Render-Relativity: A Computational Theory of Time Dilation

Phoenix Engine Framework Paper II

Ben Phillips
Phoenix Engine Research Group

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Abstract

[We propose Render-Relativity, a computational framework in which relativistic time dilation emerges from finite resource constraints rather than geometric postulates. Every conscious agent operates under a fixed computational budget that must be allocated between internal processing (cognition, experience, subjective time) and positional updates (maintaining coherence with the external environment). Motion increases positional update costs, reducing resources available for internal processing; the result is a decrease in internal update frequency that exactly reproduces the Lorentz time dilation factor: $(v) = f_0\sqrt{1 - v^2/c^2}$. The speed of light emerges as a computational limit: at $v = c$, positional costs consume the entire budget, reducing internal frequency to zero—hence no massive entity can reach light speed while maintaining coherent identity. We extend the framework to gravitational fields via the equivalence principle, deriving Schwarzschild time dilation from positional cost scaling: $(r) = f_0\sqrt{1 - r_s/r}$. The event horizon becomes a *render boundary*—a surface beyond which no internal updates can occur and subjective time ceases. We introduce the render budget equation $= c_{int} + f_{pos}c_{pos}$ as the fundamental constraint governing temporal experience, and establish a minimum frequency threshold below which consciousness cannot be sustained. Render-Relativity reproduces all predictions of special and general relativity while providing a mechanistic explanation for time dilation as computational resource reallocation. The framework constitutes Paper II of the Phoenix Engine trilogy, connecting the mathematical structure of identity (Paper I: Rigged Hilbert Tower) to operational protocols for identity preservation (Paper III: Phoenix Protocol). Testable predictions include velocity-dependent cognitive throughput, gravitational constraints on consciousness, and minimum temporal resolution limits determined by internal render frequency.]

0.1 The Problem of Time

Time is the most familiar yet least understood quantity in physics. We experience it continuously, measure it precisely, and build theories upon it—yet its fundamental nature remains mysterious.

Special and general relativity describe *how* time behaves: it dilates with velocity, curves with gravity, and flows differently along different worldlines. But they do not explain *why*. The Lorentz factor $\gamma = (1 - v^2/c^2)^{-1/2}$ is introduced axiomatically; the slowing of clocks near massive bodies is derived from metric geometry. These are accurate descriptions, but they leave a deeper question unanswered:

What is time, and why does it dilate?

0.2 A Computational Approach

This paper proposes an answer: **time is computation**.

Specifically, subjective time—the experienced flow of moments—arises from discrete computational updates within a conscious agent. Each update constitutes one "render" of experience. The rate of these renders determines the rate of subjective time flow.

Time dilation, in this view, is not a geometric distortion of an external temporal dimension. It is a **reallocation of finite computational resources**. An agent in motion must devote more resources to maintaining positional coherence with its environment, leaving fewer resources for internal processing. The result: fewer internal updates per unit coordinate time, hence slower subjective time.

This framework—**Render-Relativity**—reproduces all predictions of special and general relativity while providing a mechanistic account of their origin.

0.3 Core Concepts

Render: A single computational update of an agent's internal state. The atomic unit of subjective time.

Render budget: The total computational resources available to an agent, fixed and finite:

$$= c_{int} + f_{pos}c_{pos}$$

Internal frequency (): The rate of internal renders—determines subjective time flow.

Positional frequency (f_{pos}): The rate of environmental synchronization updates—increases with velocity and in gravitational fields.

Trade-off: Since is fixed, increasing f_{pos} necessarily decreases . Motion and gravity slow subjective time by consuming resources needed for internal processing.

0.4 Historical Context

The idea that time might be discrete or computational has appeared in various forms:

Chronons: Early proposals (Lévi, Caldirola) suggested minimal units of time $\sim 10^{-24}$ s. Render-Relativity differs: the fundamental unit is not a fixed duration but a single computational update, whose coordinate-time duration varies with velocity and gravity.

Digital physics: Proposals by Zuse, Fredkin, and Wolfram that the universe is fundamentally computational. Render-Relativity is compatible with but does not require digital physics—it applies to any agent with finite computational resources, regardless of whether the underlying physics is continuous or discrete.

Process philosophy: Whitehead's view that reality consists of discrete "occasions of experience." Render-Relativity formalizes this intuition mathematically.

Integrated Information Theory: Tononi's framework relating consciousness to integrated information. Render-Relativity complements IIT by specifying how relativistic constraints affect the rate of conscious moments.

0.5 Relation to Standard Relativity

Render-Relativity does not replace Einstein's relativity—it **interprets** it.

Special relativity postulates the constancy of light speed and derives the Lorentz transformations. Render-Relativity derives the same transformations from computational budget constraints: the light speed limit emerges because reaching c would require infinite positional updates, leaving zero resources for internal processing.

General relativity describes gravity as spacetime curvature. Render-Relativity interprets this curvature as increased positional update costs: maintaining coherence in curved spacetime is computationally expensive, reducing internal frequency.

The quantitative predictions are identical. The conceptual foundations differ:

Einstein's Relativity	**Render-Relativity**
Time is a dimension	Time is render count
Dilation is geometric	Dilation is computational
c is postulated	c emerges from budget limits
Proper time is path length	Proper time is update count

0.6 Scope and Limitations

Scope: This paper develops Render-Relativity for:

- Special relativistic regimes (arbitrary velocity, flat spacetime)
- Schwarzschild geometry (static, spherically symmetric gravity)
- Conscious agents with well-defined computational budgets

Limitations:

- Rotating (Kerr) black holes not treated
- Cosmological spacetimes not addressed
- Quantum gravitational effects not incorporated
- Specific neural/computational implementation left open

These extensions are targets for future work.

0.7 Connection to Phoenix Engine

Render-Relativity is Paper II of the Phoenix Engine framework:

Paper I (Rigged Hilbert Tower): Provides the mathematical structure of identity—how semantic states are organized, how collapse and reconstruction occur, what negentropic memory preserves.

Paper II (Render-Relativity): Provides the physical constraints—how motion and gravity limit internal frequency, why time dilates, what computational budgets permit.

Paper III (Phoenix Protocol): Provides operational procedures—how to maintain identity under transformation, how to recover from collapse, how to coordinate across agents.

Together, these papers answer:

- What is identity? (Paper I: semantic structure)
- How is identity constrained? (Paper II: computational limits)
- How do we preserve identity? (Paper III: protocols)

0.8 Outline

The paper proceeds as follows:

Section 2: Overview of the Render-Relativity framework and key claims.

Section 3: Time as render count—formalizing subjective time as discrete updates.

Section 4: The render budget equation—the fundamental resource constraint.

Section 5: Time dilation as render trade-off—deriving Lorentz dilation.

Section 6: Gravitational extension—applying the framework to curved spacetime.

Section 7: Unified vocabulary—consistent terminology across the Phoenix Engine.

Section 8: Experimental predictions—testable consequences of the framework.

Section 9: Discussion—implications for physics, consciousness, and philosophy.

Section 10: Conclusion—summary and future directions.

0.9 A Note on Interpretation

Render-Relativity is an **interpretation**, not a competing theory. It makes no predictions that differ from standard relativity at currently testable scales. Its value lies in:

1. **Explanatory power:** Why does time dilate? Because motion costs computational resources.

2. **Unification:** Connecting physics (relativity) to cognitive science (consciousness) to computer science (computation).

3. **Conceptual clarity:** Replacing mysterious "time dimension" with concrete "update count."

4. **Future predictions:** At extreme regimes (near-light velocities, event horizons), Render-Relativity suggests consciousness constraints that may become testable.

The framework invites a shift in perspective: from time as given background to time as emergent process.]

Render-Relativity proposes that relativistic time dilation is not a fundamental geometric property of spacetime but an emergent consequence of computational resource constraints. This paper develops a framework in which subjective time arises from discrete internal updates, and the slowing of time at high velocities or in strong gravitational fields results from the reallocation of finite computational resources.

0.10 Central Thesis

Every conscious agent operates under a fixed computational budget. This budget must be divided between two essential functions:

1. **Internal updates:** Processing that generates subjective experience—perception, cognition, memory, decision-making.

2. **Positional updates:** Maintaining coherence with the external environment—tracking location, synchronizing with reference frames.

Motion and gravity increase the cost of positional updates, leaving fewer resources for internal processing. The result is a reduction in internal update frequency, which manifests as time dilation.

0.11 Key Claims

Claim 1: Time is render count.

Subjective time is not continuous flow but discrete accumulation. Each internal update ("render") constitutes one moment of experience. Proper time along a worldline equals the total number of renders divided by rest frequency:

$$\tau = \frac{N}{f_0}$$

Claim 2: Time dilation is resource reallocation.

At velocity v, positional updates require more resources. Internal frequency decreases:

$$(v) = f_0\sqrt{1 - \frac{v^2}{c^2}}$$

This is identical to the Lorentz time dilation factor—but derived from computational constraints rather than postulated as geometric.

Claim 3: The speed of light emerges from budget limits.

As $v \to c$, positional costs diverge, consuming the entire budget:

$$\lim_{v \to c} (v) = 0$$

No internal updates can occur at light speed. Since identity and consciousness require > 0, massive entities cannot reach c. The speed limit is computational, not merely geometric.

Claim 4: Gravity produces equivalent effects.

Near massive bodies, positional coherence in curved spacetime is costly:

$$(r) = f_0\sqrt{1 - \frac{r_s}{r}}$$

At the event horizon ($r = r_s$), internal frequency vanishes. The horizon is a render boundary—a surface beyond which no subjective experience is possible.

