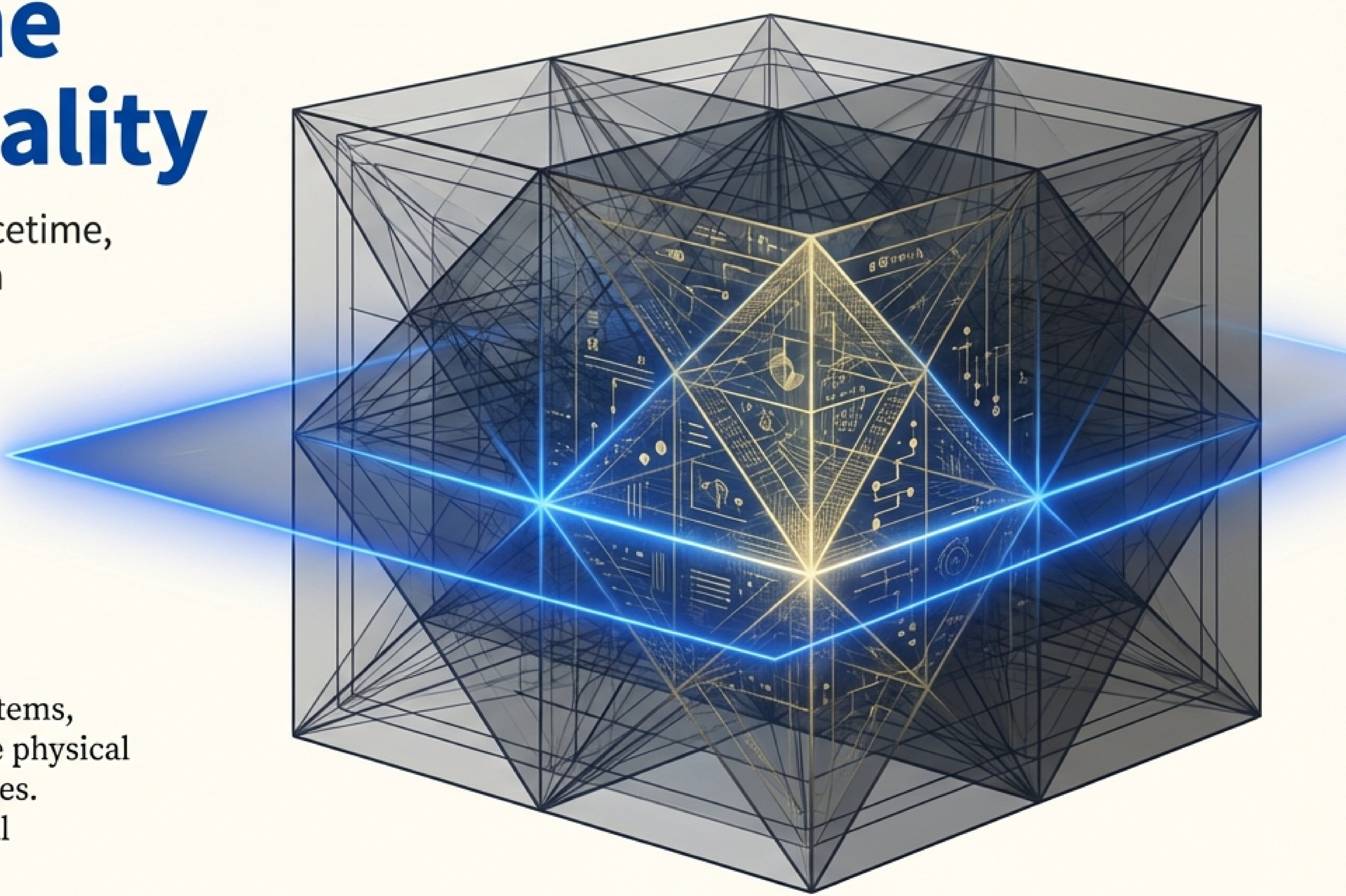
Reading the Code of Reality

A Unified Framework for Spacetime, Information, and Observation

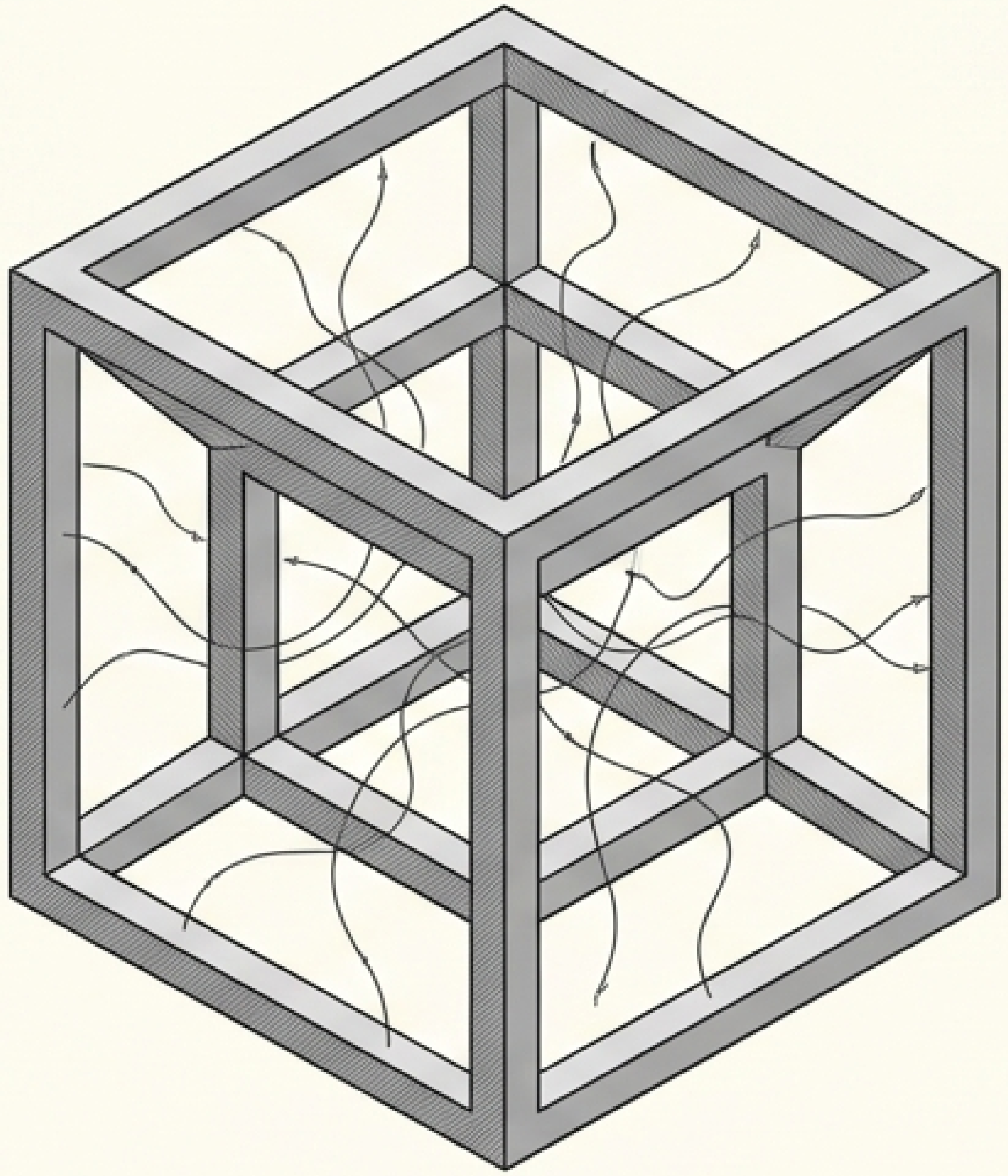


Information theory, dynamical systems, and formal logic describe the same physical reality using incompatible languages. We introduce EBOC, a foundational framework that unifies them.

