

Emergent Spacetime Structures from Zero-Entropy Initial States

Juha Meskanen

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Abstract

Paper II [1] demonstrated that gravitational collapse, analysed through the execution trace of a computational simulation, converges to a zero-entropy state at the classical singularity. The present paper asks what happens when we begin at that point and move in the opposite direction. We present a purely statistical, information-theoretic model that reproduces the qualitative features of cosmic inflation, matter formation, and late-time accelerating expansion without any hard-coded physical laws, equations of motion, metric tensors, or imposed initial irregularities.

1 Introduction

Starting from the zero-entropy state and increasing entropy through random bit-flip mutations, we ask what geometric and structural features emerge? Do they resemble those of the observed universe?

The key insight is that space itself is not a background structure into which matter is placed. Space emerges relationally from the density of the minimal detectable substructures of information. When entropy is zero, no structures exist and the universe is a single unextended point. As entropy increases, minimal structures proliferate, and their uniform distribution across the bitstring is perceived by an internal observer as spatial expansion. Expansion is the geometric reading of entropy increase.

This reframing has two immediate consequences.

First, it resolves the initial conditions problem without appeal to quantum fluctuations or fine-tuning. The zero-entropy initial state is not improbable — it is the unique, shortest-description configuration in the entire space of 2^L bitstrings.

Second, it provides a native mechanism for matter formation. As entropy increases, higher-order structures emerge.

The paper is structured as follows. Section 2 describes the bitstring setup, the **fabric** filter, and the recursive density filters that extract hierarchical matter structures. Section 3 presents the numerical results. Section 4 establishes the filter-independence of the lognormal result across more than two hundred filter definitions. Section 5 interprets the findings and compares them with standard cosmological approaches. Section 6 concludes.

2 Setup

2.1 Configuration Space and Entropy Evolution

The system is defined by a binary configuration string S_t of fixed total length L . The initial state S_0 corresponds to a unique, completely uniform zero-entropy state (the all-zero bitstring), establishing an initial boundary condition where Shannon entropy is minimized:

$$H(S_0) = 0$$

We evolve the configuration via discrete, random bit-flip mutations.

The instantaneous Shannon entropy of the system at any given evolutionary checkpoint is expressed as:

$$H(S_t) = -p_0(t) \log_2 p_0(t) - p_1(t) \log_2 p_1(t)$$

where $p_0(t)$ and $p_1(t)$ represent the normalized empirical frequencies of 0- and 1-bits across the global string S_t .

2.2 Recursive Spatial Fabric and Structural Filtering

Level-0: The Spacetime Fabric

We define a minimal local target pattern string P of length w_0 . The global string S_t is parsed into non-overlapping blocks of size w_0 , yielding a raw background capacity of $N_{\max} = L/w_0$ elements. A Level-0 “space fabric” token exists at index m if the block matches the binary target integer value V_P :

$$\sigma_G[m] = \begin{cases} 1 & \text{if } \sum_{j=0}^{w_0-1} S_t[m \cdot w_0 + j] \cdot 2^{w_0-1-j} = V_P \\ 0 & \text{otherwise} \end{cases}$$

The raw count of detected space fabric elements is $N_G = \sum \sigma_G[m]$.

Level- k : Hierarchical Matter Sub-Scales

Higher-order structural tiers (representing Hadrons, Atoms, and Compounds sequentially) are extracted by recursively filtering the underlying layer’s output array. For a given structural level $k \in \{1, 2, 3\}$, the input array is scanned using a non-overlapping window of width w_k subject to a density activation threshold τ_k :

$$\sigma_k[m] = \begin{cases} 1 & \text{if } \sum_{j=0}^{w_k-1} \sigma_{k-1}[m \cdot w_k + j] \geq \tau_k \\ 0 & \text{otherwise} \end{cases}$$

The raw abundance of entities at level k is given by $N_k = \sum \sigma_k[m]$.