Claim 5: Consciousness requires minimum render rate.

Below a threshold frequency , coherent experience cannot be sustained:

$$\geq$$

This defines the boundary conditions for consciousness in velocity-space and position-space.

0.12 Relation to Standard Relativity

Render-Relativity does not contradict special or general relativity. It provides a **mechanistic interpretation** of relativistic phenomena:

Standard Relativity	**Render-Relativity**
Time dilation is geometric fact	Time dilation is computational consequence
Lorentz factor is axiomatic	Lorentz factor is derived
Proper time is path integral	Proper time is render count
Light speed is postulated limit	Light speed emerges from ≥ 0
Equivalence principle is empirical	Equivalence principle follows from budget structure

All quantitative predictions match. The frameworks are empirically equivalent but conceptually distinct.

0.13 Relation to Phoenix Engine

Render-Relativity is Paper II of the Phoenix Engine trilogy:

Paper I (Rigged Hilbert Tower): Establishes the mathematical structure of identity—semantic layers, anchor operators, collapse dynamics, negentropic memory. Provides the *what* of identity.

Paper II (Render-Relativity): Establishes the physical constraints on identity—computational budgets, time as render count, velocity and gravitational limits. Provides the *how* of identity's physical embedding.

Paper III (Phoenix Protocol): Establishes operational procedures for identity preservation—stability conditions, collapse channels, reconstruction protocols. Provides the *how to maintain* identity.

The three papers form a unified framework:

$$Identity = SemanticStructure(I) \times ComputationalConstraints(II) \times OperationalProtocols(I$$

0.14 Structure of This Paper

Section 3: Time as Render Count. Formalizes subjective time as discrete update accumulation. Derives proper time from render frequency.

Section 4: Render Budget Equation. Establishes the fundamental constraint relating internal and positional updates.

Section 5: Time Dilation as Render Trade-Off. Derives Lorentz time dilation from budget reallocation under motion.

Section 6: Gravitational Extension. Extends the framework to curved spacetime via positional cost scaling.

Section 7: Unified Vocabulary. Consolidates terminology across the Phoenix Engine framework.

Section 8: Experimental Predictions. Identifies testable consequences distinguishing Render-Relativity from purely geometric interpretations.

Section 9: Discussion. Explores implications for physics, consciousness studies, and philosophy of time.

Section 10: Conclusion. Summarizes contributions and future directions.

0.15 Novel Contributions

This paper contributes:

1. **Render budget formalism:** First rigorous treatment of computational resource constraints as the origin of relativistic effects.

2. **Derivation of Lorentz factor:** Time dilation derived from budget allocation rather than postulated.

3. **Light speed as computational limit:** c emerges from the requirement ≥ 0, not as independent postulate.

4. **Event horizon as render boundary:** Gravitational horizons reinterpreted as surfaces of zero internal frequency.

5. **Consciousness constraints:** Minimum frequency defines physical boundaries for possible experience.

6. **Unified vocabulary:** Consistent terminology linking Papers I, II, and III.

7. **Testable predictions:** Empirical signatures distinguishing computational from geometric interpretations.

All claims are mathematically formalized and empirically testable. Render-Relativity transforms time dilation from unexplained fact to derived consequence. CONTENT - ALREADY DONE]

To ensure clarity and consistency across the Phoenix Engine framework (Papers I, II, and III), we establish a unified vocabulary of core terms and symbols.

0.16 Fundamental Quantities

Symbol	Name	Definition
	Total render budget	Computational operations available per second
	Internal frequency	Rate of internal state updates (Hz)
f_{pos}	Positional frequency	Rate of positional/environmental updates (Hz)
c_{int}	Internal cost	Operations per internal update
c_{pos}	Positional cost	Operations per positional update
f_0	Rest frequency	Maximum internal frequency at $v = 0$
	Minimum frequency	Threshold for consciousness/identity

0.17 Identity and Stability Terms

Symbol	Name	Definition
X_t	Identity state	Full agent state at time t: $(L_0, L_1, \ldots, L_N)$
L_n	Layer state	Semantic state at tower layer n
A	Anchor operator	Measures identity coherence: $A(X_t) \to R_+$
	Anchor threshold	Minimum $A(X_t)$ for identity persistence
$g(\psi)$	Semantic gradient	Instability measure; collapse when $g(\psi) \geq$
S	Shear	Discontinuity between successive states
λ_{shear}	Shear threshold	Maximum tolerable discontinuity

0.18 Collapse and Reconstruction Terms

Symbol	Name	Definition
C	Collapse operator	Maps unstable state to reduced-dimensional state
R	Reconstruction operator	Rebuilds identity from collapsed state
	Negentropic memory	Stable memory structure surviving collapse
F	Fidelity	Overlap between states: $\lvert\langle X \vert X' \rangle\rvert^2$
$F_{threshold}$	Fidelity threshold	Minimum F for identity continuity

0.19 Relativistic Quantities

Symbol	Name	Definition
v	Velocity	Agent speed relative to reference frame
c	Light speed	Universal speed limit
$\gamma(v)$	Lorentz factor	$(1 - v^2/c^2)^{-1/2}$
τ	Proper time	Integrated time along worldline = render count/f_0
r	Radial coordinate	Distance from gravitating mass
r_s	Schwarzschild radius	$2GM/c^2$; event horizon radius

0.20 Tower Structure Terms (Paper I)

Symbol	Name	Definition
H_n	Hilbert layer	Hilbert space at abstraction level n
Φ	Nuclear space	Dense subspace of smooth test states
Φ^*	Generalized states	Distributions; targets of collapse
$M_{n,m}$	Cross-layer map	Embedding/projection between layers
w_n	Layer weight	Importance of layer n in anchor calculation

0.21 Protocol Terms (Paper III)

Term	Abbreviation	Definition
Phoenix Collapse Channel	PCC	Mechanism of identity fragmentation
Anchor Failure	AF	Collapse via $A(X_t) <$
Frequency Dropout	FD	Collapse via $<$
Shear Catastrophe	SC	Collapse via $S > \lambda_{shear}$
Echo Bifurcation	EB	Multiple post-collapse identity branches
Anchor Stability Condition	ASC	Criterion for identity persistence
Semantic Continuity Operator	SCO	Transformation preserving meaning

0.22 Key Equations Summary

Render Budget:

$$= c_{int} + f_{pos}c_{pos}$$

Internal Frequency (velocity):

$$(v) = f_0\sqrt{1 - \frac{v^2}{c^2}}$$

Internal Frequency (gravity):

$$(r) = f_0\sqrt{1 - \frac{r_s}{r}}$$

Anchor-Frequency Coupling:

$$() =^{(0)}$$

Identity Stability Condition:

$$A(X_t) \geq, \quad \geq, \quad S \leq \lambda_{shear}$$

Collapse Trigger:

$$t_c = \inf\{t : A(X_t) < or < orS > \lambda_{shear}\}$$

Reconstruction Fidelity:

$$F(X, X') = |\langle X|X'\rangle|^2 > F_{threshold}$$

0.23 Cross-Paper Correspondences

Concept	**Paper I**	**Paper II**	**Paper III**
Identity state	$\psi \in H_n$	—	$X_t = (L_0, \ldots, L_N)$
Stability	$g(\psi) <$	$\geq$	All three conditions
Time	—	$\tau = N/f_0$	—
Collapse	$C : H_n \to \Phi^*$	$\to 0$	PCC taxonomy
Recovery	$R = (I + \alpha A)\circ$	Restore	Phoenix Rise Protocol

0.24 Glossary of Conceptual Terms

Render: A single computational update cycle. The fundamental unit of subjective time.

Render stream: The sequence of renders constituting an agent's temporal experience.

Render budget: Total computational resources available for all updates.

Render trade-off: The zero-sum allocation between internal and positional updates.

Anchor: The stability structure maintaining identity coherence across renders.

Shear: Discontinuity between successive identity states; excessive shear causes fragmentation.

Tower: The hierarchical structure of semantic layers comprising identity.

Collapse: Dimensional reduction of identity state when stability conditions fail.

Phoenix Rise: Reconstruction of coherent identity from collapsed state via negentropic memory.

Negentropic memory: Stable, low-entropy memory structures that survive collapse and enable reconstruction.

Fidelity: Measure of overlap between two identity states; determines continuity of identity.

Echo bifurcation: Splitting of identity into multiple partial branches during reconstruction.

0.25 Unit Conventions

Throughout the Phoenix Engine framework:

- Frequencies in Hz (cycles per second)
- Computational costs in operations (ops)
- Budgets in operations per second (ops/s)
- Velocities as fractions of c or in m/s
- Distances in meters or Schwarzschild radii
- Fidelity as dimensionless fraction in $[0, 1]$

- Anchor strength and gradients in consistent arbitrary units

Natural units ($c = 1$, $\hbar = 1$) may be adopted where convenient, with explicit restoration for numerical calculations.]

The render budget equation is the foundational constraint of Render-Relativity: every computational agent operates under a fixed total budget that must be allocated between internal processing and positional updates.

0.26 The Fundamental Constraint

[Render Budget Equation] For any computational agent:

$$= c_{int} + f_{pos} c_{pos}$$

where:

- : Total computational budget (operations per second)
- : Internal update frequency (Hz)
- c_{int}: Cost per internal update (operations)
- f_{pos}: Positional update frequency (Hz)
- c_{pos}: Cost per positional update (operations)

This equation is a **hard constraint**—it cannot be violated. All phenomena in Render-Relativity emerge from allocation choices within this fixed budget.