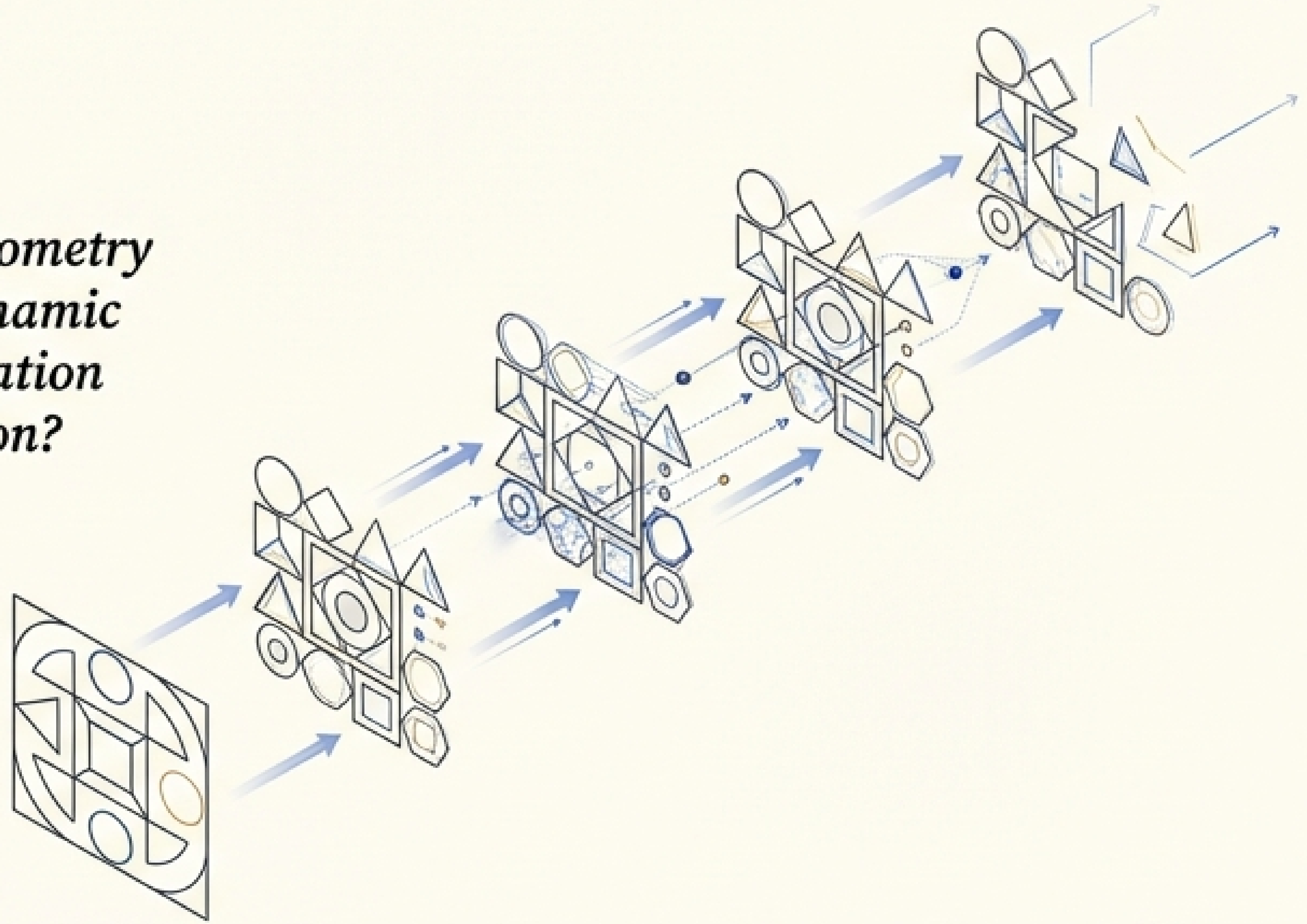
The Paradox: A Static Universe vs. The Flow of Time

Physics: The Block Universe. Timeless, geometric, and deterministic.

Experience & Computation: The Flow of Time. Operational, sequential, and seemingly full of choice.

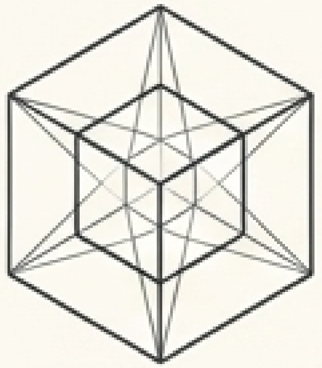


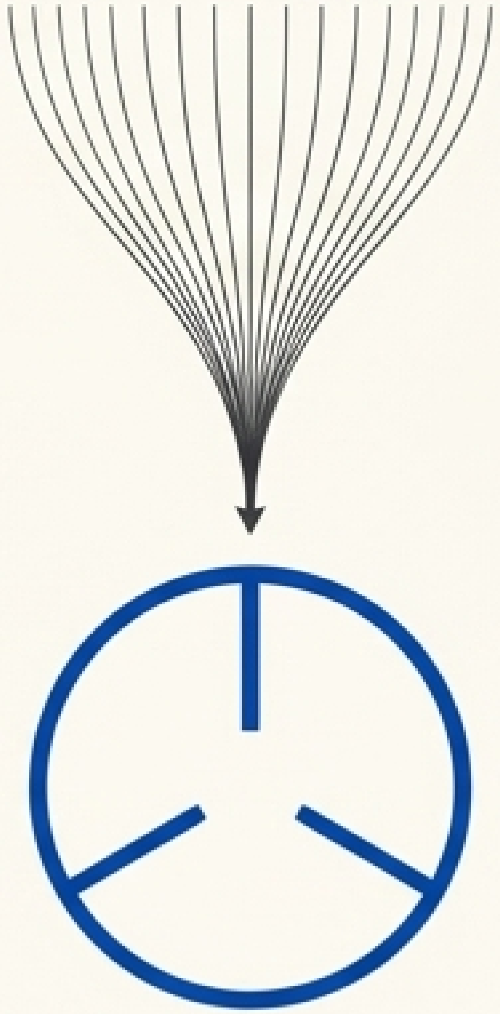
How can a static geometry give rise to the dynamic process of observation and computation?

