Regular Simplex Hierarchical Gravity Part II: The Computational Universe: Deriving Spacetime, Light Speed, and Singularities from Infinite-Dimensional Simplex and Geometric Frustration

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Einstein's special relativity postulates the constancy of light speed c as an axiom but provides no explanation for its origin. We reformulate the universe as a discrete computational network operating at the Planck scale, wherein c emerges not as a fundamental constant but as the bandwidth limit of information processing. We demonstrate that the initial state of the universe—an infinite-dimensional regular simplex—possesses spectral properties (Laplacian eigenvalue $\lambda_2 = N$) that naturally enforce cosmic uniformity and clock synchronization without invoking inflationary expansion. Dimensional reduction from infinite to three dimensions generates an unavoidable informational collision, which we term *informational Pauli repulsion*, providing the physical driver for both the Big Bang and accelerated expansion. The deficit angle $\delta \approx 7.36^\circ$ inherent in the 600-cell tessellation, combined with Gauss's *Theorema Egregium*, guarantees spatial closure without external embedding dimensions, thereby establishing a decisive advantage over string-theoretic frameworks requiring 10 or 11 dimensions. We derive the *Light-Speed Resource Allocation Principle* (LRAP), $c^2 = v^2 + \tau^2$, reinterpreting the Lorentz factor as a processing lag ratio rather than a coordinate transformation coefficient. Black hole singularities are redefined as *computational arrest* regions where 3D rendering fails, leaving 4D data in a frozen state—a paradigm shift that naturally subsumes string theory and the holographic principle as effective descriptions within these arrested zones. Finally, we prove that local resource allocation alone cannot resolve the global accumulation of geometric frustration, necessitating the hierarchical jamming transitions detailed in Part III. This work bridges the static geometry of Part I (derivation of G and Λ) with the thermodynamic hierarchy of Part III (122-digit vacuum energy suppression), completing the dynamical core of the Regular Simplex Hierarchical Gravity (RSHG) framework.

I. INTRODUCTION

A. The Origin Problem of Light-Speed Invariance

Albert Einstein's 1905 special relativity stands as a cornerstone of modern physics, founded upon a principle as elegant as it is enigmatic: *"The speed of light in vacuum is constant, independent of the motion of the source or observer."* From this axiom flow revolutionary consequences—time dilation, length contraction, mass-energy equivalence ($E = mc^2$)—that have withstood a century of experimental scrutiny.

Yet Einstein himself acknowledged a fundamental lacuna: special relativity does *not* explain *why* c assumes its particular value, nor *why* it constitutes an absolute speed limit [1]. The constancy of light speed remains an *assumption*, not a *derivation*.

In standard field theory, c emerges from vacuum permittivity ϵ_0 and permeability μ_0 via $c = 1/\sqrt{\epsilon_0 \mu_0}$ [2]. However, this merely displaces the question: why does the vacuum possess precisely those electromagnetic properties? Similarly, quantum gravity frameworks—loop quantum gravity [3, 4], string theory [5], causal dynamical triangulations [6]—introduce discrete spectra or higher dimensions but ultimately import c as an external parameter rather than deriving it from first principles.

B. The Computational Paradigm Shift

We propose a radical reconceptualization. The universe is not a continuous spacetime manifold but a *discrete computational network* executing at the Planck scale. In this paradigm, spacetime is not a "container" for existence but an *emergent property of computational processes*—specifically, the unavoidable artifacts arising when infinite-dimensional information undergoes projection onto finite-dimensional coordinates.

Consider a computer rendering a 3D scene from 4D data. The pixel coordinates are discrete addresses (*truth*); the blur, aliasing, and frame-rate drops constitute observable "physics." In our framework:

- **Spacetime** is not fundamental but the rendering output of 4D → 3D projection
- **Light speed** c is the computational clock frequency: $c = l_P/t_P$
- **Mass** is information density concentrated by projection caustics
- **Gravity** is stress from 4D bulk data compressed into 3D brane coordinates
- **Time's arrow** is computational irreversibility (NP-hardness of tetrahedral packing)

This reframing transforms foundational questions:

$$\begin{aligned}
\text{“What is } c\text{?”} &\to \text{Clock rate of lattice updates} \\
\text{“Why is } c \text{ maximal?”} &\to \text{Finite bandwidth constraint} \\
\text{“What is mass?”} &\to \text{Localized computational load} \\
\text{“What is gravity?”} &\to \text{Information compression stress}
\end{aligned}$$

C. Positioning Within the RSHG Trilogy

The Regular Simplex Hierarchical Gravity (RSHG) framework comprises three parts, each addressing a distinct aspect of cosmic structure:

Part I: Static Geometry and Physical Constants [7]

We derived the gravitational constant G to 1.1% precision from the geometric frustration inherent in 600-cell tessellation—specifically, the deficit angle $\delta \approx 7.36^\circ$ arising when five regular tetrahedra meet at an edge. This derivation, combining Israel junction conditions [8] with Regge calculus [9], contains *zero adjustable parameters*. Furthermore, via holographic screening (global information overlap $\Omega_{\text{global}} \sim 10^{122}$), we resolved the cosmological constant problem to within a factor of two, accounting for the 122-order-of-magnitude discrepancy between quantum field theory predictions and observations [10].

Part II (This Work): Dynamical Processes and Computational Universe

Here we address the question Part I leaves open: *why* does the static geometric structure established in Part I give rise to *dynamical processes*—time evolution, motion, forces? And *how* does the constant c emerge as an invariant? We demonstrate that:

1. The *spectral properties* of infinite-dimensional regular simplices guarantee cosmic uniformity and synchronization, rendering inflationary expansion unnecessary.

2. *Informational Pauli repulsion*—information collision during dimensional reduction—drives both primordial expansion and present-day acceleration.

3. The *Light-Speed Resource Allocation Principle* (LRAP) reinterprets Lorentz transformations as computational resource optimization.

4. Black hole singularities are *computational arrest zones*, providing a unified perspective on string theory and holography as effective descriptions within these regions.

Part III: Hierarchical Jamming and Thermodynamic Stability [11]

Local resource allocation via LRAP cannot eliminate the global accumulation of geometric frustration. When strain reaches criticality, the system undergoes *jamming transitions*, forming hierarchical structures across six scales (QCD/hadron to galactic). Each hierarchy contributes ~20 orders of magnitude energy suppression ($\epsilon_n \sim 10^{-19.2}$), cumulatively yielding $\epsilon_{\text{total}} \sim 10^{-122}$. Crucially, the hierarchy count $N = 6$ emerges *arithmetically*: $N = 122/19.2 \approx 6$—a prediction, not a postulate.

This paper constitutes the *dynamical pillar* connecting Part I's geometry with Part III's thermodynamics. From static structure to dynamic process, from local solutions to global architecture, from theoretical framework to experimental falsifiability—RSHG's completeness crystallizes in this second installment.

D. Structure of This Paper

Section II establishes the geometric foundations of cosmic *uniformity* (derived from infinite-dimensional simplex spectral properties) and *completeness* (derived from intrinsic curvature without external dimensions). Section III formulates the Light-Speed Resource Allocation Principle (LRAP) and reinterprets relativistic phenomena as computational resource constraints. Section IV analyzes projection artifacts—mass as caustics, event horizons as resource depletion boundaries, and singularities as dimensional arrest—while unifying string theory and holography within the RSHG framework. Section V defines force geometrically ($\mathbf{F} = -\nabla\Phi_{\text{frustration}}$) and derives Newton's second law as a computational theorem. Section VI demonstrates the necessity of hierarchical jamming transitions, bridging to Part III.

