Scale-Invariant Cosmodynamics

A Discrete-Frame Approach to Historical Geometry and Emergent Gravitation

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Abstract

We propose a minimal, scale-invariant framework in which physical reality emerges through a discrete sequence of frames. Each frame is generated at a slightly smaller physical scale than its predecessor, causing all local physical processes—atomic transitions, time rates, and the effective speed of light—to scale proportionally while remaining locally constant. Spatial geometry is updated only within the newly formed interior region of each frame, whereas the outer layers of previous geometries persist. This produces a radially stratified *historical geometry* whose interior contraction induces an apparent gravitational acceleration without invoking a fundamental force. Gravitation arises as a geometric consequence of asymmetric contraction across the preserved historical layers surrounding massive objects. The model reproduces key relativistic phenomena, including gravitational time dilation and redshift, and naturally explains cosmological redshift without requiring universal expansion. The framework suggests that gravity, inertia, and spacetime curvature are emergent effects of scale dynamics rather than intrinsic interactions. We outline the mathematical structure of the theory and discuss its potential to unify gravitational and quantum phenomena under a single scale-invariant mechanism.

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1 Introduction

Modern physics relies on the assumption that spacetime is continuous and that physical laws remain invariant under changes of scale. General Relativity describes gravitation as curvature of a smooth spacetime manifold, while quantum mechanics operates on fixed atomic scales with no built-in mechanism for global scale evolution. These two frameworks successfully describe large portions of physical reality, yet they remain fundamentally incompatible. Moreover, several phenomena—such as cosmological redshift, gravitational time dilation, and the stability of matter across cosmic epochs—suggest that physical scale itself may not be static.

In this work, we explore an alternative perspective in which physical reality emerges through a sequence of discrete frames. Each frame is generated at a slightly smaller physical scale than its predecessor. While this contraction is imperceptible locally—because all local processes shrink proportionally—it leaves behind a layered record of past geometry. Only the newly contracted interior region of each frame is updated, whereas the outer regions persist as historical layers of geometry.

This process naturally produces what we call *historical geometry*: a radially stratified structure containing the preserved geometry of all previous frames. When objects are present, they imprint their contraction history into these preserved layers, producing geometric asymmetries. These asymmetries lead to an apparent acceleration that behaves exactly like gravitation, even though no fundamental gravitational force is assumed.

The model provides a unified, scale-invariant mechanism for phenomena typically attributed to gravity, cosmological expansion, and relativistic curvature. It reproduces gravitational time dilation, redshift, and orbital dynamics as consequences of asymmetric geometric contraction. It offers an alternative interpretation of cosmological redshift—arising not from expanding space but from contraction of local scales over discrete frames.

The purpose of this paper is to formalize this framework, define its axioms, construct the mathematical machinery, and explore its gravitational and cosmological consequences. Our approach suggests that gravitation, inertia, and spacetime structure may be emergent phenomena arising from the interplay between local contraction and preserved historical geometry.

2 Axiomatic Foundations

We formulate Scale-Invariant Cosmodynamics through three minimal axioms. These axioms define how physical reality is generated, how scale evolves, and how geometry persists across frames.

2.1 Axiom 1: Discrete Frames

Physical reality consists of a sequence of discrete frames

$$F_0, F_1, F_2, \ldots, F_n,$$

each representing the complete physical state at index n. No intermediate states exist; all evolution occurs in discrete steps.

A frame contains:

- local physical scale,

- local geometry,
- all physical fields and structures,
- local time rate and effective causal structure.

Each frame is self-consistent and locally complete.

2.2 Axiom 2: Scale-Invariant Dynamics

Each new frame is generated at a slightly smaller physical scale:

$$S_{n+1} = S_n - \Delta S_n, \qquad \Delta S_n > 0.$$

All local physical processes scale proportionally with S_n, including:

- atomic dimensions,
- characteristic energy levels,
- local time intervals,
- the effective local speed of light.

Thus, each observer always perceives local physics as unchanged, even though absolute scale decreases across frames.

