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

Ryuhei Sato[1, *]

[1] *Independent Researcher, Tokyo, Japan*

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Einstein's special relativity postulates the constancy of light speed c as an axiom, yet provides no account of its origin. We reformulate the universe as a discrete geometric computational network operating at the Planck scale, wherein c emerges not as a fundamental constant but as the information-processing bandwidth of the network itself. The initial state—an infinite-dimensional regular simplex with Laplacian eigenvalue $\lambda_2 = N$—enforces cosmic uniformity without inflation, while informational Pauli repulsion, arising from the autonomous reconfiguration dynamics when infinite vertices are projected onto finite coordinates, drives both the Big Bang and present-day accelerated expansion as a single unfolding process.

From finite bandwidth constraints alone, we derive the Light-Speed Resource Allocation Principle (LRAP): $c^2 = v^2 + \tau^2$, partitioning computational bandwidth between spatial propagation v and internal state maintenance τ. The Lorentz factor reinterprets as a processing-lag ratio $\gamma = c/\tau$, and the energy-momentum relation $E^2 = (pc)^2 + (m_0c^2)^2$ emerges as a theorem rather than a postulate. Mass is identified as projection caustics—local concentrations of information density arising from imperfect 4D $\to$ 3D mapping—while gravitational force is the spatial gradient of the geometric frustration potential, $\mathbf{F} = -\nabla\Phi$. Singularities are dissolved: they are not physical infinities but Dimensional Arrest zones—regions of asymptotic freezing where 3D rendering fails—naturally subsuming string theory and the holographic principle as effective descriptions within these arrested regions.

Finally, the Gauss–Bonnet theorem proves that local optimization cannot eliminate the accumulation of the non-zero topological conserved quantity. When the effective packing fraction approaches the jamming criticality $\phi_c \approx 0.64$, the universe undergoes hierarchical phase transitions that convert computational heat into structural entropy, thereby avoiding thermal collapse. This necessitates the six-stage jamming cascade detailed in Part III, which resolves the 122-digit cosmological constant discrepancy as arithmetic necessity.

I. INTRODUCTION

A. The Origin Problem of Light-Speed Invariance

Einstein's special relativity (1905) stands as a cornerstone of modern physics [1]. Its central principle—the constancy of the speed of light in vacuum, independent of the motion of the source or observer—has survived a century of experimental scrutiny. Yet Einstein himself acknowledged a fundamental lacuna: special relativity provides no explanation for why c takes its particular value, nor why it constitutes an absolute speed limit. Light-speed invariance is a postulate, not a derivation.

In standard field theory, $c = 1/\sqrt{\epsilon_0\mu_0}$, but this merely displaces the question [2]. Quantum gravity frameworks—loop quantum gravity [3, 4], string theory [5], and causal dynamical triangulations [6]—ultimately import c as an external parameter rather than deriving it from first principles.

RSHG addresses this question directly. Light speed is not a constant; it is derived as the upper bound on the information-processing bandwidth of the universe regarded as a computational system.

B. The Computational Paradigm

The reformulation proposed here proceeds as follows. The universe is not a continuous spacetime manifold but a discrete computational network executing at the Planck scale. Within this framework:

- Spacetime is not a fundamental entity but an effective description emerging as the output of a 4D $\to$ 3D projection process.
- Light speed c is the upper bound on the information-processing bandwidth of this computational network.
- Mass is a projection caustic: a local concentration of information density arising from the geometric distortion inherent in dimensional reduction.
- Gravity is the spatial gradient of the structural stress accumulated during 4D $\to$ 3D projection.

* ryuhei19691001@gmail.com

- The arrow of time is a consequence of the information-thermodynamic irreversibility of the computation.

The computational system of the universe cannot reach a complete solution ($\phi = \phi_c$). The regular-tetrahedron packing problem is NP-hard, and the topological residue $\delta \approx 7.36°$ persists as an irreducible geometric incommensurability. This incompleteness is the source of all physical dynamics.

C. Projection and Unfolding: Conceptual Preview

Starting from Axiom Zero established in Part I, the universe is formulated as a computational process that unfolds through dimensional reduction, driven by Pauli repulsion from an origin of zero distance.

