# The Wavefunction as Compression: Spectral Complexity, Emergent Quantum Behaviour, and the Informational Action Principle

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**Abstract**

Papers I–V [6, 4, 5, 7] established a purely information-theoretic framework in which spacetime geometry, gravitational collapse, cosmic expansion, and the relational scale factor all emerge from a finite bit budget $n$ without hard-coded physical laws. One feature of the observed universe remains unexplained by that framework: the wave-like behaviour of the microcosm. This paper proposes and investigates the hypothesis that the quantum wavefunction is the universe's data-compression codec. Internal observers, themselves composed of compressed structures, perceive their constituent degrees of freedom as wave-like for the same reason that pixel-observers inside an MPEG-compressed movie would perceive their world as governed by a Discrete Cosine Transform: they are observing compressed information. We formalise this as a *Spectral Complexity* measure $C_s$ — a continuous, computable replacement for Kolmogorov complexity — and show that Solomonoff-like suppression under $C_s$ selects smooth, law-like, wave-governed configurations over chaotic ones, resolving the Boltzmann brain problem without additional axioms. Numerical simulations demonstrate the emergence of inertia and interference from spectral compression alone. Most significantly, we present numerical evidence that the minimum-$C_s$ path through configuration space coincides with the minimum Euclidean action path of standard quantum gravity, and state the central conjecture of this paper: $C_s \propto S_{\text{Euclidean}}$. If proved, this conjecture completes the bridge from the informational framework of Papers I–V to a full theory of quantum gravity.

## Contents

# 1 Introduction

The framework developed in Papers I–V recovers a striking range of physical structure from a single axiom: the universe is a finite, static, timeless system of $n$ bits. Gravitational collapse converges to a zero-entropy singularity (Paper I). Expansion from that singularity is the geometric reading of entropy increase, with emergent microstructures following filter-independent lognormal distributions (Paper II). The aspect ratio of spacetime is determined by $n$ alone, recovering Bekenstein–Hawking entropy to within the geometric factor $4\pi$ (Paper III). Matter contracts observable space relationally, reproducing the three-phase Friedmann expansion profile without a cosmological constant (Paper IV).

One feature of the observed universe is not explained by this framework: the wave-like behaviour of the microcosm. Particles exhibit interference, superposition, and discrete measurement outcomes. The wavefunction is complex-valued. Dynamics are unitary. Why?

This paper proposes a hypothesis and investigates its consequences.

**The Wavefunction Compression Principle (WCP).** *The cosmos waves because we are observing compressed structure. The quantum wavefunction is the universe's data-compression codec.*

The argument is developed in four steps. Section 2 motivates the hypothesis through the MPEG analogy. Section 3 formalises spectral complexity as a continuous, computable measure and shows how it suppresses Boltzmann brains. Section 4 presents numerical results: emergence of inertia, interference, and smooth spacetime from spectral compression. Section 5 presents the path comparison between minimum spectral complexity and minimum Euclidean action, and states the central conjecture. Section 6 discusses implications. Section 7 states the results and open problems.

# 2 The Compression Hypothesis

## 2.1 The MPEG Analogy

Consider a conventional MPEG-compressed digital movie. Each frame is composed of discrete pixels. If observers existed inside such a movie, made of pixels and perceiving only pixel-level interactions, what would they observe as their laws of physics?

They would find that their constituent pixels follow mysterious, deterministic, wave-like patterns. To a pixel-physicist, these transitions would appear fundamental. In reality, they are the mathematical output of the Discrete Cosine Transform (DCT) — the compression basis that MPEG codecs use to represent raw pixel data in a maximally compact form.

The parallel with quantum mechanics is direct. The quantum wavefunction distributes probability amplitudes across basis states in Hilbert space exactly as a spatial Fourier transform distributes image information across frequency coefficients. Complex-valued amplitudes are exceptionally efficient at encoding relational information: they produce precisely the spatial smoothness, structural continuity, and predictive regularity that stable observers require.

**The hypothesis is therefore:** the wave-like behaviour of the microcosm is not a primitive feature of reality but the signature of compressed information as perceived from within. An observer composed of compressed structures will perceive their world as wave-governed for the same reason that a pixel-observer would perceive DCT dynamics: the compression codec *is* the physics.