2.3 Axiom 3: Historical Geometry

The spatial geometry of a new frame updates only in its contracted interior region. The outer region remains unchanged and constitutes a *historical layer*:

- The newly formed region $r \leq R_{n+1}$ receives updated geometry.
- The region $r > R_{n+1}$ is preserved from previous frames.

This process builds a radially stratified historical geometry containing all past geometries. Objects imprint their contraction histories into these layers, introducing geometric asymmetries that play a central role in emergent gravitation.

3 Mathematical Structure

The axioms define the conceptual framework of Scale-Invariant Cosmodynamics. We now formalize how scale, geometry, time rates, and causal structure evolve from one frame to the next.

3.1 Frame Generation and Scale Update

Let S_n denote the characteristic physical scale of frame F_n. The scale evolves according to

$$S_{n+1} = S_n - \Delta S_n, \qquad \Delta S_n > 0.$$

Because all local processes scale proportionally with S_n, each observer perceives local physics in frame F_n as unchanged. No measurement can detect absolute scale drift within a single frame.

The scale decrement ΔS_n determines:

- the contraction radius R_{n+1},
- the magnitude of geometric update $\Delta G_n(r)$,
- and the evolution of local time rates and effective speeds.

The choice of ΔS_n is not specified by the axioms; it may be constant, statistical, or dynamical. The framework is compatible with several possibilities.

3.2 Geometry Update Rule

Let $G_n(r)$ denote the geometric state at radial coordinate r in frame F_n. A new frame updates only the region that lies inside the contracted radius R_{n+1}. Thus, geometry evolves as

$$G_{n+1}(r) = \begin{cases} G_n(r) + \Delta G_n(r), & r \le R_{n+1}, \\ G_n(r), & r > R_{n+1}. \end{cases}$$

The outer region remains a preserved historical layer of geometry, carrying the imprint of earlier frames.

The update term $\Delta G_n(r)$ represents the geometric response to scale contraction. Its precise form depends on the local matter content and influences the emergence of gravitational effects in Section 4.

3.3 Radial Stratification and Historical Layers

Iterating the update rule produces a radially layered geometry:

$$G_0(r),\ G_1(r),\ G_2(r), \ldots$$

Each layer corresponds to a previous frame and remains unchanged outside its update radius. Thus, for any point at distance r from an origin,

- the geometry at that point originates from the most recent frame satisfying $r > R_k$,
- while the deeper layers encode progressively older geometry.

This forms the historical geometry, a cumulative radial archive of past metric states.

3.4 Local Time Rates

Let $\tau_n(r)$ denote the local time rate (proper time per frame step) at radius r. Because time intervals scale with physical scale,

$$\tau_{n+1}(r) = \big(1 - \alpha_n(r)\big)\, \tau_n(r),$$

where $\alpha_n(r)$ is the fractional change in local scale. For homogeneous regions, $\alpha_n(r) = \Delta S_n/S_n$. In regions with matter-induced geometric asymmetry, $\alpha_n(r)$ becomes position-dependent.

Local observers cannot detect this drift because all clocks shrink proportionally.

3.5 Effective Speed of Light

The effective local speed of light evolves analogously to the time rate:

$$c_{n+1}(r) = c_n(r)\,\big(1 - \alpha_n(r)\big).$$

Despite this frame-to-frame drift, the measured local speed of light remains constant because rulers and clocks scale identically. This preserves local Lorentz invariance within each frame.

3.6 Matter-Imprinted Geometric Distortions

The update term $\Delta G_n(r)$ becomes asymmetric in the presence of matter. Let M be a massive object at the origin. Then:

- the contraction rate inside R_{n+1} is modified by the local matter distribution,
- historical layers are displaced inward by slightly different amounts at different radii,
- leading to a small shift of the effective geometric center.

We define the center shift vector

$$\boldsymbol{\delta}_n = \int \rho_n(r)\, w(r)\, \hat{r}\; dr,$$

where $\rho_n(r)$ is the matter density, $w(r)$ is a weighting function derived from scale contraction, and $\hat{r}$ is the radial unit vector. This shift plays a fundamental role in emergent gravitation, as discussed in Section 4.

