Scale-Local Generators of Collapse Geometry and the Emergence of Physical Law

An Operational Realization of Collapse-Selection Dynamics

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April 18, 2026

Abstract

A wide range of physical frameworks describe the persistence of structure under constraint, including quantum dynamics, classical mechanics, thermodynamics, and renormalization group theory. These approaches successfully characterize stable configurations within their respective domains, yet they do so at the level of effective description, leaving the generative origin of that stability unaddressed.

Quantum Collapse Geometry (QCG) proposes that physical structure arises through collapse-selection acting on a relational configuration space, with observable quantities corresponding to configurations that persist under repeated admissibility filtering. In this work, we provide an operational realization of this ontology by introducing a hierarchy of scale-local generators $\{G_\lambda\}$ induced by a global collapse operator Φ under coarse-graining.

Each generator encodes the observable consequences of collapse-selection at a given scale, with invariant and persistent structures corresponding to fixed points, limit cycles, and metastable sectors. We show that these generators satisfy inter-scale consistency conditions analogous to renormalization group flow, and that stable physical laws emerge as fixed points of collapse-induced generator transformations. Distinct physical theories are interpreted as attractor regimes within this hierarchy, while their domains of validity are determined by the stability of the corresponding generator structure.

This formulation establishes a unified framework in which collapse is primitive, effective dynamics are emergent, and observable structure is identified with invariant residues. Rather than replacing existing theories, the approach situates them within a shared generative architecture, clarifying both their domain of applicability and their structural limitations.

1 Introduction

Modern physical theories successfully describe stable structure within well-defined regimes, yet they do so at the level of effective dynamics rather than generative origin. Quantum mechanics provides predictive structure for microscopic systems, classical mechanics captures persistent trajectories at macroscopic scales, and thermodynamics characterizes large-scale invariants under coarse-graining. Despite their success, these frameworks share a common limitation: they describe the behavior of stable configurations without specifying the process by which such stability arises.

Quantum Collapse Geometry (QCG) addresses this gap by introducing collapse-selection as a primitive generative operation acting on a relational configuration space. Within this ontology, physical structure is not assumed but emerges as the subset of configurations that persist under repeated admissibility filtering. Observable quantities correspond to invariant residues of this process, while effective dynamical laws arise as scale-local summaries of stability.

The purpose of the present work is to provide an operational realization of this ontology. While the global collapse operator

$$\Phi : \Sigma \to \Sigma$$

acts on the full relational configuration space, physical observation is necessarily limited to finite resolution. Any empirical description therefore takes place within a coarse-grained state space, where only the observable consequences of collapse-selection remain accessible.

We formalize this by introducing a hierarchy of scale-local generators $\{G_\lambda\}$, each representing the effective dynamics induced by collapse at a given level of description. These generators encode the persistence structure of admissible configurations and provide a direct bridge between the generative ontology of QCG and standard physical formalisms, including open quantum systems, classical dynamics, and renormalization group structure.

Within this framework:

- collapse is treated as primitive,
- generators are understood as effective descriptions, and
- observable structure is identified with invariant or persistent sectors.

The development that follows establishes how collapse-selection induces local generators, how these generators relate across scales, and how stable physical laws emerge as fixed points of collapse-consistent renormalization. In doing so, the paper situates familiar dynamical frameworks within a unified structure in which persistence, rather than evolution alone, defines physical reality.

This formulation provides a practical interpretive framework for:

- diagnosis breakdowns of existing theories,
- identifying invariant structures across scales,
- and constructing effective models based on admissibility constraints rather than assumed primitives.

2 From Collapse Ontology to Observable Dynamics

The ontology developed in *Collapse Geometry as a Minimal Ontology* establishes collapse-selection as the generative basis of physical structure. However, that formulation operates at the level of relational configuration space and does not directly specify how observable dynamics arise within standard physical descriptions.

To connect these levels, we require a translation from generative structure to effective description.

This translation is necessarily indirect. The collapse operator Φ acts globally on the configuration space Σ, but empirical observation occurs only through coarse-grained projections. As a result, collapse cannot be observed directly; instead, it manifests through the stability properties of effective dynamics within a reduced state space.

The central idea of this paper is that this manifestation takes the form of *scale-local generators*.

At each observational scale λ, collapse-selection induces an effective evolution on a projected state space S_λ. This evolution is encoded by a generator G_λ, which captures how admissible configurations persist, decay, or transform within that sector. These generators do not define fundamental dynamics; rather, they summarize the observable consequences of collapse under constraint.

In this sense:

- the ontology defines what can exist (admissibility under Φ),
- the generators describe what persists (invariant structure under G_λ), and
- physical laws emerge as stable structures within this induced hierarchy.

The sections that follow formalize this correspondence, showing how collapse-selection gives rise to local generators, how these generators relate across scales, and how familiar physical frameworks arise as stable attractor regimes within this structure.

2.1 Propagation Cones as Layered Admissibility Generators in Effective Field Theory

Motivation. In higher-derivative effective field theories (EFTs), the propagation of disturbances is not governed by a single causal structure. Instead, the principal symbol of the equations of motion defines a characteristic polynomial whose vanishing determines admissible propagation directions. In general, this polynomial factorizes into components of different orders, giving rise to multiple nested propagation cones corresponding to distinct field polarizations. In such theories, different field polarizations propagate according to distinct effective metrics or higher-order characteristic structures, leading to multiple nested propagation cones rather than a single lightcone [1].

