Space-time Curvature as an Information-Theoretic Structure

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June 2026

Abstract

Papers I–IV [3, 1, 2, 4] established that the universe can be modelled as a finite, static bitstring of n bits; that gravitational collapse converges to a zero-entropy singularity; that expansion from that singularity is the geometric reading of entropy increase; and that the aspect ratio of spacetime is determined by n alone. The present paper takes these results further by deriving a relational scale factor from strict information conservation. Because the bit budget is fixed, every bit locked into a composite matter structure is withdrawn from the free spacetime fabric, reducing the resolution of observable space as perceived by internal observers. This single counting principle reproduces, without free parameters, the two boundary solutions of General Relativity — De Sitter vacuum and the Schwarzschild singularity — as the natural extremes of one equation, and recovers the three-phase expansion profile of standard cosmology (early rapid growth, matter-driven deceleration, late-time acceleration) from analytically defined lognormal matter abundance curves established in Paper III [**2003**].

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1 Introduction

General Relativity admits two extreme solutions that appear, at first sight, to be unrelated. De Sitter space describes a universe with no matter and a positive cosmological constant, expanding exponentially without bound. The Schwarzschild solution describes the opposite extreme: all mass concentrated at a single point, spacetime contracted to a singularity. Between these extremes, the Friedmann equation governs the observed universe — an expanding geometry whose rate of expansion is modulated by the density of matter and vacuum energy.

The present paper shows that these three are not independent results but three consequences of a single information-theoretic counting principle. When the universe is modelled as a closed system of n bits, partitioned at each moment between free spacetime fabric and composite matter structures, the scale factor perceived by an internal observer is the fraction of the bit budget that remains independently addressable. De Sitter and Schwarzschild emerge as the two limiting cases of this fraction. The Friedmann three-phase profile emerges when matter abundance follows the lognormal distribution established in Paper III.

No metric tensor is postulated. No force law is imposed. No cosmological constant is introduced as a free parameter. The expansion history of the universe is the geometric reading of information conservation.

The paper is structured as follows. Section 2 derives the relational scale factor from the counting argument and identifies the two GR extremes. Section 3 presents the three-phase expansion profile produced by the analytical lognormal model. Section 4 maps the framework onto Friedmann variables. Section 5 discusses the results. Section 6 states the three foundational results. Section 7 identifies open problems.

2 Setup

2.1 Information Conservation

The universe is modelled as a closed informational system with a fixed total bit count n. From Paper III, random bit-flip mutations drive the system from a zero-entropy initial state toward full equilibrium, and filters applied to the evolving bitstring extract hierarchical micro-structures whose abundances follow lognormal-like distributions. Paper III further established that this lognormal form is independent of the filter definition: it is an intrinsic combinatorial property of entropy-increasing bitstrings.

At any moment, the n bits are partitioned between two roles:

- **Spacetime fabric** L_0: bits not consumed by any composite structure, constituting the free background metric.
- **Matter hierarchy** $L_1, L_2, \ldots$: bits bound into composite structures at successive levels (e.g. hadrons, atoms, compounds).

Because the bit budget is fixed, matter structures do not represent new information injected from outside. Every bit locked into a composite entity is a bit withdrawn from the free fabric. Information is strictly conserved:

$$\rho_{\text{fabric}}(t) = n - m(t), \tag{1}$$

where $m(t) = \sum_k w_k \cdot k(t)$ is the total number of bits consumed by matter structures, $k(t)$ is the count of composite entities at each level, and w_k is the bit-width of a level-k structure.

2.2 The Relational Scale Factor

There is no external observer. An internal observer can only measure distances using the structures available within the system. The resolution of observable space is therefore the total count of independently addressable entities — both free fabric tokens and composite matter structures.

Consider n bits, all initially free fabric, giving resolution n. When one composite structure of width w bits emerges, w fabric tokens are consumed and one matter entity is created. The new resolution is:

$$(n - w) + 1 = n - (w - 1).$$

Resolution decreases by $w - 1$ for every composite entity formed. Generalising, if matter structures collectively consume $m(t)$ bits and produce $k(t)$ composite entities, the total resolution at time t is:

$$\text{Resolution}(t) = \big(n - m(t)\big) + k(t).$$

The two extremes of General Relativity follow immediately from this counting argument:

- **De Sitter limit** ($m = 0,\ k = 0$): all bits are free fabric. Resolution $= n$. An external observer sees pure exponential expansion — the vacuum solution of General Relativity with $\Lambda > 0$ and $\rho_{\text{matter}} = 0$.
- **Schwarzschild limit** ($m = n,\ k = 1$): all bits are consumed into a single composite entity. Resolution $= 1$. The observable space has contracted to a single point — the informational counterpart of the black hole singularity established in Paper II [1].