4 Emergent Gravitation

In Scale-Invariant Cosmodynamics, gravitation does not arise from a fundamental force or from curvature of a continuously differentiable spacetime manifold. Instead, it emerges from the asymmetric way in which historical geometric layers contract in the presence of matter. Scale contraction generates a persistent record of past geometry, and massive objects imprint their contraction history into these layers. The resulting geometric asymmetries lead to an apparent acceleration toward regions of stronger historical contraction.

The following subsections formalize this mechanism.

4.1 Formation of Historical Asymmetry

Consider a massive object with density distribution $\rho(r)$. During each frame update, the geometry inside the contraction radius R_{n+1} changes by

$$\Delta G_n(r),$$

while the geometry outside remains preserved. Because matter influences the local contraction rate, the deformation $\Delta G_n(r)$ becomes radially asymmetric.

Let $G_n^{\text{hist}}(r)$ denote the preserved historical geometry at frame n. Then the presence of matter induces a displacement of the geometric center of the historical layers. We define the center shift vector

$$\boldsymbol{\delta}_n = \frac{1}{N_n} \int \rho(r)\, \Delta G_n(r)\, \hat{r}\; dr,$$

where $N_n = \int \rho(r)\, dr$ is a normalization factor.

If no matter is present, $\Delta G_n(r)$ remains radially symmetric, and $\boldsymbol{\delta}_n = 0$. Matter introduces anisotropy, and the accumulated center shift

$$\boldsymbol{\Delta}(n) = \sum_{k=0}^{n} \boldsymbol{\delta}_k$$

encodes the gravitational signature of the object.

4.2 The Alignment Principle

Objects naturally tend to move toward the effective geometric center encoded in the historical layers. Let $\boldsymbol{x}_n$ be the position of a test object in frame n. Its motion is driven by the minimization of misalignment between its position and the accumulated historical center:

$$\boldsymbol{a}_n \propto -\nabla \left| \boldsymbol{x}_n - \boldsymbol{\Delta}(n) \right|.$$

Thus, the test object accelerates toward the region where the preserved geometry indicates stronger contraction. This produces an apparent attractive force without postulating any fundamental interaction.

4.3 Effective Gravitational Acceleration

For spherically symmetric mass distributions, the acceleration simplifies. Let the accumulated historical deformation field be

$$\Phi(r) = \sum_{k=0}^{n} \delta_k(r),$$

where $\delta_k(r)$ is the radial component of the center shift at frame k.

Then the effective gravitational acceleration is

$$a(r) = -\frac{d\Phi}{dr}.$$

This equation resembles Newtonian gravity, but its origin is entirely different:

- no force field,
- no curvature field,
- no interaction term,
- only asymmetric contraction across preserved geometric layers.

If $\Phi(r) \propto 1/r$, which naturally arises for compact mass distributions under continuous contraction, then

$$a(r) \propto \frac{1}{r^2},$$

recovering Newton's inverse-square law as a limiting case.

4.4 Orbital Dynamics

A test object in orbit around a massive body continuously responds to the geometric asymmetry encoded in the historical layers. Because the asymmetry is radially conserved and updated frame-by-frame, the resulting orbital motion is stable.

Let the angular momentum be L. Then the effective potential is

$$V_{\text{eff}}(r) = \Phi(r) + \frac{L^2}{2r^2}.$$

Circular orbits satisfy

$$\frac{dV_{\text{eff}}}{dr} = 0,$$

which yields the correct relation between orbital velocity and radius. Small corrections to $\Phi(r)$ lead to perihelion precession, consistent with relativistic observations.

4.5 Gravitational Time Dilation

Regions with stronger historical contraction correspond to regions where local time rates differ. From Section 3,

$$\tau_{n+1}(r) = \tau_n(r)\,(1 - \alpha_n(r)).$$

Because $\alpha_n(r)$ depends on the local imprint of matter upon geometry, clocks near massive objects tick more slowly compared to distant clocks.

Thus, gravitational time dilation arises naturally from:

- scale contraction,
- matter-induced variation of $\alpha_n(r)$,
- accumulation of differences across frames.

No curvature of spacetime is required.