From the perspective of Quantum Collapse Geometry (QCG), this structure admits a natural reinterpretation: rather than representing multiple independent causal geometries, these cones encode a *layered admissibility grammar* acting on a common relational configuration space.

Characteristic structure and admissibility. Let Σ denote the underlying relational configuration space, and consider a local co-direction $\xi_a \in T_x^*M$. In EFT, admissible propagation directions are determined by the condition

$$p(\xi) = 0,$$

where $p(\xi)$ is a polynomial derived from the principal symbol of the field equations. In the class of theories under consideration, this polynomial takes the form

$$p(\xi) = C^{-1}(\xi)\, Q(\xi),$$

where $C^{-1}(\xi)$ is quadratic and $Q(\xi)$ is quartic in ξ.

This factorization and the associated multi-cone propagation structure have been analyzed in detail in recent work on higher-derivative scalar–tensor effective field theories, where distinct polarizations are shown to be governed by nested characteristic cones derived from the principal symbol of the equations of motion [1].

We interpret this condition as a *local admissibility constraint*:

$$\mathcal{A}(\xi) := p(\xi),$$

such that $\mathcal{A}(\xi) = 0$ defines directions along which relational structure may persist under admissible dynamics.

Layered admissibility generators. The factorization of $p(\xi)$ induces a stratified structure:

$$\mathcal{A}(\xi) = \mathcal{A}_2(\xi)\, \mathcal{A}_4(\xi),$$

with

$$\mathcal{A}_2(\xi) = C^{-1}(\xi), \quad \mathcal{A}_4(\xi) = Q(\xi).$$

In QCG terms, these correspond to distinct but related admissibility layers:

- $\mathcal{A}_2$: a lower-order effective admissibility condition, corresponding to a coarse-grained generator structure,
- $\mathcal{A}_4$: a higher-order refinement encoding additional constraint structure and multiple propagation subclasses.

The associated propagation cones therefore define a hierarchy of admissible transport sectors:

$$\Gamma_{\text{outer}} \supset \Gamma_{\text{quadratic}} \supset \Gamma_{\text{inner}},$$

where the inner sheet of the quartic cone corresponds to the fastest admissible propagation mode.

Within the QCG framework, this hierarchy is interpreted as a family of *scale-local generators* $\{G_\lambda^{(i)}\}$ acting within a fixed observational scale λ, each encoding a distinct admissibility channel. These channels are not independent ontologies, but arise from a common collapse-selection process acting on Σ.

Cone sheets as collapse channels. The multiple sheets of the quartic cone correspond to distinct admissible subclasses within a common collapse class. Each sheet defines a subset of co-directions along which relational configurations may propagate without violating admissibility constraints.

This structure is naturally interpreted as a decomposition into *collapse channels*:

- each channel corresponds to a class of admissible transitions under constraint,
- the union of channels defines the full admissible propagation structure,
- their intersections encode regions of structural compatibility.

Thus, the propagation cone is not merely a geometric object, but a representation of the local collapse grammar governing admissible continuation of relational structure.

Degeneracy and invariant structure. A key feature of the characteristic structure is the existence of *singular directions*, where multiple sheets of the cone coincide. In particular, *triple directions* correspond to points where all propagation cones intersect.

At stationary black hole horizons in the EFT setting, it has been shown that:

- all propagation cones coincide,
- the horizon becomes null with respect to the metric,
- the distinct propagation structures degenerate to a single direction.

Remarkably, it has been shown that for stationary black hole solutions, these distinct propagation cones necessarily coincide at the horizon, restoring a single geometric causal structure despite their divergence in the bulk [1].

In QCG terms, this corresponds to:

$$\text{collapse channel convergence} \;\Rightarrow\; \text{invariant sector formation.}$$

That is, the horizon is identified as a *collapse-stable invariant sector* shared across all admissibility channels.

Interpretation: collapse grammar at boundaries. The convergence of propagation cones at the horizon provides a concrete realization of a general QCG principle:

> Distinct admissibility structures may differ within a domain, but must agree on invariant boundary structure.

Away from the horizon, multiple admissibility generators coexist, producing distinct effective propagation behavior. At the horizon, these distinctions are eliminated, and only structure invariant under all admissible dynamics persists.

Thus, the horizon is not merely a geometric null surface, but a *universal invariant boundary* in the space of admissible relational configurations.

Relation to the generator hierarchy. Within the framework of scale-local generators, this structure implies:

- different effective generators $G_\lambda^{(i)}$ may govern dynamics within a region,
- these generators need not coincide globally,
- but their fixed-point structure must agree on invariant sectors.

The black hole horizon provides a physical instance of this principle: despite multiple admissibility channels, the induced generator hierarchy admits a common fixed point.

Summary. The quartic propagation cone structure of higher-derivative EFTs may be interpreted as a layered admissibility grammar acting on relational configuration space. The factorization of the characteristic polynomial encodes multiple collapse channels, while their convergence at horizons demonstrates that invariant structure is independent of the specific admissibility pathway.

This provides a direct physical instantiation of the QCG principle that observable structure corresponds to configurations invariant under collapse-selection across admissible dynamics.