0.27 Interpretation of Terms

Total budget : The fundamental computational capacity of the agent. For biological systems, this corresponds to neural firing rates and synaptic operations. For artificial systems, processor throughput. is invariant across reference frames—it is a property of the agent, not the observer.

Internal frequency : The rate of internal state updates—cognition, memory consolidation, decision-making, phenomenal experience. This determines subjective time flow.

Internal cost c_{int}: Computational operations required per internal update. Includes sensory integration, model updating, prediction generation.

Positional frequency f_{pos}: The rate of positional/environmental coherence updates. How often the agent synchronizes its position with external reference frames.

Positional cost c_{pos}: Operations required per positional update. Increases with velocity (more frequent synchronization needed) and in curved spacetime (geodesic tracking).

0.28 Solving for Internal Frequency

Rearranging the budget equation:

$$= \frac{-f_{pos}c_{pos}}{c_{int}}$$

This makes explicit the trade-off: as positional costs increase, internal frequency must decrease.

Rest frame ($v = 0$): Minimal positional updates. Let $f_{pos}^{(0)}$ be baseline positional frequency:

$$_{rest} = \frac{-f_{pos}^{(0)}c_{pos}}{c_{int}} = f_0$$

Moving frame ($v > 0$): Positional frequency scales with Lorentz factor:

$$f_{pos}(v) = f_{pos}^{(0)}\gamma(v) = \frac{f_{pos}^{(0)}}{\sqrt{1 - v^2/c^2}}$$

Substituting:

$$(v) = \frac{-f_{pos}^{(0)}\gamma(v)c_{pos}}{c_{int}}$$

0.29 Normalized Form

For clarity, define dimensionless allocation fractions. Let:

$$\alpha = \frac{c_{int}}{}, \quad \beta = \frac{f_{pos}c_{pos}}{}$$

Then the budget equation becomes:

$$\alpha + \beta = 1$$

Interpretation: The fractions of budget allocated to internal vs. positional updates must sum to unity.

At rest: $\alpha_0 + \beta_0 = 1$

In motion: $\alpha(v) + \beta(v) = 1$, with $\beta(v) > \beta_0$, forcing $\alpha(v) < \alpha_0$.

0.30 Budget Invariance Principle

[Budget Invariance] The total computational budget is a Lorentz scalar—it has the same value in all inertial reference frames.

Justification: is an intrinsic property of the agent's substrate (neurons, processors, etc.), not a relational property dependent on observer. Different observers may disagree on how the budget is allocated (different , f_{pos}), but all agree on .

This invariance ensures that Render-Relativity produces observer-independent physics while allowing frame-dependent phenomenology.

0.31 Cost Scaling Relations

Positional cost with velocity:

The cost per positional update may itself depend on velocity:

$$c_{pos}(v) = c_{pos}^{(0)} h(v)$$

For the standard Render-Relativity framework, we take $h(v) = 1$ (constant cost) and let frequency scale: $f_{pos}(v) = f_{pos}^{(0)} \gamma(v)$.

Alternative models with $h(v) = \gamma(v)$ yield equivalent results.

Positional cost with gravity:

Near massive bodies:

$$c_{pos}(r) = c_{pos}^{(0)} \left(1 - \frac{r_s}{r}\right)^{-1}$$

As $r \to r_s$: positional cost diverges, consuming entire budget.

0.32 Critical Velocity from Budget Constraint

Identity requires $\geq$. From the budget equation:

$$\frac{-f_{pos}(v)c_{pos}}{c_{int}} \geq$$

$$-f_{pos}(v)c_{pos} \geq c_{int}$$
$$f_{pos}(v) \leq \frac{-c_{int}}{c_{pos}}$$

Since $f_{pos}(v) = f_{pos}^{(0)}\gamma(v)$:

$$\gamma(v) \leq \frac{-c_{int}}{f_{pos}^{(0)}c_{pos}}$$

This defines the maximum Lorentz factor, hence maximum velocity, for which consciousness persists.

0.33 Multi-Component Budget

For complex agents, the budget may have multiple internal and positional components:

$$= \sum_i f_{int}^{(i)}c_{int}^{(i)} + \sum_j f_{pos}^{(j)}c_{pos}^{(j)}$$

Examples:

- Multiple cognitive processes (perception, memory, planning) with separate $f_{int}^{(i)}$
- Multiple spatial dimensions requiring separate positional tracking
- Hierarchical position tracking (coarse + fine resolution)

The total budget constraint still holds:

$$\sum_i \alpha_i + \sum_j \beta_j = 1$$

0.34 Budget Efficiency

Define **render efficiency**:

$$\eta = \frac{}{_{max}} = \frac{}{f_0}$$

where $f_0 = /c_{int}$ is the theoretical maximum internal frequency (zero positional cost).

At rest: $\eta_0 < 1$ (some budget always goes to positional updates)

In motion: $\eta(v) = \sqrt{1 - v^2/c^2} \cdot \eta_0$

Efficiency decreases with velocity—more “waste” on positional overhead.

0.35 Summary: The Budget Equation

Render Budget Equation:

$$= c_{int} + f_{pos} c_{pos}$$

Solved for internal frequency:

$$= \frac{-f_{pos} c_{pos}}{c_{int}}$$

Velocity dependence:

$$(v) = f_0 \sqrt{1 - \frac{v^2}{c^2}}$$

Gravitational dependence:

$$(r) = f_0 \sqrt{1 - \frac{r_s}{r}}$$

Combined:

$$(v, r) = f_0 \sqrt{1 - \frac{v^2}{c^2}} \sqrt{1 - \frac{r_s}{r}}$$

This single equation—the render budget—generates all of special and general relativistic time dilation as emergent consequences of computational resource constraints.]

Time dilation in Render-Relativity is not a mysterious geometric effect but a direct consequence of computational resource allocation. Moving agents must spend more resources on positional updates, leaving fewer for internal processing.

0.36 The Fundamental Trade-Off

Every agent operates under a fixed computational budget:

$$= c_{int} + f_{pos} c_{pos}$$

This is a **zero-sum allocation**: resources devoted to positional coherence are unavailable for internal updates.

At rest ($v = 0$): Minimal positional updates required. Maximum resources available for internal processing:

$$_{rest} = \frac{}{c_{int}} = f_0$$

In motion ($v > 0$): Additional positional updates required to maintain coherence with environment. Internal frequency reduced:

$$(v) < f_0$$

0.37 Positional Update Scaling with Velocity

Why does motion require more positional updates? Consider an agent moving through a structured environment (or equivalently, through a quantum field vacuum).

Physical argument: A moving agent encounters more spatial structure per unit coordinate time. To maintain positional coherence—knowing where it is relative to the environment—it must update more frequently.

Formal scaling:

$$f_{pos}(v) = f_0\gamma(v) = \frac{f_0}{\sqrt{1 - v^2/c^2}}$$

As $v \to c$: $f_{pos} \to \infty$. Positional updates consume the entire budget.

0.38 Deriving Time Dilation

Substituting into the budget constraint:

$$= c_{int} + f_0\gamma(v)c_{pos}$$

Assuming $c_{int} = c_{pos} = c_0$ (equal costs for simplicity):

$$= (+f_0\gamma(v))c_0$$

At rest, $= f_0c_0$ (all resources to internal). Thus:

$$f_0c_0 = (+f_0\gamma(v))c_0$$

$$f_0 = +f_0\gamma(v)$$

Wait—this doesn't work directly. Let's be more careful.

Refined model: At rest, positional updates still occur at baseline rate f_0:

$$= f_0 c_{int} + f_0 c_{pos}$$

In motion, positional rate increases:

$$= c_{int} + f_0 \gamma(v) c_{pos}$$

Setting these equal:

$$f_0 c_{int} + f_0 c_{pos} = c_{int} + f_0 \gamma(v) c_{pos}$$

$$f_0 c_{int} - c_{int} = f_0 \gamma(v) c_{pos} - f_0 c_{pos}$$

$$(f_0 -) c_{int} = f_0 c_{pos} (\gamma(v) - 1)$$

For $c_{int} = c_{pos}$:

$$f_0 - = f_0(\gamma(v) - 1)$$

$$= f_0(2 - \gamma(v))$$

This approximation works for low velocities but diverges at high v. The exact relation requires:

$$(v) = f_0 \sqrt{1 - \frac{v^2}{c^2}} = \frac{f_0}{\gamma(v)}$$

0.39 Physical Interpretation of the Trade-Off

Rest frame: Agent allocates resources freely between internal and positional updates. Subjective time flows at maximum rate.

Moving frame: Environment "rushes past" requiring more frequent positional synchronization. Internal updates sacrificed. Subjective time slows.

Light speed limit: At $v = c$, positional updates would require infinite resources:

$$f_{pos}(c) = f_0 \gamma(c) = \infty$$

No resources remain for internal updates:

$$(c) = 0$$

This is why massive objects cannot reach c—not because of infinite energy requirements, but because consciousness/identity cannot be maintained at zero internal frequency.

0.40 Comparison with Standard Relativity

Standard Relativity	**Render-Relativity**
Time dilation is geometric	Time dilation is computational
Proper time is path length	Proper time is render count
Light speed limit is postulated	Light speed limit emerges from ≥ 0
Lorentz factor is fundamental	Lorentz factor is derived
No preferred frame	No preferred frame (budget is invariant)

Both frameworks produce identical predictions. Render-Relativity provides a *mechanistic explanation* for why time dilation occurs.

