Resolution-Shifted Identity and the Mechanics of Persistent Formation

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Abstract

This paper introduces a functional boundary criterion for persistent organization across scales: a system counts as bounded when its internal dynamics are more strongly coupled to one another than to the surroundings, exchange is constrained rather than unconstrained, and the resulting unit persists across the relevant dynamical timescale. Central to the framework is the claim that boundary appearance is observer-relative even when boundary function is not: systems far below mesoscopic scale can appear sharply localized because their internal dynamics are temporally unresolved at mesoscopic observation scales, while systems far above it can appear diffuse or effectively frozen because their organizing dynamics unfold too slowly to register as immediate closure. This resolution-dependent appearance is interpreted through the broader concept of resolution-shifted identity. A cross-scale comparison uses a dimensionless participation ratio, $\beta^* = L/(c\tau)$, which yields a compressed band of causality-normalized participation across hydrogenic, satellite, planetary, ring, and galactic examples. Stable formation is read as gradient-driven settlement under constraint, where dissipation enables effectively irreversible capture and coarse-graining re-expresses retained organization as next-scale effective constraint. By distinguishing persistence maintained by ongoing dissipative throughput from persistence secured by prior dissipation, binding structure, or kinetic arrest, the paper advances a cross-scale framework for persistent formation that identifies a recurring structural relation by which dissipation-enabled capture and retained architecture produce higher-order separable identity.

Keywords: resolution-shifted identity; functional boundary; dissipative structures; coarse-graining; observer-relative description; persistent formation

1. Introduction: Gradient-Driven Settlement

A central problem across the physical sciences is explaining how stable, persistent structure arises within systems governed by thermodynamic dispersal. The present framework adopts the position that persistent formation does not oppose thermodynamic dispersal, nor does it require additional organizing principles beyond established physics. Instead, stable structure arises directly from gradient-driven dynamics under constraint, provided that dissipation enables irreversible settlement into bounded configurations. In purely conservative systems, trajectories explore phase space without generically converging; interacting elements do not reliably settle into stable configurations. Persistent formation therefore requires a transition from reversible motion to an invariant, self-sustaining configuration.

Each settlement event may then be treated in two ways: physically, as a dissipative capture event; and descriptively, as the formation of a stable unit that can later be reinterpreted under coarse-graining. The central identity claim is accordingly resolution-dependent: sufficient coherent integration at scale n yields separable identity at scale n+1. The claim is not that local mechanisms are identical across scales, but that a recurring structural relation governs how dissipation-enabled capture creates units that coarse-graining can subsequently reinterpret as new degrees of freedom.

This manuscript proposes a cross-scale framework for persistent formation, not a claim that every scale transition is governed by one identical local formalism. Its claim is that persistent formation across domains can be read through a recurring structural logic, even where the local governing equations differ.

Cross-scale comparison should therefore be made with care. One should not mix raw speeds, internal rotations, and large-scale orbital motion as though they were interchangeable observables. The appropriate comparison is the characteristic recurrence or coupling timescale through which constituents at scale n participate in the organized domain of scale n+1. At different scales this may take orbital, vibrational, relaxation, or other bound-dynamical forms, but the mathematical role is the same: it measures the rate at which the lower-scale unit functions as a constituent of the higher-scale whole.

2. Boundary, Functional Separability, and Scale-Dependent Description

A persistent structure at any scale requires a boundary, but a boundary need not be a material shell. In the present framework, a system possesses a boundary when three conditions are jointly satisfied: its internal dynamics are more strongly coupled to one another than to the surrounding environment; its exchange with the outside is constrained rather than unconstrained; and it persists as a distinguishable domain across the relevant dynamical timescale. Functional separability is therefore not a visual property but a dynamical one.

Boundary appearance is observer-relative even when boundary function is not. Systems far below mesoscopic scale may appear sharply localized because their internal dynamics are unresolved in both space and time; systems far above it may appear diffuse because their organizing dynamics are unresolved in the opposite direction, unfolding too slowly to present as immediate closure within human observation. The relevant timescale is not unique in the abstract; it is the timescale associated with the mode of organization under analysis. A solar system considered as an internally organized planetary system is characterized by orbital-stability and heliophysical timescales, whereas the same solar system considered as a participant in galactic dynamics is characterized by galactic orbital and environmental timescales.

Across scales, then, the difference is not boundary versus no boundary, but rather localized versus distributed modes of boundary realization. Atomic and molecular systems present effective interaction frontiers that can look wall-like because their internal structure is unresolved at mesoscopic resolution. Planetary, stellar, and galactic systems more often present as distributed dynamical domains, defined by recurrent motion, constrained exchange, or long-lived gravitational capture. In both cases, what matters is the same functional criterion: a persistent inside-outside difference maintained under selective exchange.

