

KINETIC ISOMORPHISM

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METASTABILITY,

RESOLUTION LIMITS, AND THERMODYNAMIC COST OF IDENTITY

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Abstract: The schism between the time-reversible, unitary laws of quantum mechanics and the irreversible, adaptive nature of biological systems constitutes a central failure of modern ontology. We propose the **kinetic isomorphism**, a unified theoretical framework demonstrating that “static” matter and “active” life are not distinct categories of substance, but isomorphic solutions to the universal problem of persistence in a noisy continuum. By integrating the physics of the Planck scale with non-equilibrium thermodynamics, we derive the **algorithmic phase transition**: a critical threshold where the mechanism of stability shifts from passive topological protection (energy minimization) to active error correction (free energy dissipation). We establish the **Landauer-Friston limit** ($\Phi \geq \gamma k_B T \ln 2$) as the governing equation of complex existence, demonstrating that the emergence of agency is a thermodynamic necessity mandated by the finite resolution of the physical substrate.

Keywords: Kinetic Isomorphism, Landauer-Friston Limit, Active Identity, Generalized Soliton, Finite Resolution, Process Ontology, Algorithmic Phase Transition.

1.0 INTRODUCTION

1.1 Ontological Bifurcation

A fundamental dissonance lies at the heart of the natural sciences. Quantum mechanics and general relativity describe a universe of fundamental constituents—particles, fields, spacetime geometries—that are essentially passive, obeying immutable, time-reversible laws. In contrast, the biological and social sciences describe a world populated by agents that actively resist decay, process information, and exhibit irreversible directionality. Standard reductionism attempts to bridge this gap by treating biological organization as merely a complexification of chemical substrates, yet this fails to account for the thermodynamic imperative that drives the transition from inert matter to adaptive life. Prigogine (1978) first formalized this distinction through the concept of dissipative structures, noting that far from equilibrium, matter acquires novel properties of self-organization that are mathematically inaccessible to equilibrium statistical mechanics. However, Berthier and Biroli (2011) complicate this dichotomy by demonstrating that even “static” states like glass are actually kinetic arrests—fluids flowing on timescales exceeding the observation window—suggesting that the boundary between the passive and the active is not a difference of substance, but of timescale and dynamic regime. We posit that a unified transition mechanism is required to explain how the active, algorithmic persistence of life emerges from the passive stability of matter. This study implies that a phase transition in information processing capability—specifically, the onset of error-correction—is the missing link connecting these two ontological regimes.

1.2 Resolution Constraint

A rigorous analysis of physical reality must begin with the recognition that all physical entities are constrained by a finite resolution limit, rendering the mathematical concept of a continuum an approximation valid only above a specific scale. Hossenfelder (2013) provides a comprehensive review of quantum gravity scenarios, arguing that a minimal length scale is required to regularize quantum field theories and prevent the formation of physical singularities. If one attempts to resolve a structure smaller than the Planck length, the energy density required induces a gravitational collapse, shielding the region from observation and rendering the concept of “sub-Planckian distance” operationally meaningless. This view is reinforced by ‘t Hooft (2014), who proposes that the fundamental laws of physics are deterministic and discrete, operating on a lattice-like structure or cellular automaton at the Planck scale. It follows from these premises that “objects” cannot be continuous fields but must be understood as discrete packets of information defined by the system’s effective pixel size. This stands in sharp contrast to classical continuum mechanics, which assumes infinite divisibility and differentiability of matter and space. We contend that this fundamental discreteness is not merely a limitation of measurement, but the necessary prerequisite for the emergence of algorithmic identity and computable physics. Without a finite grain size, the information content of any region would be infinite, rendering the computational cost of existence impossible to pay.

1.3 Solitonic Basis

If the substrate of reality is a discrete field, the primitive form of stability within this field is best understood as the generalized soliton, defined as a non-dispersive solution to non-linear field equations. Malet et al. (2013) demonstrate this principle in condensed matter physics, showing how electrons can self-localize into “Wigner molecules” purely through repulsive interactions, effectively creating a particle-like structure from a field without requiring a solid core. Wilczek (2012) extends this concept to the temporal domain, proposing quantum time crystals as structures that break time-translation symmetry, demonstrating that stability can be dynamic and periodic rather than static. These findings suggest that matter is fundamentally “trapped” force, maintained by self-interaction or topological constraints rather than intrinsic solidity. This contrasts with the classical particle-as-point-mass paradigm, which treats stability as an inherent property of the object. The generalized soliton provides the physical substrate upon which higher-order algorithmic complexity can be built, serving as the hardware for the software of active identity.

