Semantic Gauge Theory

Regimes, Redundancy, and Invariant Meaning

Adrian Diamond

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Abstract

Gauge theories are traditionally understood as physical theories with redundant mathematical descriptions. This paper develops a complementary interpretation: gauge structure is fundamentally semantic rather than physical. Redundancy in gauge theory signals not surplus ontology, but the presence of equivalence relations under which meaning stabilizes.

We formalize gauge symmetry as an instance of semantic redundancy, define semantic regimes as gauge equivalence classes, and show that meaningful quantities are precisely those that descend to the gauge quotient. Gauge fixing is treated as an epistemic operation governing access and representation, not as a generator of physical or semantic structure.

By recasting gauge theory in semantic terms, we clarify the status of gauge potentials, resolve long-standing interpretive paradoxes, and establish limits on local observables. The resulting framework aligns gauge theory with Semantic Regime Theory (SRT), Quantum Observation Theory (QOT), and Field Ontology Theory (FOT), positioning gauge symmetry as a paradigmatic example of invariant meaning under admissible transformation. This paper is interpretive and foundational in nature; it introduces no new formal methods, constructions, or executable frameworks.

Contents

1 The Semantic Relativity Principle in Gauge Theories

Gauge theories exhibit a form of relativity that is not spatiotemporal but semantic. Distinct mathematical descriptions correspond to the same physical and semantic situation, differing only by representational redundancy.

1.1 Gauge Redundancy and Meaning

[Gauge Redundancy] Gauge redundancy is the presence of multiple mathematical configurations that represent a single semantic regime.

Gauge redundancy does not indicate ambiguity in reality. It indicates that meaning is invariant under a class of admissible transformations.

Gauge redundancy is not a defect of description. It is the mechanism by which semantic invariance is encoded.

1.2 Physical vs. Semantic Degrees of Freedom

[Semantic Degree of Freedom] A semantic degree of freedom is a feature that varies across physically or semantically distinct regimes.

Gauge-dependent degrees of freedom are not semantic degrees of freedom.

Gauge-dependent quantities vary within a single gauge equivalence class and therefore fail to distinguish semantic regimes. □

1.3 Scope and Non-Claims

This paper does not reinterpret gauge theory dynamically, nor does it propose new physical laws. It reinterprets the *meaning* of gauge structure.

2 Observational Outcomes and Gauge Structure

2.1 The Outcome Space in Gauge Theory

Observational outcomes in gauge theory are constrained by invariance.

[Outcome Space] The outcome space is the set of all observational results accessible under admissible epistemic conditions.

2.2 Gauge Transformations as Admissible Equivalences

[Gauge Transformation] A gauge transformation is an admissible transformation relating configurations within the same semantic regime.

Gauge transformations preserve semantic content.

2.3 Redundancy as Structural, Not Physical

Redundancy resides in description, not in ontology.

3 Semantic Regimes and the Gauge Quotient

3.1 Gauge Equivalence Classes

[Gauge Equivalence] Two configurations are gauge equivalent if they are related by a gauge transformation.

3.2 The Semantic Quotient Space

[Gauge Quotient] The semantic regime space is the quotient of configuration space by gauge equivalence.

3.3 Descent and Gauge-Invariant Meaning

Only gauge-invariant quantities descend to the quotient.

Semantic meaning is defined only on the gauge quotient.

4 Epistemic Regimes and Gauge Fixing

Gauge fixing is an epistemic operation rather than a semantic or physical one.

4.1 Gauge Fixing as Epistemic Choice

[Gauge Fixing] A gauge fixing is a choice of representative within a gauge equivalence class used to facilitate calculation or observation.

Gauge fixing does not select a physical state; it selects a description.

Distinct gauge-fixed configurations may represent the same semantic regime.

4.2 Epistemic Regimes in Gauge Theory

[Epistemic Regime] An epistemic regime is the collection of observational outcomes accessible under a fixed gauge choice and observational context.

Gauge fixing determines epistemic regimes without altering semantic regimes.

4.3 Why Gauge Fixing Does Not Create Meaning

[Epistemic Neutrality of Gauge Fixing] No gauge-fixed quantity possesses observer-independent semantic meaning unless it is gauge invariant.

This explains why gauge potentials are indispensable computational tools while remaining semantically non-fundamental.

4.4 Representation, Access, and Observation

The necessity of gauge fixing for observation does not confer semantic meaning on gauge-dependent quantities.

4.5 Interpretation

Gauge ambiguity is not a defect. Meaning lives in the quotient, not in the representation.

Gauge fixing does not change the field. It changes how we are allowed to see it.

