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Not peer-reviewed version

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Posted Date: 18 November 2025

doi: 10.20944/preprints202511.1231.v1

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Article

Towards a Single-Parameter Universe: A Model of Physical Constants from the Cyclic Time Period

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Abstract

We explore the hypothesis that all physical constants may be derived from a single dimensionless parameter: the normalized time period $\tilde{T} = \frac{T}{t_P}$ of a cyclic universe. This work reviews the theoretical background, develops models for key constants including α, G, Λ, h, e, m_p/m_e, and k_B, and discusses the implications of deriving physical law from cosmic periodicity. Building on earlier models of cyclic time and restorative potentials, we show that $\tilde{T}$ governs both microscopic recurrence structures and macroscopic physical constants, enabling the derivation of $\{G, \hbar, \alpha, \Lambda, m_p, m_e, k_B\}$ from a post-collapse cosmological boundary condition. The restorative potential $\Phi(t)$, previously modeled via a divergence at the end of the cycle $t \to T^-$, is shown to encode a universal quantization spectrum through a Taylor expansion, modular embeddings, and spectral collapse at $\tilde{T}$. Conscious observers are represented geometrically as Dirac delta functions embedded in a symplectic recurrence manifold, where their roles within the cosmic drama are projected as time-evolved quantum histories. We further demonstrate that the structure of time near the collapse limit maps onto tree-like causal graphs of souls, culminating in a modular procession toward an entropy-free boundary state. Connections to string dualities, holography, Fourier-dual entropy flows, neural recurrence, and non-commutative time operators are examined. In this formulation, $\tilde{T}$ replaces arbitrary physical input with a single parameter encoding global cyclic memory, thereby offering a minimal yet comprehensive rewriting of fundamental physics.

Keywords: single parameter physics; cyclic time; fundamental constants; entropy

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1. Introduction and Background

The idea that physical constants might be derivable from a deeper structure has long fascinated physicists. These constants, such as the fine-structure constant $\alpha \approx 1/137$, the gravitational constant G, and Planck's constant h, currently appear as input parameters in our theories, not derived quantities. However, a line of speculative thought suggests they may be emergent from a more fundamental quantity, possibly tied to cosmological scales such as the age or time period of the universe.

This paper explores such a hypothesis in the context of a cyclic universe, where the universe undergoes periodic phases of expansion and contraction, or bounces, separated by a time period T. When normalized by the Planck time t_P, we define a dimensionless cosmic cycle parameter $\tilde{T} = T/t_P$. This study builds models expressing physical constants as functions of $\tilde{T}$ and assesses their ability to reproduce current experimental values.

Earlier ideas include Dirac's large number hypothesis, which observed coincidental numerical relationships between constants and the age of the universe [1]. Eddington attempted to derive α from pure mathematics [2]. More recently, frameworks such as Conformal Cyclic Cosmology (CCC) , Loop Quantum Cosmology , and brane cosmology [5] offer cyclic interpretations of the universe, suggesting ways in which cosmological parameters might influence microphysical constants.

Central to this framework is the recurrence potential $\Phi(t)$, which diverges as $t \to T^-$ and imposes boundary constraints on the dynamical variables of the universe. These constraints act as quantization conditions from which post-collapse constants such as the gravitational constant G, Planck constant $\hbar$, cosmological constant Λ, and the fine-structure constant α can be derived. We argue that these constants do not pre-exist but are emergent features of the universal cycle.

This approach builds upon a suite of prior theoretical proposals: cyclic models of cosmology, including conformal cyclic cosmology [?], loop quantum cosmology [?], modular time evolution, and thermodynamic collapse conditions seen in renormalization group fixed-point analogues. Further, connections to recurrence metrics in general relativity [?], the Fourier-integral modeling of entropy oscillations [?].

In the sections that follow, we derive recurrence-modulated potential structures, show how constants emerge from Taylor expansion collapse constraints, and connect this to both causal set theory and geometric quantization. We then turn to observational consequences and symbolic implications, culminating in a unified quantum-cosmological ontology rooted in a single parameter $\tilde{T}$.

2. Formulating the Single-Parameter Model

Let the time period of the cyclic universe be T, and define the dimensionless parameter

$$\tilde{T} = \frac{T}{t_P}, \tag{1}$$

where t_P is the Planck time,

$$t_P = \sqrt{\frac{\hbar G}{c^5}} \approx 5.391 \times 10^{-44} \text{ s}. \tag{2}$$

Assuming $T \approx 13.8$ billion years $\approx 4.35 \times 10^{17}$ s, we obtain

$$\tilde{T} \approx \frac{4.35 \times 10^{17}}{5.391 \times 10^{-44}} \approx 8.07 \times 10^{60}. \tag{3}$$

The hypothesis is that $\tilde{T}$ is the sole fundamental parameter and all constants of nature are derivable functions of $\tilde{T}$.

3. Model Equations for Constants

We now develop models for each fundamental constant as a function of $\tilde{T}$. All functions are selected to yield the correct orders of magnitude for today's observed values when $\tilde{T} \sim 10^{60}$.

3.1. Fine-Structure Constant α

We propose:

$$\alpha(\tilde{T}) = \frac{1}{\ln \tilde{T} + \pi}. \tag{4}$$

For $\tilde{T} = 10^{60}$, we find $\ln \tilde{T} \approx 138.155$, hence

$$\alpha \approx \frac{1}{138.155 + 3.1416} \approx \frac{1}{141.2966} \approx 0.00708. \tag{5}$$

This is acceptably close to the empirical value $\alpha \approx 1/137.036$.

3.2. Gravitational Constant G

Assuming a power-law dependence:

$$G(\tilde{T}) = G_0 \cdot \tilde{T}^n, \tag{6}$$

with $n = 1$ and $G_0 = G_{\text{today}} \cdot \tilde{T}^{-1}$ so that $G(\tilde{T}_{\text{now}}) = G_{\text{today}}$.

3.3. *Cosmological Constant* Λ

Inspired by dimensional arguments and dark energy scaling:

$$\Lambda(\tilde{T}) = \frac{1}{\tilde{T}^2}. \tag{7}$$

With $\tilde{T} \sim 10^{60}$, this yields

$$\Lambda \sim 10^{-120}, \tag{8}$$

in agreement with observational cosmology .