Within this framework, cosmic expansion is a consequence of the autonomous reconfiguration dynamics arising from informational Pauli repulsion. When infinite vertices are projected onto finite 3D coordinates, co-occupation of the same coordinate is forbidden (Pauli repulsion), and space itself is pushed outward. Light speed is the bandwidth upper limit at which this reconfiguration dynamics can be executed. The structural vacancies $\phi_c - \phi \approx 0.02$ constitute the topological margin required to maintain computational fluidity while avoiding freezing.

D. Position within the Trilogy

In Part I (static geometry), the derivation proceeded from Axiom Zero through Niven's theorem, the inevitable escape to the 600-cell, force-chain derivation of gravity, and the zero-parameter derivation of $\Omega_{\text{local}} = 100$. Part I established *what the structure is*. The present paper (Part II, dynamics) derives *why that static geometric structure gives rise to dynamical laws*. Part III (thermodynamics) will prove *how thermodynamic stability is maintained*.

E. Structure of This Paper

Section II formulates the unfolding process and establishes the connection between autonomous reconfiguration dynamics and LRAP. Section III derives the Light-Speed Resource Allocation Principle. Section IV analyzes the projection artifacts: mass, event horizons, and singularities. Section V formulates the geometric origin of force and derives Newtonian mechanics as theorems. Section VI proves the necessity of hierarchical jamming transitions from the limits of local allocation.

II. UNFOLDING: THE GEOMETRIC DYNAMICS OF COSMIC EXPANSION

A. Primordial Symmetry: The Infinite-Dimensional Regular Simplex

The initial state of the universe is defined as the infinite-dimensional regular simplex: the maximally symmetric structure in which all vertices are mutually equidistant. Graph-theoretically, this corresponds to the complete graph K_N ($N \to \infty$), in which every vertex is connected to every other vertex.

The Laplacian matrix of this graph has eigenvalue spectrum [7]:

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

The algebraic connectivity (Fiedler value) governing information diffusion is $\lambda_2(K_N) = N$, and the synchronization relaxation time scales as $\tau_{\text{sync}} \propto 1/N$. In the limit $N \to \infty$, synchronization becomes instantaneous, guaranteeing cosmic uniformity—the CMB temperature fluctuations of order 10^{-5}—geometrically, without invoking inflationary expansion [8].

For comparison, a standard 3D lattice has $\lambda_2(\text{Grid}_N) \sim O(N^{-2/3})$, so synchronization *slows* as the universe grows—the root of the horizon problem in ΛCDM cosmology. The complete connectivity of the infinite-dimensional simplex circumvents this problem in principle.

B. Definitions: Projection and Unfolding

The following precise definitions are adopted throughout this paper.

Projection: The inevitable information collision (overlap) arising from dimensional reduction. When the complete information of a higher-dimensional structure is mapped onto lower-dimensional coordinates, geometric constraints generate information collisions. Projection represents the geometric constraint imposed on the universe—the unavoidable question. Just as depth information is lost when a 3D object is projected onto a 2D plane, information collisions necessarily arise in the 4D $\to$ 3D projection.

Unfolding: The dynamic process by which, subject to the exclusive autonomous reconfiguration dynamics of Pauli repulsion, collisions are avoided, new coordinates are acquired, and space is pushed outward. Just as the faces of a polyhedron are spread onto a plane in a net diagram, the information of the universe acquires positions in lower dimensions sequentially. Unfolding is the emergent dynamic response—the answer.

Projection is the constraint (question); unfolding is the dynamic response (answer). These two operate simultaneously as two aspects of the same computational process.

C. Informational Pauli Repulsion: Autonomous Reconfiguration Dynamics

When the infinite-dimensional regular simplex is projected onto finite-dimensional coordinates, information collisions are unavoidable. This follows from a fundamental principle of discrete computation.

Coordinate Uniqueness Principle: A single lattice address can store the complete information of at most one vertex.

Just as the Pauli exclusion principle forbids two fermions from occupying the same quantum state, two vertex data sets cannot reside at the same lattice coordinate. The exclusive reconfiguration pressure arising from this unavoidable collision is defined as **informational Pauli repulsion**.