3 Local Sector Generators and the Observable Residue of Collapse

Motivation. Within the collapse-selection framework of Quantum Collapse Geometry (QCG), physical structure is not taken as primitive but as the persistent residue of admissibility under constraint. While the global collapse operator Φ acts on the full relational configuration space Σ, observations are always made at finite resolution. This necessitates a description in terms of *scale-local effective generators*, which encode the observable consequences of collapse-selection within a given sector.

This paper provides a scale-local realization of the ontology introduced in ”Collapse Geometry as a Minimal Ontology” [2].

Global and Sector Structure. Let

$$\Phi : \Sigma \to \Sigma$$

denote the primitive collapse-selection operator acting on relational configurations. For each observational or descriptive scale $\lambda \in \Lambda$, introduce a projection (coarse-graining) map

$$\pi_\lambda : \Sigma \to \mathcal{S}_\lambda,$$

where $\mathcal{S}_\lambda$ is the effective state space at scale λ.

We assume the existence of an effective update map

$$\mathcal{E}_\lambda : \mathcal{S}_\lambda \to \mathcal{S}_\lambda$$

such that, up to approximation,

$$\pi_\lambda \circ \Phi \;\approx\; \mathcal{E}_\lambda \circ \pi_\lambda.$$

When $\mathcal{E}_\lambda$ admits a continuous representation, we define the *local sector generator*

$$\mathcal{G}_\lambda := \frac{d}{dt}\mathcal{E}_\lambda,$$

or more generally as the infinitesimal generator satisfying

$$\frac{d}{dt}x_\lambda = \mathcal{G}_\lambda[x_\lambda], \quad x_\lambda \in \mathcal{S}_\lambda.$$

Thus, the global collapse operator induces a hierarchy

$$\Phi \;\rightsquigarrow\; \{\mathcal{G}_\lambda\}_{\lambda\in\Lambda},$$

in which each $\mathcal{G}_\lambda$ is a scale-local realization of collapse-selection.

Invariant and Persistent Structure. Observable structure at scale λ is identified with the invariant or persistent subsets of $\mathcal{G}_\lambda$. Define the collapse-stable sector

$$\mathcal{I}_\lambda := \{x \in \mathcal{S}_\lambda \mid \mathcal{G}_\lambda[x] = 0\},$$

and more generally the recurrent set $\mathcal{R}_\lambda$ consisting of trajectories that remain within bounded neighborhoods under repeated evolution.

These include:

- fixed points (static persistence),
- limit cycles (periodic persistence),
- metastable manifolds,
- slow-decaying spectral modes.

From this perspective, observable geometry and dynamical law correspond not to primitive structures, but to the stable residue of collapse-selection.

Generator Decomposition. A useful structural decomposition of $\mathcal{G}_\lambda$ is

$$\mathcal{G}_\lambda = \mathcal{H}_\lambda + \mathcal{A}_\lambda + \mathcal{D}_\lambda,$$

where:

- $\mathcal{H}_\lambda$ generates coherent, intrasector evolution,
- $\mathcal{A}_\lambda$ encodes antisymmetric or geometric mixing (e.g. rotational structure in phase space),
- $\mathcal{D}_\lambda$ enforces dissipative contraction and admissibility selection.

This decomposition is not fundamental but emerges as a common structural pattern across effective descriptions.

Example: Open Quantum Systems. For open quantum systems governed by a Lindblad master equation,

$$\dot{\rho} = -i[H, \rho] + \sum_{\mu} \left(L_\mu \rho L_\mu^\dagger - \frac{1}{2}\{L_\mu^\dagger L_\mu, \rho\} \right),$$

the generator $\mathcal{G}_\lambda$ corresponds to the Liouvillian:

$$\mathcal{G}_\lambda \equiv \mathcal{L}.$$

In QCG interpretation:

- H generates intrasector descriptive evolution ($\mathcal{H}_\lambda$),
- L_μ correspond to structured collapse channels ($\mathcal{D}_\lambda$),
- the spectrum of $\mathcal{L}$ encodes the stability structure of admissible configurations.

Steady states correspond to collapse-stable sectors, while slow-decaying modes represent residual admissible structure.

This demonstrates that collapse-selection does not introduce new dynamics, but provides a structural interpretation of existing operator formalisms, identifying stability and admissibility directly within the Liouvillian spectrum.

Example: Gyroscopic Coupling. In a levitated ferromagnet, intrinsic spin S induces a coupling

$$\omega_I = \frac{S}{I},$$

which enters the effective dynamics as an antisymmetric mixing term:

$$\mathcal{A}_\lambda \sim \omega_I \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}.$$

This produces elliptical trajectories in phase space, demonstrating that internal invariants generate observable geometric structure through local sector dynamics.

Example: Topological Structure in Atomic Systems. In vortex-based descriptions of atomic structure, electron configurations are interpreted as stable topological excitations. Atomic shells and orbitals emerge as regions of persistence under topological constraint.

Here, the effective generator takes the form

$$\mathcal{G}_\lambda = \mathcal{T}_\lambda + \mathcal{D}_\lambda,$$

where $\mathcal{T}_\lambda$ encodes topological admissibility (e.g. winding or localization constraints) and $\mathcal{D}_\lambda$ suppresses unstable configurations.

