Epistemic Limits of the Embedded Observer

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May 30, 2026

Abstract

The Platonic observer is replaced by a physically embedded computational subsystem. Bounded by holographic encoding capacity and Conservation-Congruent Encoding (CCE), the observer is geometrically forced to project a massively large, finite set of discrete microscopic realities into a strictly smaller set of macroscopic equivalence classes. Consequently, state evolution under exact reversible dynamics becomes predictively intractable within the observer's formal system. Expanding upon the physical limits of inference and the computational capacity bounds of the universe, this framework proves that computing the precise trajectory of the universe is physically impossible without exceeding the observer's finite conserved-resource budgets.

1 Axioms of the Embedded Observer

Let an observer $\mathcal{O}$ utilize a physical encoding substrate $\mathcal{M}$ to process and store information about a discrete, finite microscopic physical system $\mathcal{E}$, which possesses state space $\Omega_{\mathcal{E}}$.

Axiom 1 (Geometric and Encoding Capacity Bounds)**.** *The observer's ability to store information is strictly bounded by its physical embedding: $\mathcal{M} \subseteq \mathcal{O} \subset \mathcal{E}$. By the Bekenstein-Hawking area law [4, 5], maximum encoding capacity is strictly monotone: $I_{\max}(\mathcal{M}) \leq I_{\max}(\mathcal{O}) < I_{\max}(\mathcal{E})$.*

Axiom 2 (Conservation-Congruent Processing)**.** *Encoded states are physical distinctions whose creation, preservation, and erasure must respect conserved quantities. In accordance with Landauer's principle and the Conservation Congruent Encodings (CCE) framework [6, 3], irreversible information processing operations (e.g., erasure or merging) of ΔI_{irr} nats demand* *a proportional export of entropy into physical resource channels. For exchanged conserved quantities Q_a and their intensive conjugates λ_a, this CCE resource cost is strictly bounded: $\sum_a \lambda_a \Delta Q_a \geq \Delta I_{\mathrm{irr}}$.*

2 The Physical Intractability Theorem

Theorem 1 (State-Level Epistemic Projection). *An isomorphic, complete microscopic model of $\mathcal{E}$ or $\mathcal{O}$ is physically forbidden. The observer must utilize a massive informational compression, mapping the finite microstate space $\Omega_{\mathcal{E}}$ into a strictly smaller finite set of discrete macroscopic encodings Z.*

Proof. An exact model of $\mathcal{E}$ requires an active encoding capacity $I(\mathcal{M}) \geq I_{\max}(\mathcal{E})$, violating the bounds of Axiom 1. Similarly, an exact live self-model demands perpetual recursive updating of the observer's encoded information. Correcting this state mismatch requires unphysical conserved-resource dissipation (Axiom 2) or prohibitive auxiliary encoding capacity (Axiom 1). Thus, the system is geometrically forced to use a many-to-one coarse-graining projection $\pi_\Phi : \Omega_{\mathcal{E}} \to Z$. Because $|Z| \ll |\Omega_{\mathcal{E}}|$ and the capacity of Z is finite, any metastable encoding basin $B_z = \pi_\Phi^{-1}(z) \subset \Omega_{\mathcal{E}}$ possesses a vast multiplicity of microstates. Therefore, there exist distinct microstates $x_1 \neq x_2 \in B_z$ that map to the exact same macroscopic encoding z, rendering them strictly indistinguishable to the observer. □

Theorem 2 (Dynamical Intractability). *For systems evolving under non-trivial discrete reversible dynamics, there exist physically realized future and past states of $\mathcal{E}$ that cannot be uniquely predicted or retrodicted by the observer's formal model π_Φ.*

Proof. Let $x_1, x_2 \in B_z$ be two distinct microstates that map to the same preserved initial macrostate z_0 at discrete time t_0. At the fundamental level, the true internal and external states evolve under an exact, deterministic, and reversible unit-step map T, so that $T_\tau = T^\tau$ for elapsed discrete time steps $\tau \in \mathbb{Z}_{>0}$. For any macrostate z, define the sets of distinct macroscopic futures and pasts by

$$\mathcal{F}_\tau(z) = \{\pi_\Phi(T_\tau x) : x \in \pi_\Phi^{-1}(z)\}, \qquad \mathcal{P}_\tau(z) = \{\pi_\Phi(T_\tau^{-1} x) : x \in \pi_\Phi^{-1}(z)\}.$$

In non-trivial systems, such measure-preserving dynamics exhibit effective mixing relative to the observer's coarse-graining, so localized microscopic differences may be dispersed across the finite system. For some $\tau \in \mathbb{Z}_{>0}$,

the forward evolutions of these initially indistinguishable microstates cross different macroscopic partition boundaries, yielding diverging macroscopic futures such that $|\mathcal{F}_\tau(z_0)| > 1$.
Conversely, macroscopic dissipation and retrodictive incompleteness emerge whenever $|\mathcal{P}_\tau(z_0)| > 1$, directly as an artifact of the many-to-one projection, which irreversibly merges distinct microscopic histories into shared macroscopic attractors.
The universe realizes exactly one microscopic trajectory. To deterministically infer this true trajectory from the macroscopic degeneracy, the observer must process $I_{\mathrm{dec}}(\tau)$ additional nats. By Axiom 2, this irreversible acquisition demands a physical resource payment $\sum_a \lambda_a \Delta Q_a^{\mathrm{dec}} \geq I_{\mathrm{dec}}(\tau)$. For dynamics with growing branch entropy relative to encoding capacity, this cost inevitably exceeds the finite conserved-resource capacity of $\mathcal{O}$, rendering the true trajectory physically intractable. □

3 Conclusion

The exact physical constraints that make observation possible—coarse-graining highly complex discrete realities into stable macroscopic basins—simultaneously impose absolute limits on predictability. Epistemic incompleteness is not a paradox of algorithmic undecidability, but a physical constraint. Computing the precise trajectory of the universe is physically intractable without exhausting the observer's finite encoding capacity and conserved-resource budgets.

References

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