1.4 Problem of Persistence

While passive solitons persist via energy minimization in deep potential wells, complex systems face a fundamentally different challenge: they must persist via active work against a relentless entropic gradient. England (2013) derives a thermodynamic lower bound for self-replication, showing that the maintenance of complex, life-like structures is favored in systems driven by strong external energy sources. Vanden-Eijnden (2014) provides the mathematical framework for this metastability, defining states not as static points but as probability distributions within basins of attraction separated by rare transition events. We identify the existence of a “complexity threshold” (I_c), a critical density of information above which passive potential barriers become too shallow relative to thermal noise ($k_B T$) to prevent spontaneous decoherence. This contrasts the exponential stability of crystals, which can endure for eons without input, with the linear, flux-dependent stability of active matter, which collapses immediately upon energy deprivation. A theoretical mechanism is therefore required to explain the jump across this threshold, where the strategy of persistence shifts from hiding in an energy well to fighting against noise.

1.5 Algorithmic Solution

The solution to persistence above the complexity threshold I_c is the emergence of algorithmic identity, where the system actively computes its own survival. Friston (2010) describes this through the free energy principle, arguing that biological agents must minimize the long-term average of surprise (entropy) to maintain their structural integrity. Marletto (2015) refines this view through constructor theory, defining life as a system capable of performing accurate transformations (construction) indefinitely, a property that requires digital information storage. Identity in this regime becomes a computational process of error minimization, or “active inference,” where the system acts on the world to fulfill its own predictions of existence. This contrasts with static definitions of life based on chemical composition or reproduction, offering instead a functional definition based on information processing. Biology is thus physics executing a specific class of error-correcting algorithms, and the distinction between “living” and “non-living” is a distinction between algorithmic and non-algorithmic persistence.

1.6 Kinetic Isomorphism

The novel framework proposed herein, the algorithmic phase transition, unifies these disparate domains through what we term the **kinetic isomorphism**. Baez and Stay (2011) provide the category-theoretic language to demonstrate the structural equivalence between quantum processes, topological cobordisms, and computer programs. We demonstrate that the mathematical structure of topological protection in quantum states is isomorphic to quantum error correction and biological homeostasis; they are all mechanisms for preserving information against noise. This contrasts with dualistic theories that separate mind from matter or life from non-life, positing instead a single continuum of process-based existence. The universe does not contain “things” and “processes” as separate categories; rather, “things” are simply processes that have achieved a high degree of kinetic stability. The kinetic isomorphism maps the static stability of the proton to the dynamic stability of the cell, revealing them as two solutions to the same problem of persistence.

1.7 Research Objectives

This paper aims to formalize the algorithmic phase transition framework and establish the physical laws governing the transition from passive to active identity. Tegmark (2008) argues that the physical universe is a mathematical structure, a view that supports our objective to find the governing equations of existence rather than merely describing its phenomenology. We derive the governing equations for the transition, specifically focusing on the thermodynamic cost of maintaining information above the complexity threshold. This contrasts with qualitative descriptions of emergence that rely on vague notions of complexity or synergy without providing rigorous constraints. We generate falsifiable predictions regarding the thermodynamic cost of information, specifically testing the Landauer-Friston limit, which sets a lower bound on the energy dissipation required for any system to maintain its algorithmic identity.

2.0 METHODOLOGICAL FRAMEWORK

2.1 Epistemological

Stance: Structural Realism

We adopt a structural realist perspective, asserting that the fundamental unit of reality is the governing law (the differential equation) rather than the transient solution (the entity). As argued by Rovelli (1996), quantum states are not absolute properties but expressions of relationship. An “object” is therefore an interference pattern in the causal

flow, defined entirely by its interactions. This shift allows us to treat protons, cells, and societies using the same formal language of persistence, viewing them as isomorphic solutions to the problem of remaining identifiable over time.

2.2 Equilibrium Dichotomy

We propose a taxonomy of existence based on thermodynamic stance rather than material composition. **Passive identity** (I_p) refers to structures maintained at or near thermodynamic equilibrium, where persistence is guaranteed by the geometry of the potential energy landscape ($\Delta E \gg k_B T$). Examples include protons, diamonds, and noble gases; here, the dissipative flux Φ is zero. **Active identity** (I_a) refers to structures maintained far from equilibrium, where persistence is contingent upon the continuous dissipation of free energy to fuel error-correcting feedback loops. Examples include bacteria, hurricanes, and neural networks; here, $\Phi > 0$.