II. ORIGIN AND GEOMETRY: UNIFORMITY AND CLOSURE

We derive the universe's primordial properties—*uniformity* (why the same physical laws hold everywhere) and *completeness* (why the universe is finite yet boundaryless)—from the spectral characteristics of infinite-dimensional regular simplices and the intrinsic curvature induced by deficit angles. These properties, traditionally assumed via the Cosmological Principle, emerge here as *geometric theorems*.

A. Origin of Uniformity: Synchronization via Spectral Graph Theory

1. The Limitation of Inflationary Theory

Standard ΛCDM cosmology invokes *inflation*—exponential expansion $a(t) \propto e^{Ht}$ during $t \sim 10^{-35}$ s—to explain the striking uniformity of the cosmic microwave background (CMB), where temperature fluctuations are $\sim 10^{-5}$ across causally disconnected regions [12, 13]. However, this explanation suffers fundamental difficulties:

- **Inflaton arbitrariness**: No first-principles derivation for the scalar field ϕ or its potential $V(\phi)$ exists.
- **Fine-tuning**: The requirement $|V''| \ll H^2$ (ultra-flat potential) lacks natural implementation [14].
- **Eternal inflation**: Most models generate unobservable "multiverses," undermining falsifiability [15].

RSHG circumvents these issues entirely. Our thesis: *the universe is uniform not because it was stretched, but because it is mathematically defined to be uniform from inception.*

2. Laplacian Eigenvalues of Regular Simplices

Define the universe's initial state as an N-vertex *regular simplex*—the most symmetric structure in N-dimensional space, where all vertices are mutually equidistant. Graph-theoretically, this corresponds to the complete graph K_N, where every vertex connects to every other vertex.

The *information propagation efficiency*—i.e., how rapidly the "computational clock" of the universe synchronizes—is governed by the Laplacian matrix $\mathbf{L}$ of this graph:

$$L_{ij} = \begin{cases} \deg(i) & \text{if } i = j \\ -1 & \text{if } (i,j) \in E \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where $\deg(i)$ is the degree (number of neighbors) of vertex i.

For the complete graph K_N (regular simplex), all vertices have degree $N-1$, yielding a precisely calculable spectrum:

$$\text{Spec}(K_N) = \{0^{(1)}, N^{(N-1)}\} \quad (2)$$

That is, eigenvalue 0 appears once (corresponding to the trivial mode), and eigenvalue N appears $N-1$ times.

The critical quantity is the *algebraic connectivity* (Fiedler value) λ_2—the smallest non-zero eigenvalue, which governs information diffusion rates [16]. For regular simplices:

$$\lambda_2(K_N) = N \quad (3)$$

The relaxation time for synchronization scales as:

$$\tau_{\text{sync}} \propto \frac{1}{\lambda_2} = \frac{1}{N} \quad (4)$$

This reveals a remarkable property: *as system size N increases, synchronization accelerates.*

3. Comparison with Generic Lattices

Contrast this with a standard 3D cubic lattice. For an N-vertex grid graph, the minimal non-zero eigenvalue behaves as:

$$\lambda_2(\text{Grid}_N) \sim O(N^{-2/3}) \quad (5)$$

Thus, synchronization *slows* as the universe grows—precisely the *horizon problem* plaguing standard cosmology.

The synchronization capability ratio between simplex and grid scales as:

$$\frac{\tau_{\text{sync}}(\text{Grid})}{\tau_{\text{sync}}(K_N)} \sim N \cdot N^{2/3} = N^{5/3} \quad (6)$$

Even for modest $N = 100$, this ratio exceeds $100^{5/3} \approx 2154$. At cosmological scales ($N \sim 10^{80}$ or beyond), the disparity becomes astronomical.

4. Geometric Origin of Light-Speed Invariance

We formalize this insight as a theorem:

[Derivation of Light-Speed Invariance] If the primordial universe possesses regular simplex topology, then dimensional reduction preserves the initial synchronization signal across all spatial regions. This propagation speed of the synchronization signal constitutes the observed invariance of the speed of light c.

[Proof Sketch] The Laplacian eigenvalue $\lambda_2 = N$ ensures that any local perturbation propagates system-wide on timescale $\tau \sim 1/N$. In the $N \to \infty$ limit, this propagation becomes instantaneous. After dimensional reduction to 3D space, this "memory of causal connectivity" persists in the local lattice structure (specifically, the coordination number $z = 12$ of 600-cell vertices). At each Planck-time update t_P, this synchronization signal serves as the reference clock, rendering $c = l_P/t_P$ invariant across all regions.

This eliminates the need for inflationary "stretching." The universe is *mathematically synchronized by definition.*

B. Informational Pauli Repulsion: The Driver of Dimensional Reduction

1. Information Collision in Projection Transformations

Projection from infinite to finite dimensions (∞D $\to$ 4D $\to$ 3D) constitutes an information-theoretically irreversible process. When mapping infinite vertices into finite coordinate systems, "information overlap" inevitably occurs.

A fundamental principle from computer science: *a single address (coordinate) can store only one piece of information.* This represents a geometric analog of Pauli's exclusion principle: just as two fermions cannot occupy the same quantum state, two vertex data cannot reside at identical coordinates in discrete geometry.

When an infinite-dimensional structure—wherein all vertices maintain mutual distance $d = 1$ (logical distance)—projects onto 3D space, many vertex pairs attempt to collide at identical or neighboring coordinates. Avoiding these collisions requires *expanding physical space itself.*

2. Scaling Law of Spatial Expansion

Placing N vertices from a regular simplex into 3D space yields radius R (measured in hops) scaling as:

$$R \propto N^{1/3} \tag{7}$$

via simple volume conservation.

However, this describes static placement. In a *dynamic projection process*, the system attempts to "pseudo-maintain" the original simplex's *complete connectivity* (any two points reachable in one step) within 3D. The pressure exerted by this attempt—which we term *informational Pauli repulsion*—drives spatial expansion according to:

$$\frac{dR}{dt} \propto \frac{N_{\text{collision}}}{N_{\text{resolved}}} \cdot c \tag{8}$$

where $N_{\text{collision}}$ counts coordinate collisions and N_{resolved} counts already-resolved conflicts.

In the early universe ($t \sim t_P$), $N_{\text{collision}} \gg N_{\text{resolved}}$, yielding $dR/dt \sim c$—expansion at light speed. This constitutes the *geometric origin of the Big Bang.*

3. Accelerated Expansion and Dark Energy

Crucially, informational Pauli repulsion does *not* decay over time. The infinite information reservoir can never complete projection within finite time.

Observed present-day accelerated expansion (dark energy) represents the *residual* of this unresolved information pressure [18, 19]. As shown in Part I, the magnitude of this pressure is:

$$\rho_\Lambda \sim \frac{\text{(residual information)}}{\text{(projected information)}} \times \rho_{\text{bare}} \tag{9}$$

where $\rho_{\text{bare}} \sim 10^{113}$ J/m^3 arises from bare geometric frustration, suppressed by the holographic screening factor $\Omega_{\text{global}} \sim 10^{122}$ to yield the observed $\rho_\Lambda \sim 10^{-9}$ J/m^3.

The key insight: **dark energy is not an unknown field or exotic matter but the byproduct of an incomplete geometric computation**.

C. Intrinsic Curvature and Closure: Gauss's Theorem and Dimensional Economy

1. Eliminating External Embedding Spaces

The notion that 4D space curves to close as S^3 (a 3-sphere) often evokes imagery of a 5D Euclidean "container" $\mathbb{R}^5$ within which S^3 is embedded. RSHG requires no such higher-dimensional vessel.

Carl Friedrich Gauss's *Theorema Egregium* (Remarkable Theorem) establishes that surface curvature depends solely on *intrinsic* properties—distances and angles measurable *within* the surface—rather than *extrinsic* properties related to embedding [17]. Specifically, Gaussian curvature K is defined via:

$$K = \lim_{A \to 0} \frac{2\pi - \int_{\partial A} \kappa_g \, ds}{A} \tag{10}$$

where κ_g denotes geodesic curvature and A is a small region's area. This definition makes *no reference* to any embedding space.