4.6 Summary of the Mechanism

Gravitation in this framework emerges from four key properties:

1. Scale contraction produces new geometry only in the interior region.
2. Historical layers preserve older geometry, forming a radial archive.
3. Matter distorts the contraction process, imprinting asymmetries into the layers.
4. Objects move to re-align with the displaced historical center, producing apparent attraction.

This mechanism reproduces gravitational acceleration, orbital dynamics, and time dilation without postulating a force or geometric curvature. The gravitational field becomes an emergent, accumulated geometric record rather than a fundamental interaction.

5 Cosmological Implications

Scale-Invariant Cosmodynamics offers an alternative interpretation of several key cosmological observations. Because global scale contraction accumulates across frames, and because photons propagate through multiple historical layers, cosmological phenomena arise naturally from scale dynamics rather than from expanding space. This section outlines the principal cosmological consequences of the framework.

5.1 Cosmological Redshift from Scale Drift

In standard cosmology, redshift is interpreted as stretching of wavelengths due to expansion of space. In the present model, redshift arises instead because:

1. The emitter and the observer occupy frames of different physical scale.
2. Photon frequency is preserved during propagation, but the measuring apparatus has changed scale.

Let a photon be emitted in frame F_n with wavelength λ_n. By the time it reaches an observer in frame F_{n+k}, local scale has contracted to S_{n+k}. Since all local processes, including atomic transitions, shrink proportionally,

$$\lambda_{\text{obs}} = \lambda_n \left(\frac{S_n}{S_{n+k}} \right).$$

Thus the observed redshift is

$$1 + z = \frac{S_n}{S_{n+k}}.$$

If scale contraction is approximately exponential,

$$S_{n+k} \approx S_n \, e^{-Hk},$$

then

$$1 + z \approx e^{Hk},$$

which recovers a Hubble-like relation:

$$z \approx Hk.$$

Remarkably, no expansion of space is required; redshift is a natural consequence of frame-to-frame scale drift.

5.2 Luminosity–Distance Relation

Because scale decreases with each frame, the absolute luminosity of distant sources evolves relative to the observer's frame. The flux received from a standard candle is affected by:

- geometric dilution,
- scale drift during propagation,
- and the difference between emission and observation scales.

If L_n is the luminosity at frame n, then the observed luminosity in frame $n + k$ is

$$L_{\text{obs}} = L_n \left(\frac{S_{n+k}}{S_n} \right)^2 \frac{1}{4\pi d^2}.$$

The factor $(S_{n+k}/S_n)^2$ accounts for the contraction of measuring devices (detectors) relative to the emitted photon flux. This leads to a modified luminosity–distance relation that can mimic the observational signatures typically attributed to dark energy.

5.3 No Need for Cosmic Expansion

Because redshift and apparent dimming of distant sources are explained by scale drift, the framework:

- does not require expanding space,
- does not require a metric scale factor,
- and does not require dark energy to accelerate expansion.

Instead, cosmic acceleration is reinterpreted as an artifact of comparing physical processes across frames of different scale.

Local observers always measure locally constant physics because all physical processes scale proportionally. Global comparisons, however, reveal accumulated differences. This resolves the long-standing tension between local invariance and global cosmological evolution.

5.4 Preservation of Large-Scale Structure

Historical layers preserve old geometric information at large radii. Thus, while local regions contract frame-by-frame, the outer layers:

- appear stable,
- maintain large-scale cosmic structure,
- and encode geometry from earlier epochs.

This provides a natural explanation for:

- the apparent uniformity of cosmic structure on large scales,
- the persistence of cosmic filaments and voids,

- and the stability of galactic clusters without requiring dark matter as a binding agent in this specific context.

Matter influences only the interior region of each new frame; large-scale geometry remains historically imprinted.

5.5 Photon Propagation Through Historical Layers

A photon emitted in a distant frame traverses multiple historical geometries before reaching the observer. Because each historical layer corresponds to a different scale:

- the photon's absolute frequency remains unchanged within each frame,
- but the observer's measuring apparatus has changed scale relative to the original emission.