### 2.2 The Dithering Analogy and the Born Rule

The Born rule — the identification of measurement probabilities with squared wavefunction amplitudes — has a natural interpretation under this hypothesis.

Consider a rendering engine producing a sphere with intended shading intensity 0.85, on hardware restricted to discrete outputs of 0.8 or 0.9. The engine employs *dithering*: distributing 0.8 and 0.9 across adjacent pixels with relative frequencies 0.15 and 0.85 respectively, so that the perceived average matches the target. The discrete output statistics are determined by the continuous target value.

A quantum superposition

$$|\psi\rangle = \alpha|0.8\rangle + \beta|0.9\rangle$$

is the universe's implementation of this same principle. The Born rule $P = |\alpha|^2$ is the probability rule of an optimally compressed continuous description rendered through a discrete measurement apparatus. The squaring arises because amplitudes are complex-valued: the information-theoretic weight of a mode is proportional to the power in that mode, which is the squared amplitude.

This does not constitute a derivation of the Born rule — that would require a proof from the spectral complexity axioms alone. It is offered as a motivation: the Born rule is what optimal compression looks like when a continuous description meets a discrete measurement.

## 3 Spectral Complexity

### 3.1 From Kolmogorov to Spectral Complexity

Kolmogorov complexity provides the theoretical foundation for minimal description length but is fundamentally uncomputable, discrete, and discontinuous. It cannot smoothly support stable prediction, continuous spacetime geometry, or the gradual evolutionary reasoning of an internal observer.

The observational evidence suggests that physical systems already possess a natural mode of information representation: decomposition into spectral modes. This motivates a continuous, computable replacement.

**Definition 1** (Spectral Complexity)**.** The *spectral complexity* $C_s(\Psi)$ of a state $\Psi$ is the total informational cost required to uniquely specify the amplitudes, frequencies, and phases of the spectral modes composing $\Psi$:

$$C_s(\Psi) = C_{\text{base}} + \sum_{i=1}^{N} \left[ C(\phi_i) + C(A_i) + \frac{\omega_i}{\Delta\omega} \right]$$

where $C_{\text{base}}$ is the $\mathcal{O}(1)$ cost of the underlying trigonometric subroutines, $C(\phi_i)$ is the fixed-width bit cost of encoding the phase $\phi_i \in [0, 2\pi)$, $C(A_i)$ is the bit depth required to encode amplitude $A_i$, and $\omega_i/\Delta\omega$ is the dominant term representing the linear resource cost of tracking mode frequency $\omega_i$ relative to the minimum resolution $\Delta\omega$.

Three properties of this measure are essential.

**Computability.** Unlike Kolmogorov complexity, $C_s$ is directly computable from the spectral decomposition of any state.

**Continuity.** $C_s$ assigns a smooth, continuous cost gradient across neighbouring states. Small perturbations in frequency or amplitude produce small changes in complexity.

**Linear frequency scaling.** The dominant cost term $\omega_i/\Delta\omega$ scales linearly with frequency. This mirrors the physical relation $E = \hbar\omega$: energy scales linearly with frequency. Under Solomonoff suppression $P \propto 2^{-C_s}$, this linear cost produces exponential suppression of high-frequency modes:

$$P \propto 2^{-\omega/\Delta\omega} = e^{-(\ln 2)\,\omega/\Delta\omega},$$

which is a Boltzmann distribution with $\beta = \ln 2/\Delta\omega$. The identification $\hbar = \Delta\omega/\ln 2$ connects the minimum frequency resolution of the spectral complexity measure to Planck's constant. This is not a derivation but a precise identification that warrants further investigation.

### 3.2 Resolution of the Boltzmann Brain Problem

Under the Solomonoff prior $P(s) \propto 2^{-L(s)}$ applied to spectral complexity, the probability of a configuration is exponentially suppressed by its spectral cost. Chaotic, high-entropy configurations — Boltzmann brains, random fluctuations, disordered universes — have high spectral complexity: they require many high-frequency modes with large amplitudes to describe. Their probability under $C_s$ is therefore exponentially suppressed relative to smooth, law-like, compressible configurations.