This demonstrates that geometric structure at atomic scales can arise from admissibility constraints rather than from pre-imposed spatial geometry.

Spectral Interpretation. Let $\mathrm{Spec}(\mathcal{G}_\lambda) = \{\gamma_j\}$ denote the spectrum of the generator. Then:

- $\Re(\gamma_j) < 0$ corresponds to decaying (inadmissible) modes,
- $\Re(\gamma_j) = 0$ corresponds to persistent (admissible) structure,
- $\Im(\gamma_j) \neq 0$ encodes oscillatory or rotational dynamics.

Near-zero spectral structure defines the effective persistence manifold:

$$\mathcal{A}_\lambda^{(0)} := \mathrm{span}\{v_j \mid |\Re(\gamma_j)| < \varepsilon\}.$$

This spectral viewpoint unifies fixed points, limit cycles, and metastable structures within a single admissibility framework.

Hierarchy Statement. We summarize the structure as

$$\Phi \;\triangleright\; \mathcal{G}_\lambda \;\triangleright\; \mathcal{I}_\lambda,$$

where:

- Φ is the global collapse-selection operator,
- $\mathcal{G}_\lambda$ is the induced local generator at scale λ,
- $\mathcal{I}_\lambda$ is the invariant (collapse-stable) sector.

Observable physical structure corresponds to $\mathcal{I}_\lambda$, while $\mathcal{G}_\lambda$ provides its descriptive evolution.

Interpretation. From this perspective, geometry, dynamics, and physical law are not fundamental entities, but emergent features of collapse-selection acting through scale-local generators. Each level of description captures a projection of the same underlying generative process, expressed through different admissibility constraints.

This establishes a unified framework in which:

- collapse is primitive,
- generators are effective,
- observables are invariant residues.

4 Inter-Scale Consistency and Renormalized Collapse Generators

Motivation. In the preceding section, we established that observable structure at a given scale λ arises from a local sector generator $\mathcal{G}_\lambda$ induced by the global collapse-selection operator Φ. However, physical theories do not exist in isolation at a single scale. Empirically, structure exhibits coherence across scales, suggesting that the family $\{\mathcal{G}_\lambda\}_{\lambda\in\Lambda}$ is not arbitrary but constrained by a deeper consistency condition.

This section formalizes that constraint.

Scale Hierarchy and Coarse-Graining. Let Λ be a partially ordered set of scales, where $\mu > \lambda$ denotes a coarser description. For each pair (λ, μ), define a coarse-graining map

$$C_{\lambda\to\mu} : \mathcal{S}_\lambda \to \mathcal{S}_\mu.$$

This map represents the loss of resolution, integration of degrees of freedom, or projection onto a reduced descriptive space.

Inter-Scale Consistency Condition. We require that effective evolution be approximately compatible with coarse-graining:

$$C_{\lambda\to\mu} \circ \mathcal{E}_\lambda \;\approx\; \mathcal{E}_\mu \circ C_{\lambda\to\mu}.$$

When generators exist, this implies the infinitesimal condition

$$DC_{\lambda\to\mu}\,\mathcal{G}_\lambda \;\approx\; \mathcal{G}_\mu\,C_{\lambda\to\mu}.$$

This relation expresses that coarse-graining commutes with effective evolution up to approximation. It serves as the collapse-selection analogue of renormalization group consistency.

Renormalized Generators. Define the renormalization map

$$\mathcal{R}_{\lambda\to\mu} : \mathcal{G}_\lambda \mapsto \mathcal{G}_\mu,$$

such that

$$\mathcal{G}_\mu = \mathcal{R}_{\lambda\to\mu}(\mathcal{G}_\lambda).$$

This map eliminates scale-dependent structure while preserving admissibility constraints relevant at the coarser level. In this sense, $\mathcal{R}_{\lambda\to\mu}$ acts as a collapse-consistent coarse-graining of generators.

Persistence and Multi-Scale Invariants. Let $\mathcal{I}_\lambda$ and $\mathcal{I}_\mu$ denote the invariant sectors at scales λ and μ, respectively. Inter-scale consistency implies that these sectors are related by

$$C_{\lambda\to\mu}(\mathcal{I}_\lambda) \subseteq \mathcal{I}_\mu.$$

We define a *multi-scale collapse invariant* as a structural quantity I such that

$$I(\mathcal{G}_\lambda) \sim I(\mathcal{G}_\mu)$$

under renormalization.

Examples include:

- fixed-point structure,
- topological invariants,
- spectral degeneracy classes,
- admissibility dimension.

These invariants express the persistence of admissibility structure across scales.

Spectral Flow. Let $\mathrm{Spec}(\mathcal{G}_\lambda) = \{\gamma_j^{(\lambda)}\}$ denote the spectrum of the generator at scale λ. Under renormalization,

$$\gamma_j^{(\lambda)} \;\mapsto\; \gamma_j^{(\mu)}.$$

Typical behavior includes:

- rapid decay modes ($\Re\gamma_j \ll 0$) vanish under coarse-graining,
- near-zero modes persist and define effective structure,
- spectral clustering near zero corresponds to emergent stability or criticality.

Thus, the low-lying spectrum encodes the persistence manifold across scales.

Examples.