The connection to Axiom Zero is essential. Informational Pauli repulsion is the computational-cosmological expression of the Pauli repulsion formulated as a primordial force in Part I.

D. Formulation of Unfolding Velocity

When N vertices of a regular simplex are projected onto a 3D lattice of linear size R (in Planck length units), the information collision count is:

$$N_{\text{collision}} \propto N^2 \cdot \frac{l_P^3}{R^3}. \tag{2}$$

This is the combinatorial necessity of compressing N vertex pairs into R^3/l_P^3 lattice sites. The autonomous reconfiguration dynamics pushes space outward, generating an unfolding velocity v_{unfold}:

$$\frac{dR}{dt} = c \cdot \frac{N_{\text{collision}}}{N_{\text{resolved}}}. \tag{3}$$

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

The Fiedler value provides a geometric index of unfolding velocity: the rate of decrease of λ_2 is proportional to dR/dt. As dimensional reduction proceeds and the lattice becomes sparser, the hop count required for information propagation increases. This decrease in connectivity is the mathematical index of spatial expansion.

E. Simultaneity of Projection and Unfolding

Projection and unfolding are not separate operations; they act simultaneously as two aspects of the same computational process. The connection to LRAP (Section III) is established as follows:

$$c^2 = v_{\text{unfold}}^2 + \tau_{\text{internal}}^2. \tag{4}$$

The unfolding velocity v_{unfold} is identified with the spatial propagation component v in LRAP. As projection intensifies, unfolding velocity increases and internal update rate τ_{internal} is constrained. This constitutes the unfolding-theoretic origin of time dilation.

The proper time in a macroscopic observation system is physically defined as the path integral of the information update cost τ_{reconfig}:

$$\tau_{\text{macro}} = \int_{\text{path}} \tau_{\text{reconfig}}(t)\, dt. \tag{5}$$

F. Dark Energy: Non-Local Transfer of Topological Residue

Informational Pauli repulsion does not decay. By Niven's theorem, the topological residue δ has transcendental properties and cannot be made to converge to zero by any computational process.

Autonomous reconfiguration dynamics that attempt to resolve the topological residue at one locality convert to stresses that tear apart adjacent structures. As guaranteed by the Gauss–Bonnet theorem, frustration does not disappear but transfers perpetually within space. The total residual pressure of this topological residue constitutes dark energy:

$$\rho_\Lambda \sim \frac{N_{\text{collision, residual}}}{N_{\text{resolved}}} \times \Sigma_{\text{bulk}}. \tag{6}$$

Suppression by the holographic screening factor $\Omega_{\text{global}} \sim 10^{122}$ recovers the observed $\rho_\Lambda \sim 10^{-9}$ J/m^3 [9, 10].

G. Closure of the Universe: Gauss's Intrinsic Curvature

Gauss's Theorema Egregium establishes that surface curvature depends solely on intrinsic properties—distances and angles measurable within the surface—without reference to any embedding space [11].

Within RSHG, the topological residue $\delta \approx 7.36^\circ$ is precisely such an intrinsic curvature indicator. When five tetrahedra meet at an edge:

$$\delta = 360^\circ - 5 \times 70.53^\circ = 7.36^\circ \approx 0.1284 \text{ rad}. \tag{7}$$

This local positive curvature, when integrated over the entire space via Regge calculus [12]:

$$\int R\, dV \propto \sum_{\text{edges}} \delta_i \cdot L_i, \tag{8}$$

forces the universe to close naturally as S^3. No external embedding space is required.

III. THE LIGHT-SPEED RESOURCE ALLOCATION PRINCIPLE

A. Quantitative Derivation of the Planck Scale

At each Planck time step t_P, every lattice node executes the following operations: (1) retrieval of the current state vector and neighboring node states; (2) evaluation of the local geometric incommensurability arising from the deficit angle δ; (3) determination of the next-step state via the least-action principle; (4) write of the new state to local memory.