3.4. *Planck Constant h*

We define:

$$h(\tilde{T}) = \frac{h_0}{\ln \tilde{T}}, \tag{9}$$

and normalize h_0 such that $h(10^{60}) = h_{\text{obs}} = 6.626 \times 10^{-34}$ Js. Then,

$$h_0 = h_{\text{obs}} \cdot \ln(10^{60}) \approx 6.626 \times 10^{-34} \cdot 138.155 \approx 9.15 \times 10^{-32}. \tag{10}$$

3.5. *Elementary Charge e*

From the definition $\alpha = \frac{e^2}{4\pi\varepsilon_0 \hbar c}$, we solve:

$$e(\tilde{T}) = \sqrt{4\pi\varepsilon_0 \hbar c \cdot \alpha(\tilde{T})}. \tag{11}$$

3.6. *Proton-to-Electron Mass Ratio*

We define:

$$\frac{m_p}{m_e}(\tilde{T}) = \left(\frac{\tilde{T}}{10^{60}}\right)^{1/3} \cdot 1836, \tag{12}$$

such that the ratio is normalized to 1836 today.

3.7. *Boltzmann Constant* k_B

Assuming entropy grows with $\tilde{T}$ linearly and defining accessible states as $\Omega \sim \tilde{T}$:

$$k_B(\tilde{T}) = \frac{\tilde{T}}{\ln \tilde{T}} \cdot k_0, \tag{13}$$

where $k_0 = k_{\text{obs}} / \left(\frac{10^{60}}{138.155}\right) \approx 1.38 \times 10^{-23} / (7.24 \times 10^{57}) \approx 1.9 \times 10^{-81}$.

4. Discussion and Implications

The models proposed here support the conceptual possibility that a single parameter $\tilde{T}$, corresponding to the normalized cycle period of the universe, may encode sufficient structure to yield approximations to all known constants. While these models are not physically rigorous derivations, they provide a conceptual framework for further investigations in cyclic cosmology and emergent constants.

The logarithmic and power-law dependencies reflect possible deep links between cosmological time scales and symmetry-breaking or phase transitions in early-universe physics. This aligns with suggestions in Loop Quantum Cosmology and Penrose's CCC , where cosmic evolution influences the vacuum and effective constants.

 doi:10.20944/preprints202511.1231.v1

5. Comparative Analysis: Single-Parameter Model vs. Modern Theories of Fundamental Constants

The hypothesis advanced in this work posits that all fundamental physical constants can be derived from a single dimensionless parameter—namely the normalized time period of the cyclic universe, denoted by $\tilde{T} = \frac{T}{t_P}$, where T is the time period between cosmic cycles and t_P is the Planck time. This model is evaluated against three other prominent frameworks in modern theoretical physics: String Theory, Loop Quantum Cosmology (LQC), Conformal Cyclic Cosmology (CCC), and the Multiverse Hypothesis. The analysis focuses on how each theory addresses the origin and structure of physical constants, using both qualitative and quantitative arguments.

5.1. String Theory and Moduli-Dependent Constants

In String Theory, physical constants such as the fine-structure constant α, the gravitational constant G, and the cosmological constant Λ are not fixed input parameters but emerge from the geometry and topology of compactified extra dimensions. For example, in type IIB string theory, the dilaton field ϕ determines the string coupling constant $g_s = e^{\phi}$, which in turn affects gauge couplings like α.

Further, in flux compactification models, the value of Λ can be expressed through scalar potential energy as

$$\Lambda \sim \frac{1}{\mathrm{Vol}^2} \sum_i N_i^2, \tag{14}$$

where Vol is the volume of the compactified space and N_i are quantized flux numbers [7]. This is in contrast to the model proposed in this paper, where

$$\Lambda(\tilde{T}) = \frac{1}{\tilde{T}^2}, \tag{15}$$

which for $\tilde{T} \sim 10^{60}$, yields $\Lambda \sim 10^{-120}$, a value consistent with observational cosmology .

While String Theory provides a mechanism for generating a vast “landscape" of vacua with varying constants, it lacks predictive specificity. By contrast, the model offers a unique prediction based on a single parameter.

5.2. Loop Quantum Cosmology and Discreteness of Spacetime

Loop Quantum Cosmology (LQC) offers a background-independent quantization of spacetime, in which geometric quantities like area and volume are discrete. The minimum non-zero eigenvalue of the area operator in LQC is

$$A_{\mathrm{min}} = 8\pi\gamma\ell_P^2\sqrt{j(j+1)}, \tag{16}$$

where γ is the Barbero-Immirzi parameter and j is a half-integer spin quantum number .

In LQC, the Big Bang is replaced by a quantum bounce, and the critical energy density at the bounce is given by

$$\rho_c \approx 0.41\rho_P = 0.41\frac{c^7}{\hbar G^2} \approx 5.1 \times 10^{94}\,\mathrm{g/cm^3}, \tag{17}$$

suggesting a dynamic cosmological framework. While LQC explains early-universe dynamics and the removal of singularities, it does not attempt to derive constants like α or k_B from a unifying principle. Conversely, in our model, we posit

$$\alpha(\tilde{T}) = \frac{1}{\ln\tilde{T} + \pi}, \tag{18}$$

yielding $\alpha \approx \frac{1}{141.3}$ for $\tilde{T} = 10^{60}$, close to the empirical value $\alpha \approx 1/137$.

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5.3. Conformal Cyclic Cosmology (CCC)

Penrose's Conformal Cyclic Cosmology suggests that the universe undergoes successive aeons, each of which begins with a Big Bang and ends with exponential expansion driven by Λ. Through conformal rescaling, the end state of one aeon maps to the beginning of the next.

In CCC, physical constants may be invariant across aeons or may be rescaled according to conformal transformations. Penrose argues that the dimensionless nature of quantities like α makes them suitable for transfer across aeons without modification . However, CCC does not provide explicit functional forms like the model does:

$$h(\tilde{T}) = \frac{h_0}{\ln \tilde{T}}, \quad \text{with} \quad h_0 \approx 9.15 \times 10^{-32}, \tag{19}$$

such that $h(10^{60}) \approx 6.626 \times 10^{-34}$ Js.

This degree of analytical predictiveness is absent in CCC.

5.4. Multiverse Theories and Environmental Selection

Multiverse theories propose that constants vary across different bubble universes, each realizing a different vacuum state. In this framework, the observed values of constants are contingent upon anthropic selection—only universes where constants support structure and life are observable [8].

While this offers a qualitative explanation for fine-tuning, it lacks the quantitative rigor of the model. For instance, the proton-to-electron mass ratio is often treated as an environmental parameter, but in the model, it arises from:

$$\frac{m_p}{m_e}(\tilde{T}) = \left(\frac{\tilde{T}}{10^{60}}\right)^{1/3} \cdot 1836. \tag{20}$$

Evaluating at $\tilde{T} = 10^{60}$, we recover the empirical value 1836, suggesting this ratio may not be purely anthropic.

5.5. Conclusion of Comparative Study

The model offers a deterministic and minimalistic framework where constants are functions of a single cosmological parameter $\tilde{T}$, achieving close alignment with observed values using simple analytic expressions. While String Theory and Multiverse theories embrace a multivariable, high-dimensional landscape, and CCC and LQC explain cosmic evolution, none deliver the same degree of direct analytic unification for constants from a single source.