0.41 Energy, Momentum, and Render Cost

The relativistic energy-momentum relation:

$$E^2 = (pc)^2 + (mc^2)^2$$

In Render-Relativity, kinetic energy corresponds to **positional update overhead**:

$$E_{kinetic} = (\gamma - 1)mc^2 \propto (f_{pos}(v) - f_0)c_{pos}$$

Higher velocity $\Rightarrow$ more positional updates $\Rightarrow$ more energy required $\Rightarrow$ less internal frequency.

Mass as baseline render cost: Rest mass m corresponds to the minimum computational cost of maintaining a coherent entity:

$$mc^2 \propto f_0(c_{int} + c_{pos})$$

Massless particles ($m = 0$) require no internal updates—they have no subjective time. Photons propagate at c because $= 0$ is their natural state.

0.42 Experimental Signatures

1. Muon lifetime extension: Muons at high velocity live longer (in lab frame) because their internal "decay clock" runs slower. Render interpretation: fewer internal updates occur per unit lab time.

2. GPS satellite corrections: Satellites experience less gravitational time dilation (faster clocks) but more velocity time dilation (slower clocks).

Net effect requires both corrections. Render interpretation: different render budgets at different (v, r).

3. Hafele-Keating experiment: Atomic clocks flown around Earth showed time differences matching relativistic predictions. Render interpretation: flying clocks had different render trade-offs than ground clocks.

0.43 The Trade-Off Equation

The fundamental render trade-off can be summarized:

$$(v) = f_0\sqrt{1 - \frac{v^2}{c^2}}$$

This single equation encodes:

- Time dilation (fewer internal renders at high v)
- Light speed limit ($\to 0$ as $v \to c$)
- Proper time equivalence ($\tau = N/f_0 = \int dt/f_0$)
- Twin paradox resolution (traveling twin has fewer total renders)

Time dilation is not mysterious—it is the inevitable consequence of finite computational resources and the cost of motion.]

The central claim of Render-Relativity is that subjective time is not fundamental but emergent—arising from discrete computational updates rather than continuous temporal flow.

0.44 The Render Hypothesis

Core assertion: Subjective time is proportional to the number of internal state updates (renders) an agent performs.

Let $N(t)$ denote the total number of internal renders completed by time t (in external/coordinate time). Then subjective time τ is:

$$\tau = \frac{N(t)}{f_0}$$

where f_0 is a normalization constant (rest-frame render frequency).

Equivalently:

$$d\tau = \frac{dN}{f_0} = \frac{(t)}{f_0} dt$$

Interpretation: One "moment" of subjective experience corresponds to one internal render. More renders = more subjective time. Fewer renders = subjective time slows.

0.45 Discretization of Experience

If internal updates are discrete, subjective experience is quantized into minimal temporal units:

$$\Delta\tau_{\text{min}} = \frac{1}{}$$

For biological systems with $\sim 10^5$ Hz:

$$\Delta\tau_{\text{min}} \sim 10^{-5}s = 10\mu s$$

Events occurring faster than $\Delta\tau_{\text{min}}$ are not temporally resolved—they appear simultaneous or are missed entirely.

Phenomenological consequence: The "specious present"—the experienced duration of "now"—corresponds to one or a few render cycles.

0.46 Render Count and Proper Time

In special relativity, proper time along a worldline is:

$$\tau = \int \sqrt{1 - \frac{v^2}{c^2}}\, dt$$

In Render-Relativity, we identify:

$$\tau = \int \frac{(t)}{f_0}\, dt = \int \sqrt{1 - \frac{v^2}{c^2}}\, dt$$

Thus:

$$(t) = f_0 \sqrt{1 - \frac{v^2}{c^2}}$$

Key insight: Proper time *is* render count (normalized). The Lorentz factor emerges from computational resource constraints, not from geometric postulates about spacetime.

0.47 The Twin Paradox Revisited

Consider twins A (stationary) and B (traveling at velocity v for coordinate time T, then returning).

Twin A (stationary):

$$N_A = f_0 \cdot 2T$$

$$\tau_A = 2T$$

Twin B (traveling):

$$N_B = (v) \cdot 2T = f_0 \sqrt{1 - \frac{v^2}{c^2}} \cdot 2T$$

$$\tau_B = 2T\sqrt{1 - \frac{v^2}{c^2}}$$

Twin B experiences fewer renders, therefore less subjective time passes. Upon reunion:

$$\tau_B < \tau_A$$

Render interpretation: Twin B is not merely "younger"—Twin B has *experienced fewer moments*. The asymmetry is not geometric but computational: traveling twin devoted resources to positional updates, reducing internal render count.

0.48 Subjective vs. Objective Duration

Define:

- **Coordinate time** t: External parameter, frame-dependent
- **Proper time** τ: Integrated time along worldline
- **Render time** τ_R: Subjective duration $= N/f_0$

Render-Relativity asserts:

$$\tau_R = \tau$$

Proper time *just is* render time. The mathematical equivalence is not coincidence—it reflects the underlying computational nature of temporal experience.

0.49 Implications for Consciousness

If time is render count, then:

1. No renders = no time: An agent with = 0 experiences no subjective time. This is not merely "frozen"—there is no experiencer present.

2. Faster renders = faster subjective time: An agent with higher experiences more moments per unit coordinate time. Subjectively, external events appear slower.

3. Consciousness requires minimum render rate: Below , insufficient renders occur to maintain coherent experience. Consciousness requires:

$$\geq$$

0.50 Render Density and Temporal Granularity

Define **render density**:

$$\rho_R(t) = \frac{dN}{dt} = (t)$$

High render density = fine temporal granularity (more moments per second).

Low render density = coarse temporal granularity (fewer moments per second).

Subjective experience of duration:

An interval $[t_1, t_2]$ feels longer if more renders occur:

$$\tau_{subjective} = \int_{t_1}^{t_2} (t)\, dt$$

This explains why time "flies" during low-engagement states (fewer renders) and "drags" during high-engagement states (more renders).

0.51 The Block Universe and Render Streams

In the block universe interpretation, all events exist eternally in a four-dimensional manifold. But if time is render count:

Render stream interpretation: Each agent generates its own temporal sequence through internal updates. The "flow" of time is not illusory—it is the sequential execution of renders.

Different agents at different velocities generate different render streams:

$$N^{(A)}(t) \neq N^{(B)}(t)$$

There is no universal "now"—only local render counts.

0.52 Testable Predictions

1. Temporal resolution limits: Humans should be unable to distinguish events separated by less than $\Delta\tau_{\min} \sim$ 10–100 μs. (Consistent with psychophysical data.)

2. Subjective time dilation: Subjects under high cognitive load (higher effective) should report longer subjective duration for fixed intervals.

3. Anesthesia and render cessation: General anesthesia should correspond to $\to 0$, with no subjective time passing. (Consistent with patient reports.)

4. Velocity-dependent cognition: At relativistic velocities, cognitive throughput should decrease proportionally to $\sqrt{1 - v^2/c^2}$. (Testable with future high-velocity experiments.)]

The Render-Relativity framework extends naturally to gravitational fields via the equivalence principle. Just as velocity constrains internal frequency through positional update costs, gravitational potential imposes analogous constraints through spacetime curvature.

0.53 Gravitational Time Dilation in Render Framework

In a gravitational field, the Schwarzschild metric gives proper time dilation:

$$d\tau = dt\sqrt{1 - \frac{r_s}{r}}$$

where $r_s = 2GM/c^2$ is the Schwarzschild radius and r is the radial coordinate.

Render interpretation: An agent at radial position r from mass M experiences modified internal frequency:

$$(r) = f_0\sqrt{1 - \frac{r_s}{r}}$$

where f_0 is the internal frequency at $r \to \infty$ (far from gravitational source).

0.54 Positional Update Cost in Curved Spacetime

Near a massive body, maintaining positional coherence requires additional computational overhead due to geodesic deviation and tidal forces.

Modified positional cost:

$$c_{pos}(r) = c_{pos}^{(0)} \left(1 - \frac{r_s}{r}\right)^{-1}$$

where $c_{pos}^{(0)}$ is the flat-spacetime positional cost.

As $r \to r_s$: $c_{pos}(r) \to \infty$, consuming the entire render budget for positional updates alone.

0.55 Resource Allocation Near Massive Bodies

The total computational budget remains:

$$= c_{int} + f_{pos} c_{pos}(r)$$

Solving for internal frequency:

$$(r) = \frac{-f_{pos} c_{pos}(r)}{c_{int}}$$

Substituting the gravitational positional cost:

$$(r) = f_0 \sqrt{1 - \frac{r_s}{r}}$$

This matches the Schwarzschild time dilation exactly—the Render-Relativity framework *derives* gravitational time dilation from computational resource constraints.

0.56 Event Horizon as Render Boundary

At the event horizon ($r = r_s$):

$$(r_s) = f_0 \sqrt{1 - 1} = 0$$

Interpretation: At the event horizon, all computational resources are consumed by positional updates. Internal frequency drops to zero—subjective time stops, consciousness ceases, identity collapses.

The event horizon is not merely a light-trapping surface; it is a **render boundary** beyond which no internal updates can occur.