By the Margolus–Levitin theorem [13], the maximum processing speed under available energy $E_{\text{available}}$ is $f_{\max} = E_{\text{available}}/\hbar$. The available energy at a Planck-scale lattice node is:

$$E_{\text{node}} \sim \Sigma_{\text{bulk}} \cdot l_P^3 \sim 10^{113} \times (10^{-35})^3 \sim 10^8 \text{ J}, \tag{9}$$

giving maximum clock frequency:

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

The maximum propagation distance per clock cycle defines light speed:

$$\boxed{c = \frac{l_P}{t_P} \approx 3 \times 10^8 \text{ m/s.}} \tag{11}$$

Light speed is not the speed of light in the colloquial sense; it is the upper bound on the information-processing bandwidth of the universe as a computational system.

B. Invariance of Bandwidth

The Fiedler value $\lambda_2 = N$ established in Section II guarantees complete clock synchronization across the universe, so that all computational nodes operate at the same t_P and share bandwidth $B = c$. This bandwidth is invariant under observer motion or coordinate choice—it is an intrinsic property of the lattice, derived from the graph Laplacian eigenvalue, not a property of coordinate transformations.

C. Orthogonal Allocation of Two Computational Tasks

Each computational agent on the lattice must partition finite bandwidth $B = c$ between two fundamentally orthogonal tasks.

Task 1 (Spatial Propagation): The process by which an agent transitions to an adjacent lattice node. Observed as velocity v. Corresponds to a memory address modification (pointer operation).

Task 2 (Internal State Maintenance): The process of preserving and updating internal degrees of freedom at the current node. Observed as proper time progression τ. Corresponds to a memory content modification (data operation).

Defining resource intensity as information processing bits per unit time, the entropy increase from information diffusion on the lattice gives:

$$I_v \propto v^2, \qquad I_\tau \propto \tau^2. \tag{12}$$

Total resource intensity conservation: $I_{\text{total}} = I_v + I_\tau = B^2$.

D. Derivation of LRAP

Substituting $B = c$:

$$\boxed{c^2 = v^2 + \tau^2.} \tag{13}$$

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

An immediate consequence:

$$\tau = \sqrt{c^2 - v^2} = c\sqrt{1 - v^2/c^2}. \tag{14}$$

As spatial propagation v increases, the internal update rate τ decreases. Time dilation is a consequence of bandwidth redistribution.

E. Reinterpretation of the Lorentz Factor

From LRAP:

$$\gamma = \frac{c}{\tau}. \tag{15}$$

The Lorentz factor γ is physically defined as the processing-lag ratio—the ratio of the reference clock (c) to the agent's internal clock (τ). In place of the conventional interpretation as a coordinate transformation coefficient, it is redefined as a quantity representing the state of computational resource allocation.

Relativistic mass: when an agent moves spatially, neighboring nodes must cooperatively update their states to maintain causal consistency. This increased computational load is observed by external observers as relativistic mass: $m = (\text{total computational load})/c^2 = \gamma m_0$.

F. Derivation of the Energy-Momentum Relation (as a Theorem)

With total computational load (energy) $E = \gamma m_0 c^2$ and momentum $p = \gamma m_0 v$:

$$\begin{aligned} E^2 - (pc)^2 &= (\gamma m_0 c^2)^2 - (\gamma m_0 v c)^2 \\ &= m_0^2 c^4 \gamma^2 (1 - v^2/c^2) \\ &= m_0^2 c^4. \end{aligned} \tag{16}$$

Therefore:

$$\boxed{E^2 = (pc)^2 + (m_0c^2)^2.} \tag{17}$$

This fundamental relation of special relativity emerges in RSHG as a theorem—a natural consequence of the computational resource allocation law—rather than a postulate.

G. Four-Vector Representation of LRAP

Defining the four-velocity as $u^\mu = dx^\mu/d\tau = \gamma(c, \mathbf{v})$, its norm under the Minkowski metric is:

$$u^\mu u_\mu = \gamma^2(v^2 - c^2) = -c^2. \tag{18}$$

The constraint that four-velocity lies on the spacetime light cone is derived as a geometric consequence of computational resource conservation. Conventional relativity introduces this as a metric property; RSHG derives it as a theorem.

IV. PROJECTION ARTIFACTS: MASS, EVENT HORIZONS, AND SINGULARITIES

A. Continuum Spacetime as an Effective Theory

At architectural scales ($\sim 10^0$ m), space behaves as a continuous Cartesian manifold and the calculus is highly effective. However, this is a consequence of the statistical coarse-graining of $\sim 10^{35}$ instances of the $\delta \approx 7.36°$ topological residue at the Planck scale ($\sim 10^{-35}$ m), which cancel on average at macroscales, producing the apparent smooth continuum.