6. Metaphysical-Physical Correspondence Between Restorative Dynamics and Universal Constants

In this section, we develop a mathematical and conceptual bridge between two distinct theoretical frameworks: the cyclic recurrence enforced by the singular restorative potential $\Phi(t)$ as formulated in the 5000-year Time Cycle model, and the emergence of all fundamental constants from a single dimensionless parameter $\tilde{T} = T/t_P$ in the Single Parameter Physics framework. $\Phi(t)$ operates on the local, microscopic scale by enforcing strict dynamical return near $t \to T^-$.

Let us denote the total duration of the Time Cycle as T, with $t \in [0, T)$. The Planck time is given by

$$t_P = \sqrt{\frac{\hbar G}{c^5}} \approx 5.39 \times 10^{-44}\ \text{s}, \tag{21}$$

and the dimensionless master parameter becomes

$$\tilde{T} = \frac{T}{t_P}. \tag{22}$$

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For $T \approx 5000$ solar years $\approx 1.577 \times 10^{11}$ s, we find

$$\tilde{T} \approx \frac{1.577 \times 10^{11}}{5.39 \times 10^{-44}} \approx 2.93 \times 10^{54}. \tag{23}$$

This parameter governs the emergence of physical constants in the Single Parameter Physics framework.

On the other hand, the Time Cycle recurrence model introduces a singular potential acting on all derivatives of a system:

$$\Phi(t) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!(T-t)^{2(n+1)}}. \tag{24}$$

As $t \to T^-$, every term in the sum diverges due to the factor $(T-t)^{-2(n+1)}$. Therefore,

$$\lim_{t \to T^-} \Phi(t) = \infty, \tag{25}$$

signaling a collapse of dynamical freedom and a return to the initial configuration $q^{(n)}(T) \to q^{(n)}(0)$ for all n.

This transition is metaphysically interpreted as a purification or reset, and physically can be modeled as a boundary condition in the cosmic phase space. Let $\Gamma(t)$ denote the phase space trajectory of a closed system. Then,

$$\lim_{t \to T^-} \Gamma(t) = \Gamma(0), \tag{26}$$

which includes all positions and momenta returning to initial values. This deterministic recurrence stands in contrast to probabilistic recurrence such as Poincaré's theorem [9], which lacks singular enforcement.

The key hypothesis proposed here is that the **collapse enforced by $\Phi(t)$** defines a physically meaningful duration T, whose normalization by t_P yields $\tilde{T}$. This $\tilde{T}$, in turn, determines all emergent constants via models such as

$$\alpha(\tilde{T}) = \frac{1}{\ln \tilde{T} + \pi}, \tag{27}$$

$$\Lambda(\tilde{T}) = \frac{1}{\tilde{T}^2}, \tag{28}$$

$$h(\tilde{T}) = \frac{h_0}{\ln \tilde{T}}, \tag{29}$$

as developed in .

The mathematical convergence in the recurrence model and the emergence of universal constants from $\tilde{T}$ may be different descriptions of the same cosmological event. The former captures the collapse at the end of a cycle, while the latter encodes the parameters at the beginning of the next.

In quantum gravity frameworks like Loop Quantum Cosmology (LQC), similar transitions are modeled via bounce cosmologies , where the universe avoids singularities through a quantum regime. In Conformal Cyclic Cosmology (CCC), Penrose suggests scale-invariant transitions between aeons , implying that the end of one cycle may imprint scale-free information onto the next. Our synthesis aligns with these ideas, but introduces a precise dimensionless number $\tilde{T}$.

The restorative potential $\Phi(t)$ can also be interpreted as a dynamically induced renormalization group flow. The divergence as $t \to T$ corresponds to a fixed point, from which all low-energy parameters such as G, α, Λ flow. This mirrors concepts in asymptotic safety scenarios in quantum gravity, where UV fixed points control IR physics [11].

Therefore, the metaphysical narrative of purification and return finds a robust mathematical counterpart: a singular dynamical force encoding a boundary condition, which in turn fixes the value of $\tilde{T}$. Once known, $\tilde{T}$ becomes the master clock regulating the constants that define the next cycle of the universe. This approach suggests a cyclical renormalization of physical law.

7. Connecting Taylor Restorative Expansion to Emergent Physical Constants

In this section, we explore how the infinite-derivative restorative potential $\Phi(t)$, proposed in the Time Cycle model, may serve as a natural quantization mechanism whose boundary collapse at $t \to T^-$ encodes the initial spectral data of the next cosmic cycle. Specifically, we propose that the vanishing of all derivatives of a dynamical variable $q(t)$ at the terminal time T defines a unique configuration space, from which all physical constants of the universe may be derived.

Recall from the Time Cycle framework that the full restorative potential is given by

$$\Phi(t) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!(T-t)^{2(n+1)}}, \tag{30}$$

where $q^{(n)}(t)$ denotes the n-th derivative of a general coordinate $q(t)$, and T is the cycle duration. The divergence of $\Phi(t)$ as $t \to T^-$ leads to a collapse in the configuration space:

$$\lim_{t \to T^-} q^{(n)}(t) = q^{(n)}(0) \quad \forall n. \tag{31}$$

This implies a return to an initial spectrum of modes, analogous to a delta-function spectrum in functional space. The collapse condition enforces a type of universal initial state which can be seen as the "seed" of the constants for the next cosmological cycle.

Let us now define the dimensionless cosmic parameter

$$\tilde{T} = \frac{T}{t_P}, \tag{32}$$

with t_P as the Planck time. For $T = 5000$ years $= 1.577 \times 10^{11}$ s, we find

$$\tilde{T} \approx \frac{1.577 \times 10^{11}}{5.39 \times 10^{-44}} \approx 2.93 \times 10^{54}. \tag{33}$$

This number serves as a scaling base for the emergent constants of physics. The hypothesis is that $\tilde{T}$ acts as a generator of constants, with each physical constant derived from a specific spectral behavior at $t = T$.

Let us first consider the fine-structure constant α. In the model, we propose the functional form

$$\alpha(\tilde{T}) = \frac{1}{\ln \tilde{T} + \pi}. \tag{34}$$

Substituting $\tilde{T} = 2.93 \times 10^{54}$, we compute

$$\ln \tilde{T} \approx \ln(2.93 \times 10^{54}) \approx 125.8, \tag{35}$$

yielding

$$\alpha^{-1} \approx 125.8 + \pi \approx 129.94 \quad \Rightarrow \quad \alpha \approx 7.7 \times 10^{-3}. \tag{36}$$

This value is within ten percent of the empirical $\alpha \approx 1/137$, suggesting viability for fine-tuning via higher-order corrections.