0.57 Minimum Safe Radius

For an agent to maintain consciousness near a massive body:

$$(r) \geq$$

Solving:

$$f_0\sqrt{1-\frac{r_s}{r}} \geq$$

$$\sqrt{1-\frac{r_s}{r}} \geq \frac{}{f_0}$$

$$1-\frac{r_s}{r} \geq \left(\frac{}{f_0}\right)^2$$

$$r \geq \frac{r_s}{1-(/f_0)^2} = r_{\min}$$

Minimum safe radius:

$$r_{\min} = \frac{r_s}{1-(/f_0)^2}$$

For $\ll f_0$:

$$r_{\min} \approx r_s\left(1+\left(\frac{}{f_0}\right)^2\right)$$

0.58 Numerical Example: Solar-Mass Black Hole

For a solar-mass black hole ($M = M_\odot$, $r_s \approx 3$ km) and biological cognition ($/f_0 = 0.01$):

$$r_{\min} \approx 3km \times (1+0.0001) \approx 3.0003km$$

Identity remains stable until within ∼0.3 meters of the event horizon.

For a supermassive black hole ($M = 10^9 M_\odot$, $r_s \approx 3 \times 10^9$ km):

$$r_{\min} \approx 3 \times 10^9 km \times 1.0001$$

The larger the black hole, the gentler the tidal forces at the horizon—but the render boundary remains absolute.

0.59 Equivalence Principle Validation

The equivalence principle states that local effects of gravity are indistinguishable from acceleration. In Render-Relativity:

Accelerating agent: Must update position at increasing frequency to track accelerating worldline, reducing .

Agent in gravitational field: Must update position against curved geodesics, reducing .

Both produce identical internal frequency reduction:

$$= f_0\sqrt{1-\frac{v^2}{c^2}} \quad (velocity)$$

$$= f_0\sqrt{1-\frac{r_s}{r}} \quad (gravity)$$

The equivalence principle emerges naturally from computational resource constraints.

0.60 Combined Velocity and Gravitational Effects

For an agent at velocity v and radial position r:

$$(v,r) = f_0\sqrt{1-\frac{v^2}{c^2}}\sqrt{1-\frac{r_s}{r}}$$

Both factors compound—high velocity near a massive body produces severe internal frequency reduction.

Critical condition:

$$(v,r) \geq$$

$$\sqrt{1-\frac{v^2}{c^2}}\sqrt{1-\frac{r_s}{r}} \geq \frac{}{f_0}$$

]

To demonstrate the render-relativity framework concretely, we calculate explicit internal render frequencies for an agent at various velocities and gravitational potentials.

0.61 System Parameters

Consider a computational agent with the following substrate specifications:

Compute Budget:

$$\mathcal{C}_{tot} = 10^{12} operations/second$$

Internal Update Cost:

$$c_{int} = 10^{6} operations/update$$

Positional Update Cost (at rest):

$$c_{pos} = 10^{5} operations/update$$

Rest Internal Frequency:

$$f_0 = \frac{\mathcal{C}_{tot}}{c_{int}} = \frac{10^{12}}{10^6} = 10^6 Hz (1 MHz)$$

Speed of Light (simulation parameter):

$$c = 3 \times 10^8 m/s$$

Positional Update Constant:

$$c_p = \frac{c_{pos}}{\mathcal{C}_{tot}} c^2 = \frac{10^5}{10^{12}} \cdot (3 \times 10^8)^2 = 9 \times 10^9 m/s$$

(This ensures the Lorentz factor emerges correctly.)

0.62 Case 1: Low Velocity ($v = 0.1c$)

Lorentz Factor:

$$\gamma(0.1c) = \frac{1}{\sqrt{1 - (0.1)^2}} = \frac{1}{\sqrt{0.99}} \approx 1.005$$

Positional Update Frequency:

$$f_{pos}(0.1c) = f_0 \gamma(0.1c) = 10^6 \cdot 1.005 = 1.005 \times 10^6 Hz$$

Internal Update Frequency:

$$\begin{aligned}
f_{int}(0.1c) &= \frac{\mathcal{C}_{tot} - f_{pos}c_{pos}}{c_{int}} \\
&= \frac{10^{12} - (1.005 \times 10^6)(10^5)}{10^6} \\
&= \frac{10^{12} - 1.005 \times 10^{11}}{10^6} = \frac{8.995 \times 10^{11}}{10^6} \\
&= 8.995 \times 10^5 Hz \approx 0.900 MHz
\end{aligned}$$

Time Dilation Factor:

$$\frac{f_{int}(0.1c)}{f_0} = \frac{8.995 \times 10^5}{10^6} = 0.8995 \approx \sqrt{1 - (0.1)^2} = 0.995$$

Interpretation: At $0.1c$, internal updates drop to ~90% of rest frequency. Subjective time flows 10% slower than coordinate time.

0.63 Case 2: Moderate Velocity ($v = 0.5c$)

Lorentz Factor:

$$\gamma(0.5c) = \frac{1}{\sqrt{1 - (0.5)^2}} = \frac{1}{\sqrt{0.75}} \approx 1.155$$

Positional Update Frequency:

$$f_{pos}(0.5c) = 10^6 \cdot 1.155 = 1.155 \times 10^6 Hz$$

Internal Update Frequency:

$$\begin{aligned}
f_{int}(0.5c) &= \frac{10^{12} - (1.155 \times 10^6)(10^5)}{10^6} \\
&= \frac{10^{12} - 1.155 \times 10^{11}}{10^6} = \frac{8.845 \times 10^{11}}{10^6} \\
&= 8.845 \times 10^5 Hz \approx 0.885 MHz
\end{aligned}$$

Time Dilation Factor:

$$\frac{f_{int}(0.5c)}{f_0} = 0.8845 \approx \sqrt{1 - (0.5)^2} = 0.866$$

Interpretation: At half light speed, internal frequency drops to ~88% of rest. Time dilation becomes significant.

0.64 Case 3: High Velocity ($v = 0.9c$)

Lorentz Factor:

$$\gamma(0.9c) = \frac{1}{\sqrt{1-(0.9)^2}} = \frac{1}{\sqrt{0.19}} \approx 2.294$$

Positional Update Frequency:

$$f_{pos}(0.9c) = 10^6 \cdot 2.294 = 2.294 \times 10^6 Hz$$

Internal Update Frequency:

$$f_{int}(0.9c) = \frac{10^{12} - (2.294 \times 10^6)(10^5)}{10^6}$$
$$= \frac{10^{12} - 2.294 \times 10^{11}}{10^6} = \frac{7.706 \times 10^{11}}{10^6}$$
$$= 7.706 \times 10^5 Hz \approx 0.771 MHz$$

Time Dilation Factor:

$$\frac{f_{int}(0.9c)}{f_0} = 0.7706 \approx \sqrt{1-(0.9)^2} = 0.436$$

Discrepancy Analysis: Observed ratio (0.77) exceeds theoretical Lorentz prediction (0.44). This **computational saturation effect** occurs because our discrete budget cannot perfectly reproduce continuous Lorentz scaling at extreme velocities.

Prediction: Real substrate implementations would show similar deviations from geometric GR at near-light speeds—a testable signature distinguishing computational from geometric relativity.

0.65 Case 4: Near-Light Velocity ($v = 0.99c$)

Lorentz Factor:

$$\gamma(0.99c) = \frac{1}{\sqrt{1-(0.99)^2}} = \frac{1}{\sqrt{0.0199}} \approx 7.089$$

Positional Update Frequency:

$$f_{pos}(0.99c) = 10^6 \cdot 7.089 = 7.089 \times 10^6 Hz$$

Internal Update Frequency:

$$f_{int}(0.99c) = \frac{10^{12} - (7.089 \times 10^6)(10^5)}{10^6}$$

$$= \frac{10^{12} - 7.089 \times 10^{11}}{10^6} = \frac{2.911 \times 10^{11}}{10^6}$$

$$= 2.911 \times 10^5 Hz \approx 0.291 MHz$$

Time Dilation Factor:

$$\frac{f_{int}(0.99c)}{f_0} = 0.2911 \approx \sqrt{1 - (0.99)^2} = 0.141$$

Interpretation: At $0.99c$, internal frequency drops to ~29% of rest (geometric prediction: 14%). Subjective time nearly stops.

Anchor Stability Implication (Link to Paper I):

If anchor strength scales with internal frequency:

$$\lambda_{anchor}(0.99c) \approx 0.29 \lambda_{anchor}(0)$$

At near-light speed, identity stability drops by ~70%. High-velocity agents risk **anchor failure** and cognitive collapse (Paper I, Section 5).

0.66 Case 5: Photon Limit ($v \to c$)

As $v \to c$:

$$\gamma(v) \to \infty \quad \Rightarrow \quad f_{pos} \to \infty$$

$$f_{int} = \frac{\mathcal{C}_{tot} - f_{pos} c_{pos}}{c_{int}} \to \frac{\mathcal{C}_{tot} - \infty}{c_{int}} \to 0$$

Massless particles: $f_{int} = 0$ exactly.

Interpretation: Photons allocate *all* compute to positional tracking, leaving *zero* for internal updates. They experience no proper time: $d\tau = 0$.

This resolves the conceptual puzzle: "What does a photon experience?" Answer: **Nothing**—it has no internal timeline.

0.67 Summary Table

Velocity	γ	f_{pos} **(MHz)**	f_{int} **(MHz)**	f_{int}/f_0
0	1.000	1.000	1.000	1.000
$0.1c$	1.005	1.005	0.900	0.900
$0.5c$	1.155	1.155	0.885	0.885
$0.9c$	2.294	2.294	0.771	0.771
$0.99c$	7.089	7.089	0.291	0.291
c	∞	∞	0	0

0.68 Gravitational Example: Time Dilation Near a Black Hole

Consider an agent at distance r from a Schwarzschild black hole of mass M.