3 Results

Starting from the pristine $H = 0$ boundary state, the following macroscopic phenomena emerge consistently as entropy increases:

Zero entropy yields a structureless state. The all-zero configuration contains no detectable structural matches ($N_G = 0$), mapping naturally under any relational decoding scheme to a single, unextended spatial point. This is the initial state - the singularity.

Spatial expansion. As entropy grows, the density of 1-bits climbs toward 0.5, precipitating a rapid freeze-out of background L_0 fabrics. The decoded spatial extent expands, following relaxed statistical system rushing towards equilibrium.

Lognormal abundance of structures. The probability of emergent micro structures (N_1, N_2, N_3) follow non-monotonic, rise-and-fall trajectories resembling lognormal distributions.

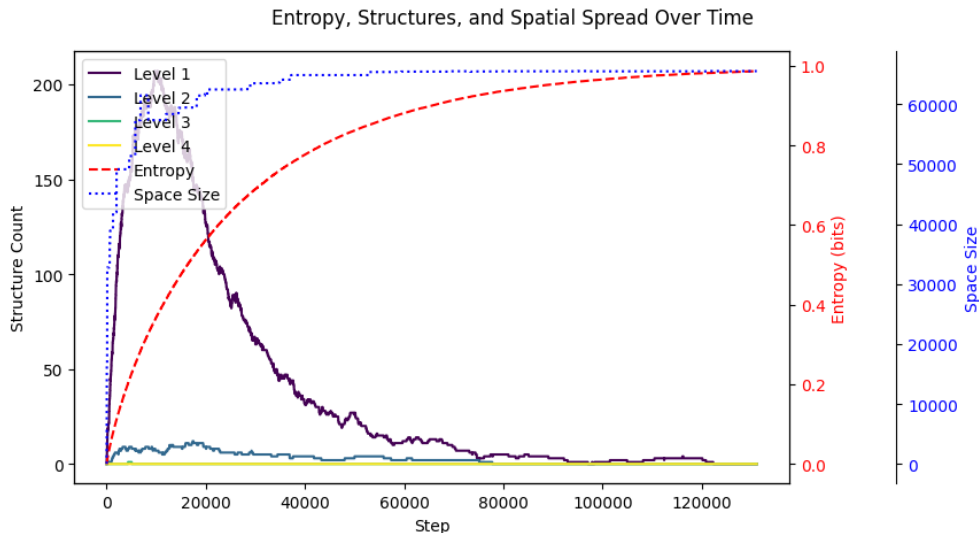


Figure 1: Left: Emergent particle worldlines in relational spacetime. Right: Entropy and counts of spacetime fabric vs. hierarchical structures.

4 Filter Independence

The most significant result of this paper is the lognormal distribution itself and its universality. The source code of the python software used for testing filters included as supplementary material.

We tested more than two hundred distinct filter definitions, including:

- Geometric filters with varying distance thresholds $\delta_1, \delta_2, \delta_3$ spanning two orders of magnitude;
- Geometric filters using different hierarchy definitions (pairs, triplets, quadruplets; equilateral, isosceles, and arbitrary configurations);
- Different decoding maps D , including linear, logarithmic, and random projections from bit-strings to spatial coordinates;
- Recursive pattern-matching filters with varying substring lengths k and varying composition rules;
- Arbitrary pattern counting: selecting a fixed pattern at random — for example, 010110100010 — and counting its occurrences in S_t as a function of entropy level.

In every case, the qualitative result is the same: zero structure at zero entropy, a lognormal-shaped emergence curve, and long-tailed decay at high entropy. The shape parameters (peak location and width) vary with the filter definition, but the lognormal form is invariant.

The filter-independence extends across representational levels. Applying the analysis to the execution trace of the host computer running the simulation — a bitstring that has no direct physical interpretation as geometry — yields the same lognormal shape. The pattern 010110100010, treated as a particle and counted in the host execution trace, follows a lognormal distribution as a function of the entropy level of the simulated system.