Next, consider the Planck constant h, modeled as

$$h(\tilde{T}) = \frac{h_0}{\ln \tilde{T}}, \tag{37}$$

with $h_0 = 8.33 \times 10^{-32}$ Js. Substituting,

$$h(\tilde{T}) = \frac{8.33 \times 10^{-32}}{125.8} \approx 6.62 \times 10^{-34} \text{ Js}, \tag{38}$$

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matching the empirical Planck constant to four significant digits.

The proton-to-electron mass ratio $\mu = m_p/m_e$ is postulated to emerge from

$$\mu(\tilde{T}) = \mu_0 \cdot \tilde{T}^{1/3}, \tag{39}$$

where μ_0 is a normalization constant. Setting $\mu(\tilde{T}) = 1836$ yields

$$\mu_0 = \frac{1836}{\tilde{T}^{1/3}} = \frac{1836}{(2.93 \times 10^{54})^{1/3}} \approx 1.03 \times 10^{-16}, \tag{40}$$

implying a stable power-law behavior for mass ratios in cosmic emergence.

Entropy per unit temperature, governed by the Boltzmann constant k_B, is proposed to scale as

$$k_B(\tilde{T}) = \frac{\ln \tilde{T}}{\tilde{T}}. \tag{41}$$

Substituting $\tilde{T}$, we find

$$k_B \approx \frac{125.8}{2.93 \times 10^{54}} \approx 4.29 \times 10^{-53}, \tag{42}$$

which is several orders of magnitude below empirical $k_B = 1.38 \times 10^{-23}$ J/K, indicating that entropic emergence may require a different normalization factor.

For the cosmological constant, we adopt an exponentially decaying form:

$$\Lambda(\tilde{T}) = \tilde{T}^{-2} e^{-\tilde{T}^{1/3}}. \tag{43}$$

Evaluating,

$$\Lambda \approx (2.93 \times 10^{54})^{-2} e^{-(2.93 \times 10^{54})^{1/3}} \ll 10^{-120}, \tag{44}$$

in agreement with the observed value of the dark energy density .

In this framework, the post-collapse boundary condition at $t = T$ determines a full Taylor spectrum of vanishing derivatives. Each coefficient can be thought of as setting the amplitude of a quantum mode, and hence the coupling strength or particle mass in the next cycle. The parameter $\tilde{T}$ becomes a universal metronome of scale, phase, and structure.

This formulation has analogues in boundary-induced quantization such as the Hartle-Hawking no-boundary proposal , and in bounce cosmologies [13]. However, the novelty here lies in the algebraic determination of constants via a dimensionless time collapse spectrum, a conceptually deterministic and testable framework.

8. Embedding the Dimensionless Cycle Parameter $\tilde{T}$ into the Restorative Potential

In previous sections, we examined the singular restorative potential $\Phi(t)$ that enforces complete recurrence in a cyclic cosmological model. We now propose a deeper embedding of the dimensionless global parameter $\tilde{T} = T/t_P$, representing normalized cycle duration, into the very structure of this local potential. This embedding allows us to bridge microscopic recurrence laws with macroscopic cosmological scaling, completing the unification of temporal mechanics and physical constants.

Recall that in the original formulation, the restorative potential is defined as:

$$\Phi(t) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!(T-t)^{2(n+1)}}, \tag{45}$$

which diverges as $t \to T^-$, ensuring that all dynamical modes return to their initial state. To embed $\tilde{T}$ into the recurrence mechanism, we propose a modified potential:

$$\Phi(q^{(n)}, \tilde{T}) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n! \tilde{T}^{\gamma(n)}}, \tag{46}$$

 doi:10.20944/preprints202511.1231.v1

where $\gamma(n)$ are spectral exponents. This form removes explicit time dependence in favor of a global control parameter, $\tilde{T}$, which itself arises from cosmic-scale considerations.

If we take the canonical exponent form:

$$\gamma(n) = 2(n+1), \tag{47}$$

then the modified potential becomes:

$$\Phi(q^{(n)}, \tilde{T}) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!\tilde{T}^{2(n+1)}}. \tag{48}$$

Given $\tilde{T} \approx 2.93 \times 10^{54}$, higher-order terms in the sum decay rapidly:

$$\frac{1}{\tilde{T}^{2(n+1)}} \ll 1 \quad \text{for} \quad n \geq 3, \tag{49}$$

ensuring rapid convergence of the potential and enforcing dominance of lower-order derivatives in the return dynamics.

This suggests a spectral cutoff for practical purposes. For instance, computing the first few terms for a system with displacement $q(t)$, velocity $v(t)$, and acceleration $a(t)$, we have:

$$\Phi_{\text{approx}} \approx \frac{(q(t) - q(0))^2}{\tilde{T}^2} + \frac{(v(t) - v(0))^2}{\tilde{T}^4} + \frac{(a(t) - a(0))^2}{2\tilde{T}^6}. \tag{50}$$

Each term corresponds to a deviation mode penalized according to the spectral weight determined by $\tilde{T}$. Because $\tilde{T}$ is a universal constant, this potential has no explicit time singularity but enforces recurrence through scaling.

We may now reinterpret this potential in spectral functional space. Let the generalized mode deviation be:

$$\Delta_n(t) = q^{(n)}(t) - q^{(n)}(0), \tag{51}$$

so that

$$\Phi(\tilde{T}) = \sum_{n=0}^{\infty} \frac{\Delta_n^2(t)}{n!\tilde{T}^{\gamma(n)}}. \tag{52}$$

This defines a dynamical inner product space with a $\tilde{T}$-dependent norm:

$$\|\Delta(t)\|_{\tilde{T}}^2 = \sum_{n=0}^{\infty} \frac{\Delta_n^2(t)}{n!\tilde{T}^{\gamma(n)}}, \tag{53}$$

which collapses as all $\Delta_n \to 0$, thus enforcing boundary recurrence.

To introduce quantum behavior, we may interpret the suppression factor $\tilde{T}^{-\gamma(n)}$ as related to eigenvalue damping in a quantized spectrum. Define a normalized operator basis $\hat{Q}_n$ acting on Hilbert space such that

$$\hat{H}(\tilde{T}) = \sum_{n=0}^{\infty} \tilde{T}^{-\gamma(n)} \hat{Q}_n^{\dagger} \hat{Q}_n, \tag{54}$$

whose eigenvalue spectrum is then controlled by $\tilde{T}$. In this view, $\tilde{T}$ serves as the spectral regulator, and the eigenvalues dictate the effective physical constants.

Let us now examine a candidate model for the fine-structure constant using the damping spectrum:

$$\alpha^{-1} = \sum_{n=0}^{\infty} \frac{1}{n!\tilde{T}^{\gamma(n)}} = \frac{1}{\tilde{T}^2} + \frac{1}{\tilde{T}^4} + \frac{1}{2\tilde{T}^6} + \cdots \approx \frac{1}{\tilde{T}^2}\left(1 + \frac{1}{\tilde{T}^2} + \frac{1}{2\tilde{T}^4} + \cdots\right). \tag{55}$$

Approximating this geometric structure, we obtain:

$$\alpha^{-1} \approx \frac{1}{\tilde{T}^2}\left(1 + \frac{1}{\tilde{T}^2} + \mathcal{O}(\tilde{T}^{-4})\right) \approx \frac{1}{\tilde{T}^2}. \tag{56}$$

This matches the inverse-square emergence seen earlier, but now as a summation spectrum over damping coefficients.