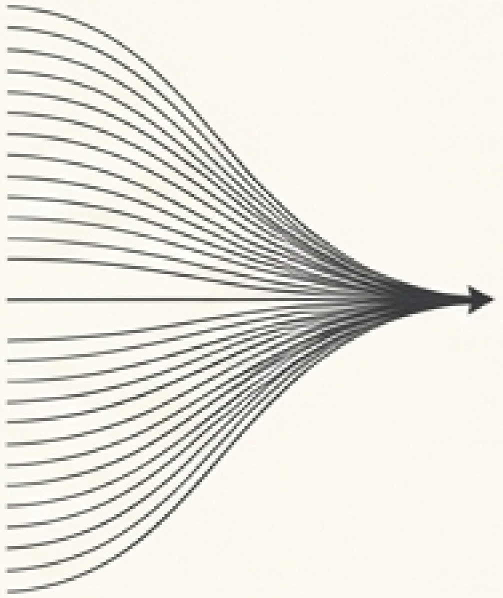


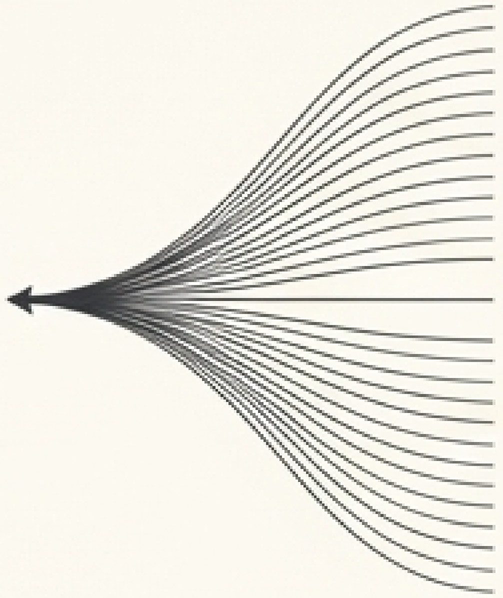
The EBOC Framework: A Unified Lens

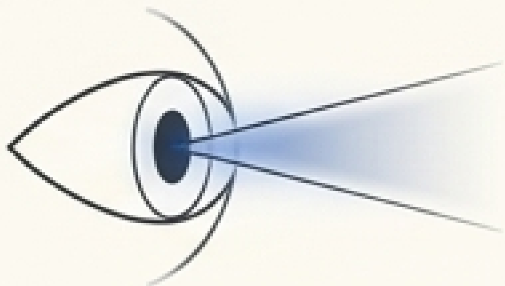
Geometric: A static spacetime block (X_f) satisfying local rules. A subshift of finite type.









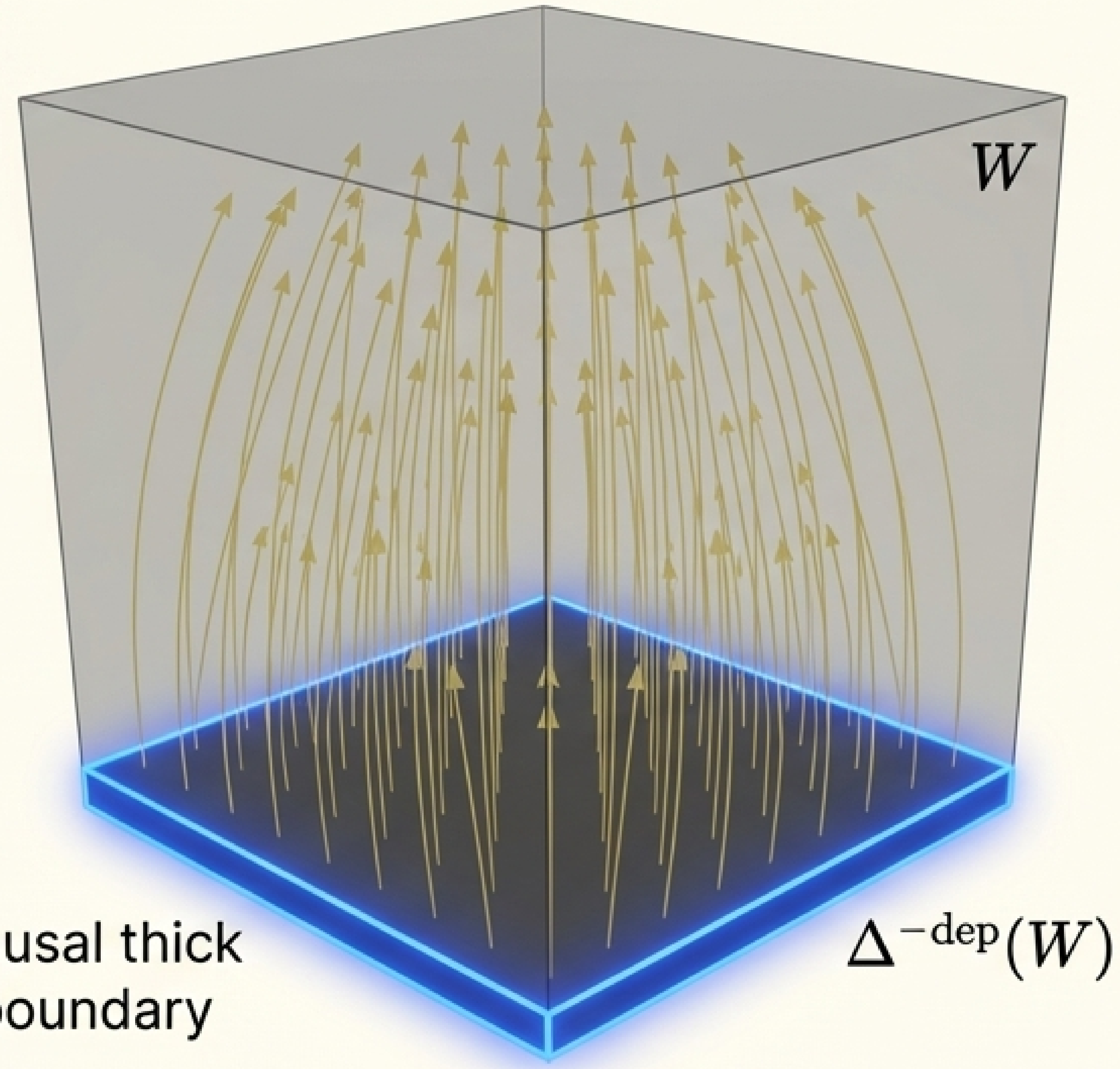


Semantic: An observer's ‘read head’ moving across the block, representing a factor map (π) that decodes information.

Informational: A visualization of a boundary containing/compressing the information of a larger volume, representing complexity bounds.

The key insight: ‘time’ is leaf-by-leaf reading, not evolution. What appears as ‘choice’ is representative selection within an equivalence class, constrained by information non-increase.