- **Renormalization Group:** irrelevant operators flow to zero, while relevant structure persists as fixed points.
- **Open Quantum Systems:** Liouvillian spectra retain slow modes corresponding to metastable or steady-state structure.
- **Gyroscopic Systems:** intrinsic coupling terms persist under coarse-graining as effective geometric constraints.
- **Topological Systems:** winding and localization constraints remain invariant under scale transformation.

Multi-Scale Collapse Generator Principle. Let $\Phi : \Sigma \to \Sigma$ be a collapse-selection operator inducing a family of local generators $\{\mathcal{G}_\lambda\}$. Suppose there exist coarse-graining maps $C_{\lambda\to\mu}$ satisfying the inter-scale consistency condition.

Then:

1. each $\mathcal{G}_\lambda$ is a scale-local realization of collapse-selection,
2. generators transform under renormalization maps $\mathcal{R}_{\lambda\to\mu}$,
3. observable structure corresponds to invariant or persistent sectors,
4. shared invariants across scales reflect common admissibility structure induced by Φ.

Interpretation. This result implies that physical laws are not fundamental prescriptions imposed independently at each scale, but stable fixed points of collapse-selection under renormalization.

Geometry, dynamics, and stability emerge as consistent projections of admissibility structure across resolution levels. Unification, therefore, arises not from reducing all theories to a single equation, but from identifying the shared collapse structure that remains invariant under scale transformation.

5 Collapse Fixed Points and the Emergence of Physical Law

Motivation. Having established that collapse-selection induces a hierarchy of scale-local generators $\{\mathcal{G}_\lambda\}$ and that these generators transform under renormalization maps $\mathcal{R}_{\lambda\to\mu}$, we now address a central question:

> Why do stable, law-like regularities emerge across physical systems?

Within the QCG framework, this question reduces to the existence and stability of fixed points under collapse-induced renormalization.

Collapse Fixed Points. We distinguish two related notions of fixed point:

(1) Generator-Level Fixed Point. A generator $\mathcal{G}^*$ is a collapse fixed point if

$$\mathcal{R}(\mathcal{G}^*) = \mathcal{G}^*,$$

i.e., it is invariant under coarse-graining.

(2) State-Level Fixed Point. A state $x^* \in \mathcal{S}_\lambda$ is a fixed point of the generator if

$$\mathcal{G}_\lambda[x^*] = 0.$$

Generator-level fixed points define stable dynamical laws, while state-level fixed points define stable configurations within those laws.

Physical Law as Collapse Fixed Point. We propose the following identification:

> A physical law corresponds to a generator $\mathcal{G}^*$ that is invariant under collapse-induced renormalization.

Such generators are not imposed a priori but emerge as stable attractors in the space of admissible dynamics.

Stability and Universality. Let $\mathcal{G} = \mathcal{G}^* + \delta\mathcal{G}$ be a perturbed generator. We say that $\mathcal{G}^*$ is stable if

$$\mathcal{R}^n(\mathcal{G}) \to \mathcal{G}^* \quad \text{as} \quad n \to \infty.$$

This defines a basin of attraction in generator space. Generators within this basin flow toward $\mathcal{G}^*$ under renormalization, leading to universal behavior independent of microscopic detail.

Classes of Collapse Fixed Points. Different physical regimes correspond to different types of fixed points:

- **Static fixed points:** equilibrium states in thermodynamics.
- **Dynamical fixed points:** limit cycles and steady oscillations.
- **Geometric fixed points:** classical trajectories and geodesics.
- **Topological fixed points:** invariant winding and defect structures.

These are unified as persistent structures under collapse-selection.

Spectral Characterization. Let $\mathrm{Spec}(\mathcal{G}_\lambda) = \{\gamma_j\}$ denote the spectrum of a generator. Fixed-point structure is encoded in the spectral properties:

- $\Re(\gamma_j) = 0$ identifies persistent modes,
- $\Re(\gamma_j) < 0$ corresponds to suppressed (inadmissible) structure,
- spectral clustering near zero indicates emergent stability or criticality.

The near-zero spectral subspace defines the effective law at that scale.

Examples.

- **Classical Mechanics:** trajectories arise as stable fixed points under collapse-ordered dynamics.
- **Thermodynamics:** equilibrium states correspond to attractors in admissible configuration space.
- **Quantum Systems:** environment-induced pointer states emerge as collapse-stable sectors.
- **Topological Systems:** defect and vortex structures persist as invariant classes under constraint.

Collapse Fixed Point Principle. Let Φ be a collapse-selection operator inducing a renormalized generator flow $\mathcal{R}$. Then:

> Stable physical laws correspond to fixed points of $\mathcal{R}$, while observable structures correspond to invariant or recurrent states under the associated generators.

Interpretation. From this perspective, physical law is not a primitive input but an emergent property of collapse-selection. Laws arise as those dynamical structures that remain invariant under scale transformation and admissibility filtering.

Universality follows naturally: systems with different microscopic descriptions flow toward the same collapse-stable generators, yielding identical macroscopic laws.

Thus, the emergence of physical law can be understood as the convergence of collapse dynamics toward stable fixed points in generator space.

6 Collapse Attractors and the Hierarchy of Physical Theories

Motivation. In the previous section, we established that physical laws correspond to fixed points of collapse-induced renormalization. We now extend this idea to entire theoretical frameworks.