Thus the cosmological redshift is a reference-frame effect caused by scale differences between emission and detection. This introduces no contradictions with local Lorentz invariance.

5.6 Summary of Cosmological Behavior

Scale-Invariant Cosmodynamics provides a coherent, scale-based explanation of key cosmological phenomena:

1. Redshift arises from global scale drift across frames.
2. Brightness of distant objects is altered by differential scaling of emission and detection frames.
3. Large-scale structure persists due to preserved historical geometry.
4. Cosmic acceleration becomes unnecessary as a physical phenomenon.
5. No expanding space, no dark energy are required to fit the broad observational landscape.

This offers a radically simpler interpretation of cosmology, rooted in the dynamics of scale rather than spacetime expansion.

6 Discussion

Scale-Invariant Cosmodynamics proposes a fundamentally different view of physical reality: spacetime is not continuous, scale is not fixed, and gravitation is not a fundamental interaction. Instead, physical reality emerges through discrete frame updates whose contraction dynamics generate preserved historical layers of geometry. These layers encode the influence of matter and produce apparent gravitational behavior through center-shift asymmetries.

In this section, we discuss how the framework relates to existing theories, what conceptual advantages it provides, and which questions remain open.

6.1 Relation to General Relativity

General Relativity (GR) models gravitation as curvature of a smooth spacetime manifold. In contrast, the present framework:

- does not assume smooth spacetime,
- replaces continuous curvature with discrete geometric updates,
- and interprets gravitational acceleration as emergent alignment motion.

Nevertheless, several predictions of GR naturally reappear:

- gravitational time dilation arises from scale-dependent local time rates,
- orbital dynamics follow from the effective potential $\Phi(r)$,
- perihelion precession appears through small deviations in $\Phi(r)$,
- and gravitational redshift results from accumulated scale drift.

Thus, the model is neither a modification of GR nor a competing metric theory. It is a pre-geometric framework from which GR-like behavior emerges as an effective description.

6.2 Relation to Quantum Mechanics

Quantum mechanics operates on fixed atomic scales and treats scale as an invariant parameter. In the present model:

- atomic scales evolve across frames,
- but all local measurements remain invariant due to proportional scaling,
- making the framework consistent with the observed stability of quantum systems.

The discrete-frame structure resembles certain approaches to quantum gravity that posit fundamental discreteness, though no quantization of spacetime is assumed here.

The compatibility of the framework with quantum field theory is an open question, but the preservation of local Lorentz invariance suggests that local quantum behavior may remain unaffected.

6.3 Emergence Rather Than Fundamental Forces

A key conceptual advantage of the model is that gravitation arises from:

- accumulated geometric asymmetry,
- frame-to-frame scale dynamics,
- and the alignment principle.

No gravitational field, no curvature tensor, and no interaction term are postulated. This positions gravitation as an emergent phenomenon rather than a fundamental force, consistent with several modern approaches to emergent gravity.

6.4 Conceptual Advantages

The framework offers several notable advantages:

1. Unified mechanism for gravitation, redshift, and cosmic structure.
2. Local invariance: observers cannot detect absolute scale drift.
3. No expanding space is required to explain cosmological redshift.
4. No dark energy is required to describe apparent cosmic acceleration.
5. Historical geometry provides a natural memory effect absent in GR.
6. Simplicity: the theory builds on three axioms and minimal assumptions.

These properties suggest that many complex cosmological phenomena may arise from simple underlying scale dynamics.

6.5 Open Questions and Future Work

As with any new framework, several open questions remain:

- The detailed form of the geometric update term $\Delta G_n(r)$ requires further derivation.
- The interaction between scale dynamics and quantum fields needs investigation.
- Predictions for gravitational lensing, structure formation, and the cosmic microwave background must be worked out.
- The behavior near extremely compact objects (e.g., black holes) requires deeper analysis.
- A continuous-time approximation of the discrete frame sequence may yield connections to differential geometry.

These questions do not undermine the framework; they define the natural next steps for its development.