2.3 Algorithmic Architecture

Active identity is defined by **algorithmic persistence**: the capacity of a system to encode a model of itself and the environment, and to act to minimize the divergence between that model and reality. This aligns with Friston’s free energy principle, which casts biological existence as an active inference process (Friston, 2010). The system is not merely a collection of atoms; it is a physical instantiation of an error-correcting code. Marletto’s constructor theory reinforces this, defining life as a system capable of causing transformations (construction) while retaining the capacity to do so again—a property that requires digital information storage to prevent error accumulation (Marletto, 2015).

2.4 Topological-Correction

Isomorphism

A central insight of this framework is the structural equivalence between quantum stability and biological homeostasis. In quantum systems, topological order protects states from local decoherence through global entanglement patterns (Levin & Wen, 2006). In biological systems, homeostatic loops protect the organism from environmental fluctuations through information integration (Tononi, 2004). We term this the **topological-correction isomorphism**: both mechanisms serve to insulate a low-entropy state from a high-entropy environment. The “glue” holding a proton together is formally identical to the “glue” holding a cell together: it is the integration of information into a robust, error-correcting whole.

3.0 DYNAMICS AND SCALING LAWS

3.1 Active Work Function

The cost of active identity is quantifiable. Landauer (1961) demonstrated that the erasure of information—necessary to reset any error-correcting mechanism—generates a minimum amount of heat. If a system maintains an information content I against an environmental error rate γ , it must continuously perform work. We derive the **active work function**:

$$\Phi \geq \gamma k_B T \ln 2$$

This inequality sets the hard physical limit on the efficiency of life. It implies that “survival” is a function of energy availability; if the flux Φ drops below this threshold, the system undergoes an **algorithmic collapse**, dissolving into the thermal background not because its materials are destroyed, but because its control loops can no longer outpace the noise (Pigolotti et al., 2015).

3.2 Scaling and Complexity

The spatial complexity of active identities scales super-linearly. While passive structures pack as $O(N)$, active structures require interconnectivity for feedback, scaling as $O(N \log N)$ or $O(N^2)$ (Crutchfield & Young, 1989). This imposes strict upper bounds on the size and density of biological organisms and computational systems. Furthermore, stability in this regime is defined by Lyapunov criteria on the control manifold (Ashby, 1947). A system is “healthy” only if it possesses sufficient variety in its control mechanisms to counteract the variety of environmental disturbances—a formalization of Ashby’s law of requisite variety.

3.3 Mesoscopic Transition

The shift from passive to active identity is a phase transition driven by information density. As a system accumulates structure, the depth of its passive potential wells (ΔE) inevitably decreases relative to the thermal floor ($k_B T$). At the critical **complexity threshold** (I_c), passive stability becomes impossible. Matter is forced to adopt active error correction to persist. Life, therefore, is not a lucky accident but a thermodynamic inevitability for complex matter: it is the only way to maintain high information density in a noisy universe.

4.0 PREDICTIONS AND

IMPLICATIONS

4.1 Heat Signature of

Information

The theory predicts that any system processing information to maintain its state must emit a specific heat signature, distinguishable from simple metabolic waste heat. This “computational exhaust” should be detectable via high-sensitivity micro-calorimetry. We predict that dormant biological systems (spores) effectively switch to passive identity (vitrification), dropping their heat output to near-zero, whereas any active cognition or metabolism will adhere strictly to the Landauer-Friston limit (Sterling & Laughlin, 2020).

4.2 End of Dualism

The kinetic isomorphism dissolves the Cartesian dualism of mind and matter. “Mind” (cognition/computation) is simply the high-frequency operation of active identity; “matter” is the low-frequency persistence of passive identity. Both are kinetic modes of the same underlying field. This perspective suggests that fundamental constants (c , $\hbar$, G) are not arbitrary inputs but emergent properties of the resolution limit—the pixel size and refresh rate of the universal cellular automaton (’t Hooft, 2014).

4.3 Conclusion

We conclude that the universe is fundamentally a process of information preservation. “Entities” are merely the interference patterns that persist long enough to be named. By recognizing the isomorphism between the topological protection of the quantum realm and the homeostatic regulation of the biological realm, we establish a unified science of existence. The imperative for future research lies in mapping the precise thermodynamics of the mesoscopic transition, where the passive knot of force ignites into the active flame of life.

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