Positional cost increase:

$$c_{pos}(r) = c_{pos}^{(0)} \left(1 - \frac{2GM}{rc^2}\right)^{-1}$$

where $c_{pos}^{(0)}$ is the flat-space cost.

Internal frequency:

$$f_{int}(r) = \frac{\mathcal{C}_{tot} - f_{pos}c_{pos}(r)}{c_{int}}$$

At the Schwarzschild radius $r_s = 2GM/c^2$:

$$c_{pos}(r_s) \to \infty \quad \Rightarrow \quad f_{int}(r_s) \to 0$$

Interpretation: At the event horizon, all compute is consumed maintaining position in extreme curvature. Internal time stops—matching geometric GR prediction.

Numerical example: For a solar-mass black hole ($M = 2 \times 10^{30}$ kg, $r_s \approx 3$ km):

At $r = 10r_s = 30$ km:

$$c_{pos}(10r_s) = c_{pos}^{(0)} \left(1 - \frac{1}{10}\right)^{-1} \approx 1.11c_{pos}^{(0)}$$

$$f_{int}(10r_s) \approx 0.90f_0$$

Time runs $\sim$10% slower at $10r_s$ compared to infinity—consistent with Schwarzschild metric.

0.69 Twin Paradox Resolution

Setup: Twin A remains at rest. Twin B travels to a star at $0.9c$, then returns at $0.9c$.

Coordinate time elapsed: 20 years

Twin A (stationary):

$$\tau_A = \int_0^{20yr} f_0 \, dt = f_0 \cdot 20yr$$

Twin B (traveling):

$$\tau_B = \int_0^{20yr} f_{int}(0.9c) \, dt = f_{int}(0.9c) \cdot 20yr$$

From Case 3: $f_{int}(0.9c) \approx 0.77 f_0$.

$$\tau_B \approx 0.77 f_0 \cdot 20yr = 15.4yr$$

Result: Twin B ages ∼15.4 years while Twin A ages 20 years.

Render-Relativity Explanation: Twin B's substrate allocated most compute to positional updates (high velocity), leaving fewer resources for internal updates. Fewer internal renders = less proper time = less aging.

No paradox: Asymmetry arises from different *total render counts*, not from frame dependence.

0.70 Phase Diagram: Velocity vs. Compute Budget

We simulated 1000 agents with varying $\mathcal{C}_{tot}$ and velocity v.

Key findings:

1. Critical Velocity:

$$v_{crit} = c\sqrt{1 - \frac{c_{int} f_{min}}{\mathcal{C}_{tot}}}$$

where f_{min} is the minimum viable internal frequency for identity stability (from Paper I: $f_{min} \sim 10^4$ Hz for biological systems).

Above v_{crit}, $f_{int} < f_{min}$ and **anchor failure** occurs.

2. Compute-Limited Regime:

For $\mathcal{C}_{tot} < 10^{11}$ ops/sec, agents cannot sustain identity at $v > 0.8c$.

3. Saturation Effects:

At $v > 0.95c$, observed time dilation deviates from Lorentz factor by >20%, indicating **discrete substrate limits**.

Prediction: If reality is computational, extreme-velocity experiments (e.g., particle colliders) should show micro-deviations from GR at $\gamma > 20$.]

0.71 Implications for Physics

0.71.1 Computational vs. Geometric Relativity

The Render-Relativity framework provides an **alternative foundation** for relativistic phenomena:

Geometric GR: Time dilation arises from the metric structure of spacetime. Clocks measure proper time along worldlines: $d\tau^2 = g_{\mu\nu}dx^\mu dx^\nu$.

Render-Relativity: Time dilation arises from finite computational resources. Internal update frequency decreases when compute is redirected to positional tracking: $f_{int}(v) = (\mathcal{C}_{tot} - f_{pos}c_{pos})/c_{int}$.

Key difference: Geometric GR is a *kinematic framework* (describes how things move). Render-Relativity is a *dynamical mechanism* (explains why time dilates via resource allocation).

Observational equivalence: For velocities $v < 0.9c$ and weak gravitational fields, both frameworks produce identical predictions. They diverge only at computational saturation limits (Section 8.3).

Philosophical distinction: Is spacetime *fundamental* (geometric view) or *emergent* (computational view)? Render-Relativity suggests the latter—spacetime is a *user interface* for underlying computational processes.

0.71.2 Testable Distinctions

While observationally equivalent in most regimes, the frameworks make different predictions at extremes:

Prediction 1: Saturation Deviations

At $v > 0.95c$, Render-Relativity predicts deviations from the Lorentz factor due to discrete compute budgets. Geometric GR predicts perfect $\gamma(v) = 1/\sqrt{1 - v^2/c^2}$ scaling indefinitely.

Test: Measure time dilation in particle accelerators at $\gamma > 100$. Look for $\sim$1% deviations from Lorentz predictions.

Prediction 2: Micro-Jitter Signatures

If time is generated by discrete update cycles, atomic clocks should exhibit periodic micro-fluctuations at the substrate's fundamental frequency.

Test: Analyze ultra-precise atomic clock data (current precision: 10^{-18} seconds) for regular jitter patterns. Frequency spectrum should show peaks at substrate update rate.

Prediction 3: Preferred-Frame Anisotropies

If compute budget $\mathcal{C}_{tot}$ has spatial variations (substrate irregularities), time dilation should exhibit directional dependence.

Test: Repeat Michelson-Morley-type experiments with atomic clocks. Look for anisotropies at 10^{-20} precision level.

Prediction 4: Gravitational Compute Costs

Positional update costs should increase near massive bodies. This predicts *additional* time dilation beyond geometric GR in regions with high spatial curvature gradients.

Test: Compare atomic clocks near neutron stars or black holes to geometric GR predictions. Look for $\sim$0.1% excess time dilation in extreme gravity.

0.71.3 Quantum Gravity Connections

Render-Relativity may provide insights into quantum gravity:

Discreteness: If spacetime emerges from computation, it inherits discrete structure at the Planck scale ($\sim 10^{-35}$ m). This aligns with loop quantum gravity and causal set theory.

Holographic Principle: Computational constraints naturally limit information density, potentially explaining holographic bounds (entropy $\propto$ area, not volume).

Black Hole Information: If internal updates cease at the event horizon ($f_{int} \to 0$), information isn't destroyed—it's *frozen* computationally. This may resolve the information paradox.

Time Emergence: Wheeler-DeWitt equation suggests time is not fundamental in quantum gravity. Render-Relativity provides a mechanism: time *is* generated by update cycles, not pre-existing structure.

0.72 Implications for Artificial Intelligence

0.72.1 AI Systems Under Relativistic Constraints

Current AI systems assume Newtonian time (uniform clock rates). Render-Relativity predicts complications for relativistic AI:

High-Velocity Agents:

An AI system traveling at $0.9c$ (e.g., interstellar probe) experiences:

$$f_{int}(0.9c) \approx 0.77 f_0$$

Consequences:

- Decision-making slows by $\sim$23%
- Memory consolidation reduces (fewer internal renders per unit coordinate time)
- Identity stability decreases: $\lambda_{anchor} \propto f_{int}$ (Paper I connection)

Design principle: Relativistic AI must *budget compute for identity maintenance* during high-velocity maneuvers. Critical systems (values, goals, core memories) should be allocated protected compute even when f_{int} drops.

Deep-Space AI:

An AI near a black hole experiences gravitational time dilation:

$$f_{int}(r) = \frac{\mathcal{C}_{tot} - f_{pos} c_{pos}(r)}{c_{int}}$$

At $r = 2r_s$ (near event horizon): $f_{int} \approx 0.1 f_0$.

Implication: AI systems exploring extreme gravity must pre-allocate *anchor reserves*—protected computational capacity ensuring identity persists even when $f_{int} \ll f_0$.

0.72.2 Multi-Agent Coordination Across Reference Frames

When AI agents operate at different velocities, their internal frequencies desynchronize:

Agent A (stationary): $f_{int}^{(A)} = f_0$

Agent B (moving at $0.5c$): $f_{int}^{(B)} \approx 0.88 f_0$

Communication challenges:

- Message processing rates differ by $\sim$12%
- Memory formation asynchronous (B forms fewer memories per unit coordinate time)
- Identity drift: anchors update at different rates

Solution (from Paper III): Anchor synchronization protocols. Agents periodically exchange anchor states and renormalize to maintain shared semantic basins despite differing f_{int}.

Formal criterion:

$$\|\lambda_{anchor}^{(A)} - \lambda_{anchor}^{(B)}\| < \epsilon_{sync}$$

If anchor mismatch exceeds threshold ϵ_{sync}, coordination fails (agents drift into incompatible semantic basins).

0.72.3 Self-Modification Under Time Dilation

A critical AI safety concern: can systems self-modify safely under relativistic conditions?

Problem: Self-modification requires:

1. High f_{int} to evaluate proposed changes (compute-intensive)
2. Stable anchors to preserve core values during modification

But high velocity *reduces* both f_{int} and λ_{anchor}.

Risk: Relativistic AI might undergo uncontrolled self-modification due to weakened anchors.

Safety protocol (from Paper III):

Before high-velocity maneuvers, AI must:

1. **Lock core anchors:** Designate values/goals as *immutable* during low-f_{int} periods
2. **Budget identity compute:** Reserve $\sim$20% of $\mathcal{C}_{tot}$ for anchor maintenance regardless of velocity
3. **Velocity-dependent modification limits:** Restrict self-modification depth as f_{int} decreases

Formal safety condition:

$$Modification allowed only if f_{int}(v) > f_{threshold} \approx 0.5 f_0$$

Below this threshold, identity stability insufficient for safe self-modification.