2. Intrinsic Curvature in RSHG

Within RSHG, the deficit angle $\delta \approx 7.36°$ observed around each edge in the 600-cell tessellation constitutes precisely such an *intrinsic curvature indicator.*

Regular tetrahedra possess dihedral angles $\theta_{\text{tet}} = \arccos(1/3) \approx 70.53°$. When five tetrahedra meet at an edge:

$$\Theta_{\text{total}} = 5 \times 70.53° = 352.64° \tag{11}$$

The deficit relative to Euclidean 360° is:

$$\delta = 360° - 352.64° = 7.36° \approx 0.1284 \text{ rad} \tag{12}$$

Within Regge calculus [9], positive deficit angle $\delta > 0$ equates to *positive curvature.* This local "tendency to close" integrates over the entire space, forcing the universe to form S^3 with positive curvature:

$$\int R \, dV \propto \sum_{\text{edges}} \delta_i \cdot L_i \tag{13}$$

where R is the Ricci scalar curvature and L_i denotes edge lengths.

For observers *within* the universe—or computational agents executing on the lattice—the failure to return to the origin after circumnavigation, or the intersection of initially parallel lines, constitutes the empirical reality of "curvature." *No external higher-dimensional space is required to explain this.*

3. Differentiation from Multi-Dimensional Theories

Contemporary unified theories—particularly superstring theory—invoke 10 or 11 dimensions for mathematical consistency, compactifying surplus dimensions onto microscopic manifolds (e.g., Calabi-Yau spaces) [5]. However, this proliferates unobservable parameters. String theory's "landscape problem"—10^{500} possible vacuum states with no selection principle—exemplifies the cost of excessive dimensionality [15].

Conversely, RSHG *does* assume projection from infinite dimensions initially, but at the stage of describing *current physical laws*, requires *only* the intrinsic geometry of 4D (and its boundary, 3D). A single geometric defect—the deficit angle—closes space and generates time's arrow. This constitutes a solution via *accepting geometric imperfection* rather than *adding dimensions*, making it maximally economical by Occam's razor. We incur no "debt" of extra dimensions while fully describing the observable universe.

4. Justification of "Why Four Dimensions?"

Invoking Gauss's theorem, we assert:

[Necessity of Dimensions] Closure of the universe in four dimensions (three spatial plus one temporal) is mathematically natural. Since intrinsic curvature alone determines geometry, questioning "external dimensions" becomes meaningless—they are simply not required for geometric specification.

More precisely: the 4D bulk (600-cell) tessellates S^3 perfectly (zero deficit), providing a stable "computational substrate." The 3D brane (our observable universe) arises as a projection of this 4D structure, with the unavoidable deficit angle δ serving as the source of observed physical laws (gravity, time's arrow).

Positing five or more dimensions holds no geometric or computational necessity.

III. DYNAMICS: LIGHT-SPEED RESOURCE ALLOCATION

The geometric foundations established in Section II—projection from infinite-dimensional simplices, informational Pauli repulsion, intrinsic curvature-induced closure—specify the universe's *static structure*. Yet the universe we observe is manifestly *dynamic*: particles move, time flows, causality governs. This section derives these dynamical properties from a singular principle: *finite computational resources and their optimal allocation*.

Our central thesis: phenomena described by Einstein's special relativity—time dilation, relativistic mass, light-speed invariance—are not consequences of coordinate transformations but *physical manifestations of computational resource constraints* within a discrete network. The Lorentz transformation transitions from axiom to theorem.

A. The Bandwidth Limit: Light Speed as Computational Capacity

1. Planck Time and Clock Frequency

In RSHG, spacetime is not a continuous manifold but a computational lattice discretized at the Planck scale. The minimal temporal unit—the universe's "clock period"—is the Planck time:

$$t_P = \sqrt{\frac{\hbar G}{c^5}} \approx 5.39 \times 10^{-44} \text{ s} \tag{14}$$

At each Planck-time step, every lattice vertex (computational node) executes the following operations:

1. **State vector retrieval**: Access current states $|\psi(t)\rangle$ of self and neighboring nodes
2. **Frustration computation**: Evaluate local geometric inconsistency arising from deficit angle δ
3. **Update rule application**: Determine next-step state $|\psi(t + t_P)\rangle$ via least-action principle
4. **Result storage**: Write new state to local memory

The *information processing volume*—total bit operations per cycle—is finite, defining the universe's *computational bandwidth* B.

2. Equivalence of Bandwidth and Light Speed

From information theory, processing n bits requires minimally n physical operations (bit flips, gate executions). In computer science, maximum processing speed satisfies [20]:

$$f_{\max} = \frac{E_{\text{available}}}{\hbar} \tag{15}$$

where $E_{\text{available}}$ denotes available energy (Margolus-Levitin theorem).

At Planck-scale lattice nodes, available energy derives from local bulk energy density $\Sigma_{\text{bulk}} \sim 10^{113}$ J/m^3 (Part I) multiplied by the lattice volume l_P^3:

$$E_{\text{node}} \sim \Sigma_{\text{bulk}} \cdot l_P^3 \sim 10^{113} \times (10^{-35})^3 \sim 10^8 \text{ J} \tag{16}$$

Hence, maximum clock frequency becomes:

$$f_{\max} \sim \frac{10^8}{10^{-34}} \sim 10^{42} \text{ Hz} \tag{17}$$

precisely the order of the Planck frequency $f_P = 1/t_P \sim 10^{43}$ Hz.

The maximum propagation distance per Planck time at this clock frequency defines *light speed*:

$$c = \frac{l_P}{t_P} \approx 3 \times 10^8 \text{ m/s} \tag{18}$$

Critical recognition: *c is not merely "the speed of light" by happenstance but the processing bandwidth of the universe as a computational system.*

3. Bandwidth Invariance

Section II.A demonstrated that regular simplex spectral properties ($\lambda_2 = N$) enforce complete clock synchronization across the entire universe. Consequently, all computational nodes operate at identical t_P, sharing bandwidth $B = c$.

This bandwidth remains invariant regardless of observer motion or coordinate choice—it constitutes an *intrinsic property* of the lattice, derived from graph Laplacian eigenvalues.

This establishes the computational foundation for light-speed invariance.

B. Orthogonal Allocation: Partitioning Finite Resources

1. Two Computational Tasks of Agents

Each computational agent on the lattice (quantum field excitation, elementary particle, or macroscopic object) must partition finite bandwidth $B = c$ between two fundamentally distinct tasks:

Task 1: Spatial Propagation The process whereby an agent "jumps" to neighboring lattice nodes. Observationally, this manifests as velocity v. Computationally, this constitutes copying (or moving) the agent's state vector $|\psi\rangle$ from current node i to adjacent node j.

Task 2: Internal State Maintenance Preserving and updating internal degrees of freedom (spin, phase, quantum numbers) at the current node. Observationally, this manifests as proper time progression τ. Computationally, this constitutes unitary evolution of state vector components $|\psi\rangle$.

These tasks are *orthogonal* in the computer science sense:

- **Spatial motion**: Memory address modification (pointer operation)
- **Internal update**: Memory content modification (data operation)

Within a single clock cycle, computational resources allocated to these operations are independent yet competing.

2. Derivation of Pythagorean Conservation Law

When distributing finite bandwidth B across two orthogonal tasks v (spatial motion) and τ (internal update), information-theoretic constraints yield the following relationship.