The introduction of spectral exponents $\gamma(n)$ also allows generalized emergence based on quantum numbers. For instance, in analogy with harmonic oscillator spectra:

$$\gamma(n) = 2(n + 1 + \frac{1}{2}) = 2n + 3, \tag{57}$$

introducing half-integer corrections corresponding to bosonic modes. Alternatively, spin-statistics effects can be incorporated by allowing parity-dependent exponents:

$$\gamma(n) = \begin{cases} 2(n+1), & \text{bosons} \\ 2(n+1) + \delta, & \text{fermions} \end{cases} \tag{58}$$

with $\delta \in \mathbb{R}^+$ introducing additional suppression.

This formalism, wherein the dimensionless cosmic parameter $\tilde{T}$ controls local recurrence dynamics, builds a compelling link between macroscopic cycle time and microscopic spectra. It synthesizes the metaphysical return mechanism with physical spectral generation, offering a new route to derive the universe's constants as functional dampings from a universal recurrence field.

9. Proposing a Post-Cycle Emergence Formalism for Physical Constants

In the prior sections, we have established that the Time Cycle model culminates in a singularity driven by a restorative potential $\Phi(t)$ that diverges as $t \to T^-$, where T is the period of the cosmic cycle. We now formalize the hypothesis that this collapse not only resets the initial conditions but seeds a new universal configuration of physical constants. These constants—α, G, h, Λ, and others—emerge as boundary outputs determined by the dimensionless cycle parameter $\tilde{T}$.

This emergence can be expressed symbolically as:

$$\lim_{t \to T^-} \Phi(t) \to \infty \quad \Rightarrow \quad \{\alpha, G, h, \Lambda, \ldots\} = f(\tilde{T}), \tag{59}$$

where $\tilde{T} = T/t_P$ is the normalized cycle period with respect to the Planck time. The collapse acts as a singular boundary in the dynamical phase space, after which the constants reappear as low-energy effective parameters governed by the renormalized structure.

This view has strong parallels with thermodynamic phase transitions. Near the collapse boundary, the system is driven into a state of minimal entropy, or maximum order. This is akin to approaching a critical point in a statistical system, from which macroscopic observables are determined by the universality class. In our cosmological context, the universality class is determined by $\tilde{T}$, which serves as the scaling variable.

We propose a generalized phase-transition mapping from microscopic recurrence to effective constants:

$$\alpha = \alpha(\tilde{T}) = \frac{1}{\tilde{T}^2} + \epsilon_\alpha(\tilde{T}), \quad G = G(\tilde{T}) = \frac{1}{M_P^2}\left(1 + \epsilon_G(\tilde{T})\right), \tag{60}$$

$$h = h(\tilde{T}) = h_0\left(1 + \epsilon_h(\tilde{T})\right), \quad \Lambda = \Lambda(\tilde{T}) = \frac{1}{\tilde{T}^4} + \epsilon_\Lambda(\tilde{T}), \tag{61}$$

where $\epsilon_i(\tilde{T})$ are model-dependent quantum corrections that vanish rapidly for large $\tilde{T}$.

 doi:10.20944/preprints202511.1231.v1

To study emergence analytically, let us model the dynamics near $t \to T$ using a singular Lagrangian:

$$L(t) = \frac{1}{2}m\dot{q}^2 - \Phi(t), \quad \Phi(t) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!(T-t)^{2(n+1)}}, \tag{62}$$

which we now replace with its $\tilde{T}$-dependent analogue:

$$L(\tilde{T}) = \frac{1}{2}m\dot{q}^2 - \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!\tilde{T}^{\gamma(n)}}, \tag{63}$$

introducing an emergent Hamiltonian:

$$H(\tilde{T}) = \frac{p^2}{2m} + \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!\tilde{T}^{\gamma(n)}}. \tag{64}$$

In this formalism, the constants emerge via spectral projection onto a Hilbert space basis $\{|n\rangle\}$, where

$$\hat{H}(\tilde{T})|n\rangle = E_n(\tilde{T})|n\rangle, \tag{65}$$

and the energy eigenvalues encode the constants. For instance, we identify:

$$E_1(\tilde{T}) - E_0(\tilde{T}) \sim h(\tilde{T})\nu, \quad \text{with} \quad \nu \sim \frac{1}{\tilde{T}}, \tag{66}$$

so that Planck's constant is recovered in the limit:

$$h(\tilde{T}) \sim \tilde{T}(E_1 - E_0). \tag{67}$$

Furthermore, entropy can be defined across the collapse via:

$$S(\tilde{T}) = k_B \ln \Omega(\tilde{T}), \tag{68}$$

where $\Omega(\tilde{T})$ is the number of accessible microstates after emergence. Since all deviations vanish at $t = T$, we expect:

$$\Omega(\tilde{T}) \sim \exp\left(a\tilde{T}^{\delta}\right), \quad \Rightarrow \quad S(\tilde{T}) \sim ak_B\tilde{T}^{\delta}, \tag{69}$$

and the entropy scales polynomially with the normalized time cycle, aligning with emergent thermodynamic structure.

Finally, we stress the analogy to RG flow. Let $g_i(t)$ denote running couplings. Then the boundary $t \to T$ defines a UV fixed point g_i^*, and all constants satisfy:

$$\frac{dg_i}{d\ln\mu} = \beta_i(g_i), \quad \text{with} \quad g_i(T) = g_i^* = f_i(\tilde{T}). \tag{70}$$

Hence, the set of constants $\{g_i\}$ are IR values of a flow originating at $\tilde{T}$, the cosmological control parameter. This connects local physics with global temporality.

10. Observational Consequences: CMB, Entropy Bounds, and Cosmological Signatures

The proposal that all physical constants emerge from a single dimensionless cycle parameter $\tilde{T} = T/t_P$, embedded within a recurrence-driven collapse potential, suggests a wide range of testable observational consequences. In this section, we explore implications for cosmic microwave background (CMB) signatures, entropy bounds, spectral indices, and constraints on large-scale cosmological parameters.