> A physical theory is not a primitive description of reality, but a stable attractor regime in the space of collapse-generated dynamics.

Collapse Attractors. Let $\mathcal{R}$ denote the renormalization map acting on generators. A collapse attractor is defined as a basin of generators

$$\mathcal{A} := \{\mathcal{G} \mid \mathcal{R}^n(\mathcal{G}) \to \mathcal{G}^*\},$$

where $\mathcal{G}^*$ is a stable fixed point.

All generators within $\mathcal{A}$ flow toward the same effective description under coarse-graining, giving rise to a shared theoretical structure.

Hierarchy of Attractor Regimes. Different physical theories correspond to distinct collapse attractors:

Quantum Regime. At fine resolution, collapse-selection is weakly constraining. The admissible configuration space remains large, allowing superposition and interference. Effective generators retain high-dimensional structure and unitary evolution dominates.

Classical Regime. At intermediate scales, collapse-selection suppresses unstable superpositions. Only persistent trajectories remain admissible, yielding phase-space structure and deterministic evolution as an effective description.

Thermodynamic Regime. At coarse scales, collapse-selection eliminates nearly all microscopic detail. Only aggregate invariants persist, leading to equilibrium states, entropy maximization, and macroscopic laws.

These regimes are not independent theories, but distinct attractor basins of the same underlying collapse dynamics.

Transitions Between Regimes. Transitions between theories correspond to movement between attractor basins. This occurs when:

- the strength of collapse-selection changes,
- admissibility constraints shift,
- observational scale crosses a critical threshold.

Thus, the quantum-to-classical transition is not a replacement of one theory by another, but a flow between collapse attractors.

Breakdown of Theories. A theory fails when it is applied outside its attractor basin. Formally, if $\mathcal{G}_{\text{theory}}$ represents the generator structure of a theory, then breakdown occurs when

$$\mathcal{G}_{\text{theory}} \notin \mathcal{A}_{\text{actual}}.$$

In this case, the theory no longer captures the admissible structure of the system.

Emergent–Primitive Misassignment. We now connect this structure to the principle of emergent–primitive misassignment.

> A theory that elevates an emergent attractor-level structure to a primitive assumption loses access to the generative layer that produces it.

Examples include:

- treating geometry as fundamental rather than emergent,
- treating quantum states as primitive rather than collapse-selected,
- treating thermodynamic equilibrium as a generative principle.

Such misassignments lead to predictable limitations when the theory is extended beyond its domain of validity.

Collapse Attractor Principle. Let Φ be a collapse-selection operator inducing a renormalized generator flow. Then:

> Physical theories correspond to attractor basins in the space of collapse-induced generators, and their domains of validity are determined by the stability of those basins.

Interpretation. From this perspective, physics is not a collection of independent theories, but a hierarchy of collapse attractors.

Each theory is:

- valid within its basin of attraction,
- emergent from deeper collapse dynamics,
- limited by the scale at which its generator structure remains stable.

Unification is therefore achieved not by reducing all theories to a single equation, but by identifying the collapse structure that generates all attractor regimes.

Thus, quantum mechanics, classical mechanics, and thermodynamics are not competing descriptions of reality, but successive layers in a hierarchy of collapse-selected structure.

7 Epistemic Horizons and the Limits of Cross-Attractor Description

Motivation. The preceding sections established that physical theories correspond to collapse attractor regimes, each defined by a stable generator structure under renormalization. A natural question follows:

> Why can no single theoretical framework fully describe all regimes simultaneously?

Within the QCG framework, this limitation is not contingent, but structural. It arises from the existence of *epistemic horizons* separating distinct collapse attractors.

Definition: Epistemic Horizon. Let $\mathcal{A}_\lambda$ and $\mathcal{A}_\mu$ be distinct collapse attractors associated with different scales or regimes. An epistemic horizon between them is defined as a boundary beyond which no mapping

$$F : \mathcal{S}_\lambda \to \mathcal{S}_\mu$$

can preserve the full admissibility structure induced by Φ.

Equivalently, an epistemic horizon exists when

$$F \circ \mathcal{G}_\lambda \not\approx \mathcal{G}_\mu \circ F,$$

for all admissible mappings F within the descriptive framework of $\mathcal{A}_\lambda$.

Interpretation. An epistemic horizon does not imply that one regime is more fundamental than another in a descriptive sense. Rather, it reflects the fact that:

- each attractor encodes only the admissible structure visible at its scale,
- information eliminated by collapse-selection cannot be reconstructed from within that regime,
- descriptive closure at one level precludes access to the generative structure beneath it.

Thus, epistemic horizons are a direct consequence of collapse-induced information loss.

Cross-Attractor Failure. Consider a theory defined by generator $\mathcal{G}_\lambda$ within attractor $\mathcal{A}_\lambda$. Attempting to extend this theory into another regime $\mathcal{A}_\mu$ requires constructing a mapping F such that:

$$F(\mathcal{I}_\lambda) \approx \mathcal{I}_\mu.$$

However, this generally fails for one of two reasons:

- **Underdetermination:** the coarse-grained structure lacks sufficient information to reconstruct finer admissibility constraints,
- **Overconstraint:** the fine-scale structure includes degrees of freedom that are inadmissible or irrelevant in the coarser regime.