The boundary criterion should also not be confused with a requirement of perfect closure. A boundary that forbids all crossing would amount to strict isolation; a boundary that constrains nothing encloses no unit at all. The cross-scale common denominator is therefore not absolute exclusion but constrained permeability: a system must be separate enough to count as a unit, and open enough to participate in higher-order formation. Constrained permeability is the operational expression of the three-condition boundary criterion: the inside-outside coupling asymmetry and selective exchange that jointly define a functional boundary.

2.1 Timescale Separation, Observer Resolution, and Boundary Appearance

The observer-relative appearance of boundaries follows from timescale separation relative to the observer's temporal resolution. In this framework, a system will often appear as a compact separable identity when its internal dynamics are unresolved within the observer's temporal window. For a mesoscopic observer, subatomic recurrence occurs at such high frequencies ($\sim 10^{-16}$ s) that the resulting unit appears effectively instantaneous and solid. Conversely, galactic recurrence ($\sim 10^{15}$ s) lies so far outside human temporal resolution that the system appears effectively frozen or diffuse. This effect is a structural consequence of the mismatch between the observer's characteristic temporal window and the recurrence timescale τ associated with the level of organization under analysis.

3. The Dynamical Lens: Conditions of Capture

The boundary criterion describes what persistent organization looks like once established. The conditions under which it comes to be established are those identified in the theory of dissipative structures developed by Prigogine and collaborators (Nicolis and Prigogine, 1977; Prigogine, 1980).

In that framework, an open system maintained far from thermodynamic equilibrium is subject to thermodynamic forces—generalized gradients such as chemical affinity, temperature difference, or concentration imbalance—that drive irreversible flows. The relationship between forces and flows is governed by kinetic constraints, which determine what pathways remain dynamically accessible. Near equilibrium, Onsager's reciprocal relations apply and the system relaxes toward a unique stationary state. Far from equilibrium, in the nonlinear regime, this uniqueness is lost: the system may reach a bifurcation point at which the previously stable homogeneous state becomes unstable and a new organized regime becomes accessible. Dissipation is not the enemy of this transition; it is its enabling condition. Entropy production, $\sigma = \Sigma J_i \cdot X_i \geq 0$, accompanies the irreversible flows that drive the system toward, and ultimately stabilize it within, the new organized state. The result is a dissipative structure: a spatiotemporally organized configuration maintained by ongoing exchange with its environment, and distinguished from its surroundings by an inside-outside difference sustained under selective exchange.

The present framework adopts this account of capture and extends its interpretive scope. What Prigogine's analysis establishes for maintained nonequilibrium systems, the coarse-graining interpretation extends to the broader class of persistent formations, including those stabilized by prior dissipation rather than ongoing throughput. In both cases the logical structure is the same: thermodynamic forcing drives dynamics along kinetically accessible pathways; dissipation renders the transition effectively irreversible; and the resulting organized state constitutes a functional boundary in the sense defined in Section 2. The formal convergence to an invariant set under dissipative dynamics is supported by LaSalle-type arguments (LaSalle, 1960), which justify the approach to an attractor basin from which no further accessible downhill direction remains.

Functional separability is therefore not an additional requirement imposed on the system. It is the macroscopic signature that the conditions of capture identified by nonequilibrium thermodynamics have produced a unit capable of acting as a distinct identity at the next scale of description.

What passes upward from any settlement includes, but is not limited to, the retained architecture of the event. The durability-conferring portion of prior-scale dynamics is coarse-grained into the effective potential, constraint terrain, and admissible configurations of the next scale, while other portions are exported as remainder. The accessibility terrain at any given scale can therefore be interpreted as the accumulated record of prior settlements: prior-scale dynamics in durable form.

4. The Thermodynamic Lens: Two Ledgers and Modes of Persistence

The emergence of stable structure is the localized product of the same energetic redistribution that the second law governs globally. The process can be read through two simultaneous ledgers: an Entropy Ledger that tracks global spread, export, or degradation of available free energy, and a Coherence Ledger that tracks local stabilization, alignment, and admissible organization. These are not two independent processes; they are complementary descriptions of the same irreversible transition.

A simple molecular example clarifies the point. In covalent bond formation, the relevant gradient is set by electronic structure and electronegativity, resistance is defined by orbital geometry and steric restriction, and dissipation accompanies relaxation toward a lower free-energy configuration. What persists upward is not an inert residue but a retained architecture: bond geometry, charge distribution, and an effective interaction landscape within which later molecular dynamics unfold.