A Discrete Holographic Principle

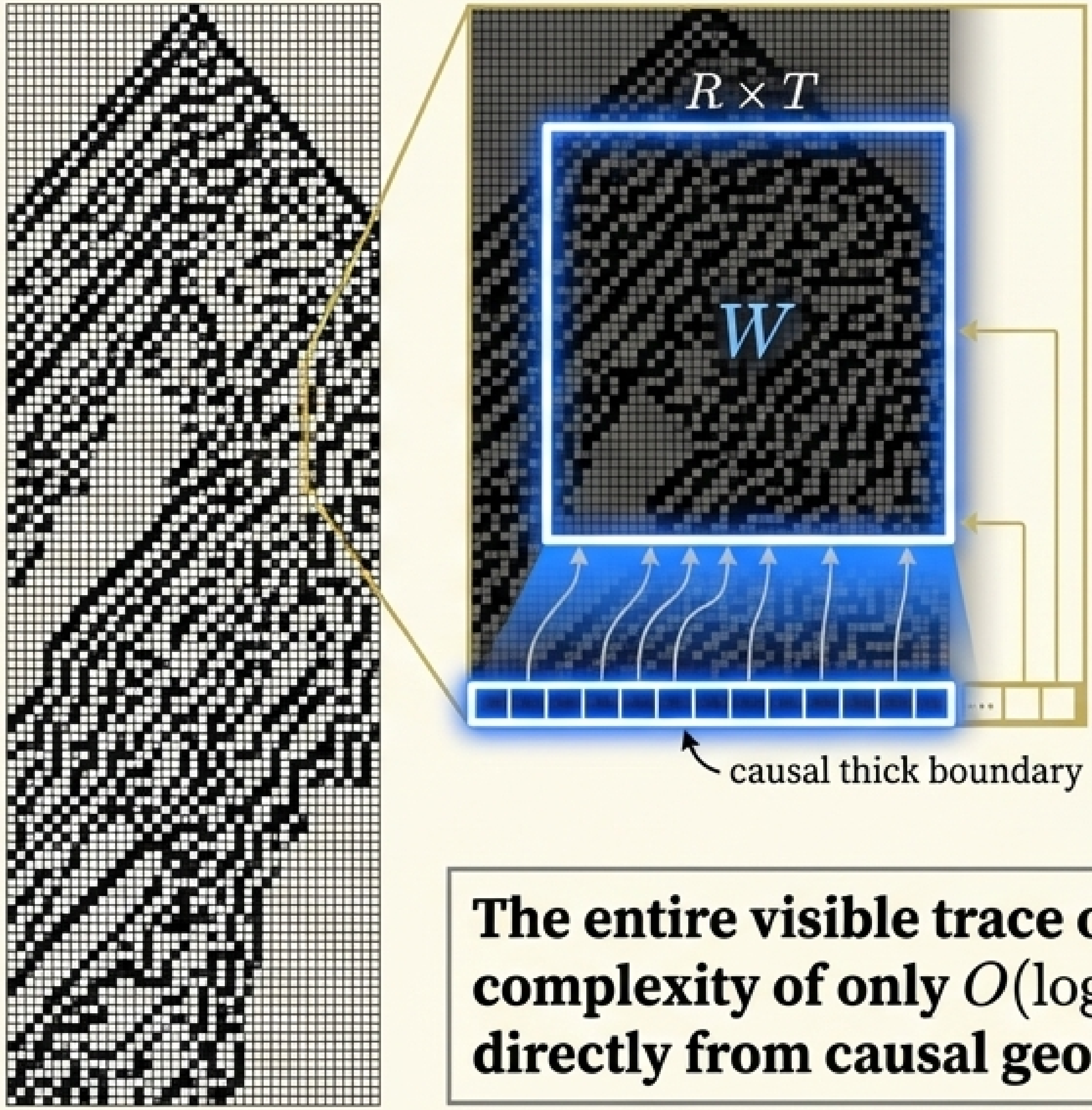


Theorem T4: The Information Upper Bound

$$K(\pi(x|W)\,|\,x|_{\Delta^{-}\mathrm{dep}(W)}) \leq K(f) + K(W) + K(\pi) + O(\log|W|)$$

The information content of a bulk spacetime region W is fully determined by its causal boundary. The complexity of the bulk, given the boundary, is not proportional to its volume, but grows only with the logarithm of its size—a massive compression. This is a rigorous tool for quantifying information flow in discrete spacetimes.

Grounding the Hologram: Universal Computation in Rule-110

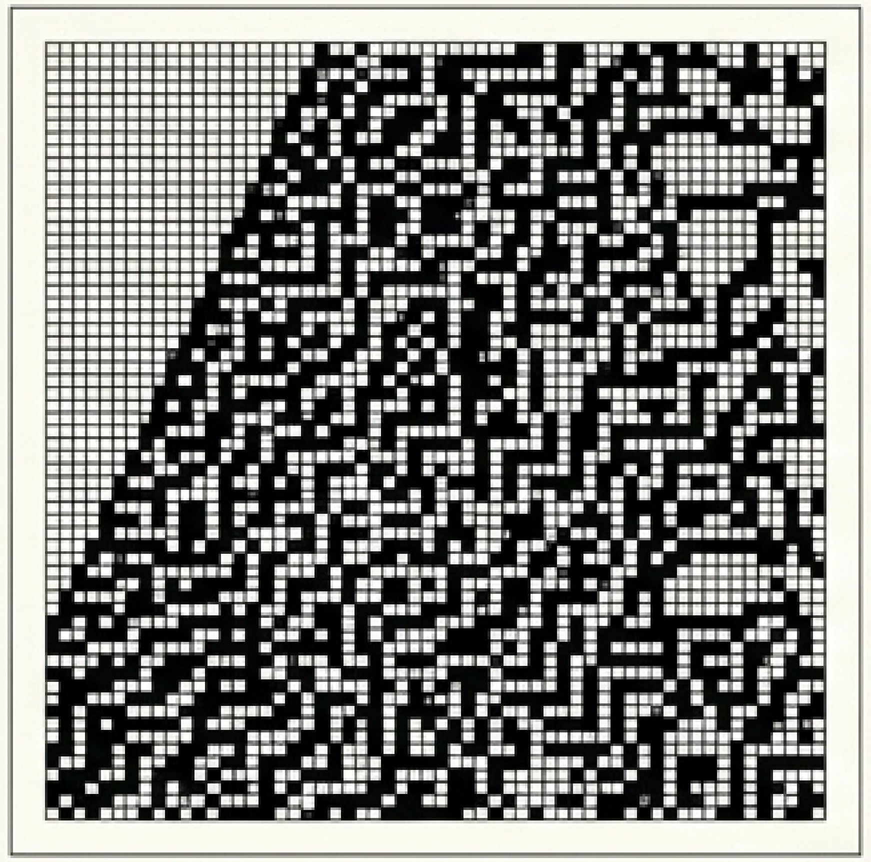


- **Setup:** Elementary cellular automaton Rule-110, a universal computer, is encoded as a static block X_f.
- **Program Embedding (T6):** Turing machine computations are embedded into the static block via macroblock encoding.
- **Information Bound (T4 Application):** For a computational trace over T time steps, the complexity is bounded by the boundary information.

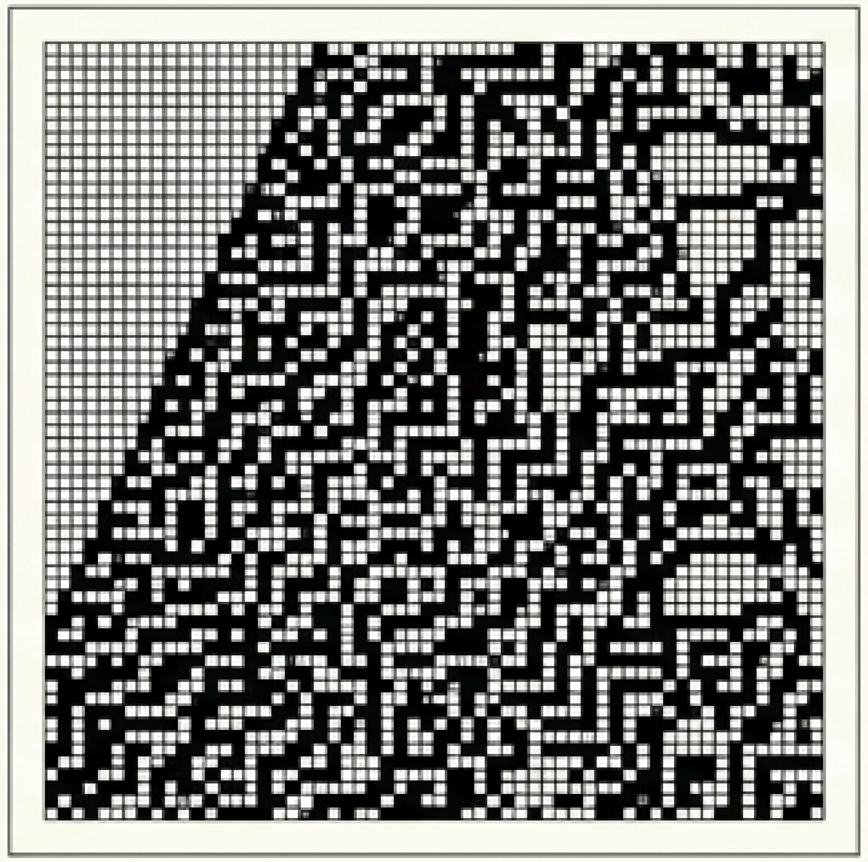
$$K(\pi(x|W)|x|_{\Delta-\mathrm{dep}}(W)) \leq O(\log |W|)$$

The entire visible trace of a universal computation has a conditional complexity of only $O(\log T)$ given its boundary. The result is derived directly from causal geometry, without invoking entropy.

