

The neutral substrate and derived regimes can be expressed in ISO/IEC 24707 Common Logic as a conservative theory, supporting interpreter-independent exchange without reliance on description-logic restrictions or fixed signatures. Here, conservative means that extensions add structure without altering the consequences derivable about substrate-level terms, ensuring that incompatible interpretive frameworks do not retroactively change the meaning of shared references. This enables compatibility with ontology exchange workflows widely used in applied ontology and digital twin contexts.

7.5   Causality, Explanation, and Infrastructure

Separating descriptive structure from causal or explanatory claims is a well-established principle in causal analysis Pearl [2009]. Similarly, research on large-scale information infrastructures emphasizes the importance of long-term stability and interpretive restraint across institutional boundaries Edwards [2011].

These perspectives align with the pre-causal and pre-normative constraints assumed in this paper. The ontology analyzed here is not an explanatory theory, but an infrastructural substrate intended to support explanation,

evaluation, and policy analysis without embedding them.

7.5.1 Relation to FAIR Data Principles

The FAIR principles promote data reuse across communities and over time, but do not specify the ontological constraints required for interoperability under persistent disagreement. In practice, reuse is often pursued through negotiated vocabularies or shared interpretations, which presuppose forms of convergence that may not be available in legal, political, or analytic settings.

The results of this paper clarify a structural precondition for FAIR-aligned reuse in pluralistic or institutionally heterogeneous contexts: stable reference must be supported independently of causal, normative, or evaluative agreement. The identity-and-persistence regimes derived here therefore constrain the ontological substrates upon which FAIR-compliant systems implicitly rely when reuse is expected across incompatible extensions.

8 Conclusion

This paper has addressed a structural question that arises when ontologies are required to function as neutral substrates under persistent disagreement. Under explicit constraints of neutrality, stability under incompatible extension, and the exclusion of hidden or interpretive distinctions, we have shown that a lower bound exists on the ontological structure required to support accountability. Ontologies with fewer than six distinct identity-and-persistence regimes cannot satisfy the stated neutrality and stability requirements; a construction with exactly six regimes suffices without excess structure.

The result is conditional rather than prescriptive. It does not claim that the identified structure is optimal for all applications, nor does it assess the adequacy of alternative modeling strategies for other objectives. It establishes only that, under a particular and explicitly stated optimization objective,

certain distinctions are structurally unavoidable.

This work clarifies the design space for neutral substrates under persistent disagreement. Under the stated constraints, it shows that minimality is fixed by structural requirements rather than by modeling preference. Future work may examine how different optimization objectives yield alternative bounds, or assess how the six-regime structure performs in practical accountability applications.

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Consent to Participate

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Appendix A. Glossary of Terms

This appendix defines key terms used throughout the paper.

Glossary

Accountability Substrate

> A representational layer intended to support attribution, inspection, and comparison of responsibility-related structures without embedding causal, normative, or evaluative commitments. In this paper, accountability is treated structurally rather than interpretively.

Applicability Context

> An enduring referent that delimits where, to whom, or under what conditions an authority-bearing structure applies. Applicability contexts persist independently of specific occurrences and must support nesting and overlap.

Hidden Regime

> An identity- or persistence-relevant distinction that is not represented as an explicit ontological kind, but is instead encoded via roles, flags, contextual predicates, or interpretive conventions supplied by extension layers. Hidden regimes are excluded under the stability optimization adopted here.

Identity-and-Persistence Regime

> A specification of the conditions under which an entity remains the same entity over time and across incompatible extensions, together with the relations it may admit without reclassification. Each regime defines a distinct mode of reference stability.

Interpretive Extension

> Any explanatory, normative, analytic, or evaluative structure added

atop the substrate that supplies meaning, causation, or judgment without altering substrate identity conditions.

Lower-Bound Result

A necessity claim establishing that no representation with fewer than a specified number of identity-and-persistence regimes can satisfy the stated requirements under the adopted optimization criterion.

Neutrality Constraint

The requirement that the substrate itself remain pre-causal and pre-normative, permitting incompatible interpretations without requiring revision of entity identity or structure.

Optimization Criterion

The objective function fixed for this paper: to minimize explicit ontological structure subject to neutrality, stable reference, and the exclusion of hidden identity regimes. Minimality is defined relative to stability, not syntactic brevity.

Persistent Disagreement

A condition in which interpretive, normative, or analytic incompatibilities are expected to endure over time, rather than converge through negotiation, evidence, or governance.

Stable Reference

The property that entities remain referable as the same entities across time and across incompatible extensions, without reclassification or reinterpretation of identity criteria.

Sufficiency Construction

An explicit ontological partition that satisfies all stated requirements using exactly the minimal number of identity-and-persistence regimes established by the lower-bound result.

Tight Bound

A result showing that the same number of regimes is both neces-

sary and sufficient under the stated assumptions and optimization objective.

Time-Indexed Occurrence

An entity whose identity is inseparable from its temporal realization and provenance. Occurrences do not persist beyond their happening and are distinct from enduring entities.

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