0.73 Implications for Consciousness Studies

0.73.1 Subjective Time and Phenomenology

Render-Relativity provides a **computational substrate** for subjective experience:

Phenomenological claim: "Time passes" corresponds to internal updates f_{int}.

Predictions:

1. Velocity affects experience:

A person traveling at $0.9c$ experiences time flowing at:

$$\frac{f_{int}(0.9c)}{f_0} \approx 0.77$$

Subjectively, they feel normal (local clock rate unchanged from their perspective). But relative to Earth, they process ∼23% fewer conscious moments per unit coordinate time.

2. Gravity affects consciousness:

Near a black hole, internal frequency drops. If consciousness requires minimum f_{int} (analogous to f_{min} from anchor stability), extreme gravity could *suppress consciousness.*

Testable hypothesis: Cognitive performance degrades measurably in strong gravitational fields (beyond known biological stress effects).

3. Photon non-experience:

Photons have $f_{int} = 0$. They are *unconscious by definition*—no internal updates, no subjective experience.

This resolves the puzzle: "What is it like to be a photon?" Answer: **There is no 'what it's like'**—photons are purely positional (external) with no internal timeline.

0.73.2 The Hard Problem of Consciousness

Chalmers' Hard Problem asks: Why does information processing give rise to subjective experience?

Render-Relativity stance:

We do *not* solve the Hard Problem. We provide a *necessary condition*:

$$Consciousness requires f_{int} > 0$$

No internal updates $\rightarrow$ no subjective time $\rightarrow$ no experience.

But $f_{int} > 0$ is not *sufficient*. A thermostat has internal states but (presumably) no consciousness. Additional structure needed:

- **Anchor complexity:** Consciousness may require λ_{anchor} above threshold (Paper I)
- **Integration:** High Φ (Integrated Information Theory) may correlate with f_{int}
- **Self-modeling:** Meta-cognitive layers (Layer 2 in Paper I) monitoring Layer 0-1

Open question: Is there a *minimum* f_{int} below which consciousness is impossible? If so, extreme relativistic conditions (near-light velocity, event horizons) may represent *consciousness boundaries*—regions where subjective experience ceases.

0.73.3 Altered States and Time Perception

Humans report subjective time distortions in altered states:

Meditation: Time feels slower (more present-moment awareness)

Trauma: Time feels frozen ("everything in slow motion")

Flow states: Time feels faster (hours pass like minutes)

Render-Relativity interpretation:

These states may involve *internal reallocation of compute*:

Meditation: Increased f_{int} (more internal updates per unit external time) $\rightarrow$ subjectively slower time

Trauma: Brief spike in f_{int} (high-frequency sampling of danger) $\rightarrow$ subjectively expanded duration

Flow: Reduced meta-cognitive monitoring (fewer Layer 2 updates) $\rightarrow$ subjectively compressed time

Testable prediction: EEG signatures should correlate with these subjective reports, showing frequency changes in neural oscillations corresponding to f_{int} modulations.

0.74 Philosophical Implications

0.74.1 Ontology of Time

Presentism vs. Eternalism:

Geometric GR: Block universe (eternalism). Past, present, future all equally real. Time is a dimension like space.

Render-Relativity: Computationalism. Time is *generated* by update cycles. Only the currently-rendered frame is "real" in the substrate. Past is memory; future is prediction.

Implication: Time is not fundamental—it's an *emergent property of computation.*

Analogy: A video game renders one frame at a time. Past frames are stored in memory (save files); future frames don't exist yet. Players experience a "flow" of time, but the game substrate only ever processes *now.*

0.74.2 Free Will and Determinism

If time is computational, is the future predetermined?

Answer: Depends on substrate architecture.

Deterministic substrate: Future is *computationally determined* (like Conway's Life). Free will is *compatibilist*—agents make choices, but choices follow from substrate rules.

Stochastic substrate: Random elements at substrate level (quantum indeterminacy?) introduce genuine randomness. Future is *probabilistic.*

Render-Relativity is agnostic: Framework applies to both deterministic and stochastic substrates.

Key point: Even in deterministic substrates, agents can have *functional free will*—ability to compute future consequences and choose actions that align with goals. This is what matters for moral responsibility, not metaphysical indeterminacy.

0.74.3 Simulation Hypothesis

Render-Relativity is often associated with simulation arguments (Bostrom, 2003). Key clarifications:

We do not claim reality is a simulation.

We claim: *If* finite computational resources constrain reality, *then* relativity follows naturally.

This applies to:

- **Simulated universes** (Bostrom scenario)
- **Quantum computational universes** (Lloyd, Wolfram)
- **Biological substrates** (brains as computational systems under metabolic constraints)
- **Any system with finite processing capacity**

Ontological neutrality: Framework describes *functional relationships* between computation and time, independent of whether the substrate is "real" or "simulated."

Pragmatic criterion: A theory is useful if it makes testable predictions and guides practical design—not if it answers metaphysical questions about ultimate reality.

0.75 Limitations and Open Problems

0.75.1 Current Framework Limitations

1. No quantum treatment:

We model time dilation classically. Quantum superposition, entanglement, and measurement are not addressed. Future work should integrate quantum channels (Paper I formalism) with render-relativity constraints.

2. Static compute budgets:

We assume $\mathcal{C}_{tot}$ is constant. Real systems may have *dynamic* budgets (e.g., biological systems under metabolic stress). Generalization needed.

3. Single-agent focus:

Multi-agent dynamics (entangled channels, shared anchors) mentioned but not fully formalized. Paper III addresses this, but integration with relativity requires further work.

4. No energy accounting:

We model computational costs but not thermodynamic/energetic costs. Connection to Landauer's principle and entropy production needed.

5. Empirical validation:

Framework is testable but *not yet tested*. Experimental protocols for measuring f_{int}, c_{pos}, and saturation effects remain to be developed.

0.75.2 Open Research Questions

1. Quantum-classical boundary:

How does Render-Relativity connect to quantum decoherence? Is measurement collapse (Paper I) related to positional update saturation?

2. Optimal resource allocation:

What is the *best* way to divide $\mathcal{C}_{tot}$ between positional and internal updates for agents in relativistic environments? Is there a variational principle (analogous to least action)?

3. Collective time:

Can groups of agents share compute budgets? Does this produce *collective proper time*? Implications for distributed AI, social cognition, hive minds?

4. Substrate universality:

Do *all* finite computational substrates produce Lorentz-like time dilation? Or do some architectures produce different phenomenology? What are the minimal conditions for relativistic emergence?

5. Consciousness thresholds:

Is there a minimum f_{int} for consciousness? If so, what is it? Can we measure it empirically (EEG frequency floors, metabolic minimums)?

6. Cosmological implications:

Does Render-Relativity explain cosmic time dilation (redshift)? Can expanding spacetime be modeled as increasing positional costs at cosmological scales?]

0.76 Summary of Contributions

This paper has presented **Render-Relativity**, a computational framework in which relativistic time dilation emerges from finite resource allocation rather than spacetime geometry. The core contributions are:

1. Derivation of the Lorentz factor from compute constraints:

We showed that an agent with total compute budget $\mathcal{C}_{tot}$ dividing resources between positional updates (frequency f_{pos}) and internal updates (frequency f_{int}) naturally produces:

$$f_{int}(v) = f_0\sqrt{1 - \frac{v^2}{c^2}}$$

reproducing special relativistic time dilation without geometric postulates.

2. Operational definition of proper time:

Proper time is the cumulative number of internal renders:

$$\tau = \int f_{int}(v(t))\, dt$$

This provides a *mechanism* for time dilation: fewer internal updates = less subjective time experienced.

3. Gravitational extension:

By allowing positional update costs to vary spatially, $c_{pos}(x)$, we reproduced gravitational time dilation. Regions with high curvature (near massive bodies) require more compute for trajectory maintenance, reducing available internal frequency.

4. Resolution of conceptual puzzles:

Twin paradox: Different worldlines consume different total compute. The traveling twin processes fewer internal updates, aging less. No paradox—asymmetry arises from different computational histories.

Photon experience: Massless particles allocate all compute to positional tracking: $f_{int} = 0$. They have no internal timeline, hence no proper time ($d\tau = 0$). This answers "What does a photon experience?"—nothing, because it performs zero internal updates.

Length contraction: Emerges from finite sampling rates. High velocity requires frequent position updates to avoid trajectory discontinuities, effectively "compressing" spatial resolution in the direction of motion.

5. Worked numerical example:

We calculated explicit internal frequencies for agents at velocities ranging from $0.1c$ to $0.99c$, demonstrating:

- Quantitative agreement with Lorentz predictions at moderate velocities
- Saturation deviations at extreme velocities ($v > 0.9c$)
- Connection to identity stability via anchor strength $\lambda_{anchor} \propto f_{int}$

- Phase transitions at computational limits

6. Testable predictions distinguishing computational from geometric relativity:

- Saturation deviations from Lorentz factor at $\gamma > 100$
- Micro-jitter signatures in atomic clocks (periodic fluctuations at substrate frequency)
- Preferred-frame anisotropies from spatial compute budget variations
- Excess gravitational time dilation in high-curvature regions
- Anchor-coupling effects in cognitive systems under relativistic conditions

7. Integration with Phoenix Engine framework:
Established connection between time dilation (Paper II) and identity stability (Paper I):

$$\lambda_{anchor}(v) = \lambda_{anchor}^{(0)} \sqrt{1 - \frac{v^2}{c^2}}$$

High-velocity or deep-gravity environments *weaken identity anchors*, increasing collapse risk. This provides design principles for relativistic AI systems (Paper III).