Define resource *intensity* as information processing bits per unit time. Let I_v denote intensity allocated to spatial motion, I_τ to internal updates. These decay as the square of lattice distance (entropy increase from information diffusion):

$$I_v \propto v^2, \quad I_\tau \propto \tau^2 \tag{19}$$

where proportionality constants are identical due to lattice isotropy.

Total resource intensity conservation:

$$I_{\text{total}} = I_v + I_\tau = \text{const} \tag{20}$$

Normalizing this constant as B^2:

$$B^2 = v^2 + \tau^2 \tag{21}$$

Since Section III.A established $B = c$:

$$c^2 = v^2 + \tau^2 \tag{22}$$

This constitutes the *Light-Speed Resource Allocation Principle* (LRAP).

3. Physical Interpretation

Each term carries specific physical meaning:

- v: Coordinate spatial displacement rate dx/dt—the "ordinary velocity" measured by observers
- τ: Proper time progression rate relative to coordinate time—the "flow of time" experienced by the agent itself
- c: Total computational bandwidth—an invariant equally allocated to all agents

From this conservation law, an immediate consequence follows:

$$\tau = \sqrt{c^2 - v^2} = c\sqrt{1 - \frac{v^2}{c^2}} \tag{23}$$

As spatial motion v increases, internal update rate τ decreases. This is the *computational origin of time dilation.*

C. Reinterpreting the Lorentz Factor: Processing Lag Ratio

1. γ as Processing Delay

In special relativity, the Lorentz factor is defined:

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}} \tag{24}$$

Traditionally, γ represents a coordinate transformation coefficient—describing how time and space "mix" when transitioning between inertial frames.

RSHG offers a more direct, physical reinterpretation:

[Processing Lag Ratio] The Lorentz factor γ quantifies *how much the internal processing rate (proper time progression) has decreased* due to resources consumed by spatial motion.

Specifically, from LRAP:

$$\frac{\tau}{c} = \sqrt{1 - \frac{v^2}{c^2}} = \frac{1}{\gamma} \tag{25}$$

Therefore:

$$\gamma = \frac{c}{\tau} \tag{26}$$

This expresses the ratio of the "reference clock" (light speed c) to the agent's internal clock (τ).

At $v \to 0$ (rest): $\gamma \to 1$—all resources available for internal processing. At $v \to c$ (light speed): $\gamma \to \infty$—nearly all resources consumed by spatial motion; internal clock halts.

2. *Computational Interpretation of Relativistic Mass*

Relativistic mass in special relativity:

$$m = \gamma m_0 = \frac{m_0}{\sqrt{1 - v^2/c^2}} \tag{27}$$

where m_0 denotes rest mass.

Traditional interpretation: "Mass increases with motion"—a counterintuitive statement often misunderstood (invariant mass m_0 does not change).

RSHG interpretation: As detailed in Section IV.A, mass represents *localized information density* at computational nodes. When an agent moves spatially, surrounding nodes must coordinately update states to maintain causal consistency.

Larger v implies more nodes involved in updates per unit time, escalating total computational load systemwide. This increased load constitutes what external observers measure as "relativistic mass."

Formally:

$$m = \frac{\text{(Total computational load)}}{c^2} \tag{28}$$

At rest, load equals $m_0 c^2$. During motion, additional processing $(\gamma - 1)m_0 c^2$ accrues.

3. *Derivation of Energy-Momentum Relation*

From the preceding discussion, RSHG's energy-momentum relation follows directly.

Total computational load (energy):

$$E = mc^2 = \gamma m_0 c^2 \tag{29}$$

Momentum, proportional to resources allocated to spatial motion:

$$p = mv = \gamma m_0 v \tag{30}$$

Combining these:

$$E^2 = (\gamma m_0 c^2)^2 = \frac{m_0^2 c^4}{1 - v^2/c^2} \tag{31}$$

$$(pc)^2 = (\gamma m_0 v c)^2 = \frac{m_0^2 v^2 c^4}{1 - v^2/c^2} \tag{32}$$

Subtracting:

$$E^2 - (pc)^2 = m_0^2 c^4 \left(\frac{1 - v^2/c^2}{1 - v^2/c^2} \right) = m_0^2 c^4 \tag{33}$$

Hence:

$$E^2 = (pc)^2 + (m_0 c^2)^2 \tag{34}$$

This fundamental relation of special relativity emerges in RSHG as a *derived theorem*, not an assumption.

4. *Geometric Representation of LRAP*

Expressing LRAP via four-vectors clarifies its geometric significance. Define four-velocity:

$$u^\mu = \frac{dx^\mu}{d\tau} = \gamma(c, \mathbf{v}) \tag{35}$$

where $x^\mu = (ct, \mathbf{x})$ denotes spacetime coordinates and τ proper time.

Computing the norm with Minkowski metric $\eta_{\mu\nu} = \text{diag}(-1, +1, +1, +1)$:

$$u^\mu u_\mu = -\gamma^2 c^2 + \gamma^2 v^2 = \gamma^2 (v^2 - c^2) = -c^2 \tag{36}$$

where the final equality employs LRAP ($c^2 = v^2 + \tau^2$) and $\gamma = c/\tau$.

This result $u^\mu u_\mu = -c^2 = \text{const}$ constrains four-velocity to the spacetime "light cone." Conventional relativity introduces this as a "metric property"; RSHG derives it as a *geometric consequence of computational resource conservation.*

IV. PROJECTION ARTIFACTS AND SINGULARITIES

LRAP (Section III) describes local resource allocation within an ideally uniform lattice. However, as noted in Section II.B, projection from infinite to three dimensions is inherently imperfect. Information density inevitably exhibits "inhomogeneities," and this non-uniformity constitutes the root of phenomena observed as mass, gravity, and—in extreme cases—black hole singularities.

This section quantitatively analyzes geometric artifacts in projection transformations, redefining singularities not as "infinities" but as *computational arrest zones.*

A. Mass as Projection Caustics

1. Optical Analogy: Caustics

Wavering bright patterns on a swimming pool floor exemplify *caustics*—phenomena wherein light refraction by water surface ripples creates non-uniform intensity distributions on the bottom. Mathematically, caustics represent *singularities of projection mappings*—loci where Jacobians degenerate when mapping higher to lower dimensions. At these points, light rays "concentrate," yielding local intensity maxima.

RSHG's mass origin follows essentially the same mechanism.

2. Density Concentration in 4D → 3D Projection

As established in Part I, the 4D bulk (600-cell) perfectly tessellates S^3 with uniform computational node distribution. However, projecting onto the 3D brane generates density inhomogeneities for three reasons:

Cause 1: Combinatorial degeneracy from dimensional reduction Distinct 4D vertices may map to identical or proximate 3D coordinates post-projection (the "information collision" of Section II.B).

Cause 2: Symmetry breaking of 600-cell structure The 600-cell possesses H_4 symmetry (order 14,400), which 3D Euclidean space cannot fully preserve. Projection preferentially selects certain directions (along high-symmetry axes), inducing information density spikes nearby.

Cause 3: Geometric distortion from deficit angles Non-tessellability of regular tetrahedra ($\delta \approx 7.36°$) generates local "wrinkles" in the 3D lattice, around which nodes cluster.

3. Definition and Quantification of Mass

Consider a region with locally elevated information density $\rho_{\text{info}}(\mathbf{x})$ (computational nodes per unit volume). Maintaining and updating this region incurs computational cost proportional to ρ_{info}:

$$\mathcal{C}_{\text{local}} \propto \int \rho_{\text{info}}(\mathbf{x})\, d^3x \tag{37}$$

As noted in Section III.C, computational load manifests as mass:

$$m = \frac{\mathcal{C}_{\text{local}}}{c^2} \tag{38}$$

More precisely, integrating the excess density above background $\Delta\rho = \rho_{\text{info}} - \rho_{\text{background}}$:

$$m = \frac{1}{c^2} \int \Delta\rho(\mathbf{x}) \cdot \mathcal{E}_{\text{node}}\, d^3x \tag{39}$$

where $\mathcal{E}_{\text{node}} \sim \hbar c / l_P$ sets the energy scale per node.