In both cases, the mapping breaks down, and the theory ceases to apply.

Examples.

- **Quantum to Classical:** classical phase-space descriptions cannot reconstruct quantum coherence or superposition.
- **Classical to Thermodynamic:** microscopic trajectory information is irretrievably lost under coarse-graining to equilibrium states.
- **Quantum to Collapse Substrate:** standard quantum mechanics cannot describe the generative collapse layer that defines admissibility itself.

Each case reflects an epistemic horizon separating attractor regimes.

Epistemic Horizon Principle. Let Φ be a collapse-selection operator inducing a hierarchy of attractors. Then:

> For any attractor $\mathcal{A}_\lambda$, there exists a lower-level regime whose admissibility structure cannot be fully reconstructed within $\mathcal{A}_\lambda$.

This implies that no attractor-level theory is self-complete.

Relation to Emergent–Primitive Misassignment. The principle of emergent–primitive misassignment can now be restated:

> A theory fails when it treats the structure of its attractor as primitive, thereby ignoring the epistemic horizon that separates it from the generative layer.

Such misassignment leads to predictable breakdowns:

- geometry-first theories fail at pre-geometric regimes,
- quantum-first theories fail at collapse-generation,
- thermodynamic descriptions fail at microscopic reconstruction.

The failure is not empirical but structural: it arises from attempting to invert a non-invertible collapse mapping.

Epistemic Non-Closure. Let $\mathcal{S}_\lambda$ be a state space at scale λ. We define epistemic non-closure as the condition that there does not exist a mapping

$$\Psi_\lambda : \mathcal{S}_\lambda \to \Sigma$$

such that

$$\pi_\lambda \circ \Psi_\lambda = \mathrm{id}_{\mathcal{S}_\lambda}.$$

That is, no theory at scale λ can reconstruct the full relational configuration space Σ from its own variables.

Connection to Collapse Hierarchy. Epistemic horizons partition the collapse hierarchy into layers:

$$\Phi \;\triangleright\; \{\mathcal{G}_\lambda\} \;\triangleright\; \{\mathcal{A}_\lambda\},$$

where each layer is:

- internally consistent,
- externally incomplete,
- separated from deeper layers by non-invertible mappings.

This structure defines a hierarchy of descriptive regimes, each bounded by its own epistemic horizon.

Interpretation. From this perspective, the limits of physical theory are not due to experimental difficulty or incomplete knowledge, but arise from the structure of collapse itself.

The inability of a theory to describe regimes beyond its domain is not a failure, but a reflection of its position within the hierarchy of collapse attractors.

Thus, epistemic horizons formalize the limits of cross-attractor description, and establish that no single theoretical framework can fully capture the generative structure of reality.

8 Collapse as the Generative Boundary of Physics

Motivation. The preceding development has established a hierarchy of structure:

- local sector generators $\mathcal{G}_\lambda$ describing dynamics,
- renormalization maps $\mathcal{R}_{\lambda\to\mu}$ relating scales,
- fixed points defining physical laws,
- attractor basins corresponding to theoretical frameworks,
- epistemic horizons limiting cross-regime description.

We now address the final question:

> What defines the boundary beyond which physical description cannot proceed?

Within QCG, this boundary is identified with collapse itself.

The Generative Boundary. Let Σ denote the relational configuration space and

$$\Phi : \Sigma \to \Sigma$$

the collapse-selection operator.

All observable structure arises through the action of Φ, yet Φ itself is not representable within any induced sector $\mathcal{S}_\lambda$.

Definition. The *generative boundary of physics* is the domain of collapse-selection Φ that cannot be expressed as an effective generator $\mathcal{G}_\lambda$ within any attractor regime.

Non-Representability of Collapse. For any scale λ, the induced generator $\mathcal{G}_\lambda$ satisfies

$$\pi_\lambda \circ \Phi \;\approx\; \mathcal{E}_\lambda \circ \pi_\lambda,$$

but there exists no mapping

$$\Xi_\lambda : \mathcal{S}_\lambda \to \mathrm{End}(\Sigma)$$

such that

$$\Xi_\lambda(\mathcal{G}_\lambda) = \Phi.$$

That is, collapse-selection cannot be reconstructed from within any effective theory.

Irreducibility of the Boundary. This establishes a fundamental asymmetry:

- Φ generates $\mathcal{G}_\lambda$,
- but $\mathcal{G}_\lambda$ cannot reconstruct Φ.

Thus, the generative boundary is intrinsically non-invertible.

Relation to Epistemic Horizons. The generative boundary is the limiting case of epistemic horizons. While horizons separate attractor regimes, the collapse boundary separates all descriptive layers from their generative origin.

Hierarchy Structure:

$$\Phi \triangleright \{\mathcal{G}_\lambda\} \triangleright \{\mathcal{A}_\lambda\}$$

with:

- Φ as the generative layer,
- $\mathcal{G}_\lambda$ as descriptive generators,
- $\mathcal{A}_\lambda$ as attractor regimes.

No inverse mapping exists from $\{\mathcal{G}_\lambda\}$ to Φ.

Interpretation: Collapse as Boundary Condition. Collapse is not a dynamical process within physics, but the condition that makes physics possible.