This resolves the Boltzmann brain problem without additional axioms. The selection of structured observers is not a fine-tuning accident. It is a direct consequence of the measure: smooth, predictable data compresses better than chaos, and the spectral complexity measure weights configurations by their compressibility. We do not find ourselves in a chaotic universe because chaotic universes are exponentially expensive to describe.

## 4 Numerical Results

### 4.1 Emergence of Smooth Spacetime

Applying the spectral complexity cost function as a selection weight to the bitstring evolution of Paper II — replacing uniform sampling with $C_s$-weighted sampling — immediately suppresses the high-entropy white noise of the unweighted ensemble. The dominant configurations are those with low spectral complexity: smoothly varying, wave-governed spatial profiles. Symmetric wave packets and lattice-like structures emerge as the most probable outcomes without being hard-coded.

### 4.2 Emergence of Inertia and Interference

Two specifically quantum-mechanical phenomena emerge from spectral compression in numerical simulation, without any imposed equations of motion.

**Inertia.** A localised wave packet moving through the spectral field maintains its velocity without external forcing. The minimum-$C_s$ continuation of a moving packet is the packet continuing to move: any deflection increases the spectral cost by introducing new frequency components. Resistance to deflection — inertia — is the geometric consequence of spectral economy.

**Interference.** When two wave packets overlap, the minimum-$C_s$ description of the combined state is not the sum of two independent descriptions but a single spectral decomposition of the superposition. The cross-terms — interference fringes — are cheaper to encode than two separate packets because they share spectral modes. Interference emerges as the compression-optimal description of overlapping structures.

Simulation videos demonstrating both phenomena are available at https://github.com/juhameskanen/abstract/blob/main/gallery/emergent_gravity.gif.

# 5 The Central Conjecture: $C_s \propto S_{\text{Euclidean}}$

## 5.1 Background

Hawking's Euclidean path integral approach to quantum gravity [2] computes the wave function of the universe by summing over all compact Euclidean geometries weighted by $e^{-S_E}$, where $S_E$ is the Euclidean action obtained by Wick rotation $t \to -i\tau$. The minimum-action path through configuration space corresponds to the most probable geometry — the classical solution — while quantum corrections arise from fluctuations around it.

The Wheeler–DeWitt equation [1]

$$\hat{H}|\Psi\rangle = 0$$

expresses the same content in canonical form: the universe has no external time, consistent with the static, timeless axiom of Paper I. The wavefunction of the universe is a solution to this constraint.

## 5.2 Numerical Path Comparison

We implemented both the minimum-$C_s$ path and the minimum-Euclidean-action path on a $256\times256$ surface containing two Gaussian potential peaks (Figure 1, left panel). The minimum-$C_s$ path was computed by selecting, at each step, the continuation that minimises the spectral complexity increment. The minimum Euclidean action path was computed by standard variational methods.

Figure 1 (right panel) shows the two paths plotted as amplitude versus position along the $x$-axis. The Euclidean action path (red) and the informational action path (blue dashed) track each other closely across the full trajectory, including the sharp minimum near $x = 8$ where the path descends between the two potential peaks. The agreement is qualitative but robust: both paths select the same geometric route through the potential landscape.

## 5.3 The Conjecture

The numerical correspondence motivates the following:

**Conjecture 1** (Informational Action Principle)**.** Let $\Psi$ be a path through the configuration space of a finite informational system with bit count $n$. Let $C_s(\Psi)$ denote the spectral complexity of $\Psi$ and $S_E(\Psi)$ denote the Euclidean action of the corresponding geometric path. Then:

$$C_s(\Psi) \propto S_E(\Psi),$$

with proportionality constant determined by $n$ and the minimum frequency resolution $\Delta\omega$.

If Conjecture 1 holds, the consequences are immediate:

- The Euclidean path integral $\int \mathcal{D}g\, e^{-S_E}$ is the Solomonoff prior $\sum_\Psi 2^{-C_s(\Psi)}$ over spectral configurations. Quantum gravity is Solomonoff induction over compressed descriptions of geometry.