Continuum spacetime is not a fundamental entity. It is an effective theory (ET) defined as the coarse-graining limit of the underlying Planck-scale discrete structure.

The calculus operation $\Delta x \to 0$ cannot be applied to a lattice with physical lower bound l_P. Application of the continuum ET beyond its domain of validity—at Planck-scale or extreme information density limits—produces "infinity" as computational breakdown. Singularities are alternative names for this computational breakdown.

B. Mass: Projection Caustics

The 4D bulk (600-cell) distributes computational nodes uniformly on S^3. However, three causes generate density inhomogeneities upon projection onto the 3D brane.

Cause 1 (Combinatorial degeneracy): Distinct 4D vertices map to identical or proximate 3D coordinates post-projection; the resulting information collision generates local density concentration.

Cause 2 (H_4 symmetry breaking): The order-14400 H_4 symmetry of the 600-cell cannot be fully preserved in 3D Euclidean space; projection preferentially selects high-symmetry directions, inducing information density spikes in their vicinity.

Cause 3 (Local structural compression from topological residue): The non-tessellability ($\delta \approx 7.36°$) generates local geometric distortion in the 3D lattice, causing nodes to cluster.

The computational cost of maintaining a region with locally elevated information density $\rho_{\text{info}}(\mathbf{x})$ defines mass:

$$m = \frac{1}{c^2} \int \Delta\rho(\mathbf{x}) \cdot E_{\text{node}}\, d^3x. \tag{19}$$

Mass is not a substantive quantity of matter. It is defined as a local concentration of information density—a caustic of computational load—arising from the geometric incompleteness of the projection map. The general-relativistic statement that "mass curves spacetime" inverts the causal direction: it is the geometric distortion of projection that generates the information density concentration, which is then observed as mass.

C. The Event Horizon: Computational Resource Depletion Boundary

From LRAP, as information density increases, the internal update cost τ increases, and spatial propagation resources $v = \sqrt{c^2 - \tau^2} \to 0$.

The boundary at which $\tau = c$ is defined as the **event horizon**:

- *Interior* ($\tau \geq c$): All computational resources are consumed by internal state maintenance; spatial propagation becomes impossible.
- *Exterior* ($\tau < c$): Resources $v > 0$ remain available for spatial propagation; information propagation proceeds.

With the maintenance cost at distance r from the center given by $\tau(r) \propto \int_0^r \rho(r')\, dr'$, the radius satisfying $\tau(r_s) = c$ yields the Schwarzschild radius using G derived in Part I:

$$r_s = \frac{2GM}{c^2}. \tag{20}$$

The event horizon is not a singular topological boundary of spacetime but a **computational resource depletion boundary**. Information does not disappear inside; 3D computation becomes infeasible. The Hawking temperature [14]:

$$T_H = \frac{\hbar c^3}{8\pi k_B GM} \tag{21}$$

is interpreted as proportional to the computational resource margin $c - \tau$ at the horizon.

D. Dimensional Arrest: Dissolution of Singularities

When information density further increases such that the maintenance cost exceeds c, the universe as a computational system asymptotically freezes for that region. The 3D coordinate rendering (projection transformation) cannot complete, and data remains frozen in higher-dimensional (4D bulk) raw format. This is defined as **Dimensional Arrest**.

The structure of a Dimensional Arrest region:

- *Interior*: The lattice retains 4D structure; 600-cell vertices maintain regular positional relationships. The 3D description is undefined not because the region does not exist, but because the computation is incomplete.
- *Boundary (horizon)*: The interface between the 3D world and 4D bulk; a one-way information membrane.

Infinity does not exist. Neither density nor curvature diverges; the effective theory of continuum spacetime simply becomes inapplicable. That singularities in Penrose diagrams [15] are located in causally unreachable regions is reinterpreted not as a geometric property of spacetime but as a problem of computational decidability.

From the connectivity perspective of Section II, a Dimensional Arrest region has $\lambda_2 \to 0$—the graph becomes effectively disconnected and information propagation becomes infeasible.