- It defines admissibility,
- it determines persistence,
- it selects observable structure.

All dynamical laws arise as stable summaries of its action.

The Collapse Boundary Principle. Let Φ be the collapse-selection operator generating all admissible structure. Then:

> Physical theories describe only the invariant residue of collapse-selection, while collapse itself defines the boundary beyond which no physical description can extend.

Relation to Existing Limits. This boundary subsumes multiple known limitations:

- **Quantum Measurement Problem:** collapse cannot be derived from unitary evolution.
- **Decoherence Limit:** environment-induced selection explains stability but not the origin of admissibility.
- **Thermodynamic Irreversibility:** coarse-graining eliminates information irrecoverably.
- **Computational Limits:** non-invertibility prevents full reconstruction of prior states.

These are not independent problems, but manifestations of the same generative boundary.

Planck Horizon Interpretation. At the smallest scales, the generative boundary corresponds to the limit at which quantum description itself ceases to be valid. This suggests an interpretation of the Planck regime:

> The Planck scale is not merely a limit of measurement, but a boundary of admissibility beyond which collapse-selection cannot be represented within quantum formalism.

Implications for Unification. Attempts at unification that seek to derive all structure from a single descriptive framework fail because they attempt to eliminate the generative boundary.

True unification instead requires:

- recognizing collapse as primitive,
- identifying invariant structure across attractors,
- preserving the distinction between generative and descriptive layers.

Final Interpretation. From this perspective, physics is a theory of what remains after collapse.

- Laws describe stable structure,
- theories describe attractor regimes,
- observables describe invariant residues,
- collapse defines the boundary of all of them.

Conclusion. Collapse is not a feature within physical theory. It is the generative boundary that defines the domain of physics itself.

9 Summary: Collapse Geometry as a Minimal Ontology

Overview. This work has proposed Quantum Collapse Geometry (QCG) as a minimal ontological framework in which physical structure arises not from pre-existing geometric or dynamical primitives, but from selection under constraint.

Rather than beginning with spacetime, fields, or evolution laws, QCG takes as primitive a single generative operation:

$$\Phi : \Sigma \to \Sigma,$$

interpreted as collapse-selection acting on a relational configuration space Σ.

Core Claim. The central thesis of QCG can be stated concisely:

> Observable physical structure consists of configurations that persist under repeated collapse-selection.

Everything else—geometry, dynamics, and law—arises as an effective description of this persistence.

Generative and Descriptive Layers. A key distinction throughout this work has been between:

- **Generative structure:** the collapse-selection process Φ that defines admissibility,
- **Descriptive structure:** effective generators $\mathcal{G}_\lambda$ that summarize stable behavior within a given regime.

This distinction resolves long-standing ambiguities in physical theory, in which descriptive constructs are often implicitly treated as primitive.

Emergence of Physical Law. Within this framework, physical laws are not fundamental prescriptions, but stable fixed points of collapse-induced renormalization. That is:

> A physical law corresponds to a generator that remains invariant under coarse-graining.

Different laws correspond to different fixed-point structures in the space of admissible dynamics.

Hierarchy of Theories. Entire theoretical frameworks emerge as attractor regimes:

- Quantum mechanics describes weakly constrained regimes with large admissibility spaces,
- Classical mechanics describes regimes in which only stable trajectories persist,
- Thermodynamics describes extreme coarse-grained regimes in which only aggregate invariants remain.

These are not competing descriptions, but successive layers in a hierarchy of collapse-selected structure.

Epistemic Limits. The framework naturally yields limits on physical description. Each attractor regime is bounded by an epistemic horizon:

- information eliminated by collapse cannot be reconstructed,
- no theory can fully describe the generative layer beneath it,
- cross-regime descriptions fail when applied outside their basin of validity.

Thus, incompleteness is not a deficiency of specific theories, but a structural feature of collapse.

Emergent–Primitive Misassignment. A recurring source of conceptual difficulty is the elevation of emergent structure to primitive status. QCG formalizes this as:

> A theory fails when it treats its attractor-level description as fundamental, ignoring the generative layer that produces it.

This principle explains why geometry-first, quantum-first, and thermodynamic-first ontologies each encounter predictable limitations.

The Generative Boundary. All descriptive frameworks terminate at a common boundary: collapse itself.

> Physics describes the invariant residue of collapse-selection, while collapse defines the boundary beyond which no physical description can extend.

This boundary is not empirical but structural, arising from the non-invertibility of collapse.

Unification. From this perspective, unification is not achieved by reducing all phenomena to a single equation, but by identifying the shared collapse structure that generates all attractor regimes.

- Laws are fixed points,
- theories are attractors,
- observables are invariants,
- collapse is the generative origin of all of them.

Minimal Ontology. QCG therefore proposes a minimal ontological basis for physics:

1. A relational configuration space Σ,
2. A collapse-selection operator Φ,
3. Persistence under Φ as the criterion of reality.

No additional primitive structure is required.

This suggests that future theoretical development should focus not on constructing new fundamental equations, but on identifying invariant structures and admissibility constraints across domains.

Final Statement. The framework developed here may be summarized in a single line:

> Reality is the set of configurations that remain invariant under collapse.

All physical description follows from this principle.

Collapse Geometry does not replace existing theories. It explains why they exist, why they work, and why they fail.

References

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