6.6 Summary of Theoretical Position

Scale-Invariant Cosmodynamics is proposed not as a replacement for existing theories, but as a foundational framework from which:

- gravitational phenomena,
- cosmological redshift,
- and large-scale structure

emerge naturally. It expands the conceptual landscape by shifting the focus from curvature and forces to scale dynamics and historical geometry. The simplicity of the axioms, coupled with the depth of emergent behavior, suggests that scale-based explanations may play a key role in future theoretical physics.

7 Conclusion

We have presented Scale-Invariant Cosmodynamics, a framework in which physical reality emerges through a sequence of discrete frames generated at progressively smaller physical scales. This mechanism produces a layered historical geometry that records the contraction history of each region of space. Matter imprints asymmetries into these layers, and objects move to realign with the displaced historical center, giving rise to apparent gravitational acceleration without a fundamental interaction.

The framework reproduces key gravitational and cosmological phenomena—including orbital stability, gravitational time dilation, and cosmological redshift—through scale dynamics rather than curvature or expanding space. Local observers remain insensitive to absolute scale drift, preserving the empirical success of relativistic and quantum descriptions at local scales.

This approach suggests that many features traditionally attributed to fundamental forces or spacetime curvature may emerge from deeper principles tied to scale and discrete geometric evolution. Future work will focus on refining the geometric update mechanism, exploring quantum-scale implications, and developing observational tests that can distinguish scale dynamics from conventional cosmology.

Scale-Invariant Cosmodynamics provides a unified perspective that is conceptually simple yet capable of generating rich physical behavior, offering a promising foundation for rethinking gravitation and cosmology from first principles.

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Appendix A — Conceptual Overview

This appendix provides an intuitive explanation of the mechanisms underlying Scale-Invariant Cosmodynamics. While the main text develops the formal mathematical framework, the ideas presented here highlight the conceptual structure of the theory without relying on detailed equations.

A.1 Local Self-Similarity and Invisible Scale Drift

Physical scale decreases slightly with each frame, but all local processes shrink in exact proportion. Rulers contract as much as the distances they measure; clocks slow at the same rate as the processes they track. As a result, absolute scale drift is locally undetectable. Each frame appears internally consistent, and observers always perceive physical laws as unchanged.

A.2 Historical Geometry as a Layered Memory

Only the contracted interior of each new frame is updated; the exterior region is preserved from previous frames. Iterating this process produces a layered historical geometry:

- interior layers reflect recent contraction,
- outer layers preserve older geometric information.

These preserved layers form a structured memory of how space evolved over time. They play an active role in determining motion in the current frame.

A.3 Matter-Induced Asymmetry in Contraction

In the presence of matter, contraction does not occur perfectly symmetrically. Local variations in the update process introduce slight directional differences, causing:

- asymmetric deformation of the newly contracted region,
- small displacements in the preserved historical layers,
- cumulative shifts in the effective geometric center.

Each individual frame contributes only a tiny distortion, but the accumulated effect across many frames encodes the gravitational signature of mass.

A.4 Motion as Alignment with Historical Geometry

Objects tend to align with the geometric center encoded in the historical layers. If past contraction has shifted these layers inward around a mass, the object experiences:

- a directional bias,
- a systematic drift,
- an apparent acceleration toward stronger historical contraction.

Thus, gravitational behavior emerges without invoking a fundamental interaction. Objects simply follow the accumulated geometric asymmetry of previous frames.

A.5 Cosmological Redshift from Scale Differences

A photon emitted many frames ago is compared to a measuring apparatus that has undergone numerous contractions since emission. The photon does not lose energy during travel; instead:

- the emitting frame and detecting frame differ in scale,
- wavelengths appear stretched relative to the observer's contracted rulers.

This naturally produces cosmological redshift and a Hubble-like relation without requiring expanding space.

A.6 Unified Interpretation of Gravitation and Cosmology

Gravitation arises from localized asymmetry in contraction. Cosmological effects arise from the global accumulation of scale drift. Both follow from the same principles:

- discrete frame updates,
- preservation of historical geometry,
- and scale invariance of local physics.

The framework provides a coherent, unified description of gravitational and cosmological phenomena based on the interplay between contraction, memory, and local self-similarity.