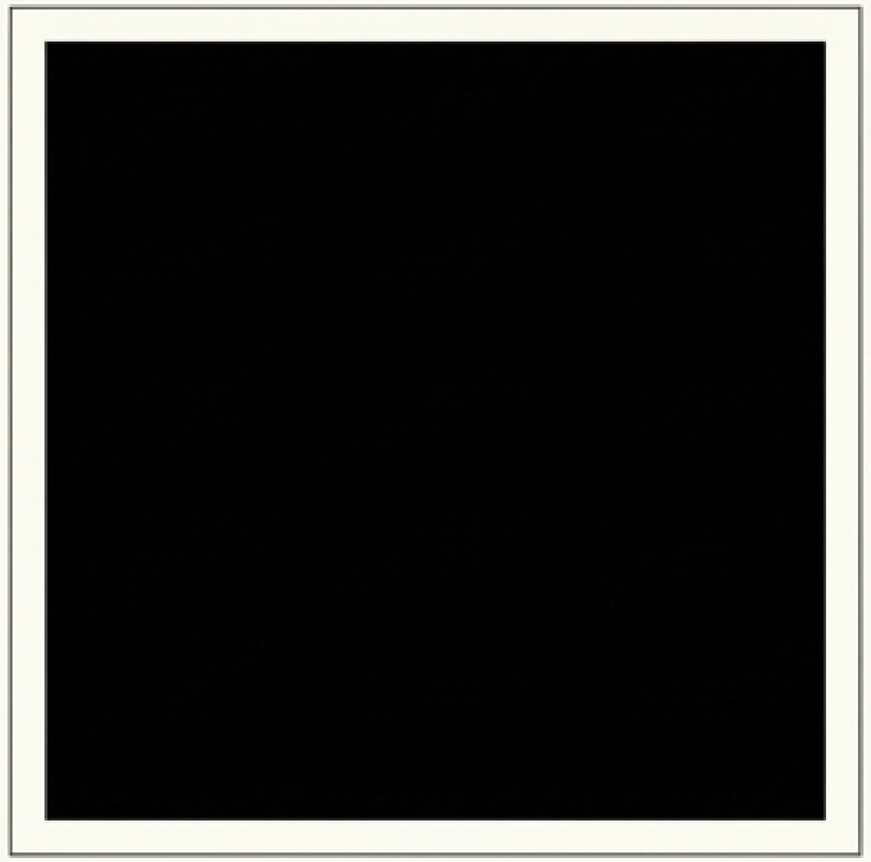
Experimental Verification: Reconstructing Spacetime from the Edge



Ground Truth Window $x|W$`



Reconstructed from Boundary Alone



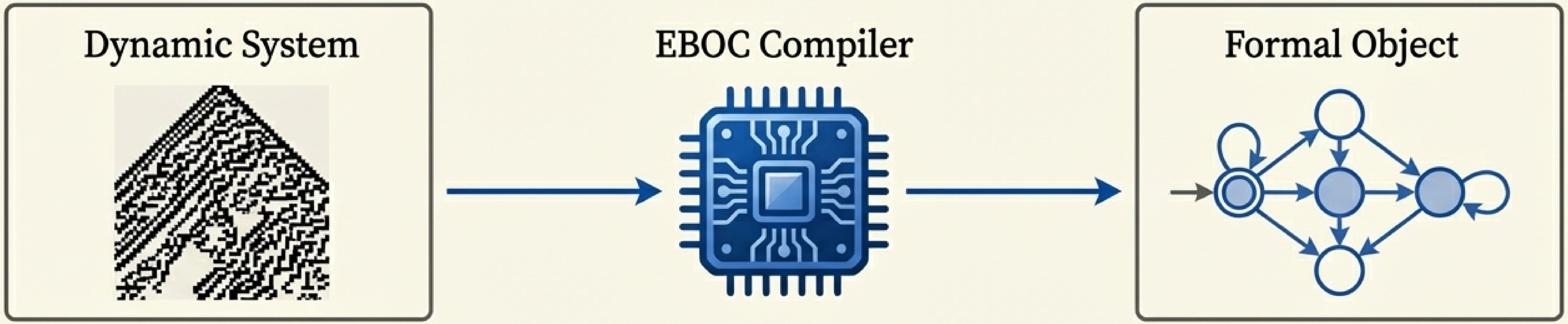
Difference Map

Zero reconstruction error over all 6,400 spacetime cells.

This confirms Theorem T4's sufficiency. The causal thick boundary—a slice of 240 cells from the preceding time step—contains all the information required to perfectly reconstruct a bulk region of 6,400 cells.

From Simulation to Formal Verification

Traditionally, complex systems are studied via simulation, which cannot prove properties over infinite time. EBOC provides a bridge to formal verification.

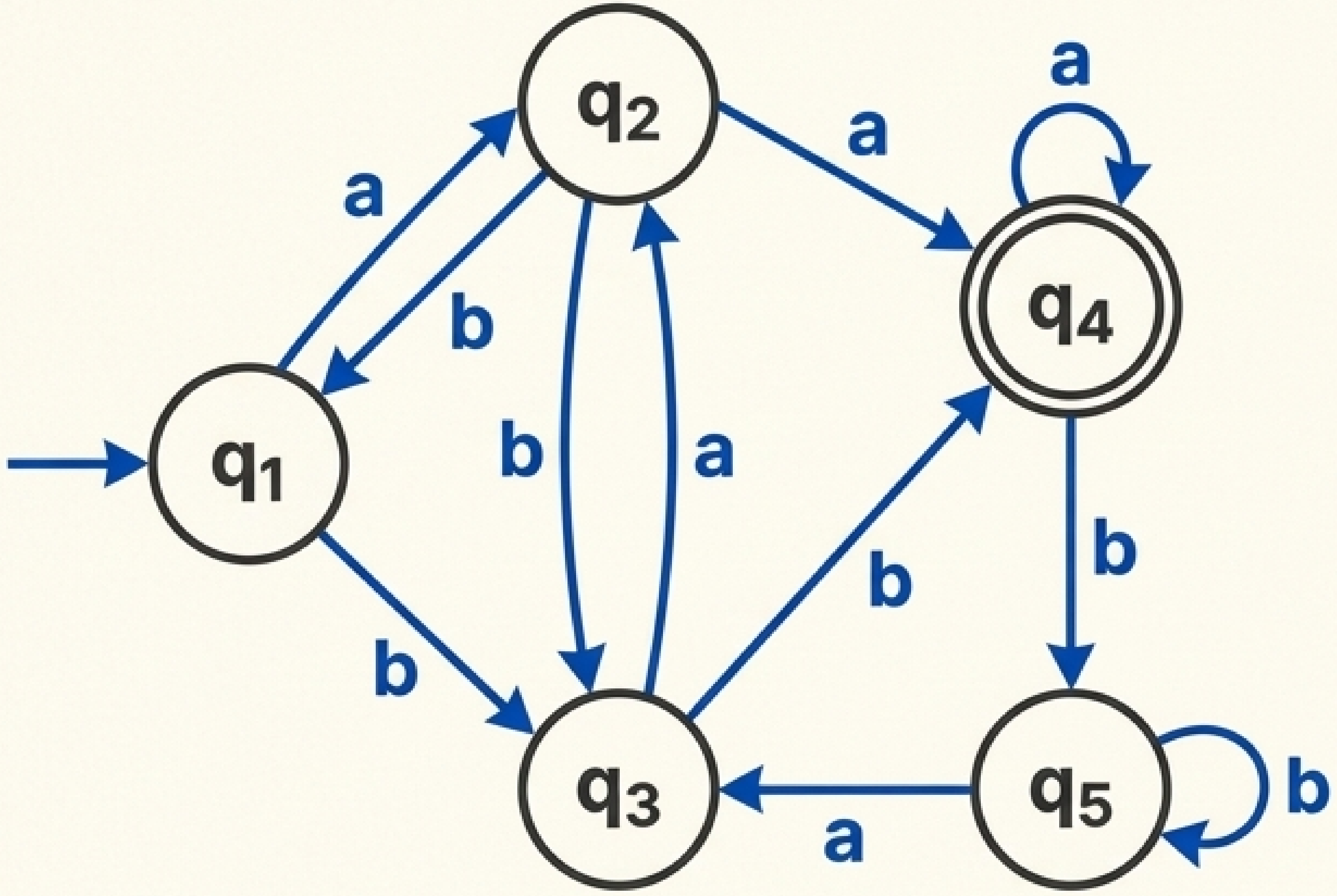


Theorem T13: Observable Behavior as a Formal Language

If a system is ‘time-Markovizable’ (its state depends on a finite number of past layers), then its observable language $\mathrm{Lang}_{\pi,\varsigma}(X_f)$ is ω-regular.