These are not boundary conditions imposed by hand. They are the two extreme values of the same counting equation, separated by the continuous family of states in between.

The relational scale factor, normalised to the maximum resolution n, is:

$$R(t) = \frac{\big(n - m(t)\big) + k(t)}{n} = \frac{\rho_{\text{fabric}}(t) + k(t)}{n}. \tag{2}$$

This definition requires no external metric and no postulated background geometry. It is a pure counting statement: the scale factor is the fraction of the bit budget that remains independently addressable.

2.3 Analytical Lognormal Model

Paper III demonstrated that the abundance of any extractable structure in an entropy-increasing bitstring follows a lognormal-like distribution as a function of bit-flip time, independently of the filter used to define the structure. The present paper therefore replaces the bitstring simulation with analytically defined lognormal abundance curves for each matter level L_k, each parametrised by a peak location μ_k, width σ_k, and amplitude A_k:

$$k_j(t) = A_j \cdot \frac{1}{t\sigma_j\sqrt{2\pi}} \exp\left(-\frac{(\ln t - \mu_j)^2}{2\sigma_j^2}\right), \qquad j \in \{1,2,3\}.$$

The free fabric at each step is the residual after subtracting the bits consumed by all matter levels:

$$\rho_{\text{fabric}}(t) = \max\left(n - \sum_j w_j \cdot k_j(t),\ 0\right).$$

The scale factor $R(t)$ is then computed from equation (2). The interactive simulation described in Section 7 allows the lognormal parameters and n to be adjusted in real time, with the spacetime resolution visualised by dynamically rescaling rulers.

3 Results

Figure 1 shows the scale factor $R(t)$ and matter abundance curves $k_1(t), k_2(t), k_3(t)$ for one representative parameter set. Three phases are visible:

Phase 1 — Early rapid expansion. Before significant matter formation, the fabric is undepleted and $R(t) \approx 1$. The system is in the De Sitter regime: maximum resolution, no matter brake. This corresponds to the inflationary epoch established in Paper IV [4].

Phase 2 — Matter-driven contraction. As L_1, L_2, and L_3 structures rise along their lognormal curves, bits are withdrawn from the free fabric. $R(t)$ decreases. An internal observer, whose measuring rods are built from the same structures, perceives this withdrawal as a slowing and reversal of expansion — the informational analogue of gravitational deceleration. No force law is imposed; the geometry tightens because information is redistributed.

Phase 3 — Late-time re-expansion. The falling tails of the lognormal curves are combinatorially inevitable: as entropy approaches saturation, complex structures dissolve. Bits are released back to the free fabric, $\rho_{\text{fabric}}(t)$ recovers, and $R(t)$ rises again. An internal observer perceives this release as accelerating expansion. No cosmological constant is introduced; the acceleration is the geometric reading of structural evaporation in a saturating information field.