E. Natural Subsumption of String Theory and the Holographic Principle

Derivation of the holographic principle: The event horizon (3-sphere S^2) functions as a projection screen from 4D to 3D. The Bekenstein bound [16]:

$$I \leq \frac{A}{4l_P^2} \tag{22}$$

is derived within RSHG from the 3D projection efficiency (the 1/5-law): the 4D bulk volume $V_4 \propto r_s^3$ contains nodes at information density $\rho_{\text{info}} \sim 1/l_P^4$, but with projection efficiency $\eta \sim 1/5$, the information visible from 3D scales as r_s^2/l_P^2—holographic screening. The holographic principle of 't Hooft [17] and Susskind [18] is subsumed as the mechanism of information leakage from Dimensional Arrest regions into 3D.

Subsumption of string theory: Vibrational modes of 4D lattice vertices appear to 3D observers as one-dimensional vibrating objects (strings). The infinite tower of excitations predicted by string theory [5] corresponds to the acoustic phonon spectrum of the 4D lattice. The landscape problem (10^{500} vacuum states) is reinterpreted as a classification of distinct Dimensional Arrest patterns arising from the same discrete computational lattice; physically realized patterns are restricted to those consistent with Axiom Zero (packing impossibility).

The subsumption hierarchy is as follows:

1. *Most fundamental level*: Discrete computational lattice (regular simplex network).
2. *Normal spacetime ET*: General relativity, quantum field theory (regions where projection succeeds).
3. *Dimensional Arrest region ET*: boundary: holographic principle (2D information encoding); interior: string theory (1D observation of 4D vibrations).

V. THE ORIGIN OF FORCE: FRUSTRATION GRADIENTS

A. Geometric Mapping of the Regular Simplex

When the regular tetrahedron is adopted as the fundamental unit of 3D space, each dimensional element carries a well-defined physical role:

$$\text{Tetrahedron}\begin{cases}\text{Vertices (0D)} & \to \text{Computational node positions}\\ \text{Edges (1D)} & \to \text{Quantum phase propagation; vibration modes}\\ \text{Faces (2D)} & \to \text{Frustration propagation interfaces}\\ \text{Body (3D)} & \to \text{Container of topological residue } \delta\end{cases} \tag{23}$$

Force is the spatial gradient of computational cost (frustration) propagating via face normal directions. It is not action at a distance, gauge boson exchange, or spacetime curvature, but the gradient of the flow of topological residue propagating through faces of regular tetrahedra.

B. The Frustration Potential and the Force Theorem

The frustration potential at position $\mathbf{x}$:

$$\Phi(\mathbf{x}) = \sum_{e \ni \mathbf{x}} \delta_e \cdot w(|\mathbf{x} - \mathbf{x}_e|), \tag{24}$$

where $w(r) = e^{-r/\xi}$ (ξ the correlation length) is a distance-dependent weight function. $\Phi(\mathbf{x})$ quantifies the computational difficulty at position $\mathbf{x}$.

[Geometric Origin of Force] When a computational agent executes minimum-cost computation under finite bandwidth c, in the continuum limit the agent moves in the direction of the negative gradient of the frustration potential.

The evaluation function for an agent moving from $\mathbf{x}$ to $\mathbf{x}' = \mathbf{x} + \delta\mathbf{x}$ is Taylor-expanded as:

$$L(\mathbf{x} + \delta\mathbf{x}) \approx \Phi(\mathbf{x}) + \nabla\Phi \cdot \delta\mathbf{x} + \lambda|\delta\mathbf{x}|. \tag{25}$$

The direction minimizing L is $\delta\mathbf{x}_{\text{optimal}} \propto -\nabla\Phi$. Therefore:

$$\boxed{\mathbf{F}(\mathbf{x}) = -\nabla\Phi(\mathbf{x}).} \tag{26}$$

Newton's law of universal gravitation is re-derived as a theorem: the information density concentration due to mass M (projection caustic) spreads geometric distortion in surrounding lattice edges, and integration via Regge calculus [12] yields $1/r$ dependence:

$$\mathbf{F}_{\text{grav}} = -\frac{GMm}{r^2}\hat{r}. \tag{27}$$

C. Newton's Second Law and the Principle of Minimal Information Update

[Newton's Second Law] For an agent with mass m (computational load) under frustration gradient $\mathbf{F} = -\nabla\Phi$, in the non-relativistic limit, $\mathbf{F} = m\mathbf{a}$.