The same framework must, however, distinguish between formation and maintenance. Every persistent structure pays the dissipation cost at least once in formation: accessible alternatives are reduced, remainder is exported, and a more stable configuration is obtained. Not every structure must continue paying that cost at the same rate to remain itself. The framework therefore distinguishes between persistence secured by ongoing dissipative throughput, as in maintained nonequilibrium systems, and persistence secured by prior dissipation that has locked the system into stable or metastable form, as in bound states and kinetic arrest. This distinction carries downstream consequence for the coarse-graining interpretation: structures in the first class contribute ongoing remainder to the ambient gradient context of higher scales, while structures in the second class contribute durable constraint geometry. Both modes propagate retained architecture upward, but through different channels. Living cells, atmospheres, and other open nonequilibrium systems require continued entropy export for maintenance; crystals, diamonds, and many glasses do not metabolize in order to remain what they are, even though they remain selectively coupled to their surroundings through permitted channels of exchange and eventual transformation.

5. Cross-Scale Comparison of Participation Rates

If the boundary claim is to be compared across scales in a single mathematical register, the comparison should be made not by mixing raw speeds, internal rotations, and large-scale orbital motion, but by comparing the characteristic recurrence or coupling timescale through which constituents at scale n participate in the organized domain of scale $n+1$. For a loop-like participation mode, let L denote the characteristic participation path and τ the corresponding recurrence time. Define the dimensionless participation ratio as $\beta^* = L/(c\tau)$. For orbit-like or recurrence-like cases in which $L = 2\pi R$, β^* reduces to v/c.

This quantity is introduced as a cross-scale normalizer for comparing constituent participation under bounded recurrence. Its role is not to erase mechanistic differences across scales, but to place recurrence-governed participation into a common causal register. The relevant empirical question is not whether time scales by one clean universal factor across all levels of organization. A first-pass comparison already suggests that it does not. The more important question is whether causality-normalized participation rates occupy a narrower band than raw size and period alone, and whether that compression helps explain why mesoscopic observers encounter small-scale systems as effectively instantaneous and large-scale systems as effectively frozen.

Scale relation	**Participation mode**	**Characteristic speed**	**Recurrence time τ**	**β* = v/c**
Electron in atom	hydrogenic electronic recurrence	2.19×10^{6} m/s	1.52×10^{-16} s	7.30×10^{-3}
Moon around Earth	orbital recurrence	1.02×10^{3} m/s	2.36×10^{6} s	3.41×10^{-6}
Io around Jupiter	orbital recurrence	1.73×10^{4} m/s	1.53×10^{5} s	5.79×10^{-5}
Saturn ring particles	orbital recurrence (Cassini Division)	1.77×10^{4} m/s	4.25×10^{4} s	5.90×10^{-5}
Earth in solar system	orbital recurrence	29.78×10^{3} m/s	3.16×10^{7} s	9.93×10^{-5}
Jupiter in solar system	orbital recurrence	13.07×10^{3} m/s	3.74×10^{8} s	4.36×10^{-5}
Neptune in solar system	orbital recurrence	5.44×10^{3} m/s	5.20×10^{9} s	1.81×10^{-5}
Solar system in galaxy	galactic orbital recurrence	2.30×10^{5} m/s	7.26×10^{15} s	7.68×10^{-4}

Table 1. Participation ratios across selected recurrence-governed atomic, satellite, planetary, ring, and galactic scales

5.1 Normalizing the Temporal Gap

The primary utility of the dimensionless participation ratio, β*, is its role as a cross-scale normalizer that reduces the descriptive dominance of raw recurrence-time differences. While raw recurrence times (τ) vary by over 30 orders of magnitude between hydrogenic and galactic scales, the causality-normalized participation values cluster within a much narrower band (roughly 10^{-6} to 10^{-3}). This compression supports the claim that observer-relative appearance is systematically shaped by timescale separation relative to observer resolution. On that reading, the enormous dispersion in raw periods is not itself evidence of structural discontinuity, but part of the descriptive signature of resolution-shifted identity. The selected cases establish the point across widely separated scales and broaden the comparison across additional recurrence-governed systems. The clustering of β* values within roughly three orders of magnitude—amidst a raw temporal dispersion of more than thirty-one orders of magnitude—suggests that causality-normalized participation is substantially less scale-sensitive than raw recurrence times alone. This compression supports the claim that what appears as structural discontinuity across scales is in part a descriptive artifact of observer resolution. The slight variation in participation rates across the selected cases reflects different governing mechanisms solving the same functional problem: maintaining a separable identity against thermodynamic dispersal.