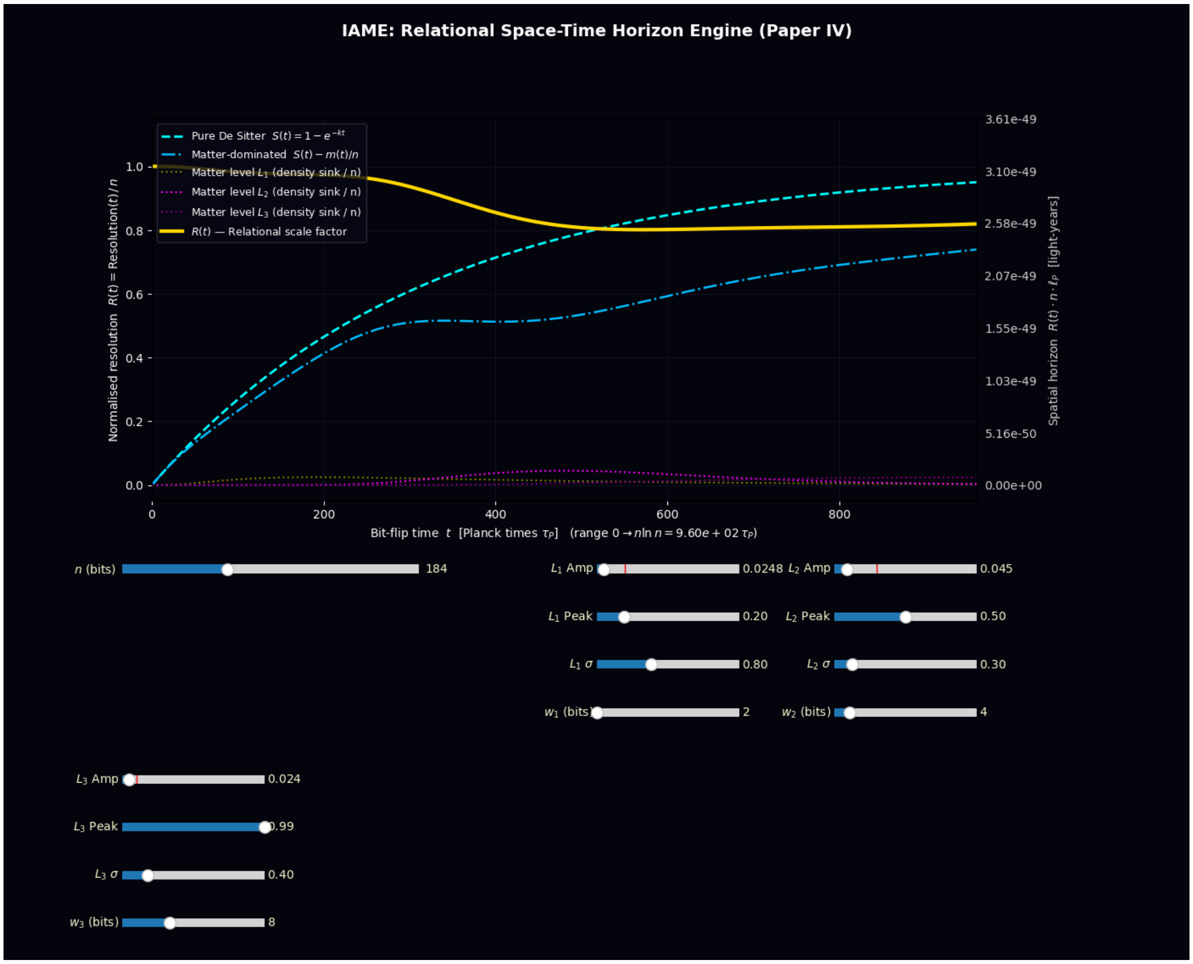
4 Mapping to General Relativity

The Friedmann equation governs the expansion of a homogeneous, isotropic universe in General Relativity:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho_{\text{matter}} + \frac{\Lambda}{3}.$$

The present framework maps onto this equation under the identifications:

$$\rho_{\text{matter}} \;\longleftrightarrow\; \frac{\sum_j k_j(t)}{n}, \qquad \Lambda \;\longleftrightarrow\; \frac{\rho_{\text{fabric}}(t)}{n}, \qquad a \;\longleftrightarrow\; R(t). \tag{3}$$



n (bits) 184

L_1 Amp 0.0248

L_2 Amp 0.045

L_1 Peak 0.20

L_2 Peak 0.50

L_1 σ 0.80

L_2 σ 0.30

w_1 (bits) 2

w_2 (bits) 4

L_3 Amp 0.024

L_3 Peak 0.99

L_3 σ 0.40

w_3 (bits) 8

Figure 1: Output of the Space-Time Horizon Engine for one representative parameter set ($n = 1.6$, three lognormal matter sinks). The cyan dashed curve shows the pure De Sitter background $S(t)$ — the expansion that would be observed in the absence of any matter. The yellow curve (*Real Universe Geometry*) is the relational scale factor $R(t)$: the De Sitter background depleted by the bits consumed by three hierarchical matter structures (dark matter, hadrons, neutrinos), each following an independently parametrised lognormal abundance curve (dotted lines, lower portion of plot). The vertical red dashed line marks a reference epoch. Two features are immediately visible: first, the yellow curve tracks the De Sitter background closely at early and late times, departing from it during the epoch of peak matter abundance; second, the departure produces a visible deceleration followed by late-time re-acceleration as the matter curves fall. Both features emerge from information conservation alone, with no cosmological constant, inflaton field, or dark energy term introduced. The interactive simulator allows all lognormal parameters and n to be adjusted in real time; the figure shows one illustrative configuration.