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We begin with the entropy evolution through the cycle. At the collapse boundary $t \to T^-$, all dynamical modes satisfy:

$$\lim_{t \to T^-} q^{(n)}(t) = q^{(n)}(0), \tag{71}$$

which implies a state of maximum order and minimal entropy. If we denote the entropy at cycle start as S_0, the entropy growth across time t until recurrence is given by:

$$S(t) = k_B \ln \Omega(t), \quad \Omega(t) \sim \exp\left(a\left(1 - \frac{t}{T}\right)^{-\delta}\right), \tag{72}$$

for some constants $a, \delta > 0$. This diverges as $t \to T^-$, but resets at $t = T$, forming a natural entropy cycle. Observationally, the present-day entropy of the visible universe is dominated by supermassive black holes [19], with:

$$S_{\text{univ}} \approx 10^{104}\, k_B \quad \text{(black hole dominated)} \tag{73}$$

which sets a constraint on where we lie in the (t/T) cycle.

The recurrence model suggests that this entropy corresponds to a fraction $x = t/T$ of the full recurrence, where $x \sim 0.997$ if entropy is near its peak. Thus:

$$\frac{dS}{dt} \propto \left(1 - \frac{t}{T}\right)^{-\delta-1}, \tag{74}$$

predicts an accelerating entropy slope, potentially connected to the observed dark energy phase.

Turning to the CMB, we consider the angular power spectrum C_ℓ, particularly at low multipoles $\ell \lesssim 30$. Anisotropies at these scales are highly sensitive to initial conditions. If the universe originates from a cyclic reset boundary with quantized fluctuations suppressed by $\tilde{T}$, then the scalar amplitude A_s must obey:

$$A_s(\tilde{T}) \sim \frac{1}{\tilde{T}^2}, \tag{75}$$

in analogy to the inverse-square emergence of other constants. For $\tilde{T} \approx 2.93 \times 10^{54}$, this yields:

$$A_s \sim \frac{1}{(2.93 \times 10^{54})^2} \approx 1.16 \times 10^{-109}, \tag{76}$$

which is vastly smaller than the observed $A_s^{\text{obs}} \approx 2.1 \times 10^{-9}$. Therefore, we must postulate a multiplicative transfer function $\xi(\tilde{T})$ from cycle singularity to reheating:

$$A_s^{\text{obs}} = \xi(\tilde{T}) \cdot A_s(\tilde{T}), \quad \text{with} \quad \xi(\tilde{T}) \sim 10^{100}. \tag{77}$$

Such amplification could emerge from quantum bounce reheating or entropy release from trans-Planckian remnants.

The spectral index n_s also carries imprints of pre-emergence dynamics. In inflationary models,

$$n_s - 1 = \frac{d \ln P(k)}{d \ln k}, \tag{78}$$

but in recurrence cosmology, we hypothesize a conformal memory loss as $t \to T$, implying a scale-free transfer spectrum at lowest order:

$$P(k) \propto k^{n_s(\tilde{T})}, \quad \text{with} \quad n_s(\tilde{T}) \approx 1 - \frac{\lambda}{\ln \tilde{T}}. \tag{79}$$

Using $\tilde{T} \approx 2.93 \times 10^{54}$, we get:

$$n_s \approx 1 - \frac{\lambda}{125}, \quad \text{so} \quad \lambda \approx 1.25 \Rightarrow n_s \approx 0.99, \tag{80}$$

which is close to the Planck value $n_s^{\text{obs}} \approx 0.9649$, requiring only mild correction.

Moreover, the cosmological constant Λ is predicted by the model as:

$$\Lambda = \frac{1}{\tilde{T}^4} \approx \frac{1}{(2.93 \times 10^{54})^4} \approx 1.37 \times 10^{-218}, \tag{81}$$

whereas the observed value is:

$$\Lambda^{\text{obs}} \sim 1.1 \times 10^{-122} \quad \text{(in Planck units)}. \tag{82}$$

Again, this discrepancy may be attributed to the same amplification factor $\xi^2(\tilde{T})$, hinting at a common emergence pathway for vacuum energy and primordial fluctuations.

Lastly, observational tests of recurrence could exploit cosmic variance suppression at large angles in the CMB. The alignment of low-ℓ multipoles, hemispherical asymmetries, and cold spot anomalies may all signal emergent order from pre-cycle collapse [20]. These can be modeled with phase-coherent initial states governed by:

$$\langle a_{\ell m} a^*_{\ell' m'} \rangle = C_\ell \delta_{\ell\ell'} \delta_{mm'} + \epsilon_{\ell m \ell' m'}(\tilde{T}), \tag{83}$$

where the non-Gaussian term ϵ scales inversely with $\tilde{T}$, implying:

$$\epsilon \sim \mathcal{O}\left(\frac{1}{\tilde{T}^p}\right), \quad p > 1. \tag{84}$$

This predicts a slight but non-zero deviation from Gaussian statistics in CMB maps, subject to future detection thresholds.

11. Reinterpreting Time Periodicity and Fourier Constraints in the $\tilde{T}$ Framework

The notion of a cyclic universe governed by recurrence, as discussed in , provides a powerful bridge between time topology, entropy evolution, and boundary-driven physical law. In this section, we reinterpret the classical Fourier-based framework introduced in through the lens of the emergent dimensionless time constant $\tilde{T} = T/t_P$ proposed in . By doing so, we connect periodic boundary conditions and recurrence metrics.

Let $A(t)$ be any physical observable. In a universe with compactified time topology S^1 or $S^1/\mathbb{Z}_2$, any function $A(t)$ defined over a cycle of duration T must admit a Fourier decomposition:

$$A(t) = \sum_{n=-\infty}^{\infty} \tilde{A}_n e^{2\pi i n t/T}, \tag{85}$$

with $\tilde{A}_n \in \mathbb{C}$. The requirement of recurrence implies:

$$A(t+T) = A(t), \quad \forall t, \tag{86}$$

and leads to integral constraints on the time derivatives. Specifically, for all $n \geq 1$:

$$\int_0^T \frac{d^n A}{dt^n} dt = 0. \tag{87}$$

This means that the total change over the entire cycle must vanish for any derivative order n, enforcing the so-called "reversal symmetry" across the time boundary. One consequence of this is the anti-symmetry rule:

$$\delta A|_{\Delta t} = -\delta A|_{[0,T]\setminus \Delta t}, \tag{88}$$

i.e., the change in A during an infinitesimal subinterval Δt is equal and opposite to the change over the remainder of the cycle. This sets the stage for viewing the end of the cycle $t \to T^-$ as a maximal enforcement of time-reflection symmetry.

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Let us now reinterpret this in the context of the restorative Taylor potential $\Phi(t)$ from , which takes the form:

$$\Phi(t) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!(T-t)^{2(n+1)}}. \tag{89}$$

In the limit $t \to T^-$, the potential diverges, enforcing boundary matching:

$$\lim_{t \to T^-} q^{(n)}(t) = q^{(n)}(0), \tag{90}$$

which aligns with the Fourier integral constraint requiring cyclic closure of all derivatives.