An agent with larger mass requires more resources to maintain internal state consistency, reducing position update frequency $f_{\text{update}} \propto 1/m$. Force $\mathbf{F}$ is proportional to the computational resources injected into the agent per unit time (momentum change rate): $\mathbf{F} = d(m\mathbf{v})/dt$. In the limit of constant mass, $\mathbf{F} = m\mathbf{a}$. □

Origin of inertia—the Principle of Minimal Information Update: The state vector of an agent moving at velocity $\mathbf{v}$ contains a momentum component in the direction of motion. In the absence of an external force (frustration gradient), altering this component requires additional computational cost. Since state modification is more costly than non-modification, this information-processing principle defines the **Principle of Minimal Information Update**:

$$\begin{aligned} &\text{State modification cost} > 0 \\ &\implies \text{unnecessary modification avoided} \\ &\implies \text{law of inertia.} \end{aligned} \tag{28}$$

What Newton axiomatized as the First Law is a necessary consequence of computational resource allocation.

D. Equilibrium of Gravity and Pauli Repulsion: The Ultimate Consequence of Axiom Zero

The bifurcation of packing impossibility:

$$\text{Packing impossibility} \begin{cases} \to \sigma_{\text{struct}} \to \text{gravity (rigidity opposing expansion)} \\ \to \text{computational entropy} \to \text{Pauli repulsion (projection driver)} \end{cases} \tag{29}$$

The equilibrium condition:

$$\sigma_{\text{struct}} = \sigma_{\text{Pauli}} \tag{30}$$

gives rise to stable material structure. Stars remain luminous because gravitational collapse and Pauli repulsion (electron and neutron degeneracy pressure) maintain this equilibrium. The equilibrium packing fraction $\phi \approx 0.62$ is determined geometrically from the competition between these two forces, not assigned as an external parameter. This is the ultimate consequence of Axiom Zero.

E. The Arrow of Time: Information-Thermodynamic Irreversibility

Although Newton's equations of motion are time-reversal symmetric, the computational process of RSHG is irreversible by three independent sources.

Source 1 (Information erasure cost): By Landauer's principle [19], erasure of one bit requires release of at least $k_B T \ln 2$ as heat. Each lattice node generates heat at every state update, and this generation is irreversible by the second law of thermodynamics.

Source 2 (Computational complexity): The 3D regular-tetrahedron packing problem is NP-complete. Unique reconstruction of the past path leading to configuration $C(t)$ at time t is computationally infeasible: exponentially many paths can reach the same configuration. Computing future states costs polynomial time; recomputing past states costs exponential time. This asymmetry defines the arrow of time.

Source 3 (Projection unidirectionality): The 4D $\to$ 3D projection is a many-to-one map with information loss; its inverse is not uniquely defined.

Time t is defined as the number of computational steps n executed from the initial state: $t = n \times t_P$. The arrow of time is synonymous with this computational irreversibility. The state transition history is defined only in the forward direction.

VI. LIMITS OF LOCAL ALLOCATION: ACCUMULATION OF GLOBAL DISTORTION AND THE BIRTH OF HIERARCHY

A. The Non-Zero Topological Conserved Quantity and the Limits of Local Optimization

The LRAP of Section III provides a local optimization strategy for individual agents. However, the Gauss–Bonnet theorem guarantees that the sum of all deficit angles on a closed manifold is fixed by the Euler characteristic χ [11]:

$$\sum_{\text{all edges}} \delta_i = \text{const} \propto \chi(S^3). \tag{31}$$

This constant is a non-zero topological conserved quantity that cannot be altered by local rearrangements. Reducing δ locally necessarily increases it elsewhere—frustration does not disappear but transfers.

Cosmic expansion dilutes the frustration density ($\rho_\delta \propto a(t)^{-3}$), but autonomous reconfiguration dynamics (informational Pauli repulsion) perpetually generates new information collisions. The total frustration:

$$\Phi_{\text{total}}(t) = \int \Phi(\mathbf{x}, t)\, d^3x \sim \text{const} + \Delta\Phi_{\text{new}}(t) \tag{32}$$

accumulates monotonically, since $\Delta\Phi_{\text{new}}(t) \neq 0$.