6. Structural Correspondence with Coarse-Graining, RG, and Effective Description

The scaling of complexity described here is a form of recursive isomorphism: the same structural relation recurs across scales even though the constituents and local mechanisms differ. Every settlement event produces a structure and a remainder. The dissipated remainder is irreversibly exported, altering the ambient gradient context in which later dynamics unfold, while the retained organization becomes part of the effective constraint terrain of the next scale.

This framework aligns structurally with renormalization-group and effective-field-theoretic reasoning (Goldenfeld, 1992; Wilson and Kogut, 1974). Coarse-graining provides the physical rationale for reading lower-scale kinetics as higher-scale effective potential, constraint, and admissible configuration. The relation is therefore one of identity at resolution: retained lower-scale organization reappears at coarser description as effective potential, constraint, and admissible configuration. At coarser resolution, retained architecture persists across a scale boundary not as a new substrate, but as effective constraint geometry: the landscape within which next-scale dynamics become admissible.

7. Selected Cross-Domain Realizations

The framework is best read as a cross-scale account of how separable higher-order units arise under differing local mechanisms. The point is that persistent systems across scales can be understood through a recurring formation logic, even where their local mechanisms and modes of boundary realization differ.

Scale	Coherent integration	Dissipation-enabled capture	Separable identity
Subatomic	Quarks under color asymmetry / confinement	Gluon-mediated binding into color-neutral closure	Hadron (proton/neutron)
Nuclear	Hadrons in nuclear interaction potentials	Gamma emission; neutrino loss; binding into stable nuclear configuration	Stable nucleus
Atomic	Nucleus and electrons in electromagnetic potential	Photon emission; radiative relaxation; stable electronic structure	Atom
Molecular	Atoms across electronic gradients	Infrared relaxation; heat; bonding and molecular formation	Molecule
Macromolecular	Molecules under templating, folding, and sequence constraints	Thermal loss to solvent; conformational stabilization; retained template architecture	Macromolecule /polymer
Cellular	Macromolecular networks under membrane chemistry	Metabolic heat; chemical waste; compartmentalization and homeostatic closure	Cell
Organismal	Cells under developmental and physiological coupling	Metabolic and excretory loss; regulated functional integration	Organism
Ecological	Organisms across niche and resource gradients	Waste, heat, mortality, turnover; coupled ecological organization	Ecological web
Planetary	Atmosphere, hydrosphere, lithosphere, and biosphere under solar-radiative contrast	Radiative and hydrological export; Earth-system stabilization; biogeochemical steady state	Self-regulating planet
Stellar System	Stars, planets, and minor bodies under gravitational coupling	Radiative loss, tidal dissipation, and orbital stabilization	Stellar system
Galactic	Stars, gas, dust, and dark-matter mass distribution under gravitational coupling	Radiative cooling, dynamical relaxation, and long-term orbital organization	Galaxy

Table 2. Selected cross-domain realizations of recursive integrated separability. The rows do not imply one identical local formalism at every scale; they identify a recurring formation logic in which coherent integration, dissipation-enabled stabilization, and constrained exchange produce separable higher-order units under different physical mechanisms.

8. Conclusion

Sufficient coherent integration at scale n yields separable identity at scale n+1. This follows from the recursive inheritance rule in which the retained architecture of a settlement event becomes part of the effective constraint terrain of the next scale. The present manuscript strengthens that claim in four ways. First, it defines boundaries functionally rather than visually. Second, it makes explicit that the boundary criterion is the macroscopic signature of successful capture rather than an additional condition. Third, it distinguishes between dissipative maintenance and persistence secured by prior dissipation, binding structure, or kinetic arrest. Fourth, it shows by a preliminary cross-scale test that observer-relative boundary appearance can be disciplined mathematically without pretending that all scales collapse to one clean universal factor.

By reading persistent formation through the lens of gradient-driven settlement and coarse-grained inheritance, established theories can be organized into a coherent cross-scale picture. Its value lies in providing a single cross-scale framework, expressed in established physical language, for understanding how persistent complexity propagates through nature through dissipation-enabled capture, functional boundary, and coarse-grained inheritance.

9. Statements and Declarations

Author Contributions: The author solely conceived the framework, conducted the analysis, and wrote the manuscript.
Data Availability: No datasets were generated or analyzed during the current study beyond illustrative use of standard reference values reported by NIST and NASA.

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