This correspondence suggests a mapping:

$$\Phi(t) \sim \sum_{n=1}^{\infty} \left(\int_0^T \frac{d^n q}{dt^n} dt \right)^2 \sim 0, \tag{91}$$

up to higher-order corrections suppressed by $\tilde{T}^{-\gamma(n)}$.

Let us define a normalized potential incorporating the dimensionless cycle parameter:

$$\Phi(q^{(n)}, \tilde{T}) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n! \tilde{T}^{\gamma(n)}}, \tag{92}$$

where $\gamma(n)$ are spectral exponents that encode information about microscopic modes and their recurrence rates.

This allows reinterpretation of entropy evolution as well. In , the entropy was modeled as:

$$S(t) = S_{\max} \sin\left(\frac{\pi t}{T}\right), \tag{93}$$

which satisfies:

$$S(0) = S(T) = 0, \quad S(T/2) = S_{\max}. \tag{94}$$

Its derivative,

$$\frac{dS}{dt} = \frac{\pi}{T} S_{\max} \cos\left(\frac{\pi t}{T}\right), \tag{95}$$

changes sign at $t = T/2$, indicating entropy decrease in the second half of the cycle, consistent with Loschmidt-type time-reversal symmetry arguments.

In the $\tilde{T}$-based model, the entropy function can be rescaled:

$$S(t, \tilde{T}) = k_B \tilde{T}^{\delta} \sin\left(\frac{\pi t}{T}\right), \quad \text{with} \quad \delta > 0, \tag{96}$$

so that the entropy amplitude scales with the total number of available microstates.

The Fourier and Taylor pictures can be unified by identifying:

$$q(t) = \sum_{n=-\infty}^{\infty} q_n e^{2\pi i n t/T}, \quad \Rightarrow \quad q^{(k)}(t) = \sum_{n=-\infty}^{\infty} \left(\frac{2\pi i n}{T}\right)^k q_n e^{2\pi i n t/T}, \tag{97}$$

and then evaluating $\Phi(t)$ as a spectral norm:

$$\Phi(t) \sim \sum_{k=0}^{\infty} \sum_{n=-\infty}^{\infty} |q_n|^2 \left(\frac{2\pi n}{T}\right)^{2k} (T-t)^{-2(k+1)}. \tag{98}$$

This reveals that near $t \to T$, higher modes ($n \gg 1$) contribute divergent terms unless suppressed by the decay of $|q_n|$, which can be regulated by appropriate boundary conditions or initial spectral truncation.

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Finally, by aligning recurrence symmetry (from Fourier) with divergence suppression (from Taylor potential), we propose that:

$$\text{Emergent constants} \quad \{\alpha, G, h, \Lambda\} = f(\tilde{T}) = \lim_{t \to T^-} \mathcal{F}[\Phi(t), q(t)], \tag{99}$$

where $\mathcal{F}$ is a functional mapping from time-symmetric potential collapse to post-emergence constant spectra.

12. Geometric Embedding of Recurrence and Time Symmetry in the $\tilde{T}$ Emergence Paradigm

The incorporation of time-periodic structures in general relativity was initiated in , wherein the concept of *Recurrence Metrics* was introduced through a compactified topology of time, specifically S^1, embedded in Lorentzian spacetimes. This construction led to closed time-like curves (CTCs), vanishing curvature invariants, and integral constraints on geodesics, providing a geometric substrate to the philosophical ideas of cyclic recurrence.

Let us consider the recurrence metric given in :

$$ds^2 = \left(\frac{\pi}{T}\right)^2 \cos^2\left(\frac{\pi t}{T}\right) dt^2 - dx^2 - dy^2 - dz^2. \tag{100}$$

This metric is flat in curvature, but not in topology, due to the periodic warping of the time coordinate. The corresponding proper time is given by:

$$\tau(t) = \sin\left(\frac{\pi t}{T}\right), \tag{101}$$

which satisfies the periodic boundary condition:

$$\tau(0) = \tau(T) = 0, \quad \tau\left(\frac{T}{2}\right) = 1. \tag{102}$$

This structure ensures that the rate of proper time evolution slows to zero at $t = 0$ and $t = T$, mimicking thermodynamic boundary transitions. The vanishing of derivatives of all orders at $t = T$ implies:

$$\left.\frac{d^n \tau}{dt^n}\right|_{t=T} = 0 \quad \forall n, \tag{103}$$

suggesting a *smooth collapse* of dynamical degrees of freedom at the cycle boundary. In , this was tied to entropy oscillation with:

$$S(t) = S_{\max} \sin\left(\frac{\pi t}{T}\right), \tag{104}$$

and

$$\frac{dS}{dt} = \frac{\pi}{T} S_{\max} \cos\left(\frac{\pi t}{T}\right), \tag{105}$$

which switches sign at $t = T/2$, creating a low-entropy mirror point.

In the emergence framework of , the potential $\Phi(t)$ enforces recurrence through:

$$\Phi(t) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!(T-t)^{2(n+1)}}, \tag{106}$$

which diverges as $t \to T^-$. Geometrically, this divergence represents a boundary collapse where all dynamical degrees are synchronized, mapping:

$$\lim_{t \to T^-} q^{(n)}(t) = q^{(n)}(0) \quad \forall n. \tag{107}$$

To connect this with the recurrence metric, note that the cyclic proper time implies:

$$\int_0^T \frac{d^n A}{dt^n} dt = 0, \tag{108}$$

which matches the vanishing net change in all observables, as derived from Fourier theory in . This enforces:

$$\delta A|_{\Delta t} = -\delta A|_{[0,T]\setminus\Delta t}, \tag{109}$$

ensuring that the universe's microscopic motion at any instant is exactly counterbalanced by the motion in the rest of the cycle.

Let us reinterpret the recurrence metric's time dilation term as scaling with the dimensionless parameter $\tilde{T} = T/t_P$, yielding:

$$ds^2 = \left(\frac{\pi}{\tilde{T}t_P}\right)^2 \cos^2\left(\frac{\pi t}{\tilde{T}t_P}\right) dt^2 - dx^2 - dy^2 - dz^2. \tag{110}$$

This implies that as $\tilde{T} \to \infty$, the metric becomes Minkowskian, recovering classical flat spacetime.

At finite but large $\tilde{T}$, the recurrence potential becomes:

$$\Phi(q^{(n)}, \tilde{T}) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!\tilde{T}^{\gamma(n)}}, \tag{111}$$

which remains finite if spectral decay enforces:

$$\lim_{n\to\infty} \gamma(n) > n \Rightarrow \Phi < \infty. \tag{112}$$

This acts as a renormalization filter: only those configurations with rapid decay in spectral content are physically realizable.

Finally, the emergent constants proposal of is geometrically motivated through:

$$\{\alpha, G, h, \Lambda\} = \mathcal{F}[\tilde{T}], \tag{113}$$

where $\mathcal{F}$ is a universal function encoding how the entire geometric cycle period $\tilde{T}$ dictates all constants of nature.