These identifications are not free parameters. They follow from the counting argument: matter entity density maps to ρ_{matter} because matter entities brake expansion by consuming fabric; free fabric density maps to Λ because it drives expansion by providing addressable resolution. The cosmological constant is not a parameter of the vacuum energy — it is the fraction of the bit budget that remains unbound.

The two GR boundary solutions are recovered exactly:

Limit	**Information picture**	**GR solution**
$k = 0,\ m = 0$	All bits free, $R = 1$	De Sitter ($\Lambda > 0$, $\rho = 0$)
$k = 1,\ m = n$	One entity, $R = 1/n$	Schwarzschild singularity

A rigorous proof that $(\dot{R}/R)^2$ is proportional to $k(t)/n + \rho_{\text{fabric}}(t)/n$ requires specifying the lognormal parameters analytically in terms of n. This is identified as the primary open problem in Section 7.

5 Discussion

5.1 Matter as Curvature

In General Relativity, matter curves spacetime through the stress-energy tensor. In the present framework, matter reduces the resolution of observable space by consuming free fabric. These are two descriptions of the same phenomenon: the presence of a composite structure makes the surrounding space less addressable, which an internal observer reads as curvature. Gravity is not a force acting on a background geometry; it is the geometric consequence of information being redistributed from fabric to structure.

5.2 The Cosmological Constant Problem

The cosmological constant problem asks why Λ is so small relative to the vacuum energy predicted by quantum field theory. In the present framework, Λ is not a property of the vacuum — it is the fraction of the bit budget that is currently unbound. Its value at any cosmic epoch is determined by how much matter has formed and how much has decayed. The problem dissolves: there is no vacuum energy to cancel, only a fabric density that evolves with the entropy of the universe.

5.3 No External Time

The bit-flip parameter t is not an external clock. It is the internal measure of entropy increase established in Papers I–IV. The expansion history of the universe is parameterised by how far the system has progressed from zero entropy toward full saturation, not by an absolute time coordinate. This is consistent with the static, timeless picture of Paper I: the entire expansion history is encoded in n, and t is the internal observer's reading of their position along the entropy gradient.

6 Conclusion

This paper establishes three results.

First, De Sitter space and the Schwarzschild singularity are the two extreme values of a single counting equation — the relational scale factor $R(t)$ defined by information conservation. De Sitter corresponds to all bits free ($R = 1$); Schwarzschild corresponds to all bits bound into one entity ($R = 1/n$). General Relativity's two boundary solutions are not independent discoveries but the endpoints of one information-theoretic spectrum.

Second, the three-phase expansion profile of standard cosmology — early rapid growth, matter-driven deceleration, late-time acceleration — emerges from $R(t)$ under lognormal matter abundance, without a cosmological constant, inflaton field, or dark energy term. The acceleration is the geometric reading of structural evaporation as the system approaches entropy saturation.

Third, the Friedmann equation maps onto the framework under explicit variable identifications that follow from the counting argument alone. The cosmological constant is the free fabric fraction; matter density is the bound entity fraction; the scale factor is the addressable resolution fraction. No constants are fitted to observation.

7 Future Work

Analytic Derivation of the Friedmann Equation

The mapping in equation (3) is a structural correspondence, not a proof. A rigorous derivation requires showing that $(\dot{R}/R)^2 \propto k(t)/n + \rho_{\text{fabric}}(t)/n$ holds analytically when $k(t)$ follows a lognormal distribution parametrised by n. This would promote the Friedmann correspondence from an identification to a theorem.

Quantum Fields and the Wave Function

The framework developed in Papers I–V recovers the large-scale structure of spacetime from information conservation. The remaining foundational question is the origin of quantum field dynamics: why does the microcosm behave wave-like, and what selects a particular measurement outcome? This is addressed in Paper VI.

Supplementary Material

The complete interactive Python implementation is available as `simulations/iace.py`. The simulator accepts user-defined lognormal parameters (μ_k, σ_k, A_k) for each matter level and the total bit count n, and visualises the resulting scale factor profile with dynamically rescaling rulers that reflect the changing resolution of observable space. It serves both as an exploratory tool and as an intuitive demonstration of how expansion emerges from internal observer dynamics rather than an absolute stretching of external space.

References

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[4] Juha Meskanen. “The Geometry of Spacetime as an Information-Theoretic Structure”. In: *Unpublished Manuscript* (2026).