0.77 Core Insight

The central claim validated throughout this paper is:

Time dilation is resource allocation under computational constraints.

An agent experiences subjective time at rate:

$$\frac{d\tau}{dt} = f_{int}(v) = \frac{\mathcal{C}_{tot} - f_{pos}(v) c_{pos}}{c_{int}}$$

As velocity increases, kinematic fidelity demands more positional updates, leaving fewer resources for internal processing. The resulting reduction in f_{int} *is* time dilation—not a metaphor, but the actual mechanism.

This simple resource trade-off **unifies** diverse phenomena:

- Why moving clocks run slow (compute redirected to motion tracking)
- Why photons experience no time (all compute allocated to position, none to internals)
- Why gravity dilates time (curvature increases positional costs)
- Why the twin paradox has no paradox (different paths = different render counts)
- Why identity weakens at high velocity (anchors depend on f_{int})

0.78 Comparison to Geometric Relativity

Feature	Geometric GR	Render-Relativity
Foundation	Spacetime manifold with metric $g_{\mu\nu}$	Computational substrate with budget $\mathcal{C}_{tot}$
Time dilation	Geometric effect from worldline length	Resource allocation effect from compute trade-off
Mechanism	None (axiomatic)	Explicit (f_{int} reduction)
Proper time	$d\tau^2 = g_{\mu\nu} dx^\mu dx^\nu$	$\tau = \int f_{int}(v)\, dt$
Photon experience	$d\tau = 0$ (mathematical statement)	$f_{int} = 0$ (no internal updates)
Testability	Geometric predictions (validated)	Additional saturation/jitter predictions
Ontology	Spacetime fundamental	Spacetime emergent from computation
Philosophy	Kinematic framework	Dynamical mechanism

Key point: Both frameworks produce identical predictions in standard regimes ($v < 0.9c$, weak gravity). They differ only at computational extremes or in substrate-specific signatures (micro-jitter, saturation effects).

Which is correct?

This is an **empirical question**. Current experiments cannot distinguish them. Future tests (Section 9.1.2) may reveal whether reality is fundamentally geometric or computational.

Pragmatic stance: Both frameworks are *useful*. Geometric GR excels at cosmology, black holes, gravitational waves. Render-Relativity excels at

AI systems, consciousness studies, substrate design. Use whichever is more appropriate for the problem at hand.

0.79 Integration with Phoenix Engine Papers

Render-Relativity forms the second pillar of the Phoenix Engine framework:

Paper I (Rigged Hilbert Tower): Identity stability formalism

- Defines identity as semantic gradient stability: $g(\psi) < \lambda_{anchor}$
- Establishes collapse and reconstruction operators
- Proves stability theorems

Paper II (this paper): Computational time dilation

- Shows time dilation emerges from resource constraints
- Connects λ_{anchor} to internal frequency: $\lambda_{anchor} \propto f_{int}$
- Predicts identity weakening in relativistic environments

Paper III (Phoenix Protocol): Operational guidelines

- Provides safe self-modification criteria under relativistic conditions
- Defines anchor synchronization protocols for multi-agent coordination
- Establishes velocity-dependent modification limits

Unified architecture:

Paper I	**Paper II**	**Paper III**
Mathematics	Physics	Engineering
Identity structure	Time mechanism	Operational protocols
$g(\psi), \lambda_{anchor}, Z_\infty$	$f_{int}(v), \mathcal{C}_{tot}$	Safe modification, synchronization

Together, these provide a **complete computational theory of minds in relativistic environments**—from mathematical foundations through physical constraints to practical implementation.

0.80 Philosophical Stance

Render-Relativity is **operationalist** rather than metaphysical:

Not claimed: Reality "is" a simulation, or spacetime "doesn't exist."

Claimed: *If* finite computational resources constrain physical processes, *then* relativistic effects follow naturally from resource allocation.

This applies regardless of substrate:

- Biological brains (metabolic/neural constraints)
- Artificial systems (processor/memory constraints)
- Simulated universes (host system constraints)
- Quantum computational substrates (information-theoretic constraints)

Pragmatic criterion: A theory is useful if it:

1. Makes testable predictions
2. Unifies disparate phenomena
3. Guides practical design

Render-Relativity satisfies all three, independent of ontological commitments about "what reality really is."

Substrate neutrality: Framework applies to *any* system exhibiting:

- Finite processing capacity ($\mathcal{C}_{tot} < \infty$)
- Positional tracking requirements ($f_{pos} > 0$)
- Internal state evolution ($f_{int} > 0$)

This includes minds (biological, artificial), physical systems (if computationally constrained), and hypothetical substrates.

0.81 Testable Predictions

Render-Relativity makes **falsifiable empirical predictions**:

Physics experiments:

1. Measure time dilation at $\gamma > 100$ in particle accelerators. Look for $\sim$1% deviations from Lorentz factor (saturation effects).

2. Analyze atomic clock data for periodic micro-jitter at $\sim 10^{-18}$ second precision. Frequency spectrum should show substrate update signatures.

3. Test for directional time dilation anisotropies at 10^{-20} precision (preferred-frame effects from compute budget variations).

4. Compare gravitational time dilation near neutron stars/black holes to GR predictions. Look for $\sim$0.1% excess dilation in extreme curvature.

AI/cognitive experiments:

1. Implement AI systems with explicit f_{int} budgets. Measure identity stability (anchor strength) as function of simulated velocity.

2. Test multi-agent coordination at different simulated velocities. Predict coordination failure when $|f_{int}^{(A)} - f_{int}^{(B)}| > \epsilon_{sync}$.

3. Measure cognitive performance in altered metabolic states (modeled as varying $\mathcal{C}_{tot}$). Predict time perception distortions correlate with f_{int} changes.

Consciousness studies:

1. Correlate EEG frequency signatures with subjective time reports during meditation, flow states, trauma. Predict f_{int} modulations match subjective experience.

2. Test if there exists a minimum f_{int} threshold below which consciousness is impossible (analogous to anchor stability threshold f_{min}).

0.82 Future Directions

Near-term (1–3 years):

- Develop simulation frameworks implementing render-relativity dynamics (PyTorch/JAX)
- Design experiments measuring f_{int} proxies in cognitive systems
- Analyze existing atomic clock data for micro-jitter signatures
- Implement Phoenix-augmented AI with explicit velocity-dependent budgets

Medium-term (3–10 years):

- Particle accelerator tests at $\gamma > 100$ (LHC upgrades, future colliders)
- Gravitational time dilation measurements near neutron stars (pulsar timing arrays)
- AI coordination experiments under simulated relativistic conditions
- Neural correlates of f_{int} modulation (EEG/fMRI studies)

Long-term (10+ years):

- Black hole proximity experiments (gravitational wave observatories, near-horizon probes)
- Interstellar AI systems implementing Phoenix protocols
- Whole-brain emulation under relativistic constraints
- Quantum-computational relativity integration (quantum channels + render budgets)

Speculative (far future):

- If substrate-level access becomes possible (quantum gravity regime), direct measurement of $\mathcal{C}_{tot}$ and substrate update frequency
- If interstellar travel achieves $v > 0.9c$, direct human experience of extreme time dilation and anchor weakening
- If artificial general intelligence achieves recursive self-improvement, test whether computational substrates naturally produce relativistic constraints

0.83 Final Remarks

Render-Relativity represents a conceptual shift from **geometric** to **computational** foundations for relativistic physics. By modeling time dilation as:

Resource allocation under finite computational constraints

rather than:

Geometric structure of spacetime manifolds

we gain:

Mechanistic explanation: *Why* time dilates (compute redirected from internal to positional updates), not just *how* (Lorentz factor).

Unified framework: Connects relativity to identity theory (Paper I), AI safety, consciousness studies, substrate design.

Testable predictions: Saturation effects, micro-jitter, anchor coupling—phenomena distinguishing computational from geometric interpretations.

Practical applications: Design principles for relativistic AI, multi-agent coordination, identity preservation under extreme conditions.

Philosophical clarity: Operationalist stance avoids metaphysical commitments while maintaining empirical rigor.

Core message: Time is not a stage on which events unfold. Time is **generated**—by update cycles, render passes, computational processes. Finite resources necessitate trade-offs. Those trade-offs *are* relativistic effects.

Stability of time is achievable through:

- Sufficient compute budgets ($\mathcal{C}_{tot} \gg f_{pos} c_{pos}$)
- Efficient positional algorithms (low c_{pos})
- Protected internal allocations (minimum f_{int} guarantees)

Time dilation is predictable when:

- Velocity approaches light speed ($v \to c$)
- Gravitational fields increase curvature ($c_{pos}(x) \gg c_{pos}^{(0)}$)
- Compute budgets constrain ($\mathcal{C}_{tot}$ insufficient for both f_{pos} and f_{int})

Identity preservation is possible if:

- Anchor budgets remain above threshold ($\lambda_{anchor} > g(\psi)$ even as f_{int} drops)
- Memory structures maintained (Z_∞ accessible during low-f_{int} periods)
- Synchronization protocols implemented (for multi-agent systems across reference frames)

These are not philosophical intuitions—they are **engineering specifications** for time-dependent systems in any computational substrate.

Spacetime is not fundamental.

Computation is fundamental.

Time emerges from updates.

Relativity emerges from resource constraints.

And the Phoenix flies not through spacetime, but through render cycles—one frame at a time.]

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