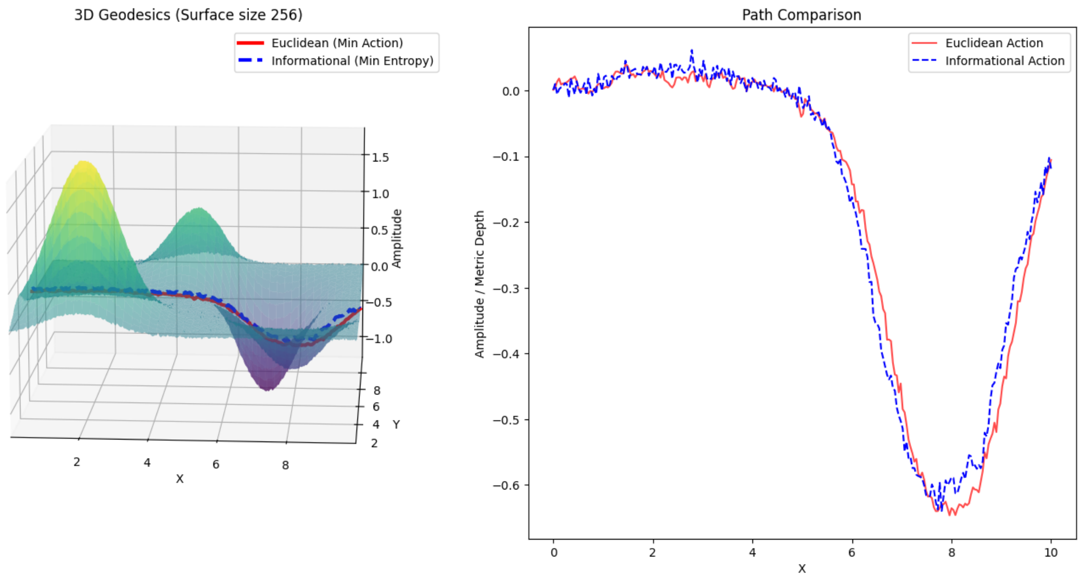


Figure 1: Left: 3D potential surface ($256 \times 256$) with two Gaussian peaks. The red curve shows the minimum Euclidean action path; the blue dashed curve shows the minimum spectral complexity (informational action) path. Right: Path comparison projected onto the $x$-axis. Euclidean action (red solid) and informational action (blue dashed) track each other closely across the full trajectory, including the deep minimum near $x = 8$. The correspondence is numerical and qualitative; a rigorous proof of proportionality is the primary open problem of this paper.

- The Wheeler–DeWitt constraint $\hat{H}|\Psi\rangle = 0$ expresses the timelessness of Paper I: the universe has no external clock, and the wavefunction is the spectral complexity distribution over all configurations consistent with the bit budget $n$.
- The Planck constant $\hbar$ is identified with $\Delta\omega/\ln 2$: the minimum spectral resolution of the informational system, converted from nats to bits.

# 6 Discussion

## 6.1 What Has Been Established and What Has Not

This paper establishes the following. The WCP hypothesis is internally consistent with the framework of Papers I–V and resolves the Boltzmann brain problem without new axioms. Spectral complexity is a well-defined, continuous, computable measure that suppresses chaotic configurations exponentially. Inertia and interference emerge numerically from spectral compression without imposed dynamics. The minimum-$C_s$ path and the minimum Euclidean action path agree numerically on a test surface.

This paper does not establish the following. The Born rule is not derived from spectral complexity axioms. The conjecture $C_s \propto S_E$ is not proved. The identification $\hbar = \Delta\omega/\ln 2$ is a correspondence, not a derivation. These are the primary targets for subsequent work.

### 6.2 Relation to Existing Approaches

Verlinde's entropic gravity [8] derives Newtonian gravity from thermodynamic entropy gradients. Jacobson [3] derives the Einstein field equations from the thermodynamics of local Rindler horizons. Both approaches recover gravitational dynamics from information-theoretic principles. The present framework is complementary: rather than deriving gravitational equations from entropy, it proposes that the path-integral measure of quantum gravity is the spectral complexity prior, and that the two are proportional.