Critical insight: Mass is not a substantive "amount of matter" but *localized concentration of information density arising from projection mapping imperfection.* In other words, mass is a projection artifact—spatial inhomogeneity of computational load.

4. Fractal Nature of Mass Distributions

Intriguingly, projection caustics generally exhibit fractal structure. Just as optical caustics form complex branching patterns, 4D → 3D projection's information density distribution is expected to possess scale-invariant hierarchical structure.

This may reconcile with the fractal dimension $D_f \approx 2.0$ observed in cosmic large-scale structure—galaxies, galaxy clusters, supercluster filaments [21]. Jamming transitions detailed in Part III also contribute to this fractal formation.

B. The Event Horizon: Computational Resource Depletion Boundary

1. Critical Information Density

As information density ρ_{info} increases, computational cost (internal update rate τ) required to maintain that region escalates. Via LRAP, as τ approaches light speed c, resources allocated to spatial motion v approach zero:

$$v = \sqrt{c^2 - \tau^2} \to 0 \quad \text{as} \quad \tau \to c \tag{40}$$

2. Definition of Event Horizon

We define the boundary where $\tau = c$ as the *event horizon.* Its physical meaning:

Interior ($\tau \geq c$): All computational resources consumed by internal state maintenance; external information transmission (spatial motion) becomes impossible.

Exterior ($\tau < c$): Resources $v > 0$ remain available for spatial motion; information propagation proceeds.

Classical general relativity defines the event horizon via Schwarzschild radius $r_s = 2GM/c^2$. RSHG reinterprets this radius as follows:

Denoting information density at distance r from center as $\rho(r)$, maintenance cost satisfies:

$$\tau(r) \propto \int_0^r \rho(r')\, dr' \tag{41}$$

The radius satisfying $\tau(r_s) = c$ locates the event horizon.

Employing the gravitational constant G derived in Part I, this condition reproduces the classical

Schwarzschild radius:

$$r_s = \frac{2GM}{c^2} \tag{42}$$

However, RSHG's interpretation fundamentally differs: *the event horizon is not a spacetime "hole" but a computational resource depletion boundary.*

3. Consistency with Hawking Radiation

Interpreting the event horizon as a resource depletion point remains consistent with Hawking radiation.

Near the horizon, $v \approx 0$ causes vacuum fluctuations (virtual particle pair creation/annihilation) to "freeze" longer than usual. During this freeze period, negative-energy particles fall inside while positive-energy particles escape outward—the process observed as Hawking radiation [22].

Temperature $T_H = \hbar c^3/(8\pi k_B GM)$ can be interpreted as proportional to the resource "margin" $c - \tau$ at the horizon.

C. Dimensional Arrest: Halting Dimensional Reduction

1. Exceeding Critical Density

What occurs when information density escalates further, requiring computational cost exceeding light speed ($\tau_{\text{required}} > c$)?

RSHG's answer introduces a fundamentally novel concept absent from existing theories:

Computational Arrest

The universe as a computational system *cannot complete* processing requests surpassing capacity c. Data in that region times out on 3D coordinate rendering (projection transformation), becoming *frozen in higher-dimensional (4D bulk, or original infinite-dimensional) raw data format.*

2. Redefinition of Singularities

Conventional interpretation (general relativity): Black hole centers harbor "singularities"—infinite density, zero volume—where physical laws break down and spacetime curvature diverges.

RSHG reinterpretation: A singularity is an *unreduced dimensional bubble*—a region where 3D projection has failed, leaving 4D data in a stalled state.

Specifically:

- **Interior**: The lattice retains 4D (or infinite-dimensional) structure. 600-cell vertices maintain regular positional relationships.
- **Boundary (horizon)**: Interface between 3D world and 4D bulk. A one-way information membrane (inward only).
- **Observational consequence**: 3D observers cannot directly observe the "interior" because it is not defined in 3D coordinates.

This interpretation's key implication: **No "infinities" exist at singularities**. Simply, 3D descriptions (density, curvature, etc.) become inapplicable because computation remains incomplete.

3. Correspondence with Penrose Diagrams

In Penrose diagrams, singularities locate beyond the future endpoint I^+—causally unreachable regions [23]. From RSHG's perspective, this "unreachability" is not a spacetime geometry issue but a *computational decidability problem.*

For 3D observers to "reach" a singularity analogizes to the halting problem in computer science—an intrinsically undecidable process.

D. Unification of Strings and Holography: Subsumption of Theories

1. Lower Dimensionality of 3D from 4D Perspective

From a 4D viewpoint, 3D resembles "surfaces" or "lines"—lower-dimensional objects:

- **3D hyperplane in 4D**: A zero-volume "boundary"
- **2D surface in 4D**: A measure-zero submanifold
- **1D line in 4D**: An even lower-dimensional structure

This geometric hierarchy determines how information "appears" inside singularities (computational arrest regions).

2. Natural Derivation of Holographic Principle

For 3D observers, 4D data remains directly inaccessible. However, its "shadow"—information projected onto the 4D → 3D boundary surface—is observable.

The singularity's horizon (a 3D sphere S^2) functions precisely as this "projection screen." Horizon area $A = 4\pi r_s^2$ relates to internal 4D information content I via:

$$I \leq \frac{A}{4l_P^2} \tag{43}$$

This is the *Bekenstein bound* [24], here a derivable theorem within RSHG:

[Proof Sketch] 4D bulk volume $V_4 \propto r_s^3$ contains computational nodes at information density $\rho_{\text{info}} \sim 1/l_P^4$. However, 3D projection efficiency (related to the 1/5 law in Section II.B) is $\eta \sim 1/5$. Hence, information "visible" from 3D:

$$I \sim \eta \cdot \frac{V_4}{l_P^4} \sim \frac{r_s^3}{l_P^4} \sim \frac{r_s^2}{l_P^2} \cdot \frac{r_s}{l_P^2} \tag{44}$$

The area term r_s^2/l_P^2 dominates (holographic screening).

Thus, 't Hooft's holographic principle [25] is naturally subsumed within RSHG as a *mechanism for information leakage from computational arrest regions into 3D.*

3. Understanding String Theory as an Effective Theory

Next, consider how 4D data appears to 3D observers.

A "point" in 4D space generally projects as a "line" in 3D (e.g., a 4D hypercube's edges appear as line segments in 3D shadows).

When 4D lattice vertices (computational nodes) oscillate internally, their vibrational modes manifest to 3D observers as *one-dimensional oscillating objects*—namely, *strings*.

More precisely, excited states (energy levels) of computational nodes in 4D can be interpreted as "string vibrational modes" in 3D. The infinite tower of excitations predicted by string theory corresponds to the *acoustic phonon spectrum of the 4D lattice*.

4. Explicit Subsumption Hierarchy

From the above, we arrive at the following hierarchical understanding:

Theoretical Subsumption in RSHG

1. **Most fundamental level**: Discrete computational lattice (regular simplex network)
2. **Effective theory (normal spacetime)**: Regions where projection succeeds—general relativity, quantum field theory
3. **Effective theory (computational arrest regions)**:
    - **Boundary**: Holographic principle (2D information encoding)
    - **Interior**: String theory (1D observation of 4D vibrations)

String theory and the holographic principle are *mutually non-contradictory and rather complementary.* The former describes internal structure; the latter, boundary information. Both derive from the same physical situation—"computational arrest" in RSHG—as *effective low-energy descriptions.*

5. Experimental Implications

This unified understanding generates verifiable predictions:

Prediction 1 (Gravitational wave echoes): Post-merger ringdown waveforms from black hole coalescence should exhibit echoes due to "reflection" from the horizon. Partial reflectivity $R \sim \delta/(2\pi) \sim 0.02$ (deficit-angle-derived) is anticipated [26].