B. Approach to the Jamming Critical Point and the Role of Structural Vacancies

The accumulation of Φ_{total} manifests as an increase in the effective packing fraction ϕ, driving it toward the jamming critical point $\phi_c \approx 0.64$. Near this point, the reconfiguration time diverges exponentially:

$$\tau_{\text{reconfig}} = \tau_0 \exp\left(\frac{E_0}{\phi_c - \phi}\right) \xrightarrow{\phi \to \phi_c} \infty. \tag{33}$$

At $\phi \approx 0.62$, $\tau_{\text{reconfig}} \approx 12\, t_P$—the universe operates just short of freezing [20].

The role of the structural vacancies $\phi_c - \phi \approx 0.02$ is threefold: (1) local rearrangements remain feasible, maintaining computational fluidity; (2) the unfolding process (autonomous reconfiguration dynamics) can continue; (3) frustration leaks from boundaries to generate observable forces. This value is not an adjustable parameter; it is determined geometrically from the equilibrium between gravity (σ_{struct}) and Pauli repulsion (σ_{Pauli}).

Local approach to $\phi \to \phi_c$ generates two computational crises. The first is Dimensional Arrest (Section IV)—computation cannot complete and 4D data freezes. The second is computational heat accumulation—failed reconfiguration attempts accelerate heat release via Landauer's principle [19].

C. Birth of Hierarchical Scaling: Thermodynamic Optimization Necessity

When a local region reaches $\phi \to \phi_c$, optimization at the individual node level is no longer functional. The only available strategy is **phase redefinition**: rebundling the cluster that has reached its limit as a new single node at the next higher scale.

This is the essential role of the jamming transition. When the transition from fluid (unjammed) to solid (jammed) state occurs, a large number of individual nodes form a "supernode" that behaves as a collective. This supernode operates at a scale $\sim 10^6$ times larger than the original nodes, and the effective packing fraction at that scale resets to $\phi \approx 0.62$.

The total frustration is partitioned by the hierarchical structure:

$$\Phi_{\text{total}} = \Phi_{\text{micro}} + \Phi_{\text{meso}} + \Phi_{\text{macro}} + \cdots \tag{34}$$

Each hierarchy partially absorbs frustration at its own scale and suppresses leakage to higher hierarchies. Simultaneously, computational heat is converted into structural entropy (computational encapsulation) [20, 21]:

$$\frac{dS_{\text{thermal}}}{dt} < 0, \quad \frac{dS_{\text{structural}}}{dt} > 0, \quad \frac{dS_{\text{total}}}{dt} \geq 0. \tag{35}$$

Computational heat is converted into structural order in compliance with the second law of thermodynamics—the mechanism for avoiding thermal collapse.

D. Preview of Part III: The Arithmetic Necessity of 122 Digits

The "limit reached → phase redefinition by scale-up" cascade is the six-stage hierarchical jamming transition detailed in Part III:

$$\underbrace{\underbrace{\text{QCD} \to \text{Molecular} \to \text{Cellular} \to}_{} \; \text{Geological} \to \text{Planetary} \to \text{Galactic}}_{\text{6 stages}} \tag{36}$$

The reason each hierarchy generates approximately 20 digits of energy suppression—$\varepsilon_n \approx 10^{-19.2}$—is determined geometrically from the structural vacancies (0.02) and the critical exponent ($\alpha = 3\nu = 2.64$). The six-stage cumulative suppression:

$$\varepsilon_{\text{total}} = (10^{-19.2})^6 \times (\text{geometric corrections}) \approx 10^{-122.2}. \tag{37}$$

The hierarchy count $N = 6$ is not an adjustable parameter; it is the arithmetic consequence of dividing the target suppression (122 digits) by the single-stage suppression (~ 19.2 digits) [22]:

$$N = \frac{122}{19.2} \approx 6.35 \approx 6. \tag{38}$$

This is the resolution of the cosmological constant problem. Part III provides the thermodynamic analysis of this structure.

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