5 Invariants in Gauge Theory

5.1 Field Strength and Curvature

[Field Strength] Given a gauge connection A, the field strength is

$$F = dA + A \wedge A.$$

Gauge-invariant functions of F possess local semantic meaning.

5.2 Wilson Loops and Holonomy

[Wilson Loop] Given a closed loop γ,

$$W(\gamma) = \mathrm{Tr}\,\mathcal{P}\exp\left(\oint_{\gamma} A\right).$$

Wilson loops define global semantic invariants.

5.3 Topological and Global Invariants

[Topological Invariant] A quantity invariant under continuous deformations of the gauge field.

Topological invariants possess observer-independent semantic meaning.

5.4 What Does Not Survive

Gauge potentials do not possess semantic meaning.

Fields are convenient. Curvature is meaningful. Holonomy remembers what fields forget.

In gauge theory, nothing meaningful lives upstairs. Meaning lives in the quotient.

6 Observation Without Gauge Intervention

6.1 Observation as Projection, Not Execution

[Observational Projection] Observation is a projection from epistemic outcomes to gauge-invariant semantic regimes.

Observation does not alter gauge equivalence classes.

6.2 Observation Requires Gauge Fixing but Does Not Justify It

Gauge fixing is required for observation but does not gain semantic status.

6.3 Observables and Gauge-Invariant Access

[Observable] An observable is a gauge-invariant quantity accessible across epistemic regimes.

A quantity is observable if and only if it is gauge invariant.

6.4 Resolution of Measurement Confusion

Gauge-dependent quantities cannot be directly measured.

6.5 Interpretation

Observation never breaks gauge symmetry. It simply refuses to see it.

7 Consequences of Semantic Gauge Theory

7.1 Why Gauge Potentials Are Not Meaningful

Gauge potentials are representational scaffolding, not semantic content.

7.2 Resolution of Gauge Paradoxes

Many interpretive paradoxes dissolve once redundancy is recognized as semantic.

7.3 Limits on Local Observables

Local observability is constrained by global invariance.

8 Relation to Quantum Field Theory and Gravity

8.1 Gauge Structure as a Precursor to QFT

Quantum field theory presupposes semantic gauge structure.

8.2 Comparison with Diffeomorphism Invariance

Diffeomorphism invariance in gravity mirrors gauge redundancy.

8.3 Toward Unified Regime Semantics

Gauge theory, gravity, and quantum observation share a regime-theoretic core.

9 Conclusion

Gauge theory is not merely a theory of forces. It is a theory of meaning under redundancy.

Redundancy is not excess structure. Invariance is not optional. Meaning is what survives admissibility.

A Formal Construction of the Gauge Quotient

The gauge quotient may be understood abstractly as the identification of configurations related by gauge transformation, without commitment to a particular categorical or computational construction.

B Universality and BRST Cohomology

BRST cohomology provides a well-known mathematical language for expressing gauge-invariant structure, and may be viewed as one among several formal perspectives compatible with semantic descent.

C Examples: Abelian and Non-Abelian Gauge Theories

Electromagnetism and Yang–Mills theory illustrate identical semantic structure under differing group action.

D Semantic vs Ontic Redundancy

Ontic redundancy multiplies entities. Semantic redundancy multiplies descriptions.

References

[1] C. N. Yang and R. L. Mills, *Conservation of Isotopic Spin and Isotopic Gauge Invariance*, Physical Review, 96(1):191–195, 1954.

[2] P. A. M. Dirac, *The Principles of Quantum Mechanics*, Oxford University Press, 4th Edition, 1958.

[3] S. Weinberg, *The Quantum Theory of Fields, Vol. I*, Cambridge University Press, 1995.

[4] M. Nakahara, *Geometry, Topology and Physics*, CRC Press, 2nd Edition, 2003.

[5] J. C. Baez and J. P. Muniain, *Gauge Fields, Knots and Gravity*, World Scientific, 1994.

[6] M. Henneaux and C. Teitelboim, *Quantization of Gauge Systems*, Princeton University Press, 1992.

[7] B. Coecke, T. Fritz, and R. W. Spekkens, *A Mathematical Theory of Resources*, Information and Computation, 250:59–86, 2016.

[8] S. Abramsky, *Domain Theory and the Logic of Observation*, Proceedings of the Logic in Computer Science Conference, 1991.

[9] A. Diamond, *Semantic Regime Theory: From Metric Spaces to Action-Invariant State Spaces*, 2026.

[10] A. Diamond, *Quantum Observation Theory: A Non-Executing Semantics for Quantum Program Inspection*, 2026.

[11] A. Diamond, *Field Ontology Theory: A Semantic Ontology for Regime-Stable Structure*, 2026.