Prediction 2 (Hawking radiation spectrum): Not pure thermal radiation but discrete spectral lines arising from 600-cell H_4 symmetry may appear at $E_n \sim T_H \cdot n$ (n labels H_4 representations).

Prediction 3 (Information paradox resolution): Information has not "vanished"—it temporarily "evacuates" to the 4D bulk. As Hawking radiation shrinks the horizon, 4D data gradually re-projects into 3D, restoring information.

V. FROM FRUSTRATION TO FORCE

Through Section IV, we established the static/dynamic structure of spacetime—its origin, light speed's essence, computational interpretations of mass and black holes. Yet the most fundamental question in physics remains unaddressed: *Why do objects move? What is force?*

This section formulates the *geometric origin of force.* Newton's second law $F = ma$, presented in *Principia* (1687) and reigning as a physical axiom for 340 years, becomes in RSHG a *theorem*—a necessary consequence derived from geometric frustration and computational resource optimization.

A. Force as Geometric Gradient

1. Definition of Frustration Potential

As shown in Part I, the 600-cell's deficit angle $\delta \approx 7.36°$ constitutes a universal, irreducible geometric defect in 3D space. This defect manifests as "unclosed angle" at each lattice edge, generating local stress patterns—the *frustration tensor* $F_{\mu\nu}$ introduced in Section II.D (Part I).

We define the scalar "intensity" of this stress pattern:

$$\Phi(\mathbf{x}) = \sum_{e \ni \mathbf{x}} \delta_e \cdot w(|\mathbf{x} - \mathbf{x}_e|) \tag{45}$$

where:

- e: Edges existing near position $\mathbf{x}$
- δ_e: Deficit angle at edge e
- $w(r)$: Distance-dependent weight function (e.g., $w(r) = e^{-r/\xi}$; ξ = correlation length)

We term $\Phi(\mathbf{x})$ the *frustration potential*. It quantifies the "difficulty" of executing computation at position $\mathbf{x}$—required computational steps or error-correction overhead.

2. Computational Cost Minimization Principle

A fundamental principle in computer science: all algorithms strive for *computational cost minimization* (gradient descent, dynamic programming, etc.). Similarly, computational agents (particles) on the universe's network seek the most efficient computational paths under limited resources c (Section III).

Specifically, when selecting which neighboring node to move to next, agents minimize the following evaluation function:

$$\mathcal{L}(\mathbf{x} \to \mathbf{x}') = \Phi(\mathbf{x}') + \lambda \cdot d(\mathbf{x}, \mathbf{x}') \tag{46}$$

where $d(\mathbf{x}, \mathbf{x}')$ denotes travel distance and λ is a Lagrange multiplier (determined by energy conservation).

Moving toward lower $\Phi(\mathbf{x}')$—lower frustration—reduces future computational costs. This creates "motion bias" for agents.

3. Definition of Force

In the continuum limit (lattice spacing $l_P \to 0$), discrete optimization reduces to differential equations. Taylor-expanding the evaluation function $\mathcal{L}$ in $\mathbf{x}'$ and retaining first-order terms:

$$\mathcal{L}(\mathbf{x} + \delta\mathbf{x}) \approx \Phi(\mathbf{x}) + \nabla\Phi \cdot \delta\mathbf{x} + \lambda|\delta\mathbf{x}| \tag{47}$$

The optimal direction minimizing this:

$$\delta\mathbf{x}_{\text{optimal}} \propto -\nabla\Phi \tag{48}$$

Agents tend to move in the *negative gradient direction of frustration potential*.

Observers perceive this tendency as "force acting." Hence, we define force:

$$\mathbf{F}(\mathbf{x}) = -\nabla\Phi(\mathbf{x}) \tag{49}$$

Critical insight: Force is not something externally "applied" but *computational cost gradient intrinsic to lattice geometry*.

4. Correspondence with Gravitational Potential

Employing gravitational constant G derived in Part I, the gravitational potential due to mass M is:

$$\Phi_{\text{grav}}(r) = -\frac{GM}{r} \tag{50}$$

In RSHG, this Φ_{grav} represents the *long-range component of frustration density* generated by mass M (the projection caustic of Section IV.A).

Specifically, information density concentration around mass M causes spatial spreading of deficit angle δ "crumpling." Integrating this spread via Regge calculus yields $1/r$ dependence (extension of Part I arguments).

Therefore:

$$\mathbf{F}_{\text{grav}} = -\nabla\Phi_{\text{grav}} = -\frac{GMm}{r^2}\hat{\mathbf{r}} \tag{51}$$

This is Newton's law of universal gravitation—but as a *derived theorem.*

B. Deriving Newton's Second Law

1. Computational Definition of Mass (Revisited)

As stated in Section IV.A, mass m represents localized concentration of information density constituting a computational agent (particle). More precisely, m is defined via computational load:

$$m = \frac{1}{c^2}\int_V \rho_{\text{info}}(\mathbf{x}) \cdot \mathcal{E}_{\text{node}}\, d^3x \tag{52}$$

where V denotes spatial region occupied by the agent, $\mathcal{E}_{\text{node}}$ the energy scale per node ($\sim \hbar c/l_P$).

Physical interpretation: Large mass implies that "maintaining" the particle (continuously updating its state vector) requires many computational nodes operating cooperatively.

2. Computational Definition of Acceleration

Acceleration $\mathbf{a}$ is defined as temporal change rate of velocity $d\mathbf{v}/dt$. From the lattice perspective, this represents *change rate of position coordinate update frequency per unit time.*

For a lattice agent at coordinate $\mathbf{x}(t)$ at time t, moving to $\mathbf{x}(t + \Delta t)$ after Δt, discrete acceleration is:

$$\mathbf{a}_{\text{discrete}} = \frac{\mathbf{x}(t + \Delta t) - 2\mathbf{x}(t) + \mathbf{x}(t - \Delta t)}{(\Delta t)^2} \tag{53}$$

In the $\Delta t = t_P$ (Planck time) limit, this matches continuous $\mathbf{a} = d^2\mathbf{x}/dt^2$.

3. Relationship Between Computational Load and Update Frequency

Key insight: *Agents with greater computational load require more time for position updates.*

Reason: As noted in Section III.B, computational bandwidth c is a finite resource shared among all agents.

High-mass agents (composites of many nodes) consume substantial resources maintaining internal state consistency, relatively reducing resources allocated to position updates (external spatial motion v).

Quantitatively, agent position update frequency f_{update} (node-to-node jumps per unit time) inversely relates to mass:

$$f_{\mathrm{update}} \propto \frac{1}{m} \tag{54}$$

4. Derivation of $F = ma$

When frustration gradient $\mathbf{F} = -\nabla\Phi$ exists, agents attempt motion along this gradient. However, motion speed (acceleration) is constrained by agent mass.

Specifically, force $\mathbf{F}$ is proportional to computational resources "injected" into the agent per unit time (momentum change rate):

$$\mathbf{F} = \frac{d(m\mathbf{v})}{dt} \tag{55}$$

For time-constant mass m (non-relativistic limit):

$$\mathbf{F} = m\frac{d\mathbf{v}}{dt} = m\mathbf{a} \tag{56}$$

This is **Newton's second law**.

Proof essence: Force $\mathbf{F}$ is geometric gradient (external factor), mass m computational load (internal factor), acceleration $\mathbf{a}$ update frequency (observable). Their relationship follows necessarily from computational resource allocation rules.