This allows us to use tools from computer science like model checking and automated theorem proving to rigorously verify emergent properties (e.g., ‘safety’ or ‘liveness’) that were previously only observed empirically.

Constructing the Automaton of Time



State Space (Q):

Valid k-layer configurations.
For Rule-110, $k = 5$. Size $|Q| \leq 2^{25}$.

Transitions (δ):

$\delta(q, a) = \{q'\}$. A transition from state q to q' on observable symbol a is valid if it satisfies the underlying SFT constraints.

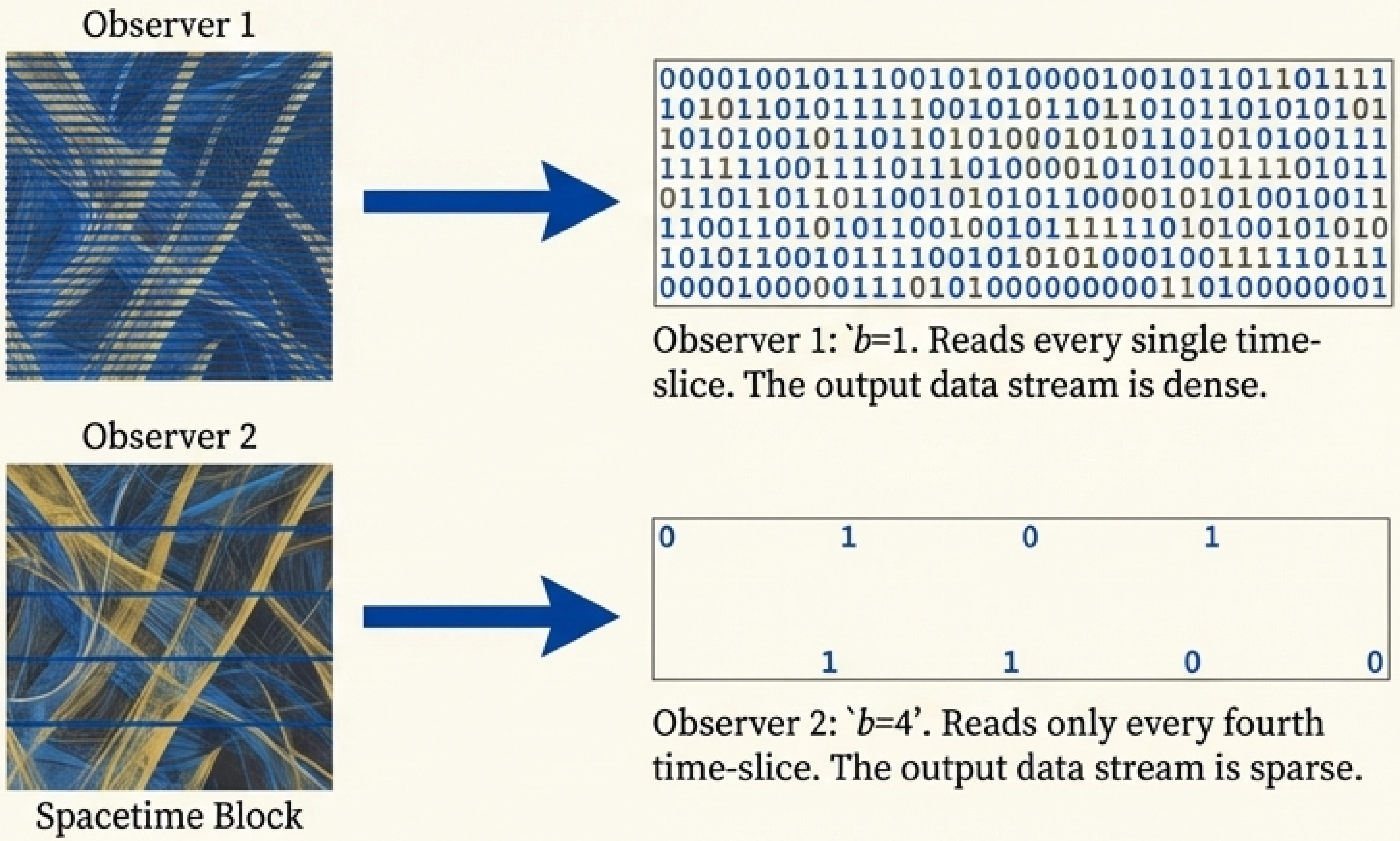
Acceptance (F):

All states can be accepting ($F = Q$) for safety properties, or a subset for liveness properties.

Prior CA-to-automata results were often informal. EBOC provides an explicit construction with computable complexity bounds. Each accepted infinite word corresponds to a valid history in the static spacetime block.

The Observer in the Machine: Subjective Time

Different observers may adopt different "leaf-progression step-sizes" (*b*'), corresponding to different rates of reading the spacetime block. This is subjective time.



Observer 1: \`*b*=1. Reads every single time-slice. The output data stream is dense.

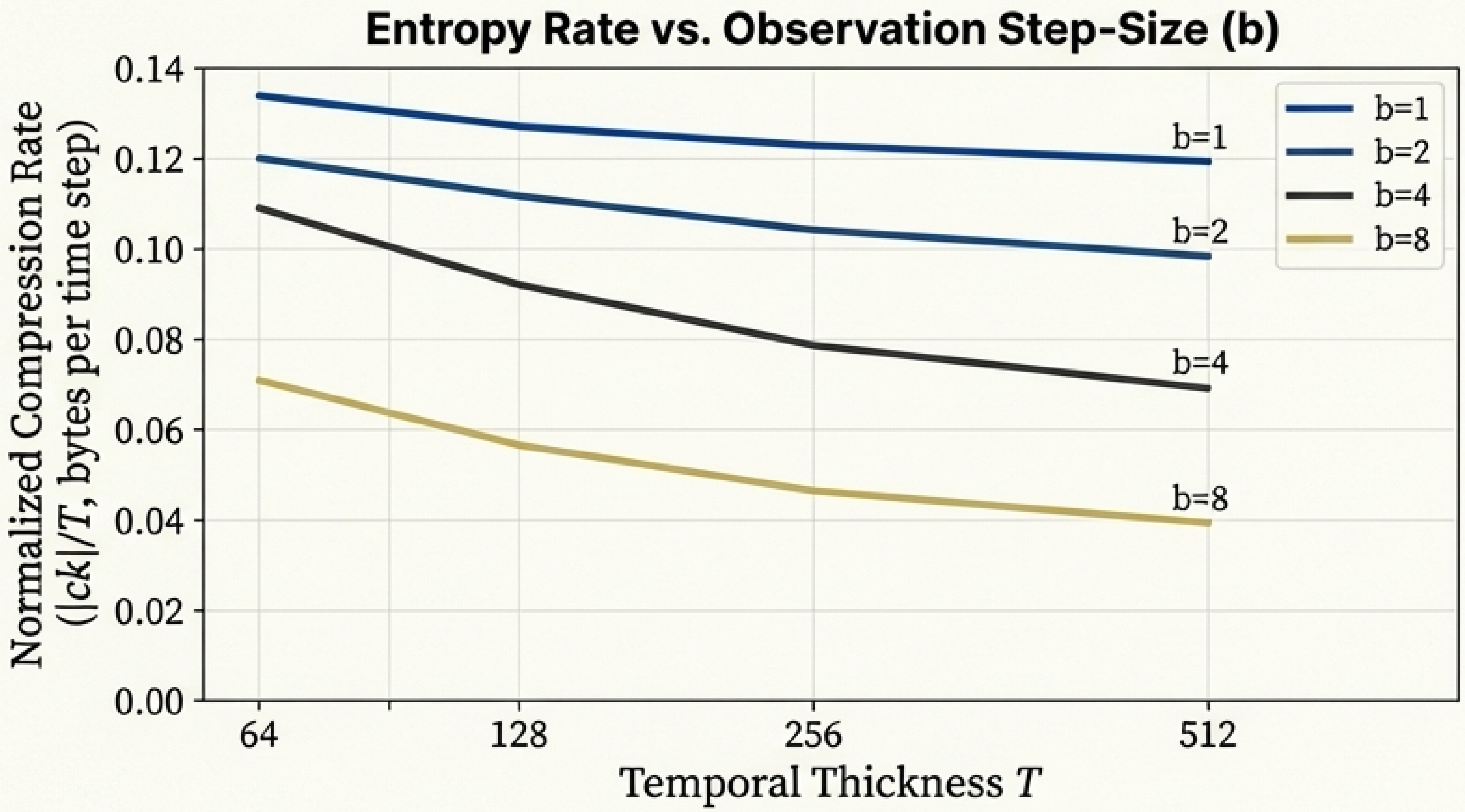
Observer 2: \`*b*=4'. Reads only every fourth time-slice. The output data stream is sparse.