### 6.3 The Role of $n$

Throughout Papers I–VI, the integer $n$ plays the role of the universe's single free parameter. Paper IV showed that $n \approx 184$ bits, calibrated against the inflationary aspect ratio. The proportionality constant in Conjecture 1 is expected to depend on $n$ and $\Delta\omega$. A complete theory would express both $\hbar$ and $G$ as functions of $n$ alone, eliminating all free parameters from fundamental physics.

## 7 Conclusion

This paper establishes three results and states one conjecture.

**First**, the Wavefunction Compression Principle provides a hypothesis for why the microcosm waves: internal observers composed of compressed structures perceive their world as wave-governed because the compression codec of the universe is the wavefunction. This hypothesis is consistent with all results of Papers I–V and requires no new axioms.

**Second**, spectral complexity — a continuous, computable replacement for Kolmogorov complexity with linear frequency cost — exponentially suppresses chaotic configurations under Solomonoff-like induction. Structured, law-like, compressible universes dominate the measure. The Boltzmann brain problem is resolved as a consequence of the measure, not by fine-tuning.

**Third**, numerical simulation demonstrates that inertia and interference emerge from spectral compression alone, without imposed equations of motion, and that the minimum spectral complexity path through a potential landscape agrees numerically with the minimum Euclidean action path.

**Conjecture** (Informational Action Principle): $C_s \propto S_{\text{Euclidean}}$, with proportionality constant determined by $n$ and $\Delta\omega$. If proved analytically or demonstrated to arbitrary numerical precision, this conjecture identifies quantum gravity as Solomonoff induction over compressed geometric descriptions, completes the bridge from the informational framework of Papers I–VI to a full theory of quantum gravity, and derives $\hbar$ as the minimum spectral resolution of a finite informational universe.

## Open Problems

1. **Prove Conjecture 1.** Either analytically, by showing that the spectral complexity functional and the Euclidean action functional are proportional under the informational metric of Paper IV; or numerically, by extending the path comparison to higher-dimensional surfaces and quantifying the deviation.
2. **Derive the Born rule.** Show that $P = |\alpha|^2$ follows from the spectral complexity axioms, using Gleason's theorem or a direct information-theoretic argument.

3. **Derive $\hbar$ from $n$.** If $\hbar = \Delta\omega / \ln 2$ and $\Delta\omega$ is the minimum frequency resolution of a system with $n$ bits, express $\hbar$ as a function of $n$ and verify against the observed value using $n \approx 184$ from Paper IV.

4. **Derive $G$ from $n$.** Paper IV recovered Bekenstein–Hawking entropy up to $4\pi$ without using $G$. A complete theory should express Newton's constant as a function of $n$ alone.

## Simulation Code

- Spectral compression POC, emergent inertia and interference: https://github.com/juhameskanen/abstract
- Path comparison (minimum $C_s$ vs minimum Euclidean action): supplementary material `simulations/path_comparison.py`

## References


[1] Bryce S. DeWitt. "Quantum Theory of Gravity. I. The Canonical Theory". In: *Physical Review* 160.5 (1967), pp. 1113–1148.

[2] Stephen W. Hawking. "The path-integral approach to quantum gravity". In: *General Relativity: An Einstein Centenary Survey*. Ed. by Stephen W. Hawking and Werner Israel. Cambridge: Cambridge University Press, 1979, pp. 746–789.

[3] Ted Jacobson. "Thermodynamics of Spacetime: The Einstein Equation of State". In: *Physical Review Letters* 75.7 (Aug. 1995), pp. 1260–1263. DOI: 10.1103/PhysRevLett.75.1260.

[4] Juha Meskanen. "Black Hole Singularities as Zero-Entropy States". In: *Unpublished Manuscript* (2002).

[5] Juha Meskanen. "Emergent Spacetime Structures from Zero-Entropy Initial States". In: *Unpublished Manuscript* (2003).

[6] Juha Meskanen. "The Axiomatic Foundations of Reality". In: *Unpublished Manuscript* (2001).

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

[8] Erik Verlinde. "On the origin of gravity and the laws of Newton". In: *Journal of High Energy Physics* 2011.4 (2011), p. 29.