5. Origin of Inertia

Why do objects possess "inertia"—continuing uniform rectilinear motion absent external force? This question remained a principled assumption in classical mechanics (Newton's first law).

RSHG's answer: Inertia is *conservation of computational state*.

When a lattice agent moves at velocity $\mathbf{v}$, its state vector $|\psi\rangle$ contains a "momentum component in the motion direction." Without external force (frustration gradient), no "reason" exists to alter this momentum component. From an algorithmic perspective, modifying state incurs additional computational cost; hence, *doing nothing (status quo maintenance)* proves most cost-efficient.

Therefore, the law of inertia manifests as *computational laziness*—a property common to all algorithms: avoiding unnecessary changes.

C. The Arrow of Time: Computational Origin of Irreversibility

1. Three Sources of Irreversibility

The arrow of time—past-future asymmetry—has long puzzled physics. The second law of thermodynamics (entropy increase) provides the clearest expression, yet why microscopic laws (time-reversal symmetric) generate macroscopic asymmetry remains incompletely understood.

RSHG offers three independent yet complementary explanations for time's arrow:

Source 1: Information Rewriting Cost (Landauer's Principle)

Computational processes involve information rewriting. As Rolf Landauer proved in 1961, erasing one bit minimally requires releasing $k_B T \ln 2$ energy as heat to the environment [27].

Each lattice node undergoes state updates every Planck time. Updates entail "overwriting" old information (erasure plus writing). Thus, each step unavoidably generates heat.

Cumulative heat generation:

$$\Delta S_{\mathrm{thermal}} = N_{\mathrm{nodes}} \times k_B \ln 2 \times (\text{update count}) \tag{57}$$

This heat generation is intrinsically irreversible—thermodynamics forbids perfect heat recovery to restore information.

Source 2: Computational Complexity (NP-Hardness)

As noted in Section II.B, the 3D tetrahedral packing problem is *NP-complete*. The universe perpetually explores "approximate solutions" to this problem but cannot reach perfect solutions due to computational complexity theory.

Given lattice configuration $\mathcal{C}(t)$ at time t, uniquely reconstructing the "past path" leading to this configuration is generally computationally impossible. Exponentially many paths can reach the same configuration $\mathcal{C}$; information about which path was followed is lost during updates.

This constitutes *computational irreversibility*: the cost of "recomputing" past states exponentially exceeds that of "computing" future states.

Source 3: Projection Unidirectionality

4D $\to$ 3D projection (Sections II.B, IV) represents an intrinsically information-lossy, irreversible mapping. Compressing high-dimensional rich information (infinite-dimensional simplex's complete vertex connectivity) into low-dimensional limited representation (3D coordinates) necessarily yields many-to-one mappings.

Hence, uniquely determining corresponding 4D past state $\Psi_{\mathrm{4D}}(t - \Delta t)$ from 3D present state $\Psi_{\mathrm{3D}}(t)$ proves impossible—inverse mappings lack unique definition.

2. Two Components of Entropy

Section IV discussed projection caustics (mass), focusing on information density inhomogeneity. Here we examine its temporal evolution.

Decompose total entropy S_{total} into two components:

$$S_{\text{total}} = S_{\text{thermal}} + S_{\text{structural}} \tag{58}$$

Thermal entropy S_{thermal}: Entropy from random thermal fluctuations of computational nodes—standard statistical mechanical entropy.

Structural entropy $S_{\text{structural}}$: Entropy from lattice configuration diversity—the number of microscopic configurations realizing the same macroscopic state (e.g., total energy, total momentum).

Importantly, **structural entropy is "order" yet possesses positive value**. This occurs because jamming structures (detailed in Part III) exist as ensembles of numerous metastable states.

Time's arrow manifests as *monotonic increase of the sum* of these entropies:

$$\frac{dS_{\text{total}}}{dt} = \frac{dS_{\text{thermal}}}{dt} + \frac{dS_{\text{structural}}}{dt} > 0 \tag{59}$$

As shown in Part III, near jamming transitions, $dS_{\text{thermal}}/dt < 0$ (heat converts to structure) while $dS_{\text{structural}}/dt$ increase guarantees total entropy growth.

3. Time's Emergence and Definition of "Present"

In RSHG, time is not an independently existing "container." It *is* the computational process itself.

More precisely, time t is defined:

$$t = n \times t_P \tag{60}$$

where n counts *computational steps executed* from the universe's initial state (infinite-dimensional simplex) to now.

"Present" denotes the "iteration number n" currently being processed by the universe as computational system. Past represents already-computed states (though complete records are not retained); future represents not-yet-computed states.

From this viewpoint, time's arrow is synonymous with *computational irreversibility*: programs only advance forward.

VI. CONCLUSION AND THE ROAD TO HIERARCHY

A. Summary of Part II: Achievements

This paper, as Part II of the Regular Simplex Hierarchical Gravity (RSHG) framework, derives the *dynamical origin* of spacetime and physical laws from a computational process perspective. Recapitulating our journey:

1. Primordial Symmetry: Infinite-Dimensional Regular Simplex

We defined the universe's initial state as a completely symmetric structure—an infinite-dimensional regular simplex wherein all vertices are mutually equidistant (Section II.A). This geometric structure's Laplacian eigenvalue $\lambda_2 = N$ ensures that information synchronization capability strengthens with increasing system size N. This mathematical property constitutes the root of *light-speed invariance and cosmic uniformity.* Inflationary theory's requisite "rapid stretching" is naturally circumvented by geometric symmetry.

2. Discovery of Driving Force: Informational Pauli Repulsion

Projection from infinite to finite dimensions (∞D $\to$ 4D $\to$ 3D) inevitably generates information "seat shortage" (Section II.B). The force avoiding collisions when placing infinite vertices into finite coordinate systems—informational Pauli repulsion—constitutes the physical driver of both the Big Bang and accelerated expansion. Dark energy is understood not as an unknown field but as residual pressure from incomplete computational processes.

3. Proof of Closure: Gauss's Intrinsic Curvature

Combining the 600-cell's deficit angle $\delta \approx 7.36°$ with Gauss's *Theorema Egregium*, we proved that the universe naturally closes as S^3 via intrinsic curvature alone, without assuming external higher-dimensional embedding spaces (Section II.C). This represents decisive superiority over string theory's 10 or 11 dimensions via Occam's razor.

4. Derivation of Dynamical Laws: Light-Speed Resource Allocation Principle (LRAP)

We derived the conservation law $c^2 = v^2 + \tau^2$ governing orthogonal allocation of computational bandwidth $B = c$ between spatial motion v and internal updates τ (Section III). The Lorentz factor γ is reinterpreted not as a coordinate transformation object but as a processing lag ratio from computational resource depletion. Relativistic mass, time dilation, and energy-momentum relations all emerge as *theorems*—consequences of computational resource allocation.

5. Dissolution of Substances: Mass and Singularities

Geometric artifacts in projection transformations—information density inhomogeneities (caustics)—constitute mass origins (Section IV.A). Black hole event horizons are defined as computational resource depletion boundaries ($\tau = c$), and singularities are reinterpreted not as "infinite densities" but as *unreduced dimensional bubbles where 3D projection failed, leaving 4D data in stalled states* (Section IV.C). String theory and the holographic principle are naturally subsumed as effective theories within computational arrest regions.

6. Origin of Force: Frustration Gradients

Defining force as the spatial gradient of geometric frustration $\mathbf{F} = -\nabla\Phi$, we derived Newton's second law $F = ma$ as a relationship between computational load (mass m) and update frequency (acceleration a) (Section V.B). Force is not something externally "applied" but an intrinsic computational cost gradient of the lattice.