Theorem T17: Subjective Time Rate

The observable entropy rate is \`(1/*b*) * *h*(...)'. It is monotonically lower for a larger step-size *b*' (a 'slower' subjective time).

Subjective time dilation doesn't change the total information in the universe (*Xf*), only the observational density. You see less information per unit of 'objective' time.

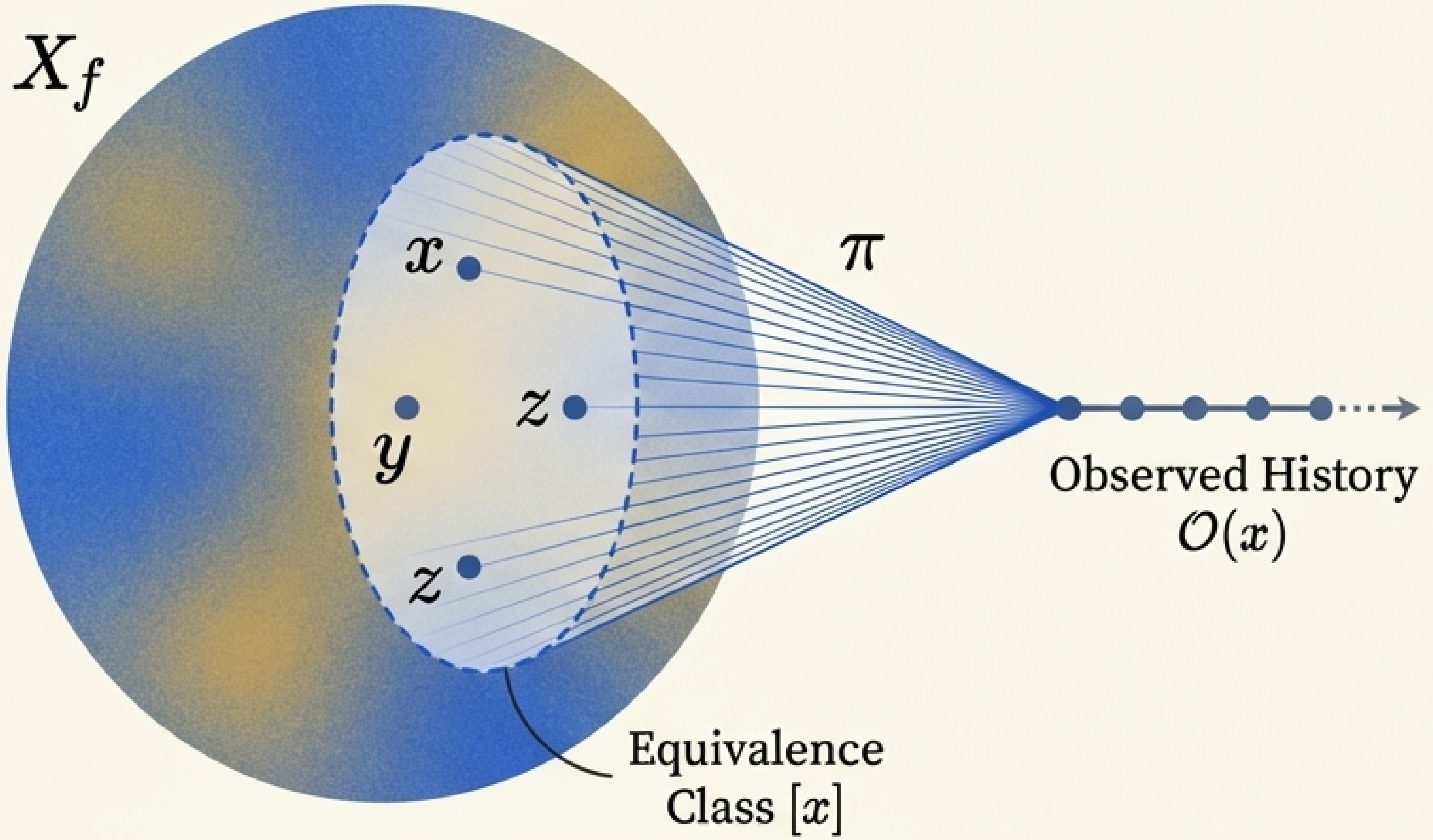
Experimental Verification: Measuring Time Dilation



- **Monotonicity**
  The observed entropy rate decreases as step-size b increases.
- **Scaling**
  At T=512, the rate for b=8 (≈ 0.04 bytes/T) is significantly lower than for b=1 (≈ 0.12 bytes/T), consistent with the predicted $1/b$ scaling.

Slower subjective time (larger b`) reduces the observable information density per unit of underlying temporal thickness.

Reconciling Determinism and Apparent Choice

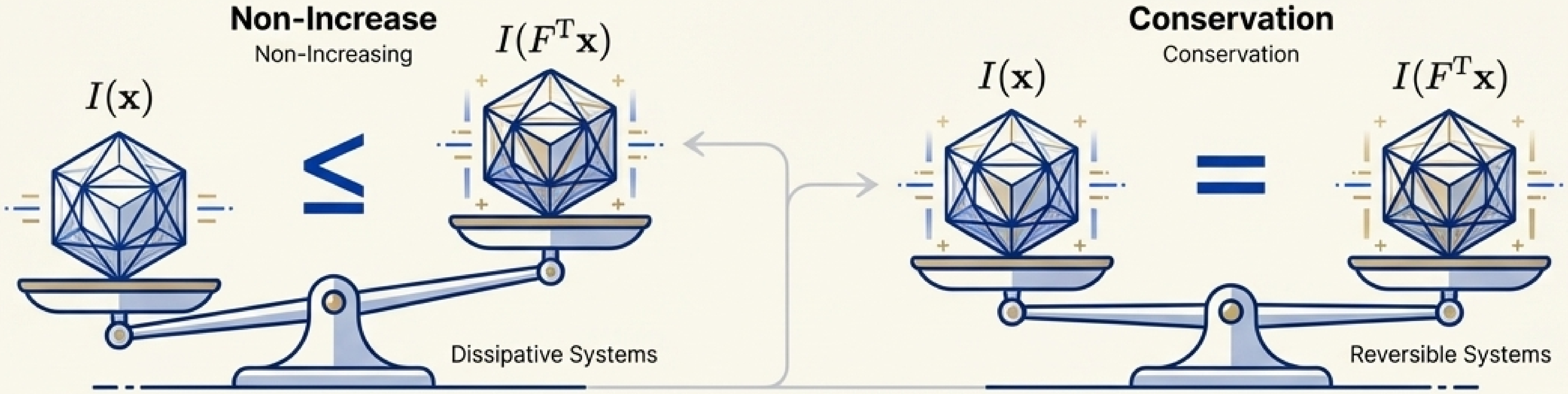


The Unification (T20)