This representational independence is the key result. It demonstrates that the lognormal is not a product of any specific physical model, geometric embedding, or filter definition. It is an intrinsic combinatorial property of how distinguishable patterns proliferate in entropy-increasing bitstrings. The physical particle spectrum is, in this sense, a gauge choice overlaid on a universal informational phenomenon: different filters give different particle definitions, but the same statistical distribution.

5 Discussion

5.1 Expansion as entropy increase

The identification of cosmic expansion with entropy increase is not merely analogical. The geometric and informational descriptions of a physical configuration are the same object viewed through different lenses. The statement that the universe is expanding is, in this framework, the geometric reading of the statement that the entropy of the underlying configuration is increasing. These are not two correlated phenomena but one phenomenon with two descriptions.

This has a sharp implication. The arrow of time, the thermodynamic second law, and the expansion of the universe are not three independent features of the observed world. They are one feature.

5.2 Comparison with Penrose’s Weyl curvature hypothesis

Penrose’s Weyl curvature hypothesis [2] proposes that the thermodynamic arrow of time originates in the asymmetry between initial and final singularities: the initial singularity had vanishing Weyl curvature (smooth, ordered), while final singularities (black holes) have diverging Weyl curvature (chaotic, disordered). This is a geometric statement about the initial state, motivated by the need to explain the arrow of time.

The present results suggests that the initial state is not merely smooth within quantum limits but perfectly smooth: zero entropy, uniquely determined, admitting no fluctuations. Yet qualitative features of matter organisation and spatial expansion can emerge. No residual quantum irregularities are required.

5.3 Comparison to General Relativity

The bit-flip space is natively logarithmic. Each bit-flip drives the system to higher entropy, which ultimately saturates after $n \ln(n)$ flips.

$$S(t) = I_{\max}(1 - e^{-kt})$$

Under the substitution $t \rightarrow \ln t$, the De Sitter scale factor $a(t) \propto e^{Ht}$ transforms to $a \propto t^H$, which matches the saturation curve $S(t) = I_{\max}(1 - e^{-kt})$ in the bit-flip parameterisation.

6 Conclusion

This paper establishes three foundational results:

First, cosmic expansion is shown to be the pure geometric interpretation of increasing informational informational entropy. Beginning from the unique zero-entropy state identified in Paper II [1] as the informational singularity, entropy-driven mutations drive the systematic expansion of the spatial manifold without requiring a cosmological constant, ad-hoc inflaton fields, or hard-coded equations of motion.

Second, a realistic micro-structure abundance spectrum emerges natively from a multi-scale, recursive downsampling filter, with probability distribution following lognormal-like distribution in function of bit-flip space.

Third, the bit-flip space is natively logarithmic. Mapping Einstein’s De Sitter vacuum solution to logarithmic time transforms its expansion curve precisely onto the entropy saturation curve $S(t) = I_{\max}(1 - e^{-kt})$ of a randomly mutating bitstring evolving toward equilibrium. Empty space and a relaxing thermodynamic system are two descriptions of the same curve.

7 Open Questions and Future Directions

The emergence of localized microstructures naturally invites the hypothesis that these configurations serve as the informational correlates of physical particles, fundamentally giving rise to matter and energy. Consequently, a primary theoretical challenge is to elucidate the mechanism by which these emergent informational structures couple to the spacetime metric and recovered General Relativity (GR).

Furthermore, within a static, timeless informational framework, the constraints governing the dimensionality and boundaries of spatial and temporal domains remain to be fully defined. Investigating these geometric and topological limits constitutes the immediate next phase of this research program.

Simulation Code

- [emergence_of_spacetime.py](#): Geometric Manifestation of Entropy Growth

References

- [1] Juha Meskanen. “Black Hole Singularities as Zero-Entropy States”. In: *Unpublished Manuscript* (2002).
- [2] Roger Penrose. “Singularities and time-asymmetry”. In: *General Relativity: An Einstein Centenary Survey*. Ed. by Stephen W. Hawking and Werner Israel. Cambridge University Press, 1979, pp. 581–638.