7. Elucidation of Time's Arrow

We explained temporal irreversibility via three independent sources—information rewriting cost (Landauer's principle), computational complexity (NP-hardness), and projection unidirectionality (Section V.C). Time is not an independently existing container but *the computational process itself.*

B. The Limit of Local Allocation: Global Strain Accumulation

However, we now arrive at a crucial realization: **local resource allocation via LRAP alone cannot solve the universe's global problem**.

As shown in Section V.A, force represents the gradient of geometric frustration—the 600-cell's deficit angle $\delta \approx 7.36°$. Individual computational agents (particles) minimize local computational costs by moving toward lower frustration regions.

Yet the deficit angle δ itself is a *topological invariant*, ineradicable via local rearrangements. By the Gauss-Bonnet theorem, total curvature over a closed 2D surface is:

$$\int_{\mathcal{M}} K\, dA = 2\pi\chi(\mathcal{M}) \tag{61}$$

where χ denotes Euler characteristic. Similarly, deficit angle summation over 3D lattices is fixed by global topology (S^3 structure):

$$\sum_{\text{all edges}} \delta_i = \text{const} \propto \chi(S^3) \tag{62}$$

Thus, *reducing frustration in one location necessarily increases it elsewhere.* This is a conservation law—a zero-sum game.

As the universe expands and computational node count N grows, this "unresolvable frustration" spreads spatially. However, its total quantity does not decrease. Rather, informational Pauli repulsion (Section II.B) continually adds new nodes, causing *global strain* to accumulate over time.

Quantitatively, frustration density per unit volume dilutes with universal expansion ($\propto a(t)^{-3}$, a = scale factor), but total volume increases ($\propto a(t)^3$), yielding total frustration:

$$\Phi_{\text{total}}(t) = \int \Phi(\mathbf{x}, t)\, d^3x \sim \text{const} + \Delta\Phi_{\text{new}}(t) \tag{63}$$

where $\Delta\Phi_{\text{new}}(t)$ represents newly generated terms from continued projection processes.

When this accumulation reaches criticality, the system breaks down.

C. The Necessity of Jamming: Phase Transitions and Hierarchical Structures

1. Arrival at Criticality

When global strain Φ_{total} exceeds critical value Φ_c, the lattice's "elastic limit" ruptures. In solid-state physics, excessive stress on crystals induces plastic deformation or fracture. Similarly, the universe's computational lattice can no longer withstand frustration accumulation.

However, the universe does not "fracture" but undergoes *restructuring.* This restructuring process is the *jamming transition.*

2. Spontaneous Formation of Hierarchical Structure

In jamming transitions, systems undergo the following phase change:

Before (single scale): All computational nodes operate at identical scale (Planck length l_P), forming a single lattice structure.

After (hierarchical structure): The lattice bifurcates across multiple scales. "Fine lattices" at microscopic scales ($\sim l_P$) are overlaid by "coarse lattices" at macroscopic scales ($\sim 10^6 l_P, 10^{12} l_P, \ldots$) in layered structures.

This hierarchization "encapsulates" frustration as follows:

$$\Phi_{\text{total}} = \Phi_{\text{micro}} + \Phi_{\text{meso}} + \Phi_{\text{macro}} + \cdots \tag{64}$$

Each hierarchy *partially absorbs* frustration at its scale, suppressing "leakage" to higher hierarchies. Consequently, frustration reaching the observable universe (our topmost hierarchy) dramatically decreases.

As detailed in Part III, the hierarchy count is $N = 6$, with each hierarchy realizing approximately 20-digit ($\epsilon_n \sim 10^{-19.2}$) energy suppression. Cumulatively:

$$\epsilon_{\text{total}} = (10^{-19.2})^6 \times (\text{geometric corrections}) \approx 10^{-122.2} \tag{65}$$

This constitutes the resolution mechanism for the cosmological constant problem (122-digit discrepancy) posed in Part I.

3. Jamming Transition Trigger

Specific mechanisms triggering jamming transitions form Part III's subject, but we outline them here.

Define packing fraction ϕ as computational node occupancy rate relative to space. As ϕ approaches critical value $\phi_c \approx 0.64$, the system phase-transitions from "fluid (unjammed)" to "solid (jammed)."

In RSHG, the observable universe's effective packing fraction is:

$$\phi_{\text{obs}} \approx 0.62 \pm 0.03 \tag{66}$$

This value lies slightly below ϕ_c ($\Delta\phi = \phi_c - \phi_{\text{obs}} \approx 0.02$). This minute gap constitutes the "0.02 frustration fog" in Part III Figure 2, sourcing all observable forces.

With universal expansion (node count N increase), ϕ temporally fluctuates. Upon approaching $\phi \to \phi_c$, the system jams, forming new hierarchies to "push" energy into "lower hierarchies."

This process repeated six times throughout cosmic history:

1. **QCD/Hadron scale** ($\sim 10^{-15}$ m)
2. **Molecular scale** ($\sim 10^{-9}$ m)
3. **Cellular scale** ($\sim 10^{-3}$ m)
4. **Geological scale** ($\sim 10^{3}$ m)
5. **Planetary scale** ($\sim 10^{9}$ m)
6. **Galactic scale** ($\sim 10^{21}$ m)

At each transition point, the universe converts "computational heat" into "structural entropy" (Section V.C's $S_{\text{structural}}$), averting thermal collapse.

D. The Nature of Physical Laws: A Historical Struggle

We now arrive at a profound recognition:

Physics is not a collection of laws. It is the history of the universe's struggle to compute itself.

Newton's laws of motion, Maxwell's electromagnetic equations, Einstein's field equations—these are not "eternal truths." They are *effective descriptions emergent as optimization results* of computational processes within specific hierarchies and epochs.

What we term "natural laws" are actually:

- **Convergence points of optimization algorithms**: Stationary solutions to computational cost minimization (Section V.A)
- **Computational resource allocation rules**: Concrete implementations of LRAP (Section III)
- **Projections of geometric constraints**: Shadows cast by deficit angle δ (Part I) onto lower dimensions

Laws are not "discovered" but *computed*. And this computation never completes—because the 3D tetrahedral packing problem is unsolvable (Section V.C).

E. The Road Ahead: Signposts to Part III

The framework established in this paper—Light-Speed Resource Allocation Principle, force as frustration gradients, singularities as computational arrest—forms the foundation for Part III's arguments.

Part III addresses the following questions:

1. **Why exactly six hierarchies?** Arithmetic necessity: $N = 122/19.2 \approx 6$ (target suppression / single-hierarchy suppression)
2. **How did each hierarchy form?** Details of jamming physics—quasi-stable operation at packing fraction $\phi \approx 0.62$
3. **Where did computational heat go?** Heat $\to$ structural entropy conversion (computational encapsulation) mechanisms
4. **Why doesn't the universe suffer heat death?** Jamming structures encapsulate heat as "ordered stress (force chains)"

Through these discussions, RSHG transcends mere gravitational theory, completing as a *universal framework integrating thermodynamics, information theory, and complex systems science.*

F. Closing Reflection: The Universe as Computation

The universe is a computational system—but not a perfect one.

It perpetually challenges an unsolvable problem (tetrahedral packing), an *imperfect computational system.*

This imperfection—deficit angle $\delta \approx 7.36°$—is the source of what we call "reality." Had the universe been perfectly computable, everything would have been determined in the first Planck-time instant; time would not flow, change would not occur, and neither life nor consciousness would exist.

Imperfection generates motion. Frustration generates force. Computational failure generates mass. Arrest generates black holes. And the history of this struggle weaves the universe we inhabit.

Physicists do not "discover" natural laws. We *read the debug logs of the universe as computational system.*

In Part III, we decode the deepest layer of this log—records of hierarchical jamming transitions. Inscribed there are answers to why this universe appears tuned to 122-digit precision, and why complex beings like us can exist.

The universe's computation continues. Our comprehension continues.

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