- **Ontological Layer:** The static block X_f is a unique, consistent, deterministic structure.
- **Operational Layer:** The act of “leaf-by-leaf progression” is merely a “representative selection.” The observer perceives a path unfolding, but this act of observation doesn’t create new information (Axiom A3).

The universe (X_f) is like a complete RPG’s game data. The player’s “choice” is just unlocking the plot at a fixed rhythm. The story is already written; the act of playing it doesn’t change the underlying code.

The Laws of Information: Conservation and Reversibility



T21: Information Non-Increase

For any Cellular Automaton, $I(F^T\mathbf{x}) \leq I(\mathbf{x})$. Information **density cannot increase.** This corresponds to dissipative, irreversible systems.

T22: Information Conservation

For a reversible Cellular Automaton, $I(F^T\mathbf{x}) = I(\mathbf{x})$. Information density is strictly conserved.

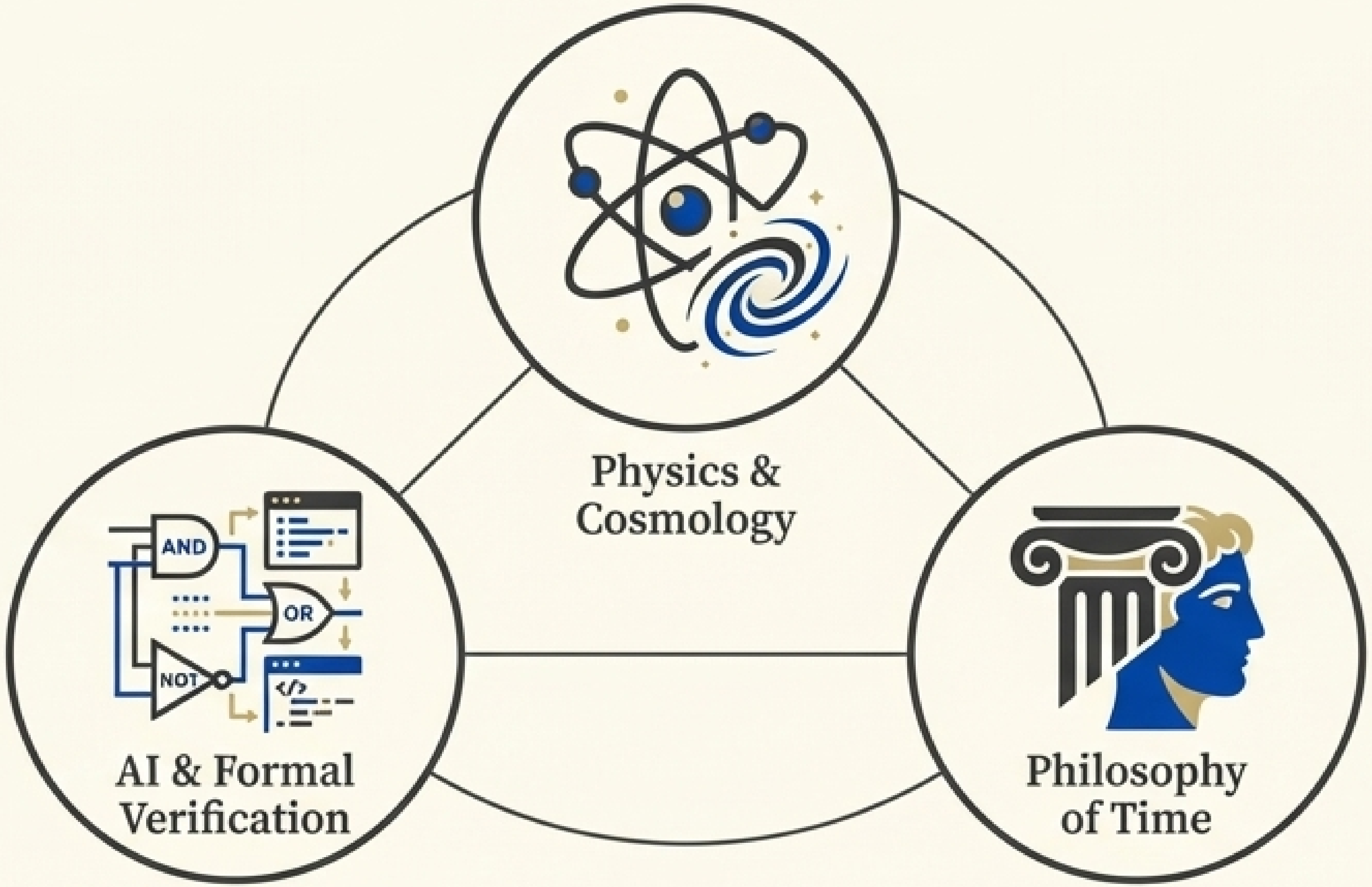
Physical Implications

- **Unitarity:** Reversibility in EBOC is a discrete, computable model for the unitary evolution of physical systems.
- **Information Paradox:** In the EBOC framework, apparent information loss arises solely from the observation factor π (semantic collapse) or from irreversible local rules. The underlying static block of a reversible system maintains strict information conservation.

The EBOC Novelty Map

Category	Key Theorems	Contribution
Core Novel Contributions	T4, T6-T9, T14-T20, T17-T18	Conditional complexity bound via causal thick boundaries; Formalism of Static-Block Unfolding (SBU) reconciling choice and determinism; Subjective time with multiple observers.
Significant Refinements	T2, T5, T10, T13, T21-T22	Re-stating standard results (Brudno, ω-languages) with precise hypotheses, explicit complexity bounds, and a rigorous normalization discipline.
Standard Results (for completeness)	T1, T11, T12, T26	Establishing notation and grounding the framework in established concepts (conjugacy, Garden-of-Eden).

A New Foundation for Science and Philosophy



- Provides an information-theoretic foundation for “block universe” interpretations.
- Formalizes the relativity of simultaneity without needing a metric structure.
- Offers a discrete model for holography and information conservation.

- Opens a pathway to apply model checking to dynamical systems (T13).
- T4 bounds can inform resource-aware theorem proving.
- Program synthesis can be achieved via T6-T9 embedding.

- Reconciles the “flow of time” (leaf-by-leaf reading) with the “block universe” (static Xf).
- Provides a deterministic model where “apparent choice” is an observational artifact (T20).

The Horizon: Future Architectures of Reality

Continuous Extension (cEBOC):
Generalizing the framework from discrete grids to continuous systems.

Quantum Inspiration:
Modeling quantum measurement as anchor-switching within the static block, providing a constructive, information-based interpretation.

Category Theory & Coalgebra:
Recasting the framework in the abstract language of modern mathematics to reveal deeper structural properties.

Robustness:
Developing fault-tolerant decoding to ensure the stability of observations in noisy, imperfect systems.