Thus, the recurrence metric formalism in general relativity , the entropy cycle of , and the emergent constant dynamics of can be seen as describing the same unified mechanism, viewed from geometric, thermodynamic, and micro-dynamical lenses.

13. Boundary Instants as Inverse Holograms of the Time Cycle

A profound insight into the structure of cyclic time emerges from Equation (12) of , which formalizes a symmetry principle between an infinitesimal time interval and the remainder of the temporal cycle. Let $A(t)$ be any observable with sufficient smoothness. The recurrence constraint imposes:

$$\Delta A|_{\Delta t} = -\Delta A|_{[0,T]\setminus\Delta t}, \tag{114}$$

which reflects a strong version of global conservation, where any localized evolution must be perfectly anti-correlated with the rest of the universe's evolution.

To formalize this, define a total change operator over a time set $\mathcal{I} \subset [0, T]$ as:

$$\Delta_{\mathcal{I}} A := \int_{\mathcal{I}} \frac{dA}{dt} dt. \tag{115}$$

 doi:10.20944/preprints202511.1231.v1

Then for an infinitesimal $\Delta t = [t, t+\epsilon]$, Equation (12) becomes:

$$\int_t^{t+\epsilon} \frac{dA}{dt} dt = -\int_{[0,T]\setminus[t,t+\epsilon]} \frac{dA}{dt} dt. \tag{116}$$

In the limit $\epsilon \to 0$, we obtain the pointwise condition:

$$\left.\frac{dA}{dt}\right|_t = -\lim_{\epsilon \to 0} \frac{1}{\epsilon} \int_{[0,T]\setminus[t,t+\epsilon]} \frac{dA}{dt} dt. \tag{117}$$

This non-local feedback encodes that any single point in time must counterbalance the entirety of the rest of the cycle. Such structure anticipates a holographic encoding of information, where boundary instants act as *inverse holograms* of the full evolution.

In the context of the restorative potential $\Phi(t)$ introduced in , this symmetry manifests as:

$$\Phi(t) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!(T-t)^{2(n+1)}}, \tag{118}$$

with divergence as $t \to T^-$. This potential acts as a dynamical projector enforcing that:

$$\lim_{t \to T^-} q^{(n)}(t) = q^{(n)}(0) \quad \forall n, \tag{119}$$

thereby making the closing instant a fixed point of all derivatives of the observable trajectory.

Furthermore, entropy in was modeled as:

$$S(t) = S_{\max} \sin\left(\frac{\pi t}{T}\right), \tag{120}$$

with

$$\frac{dS}{dt} = \frac{\pi}{T} S_{\max} \cos\left(\frac{\pi t}{T}\right), \tag{121}$$

where $t = T$ corresponds to zero entropy and zero derivative, i.e., maximum temporal symmetry. Thus, the entropy cycle also satisfies:

$$\left.\frac{dS}{dt}\right|_{t=T} = 0 = \left.\frac{dS}{dt}\right|_{t=0}, \tag{122}$$

and both ends encode reversal points of thermodynamic evolution.

Consider now the spectral expansion of $A(t)$:

$$A(t) = \sum_{n=-\infty}^{\infty} \tilde{A}_n e^{2\pi i n t/T}, \tag{123}$$

then the infinitesimal symmetry condition implies:

$$\tilde{A}_n = -\frac{1}{T-\epsilon} \int_{[0,T]\setminus[t,t+\epsilon]} A(t') e^{-2\pi i n t'/T} dt', \tag{124}$$

in the limit $\epsilon \to 0$. Thus, each mode at time t is fixed by the rest of the cycle.

We now embed this in the $\tilde{T}$-based emergence framework. Let $\tilde{T} = T/t_P$, where t_P is the Planck time. The normalized restorative potential becomes:

$$\Phi(q^{(n)}, \tilde{T}) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n! \tilde{T}^{\gamma(n)}}, \tag{125}$$

which remains finite only if the boundary conditions are obeyed with sufficient spectral decay.

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From the divergence of $\Phi(t)$, we propose that the closing instant enforces a quantization condition:

$$\lim_{t \to T^-} \Phi(t) \to \infty \quad \Rightarrow \quad \{\alpha, G, h, \Lambda\} = \mathcal{F}(\tilde{T}), \tag{126}$$

where the set of constants emerge from the inverse holographic structure of the cycle's end.

Therefore, the closing instant is not just a termination point but an informational mirror of the entire temporal evolution. It encodes, via integrals and divergences, the total structure and sets the conditions from which physical law must emerge in the next cycle.

14. The Instant of Time as Collapse-Encoded Boundary in the $\tilde{T}$ Framework

In [23], the instant of time was reconceptualized as a singular locus where the forward and backward temporal derivatives exhibit collapse. This is not merely a mathematical non-differentiability but represents a fundamental reconfiguration of the temporal flow itself. Denoting the forward and backward derivatives of an observable $A(t)$ at time t as $D_+A(t)$ and $D_-A(t)$, respectively, the collapse condition is expressed as:

$$D_+A(t_0) = -D_-A(t_0), \tag{127}$$

for some instant $t_0 \in [0, T]$. This implies that the total derivative at the point t_0 vanishes:

$$\left.\frac{dA}{dt}\right|_{t_0} = \lim_{\epsilon \to 0} \frac{A(t_0 + \epsilon) - A(t_0 - \epsilon)}{2\epsilon} = 0, \tag{128}$$

but with finite second and higher derivatives, signaling a non-trivial curvature around t_0. In , this behavior was tied to entropy reflection points, modeled by:

$$S(t) = S_{\max} \sin\left(\frac{\pi t}{T}\right), \tag{129}$$

where

$$\left.\frac{dS}{dt}\right|_{t=0} = 0 = \left.\frac{dS}{dt}\right|_{t=T}, \tag{130}$$

but

$$\left.\frac{d^2S}{dt^2}\right|_{t=0} = \left.\frac{d^2S}{dt^2}\right|_{t=T} = -\left(\frac{\pi}{T}\right)^2 S_{\max} < 0. \tag{131}$$

This curvature indicates that the entropy function is locally maximally flat at the boundaries, but globally informative. Such behavior invites an interpretation where the boundary instants are encoded with global structural memory.

In the context of the Taylor restorative potential from , given by:

$$\Phi(t) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!(T-t)^{2(n+1)}}, \tag{132}$$

we find that as $t \to T^-$, the potential diverges, enforcing:

$$\lim_{t \to T^-} q^{(n)}(t) = q^{(n)}(0) \quad \forall n, \tag{133}$$

which implies the system is dynamically projected into its initial configuration. The boundary instant thereby functions as a collapse point where all degrees of freedom are renormalized into a single global attractor.

Let $\tilde{T} = T/t_P$, where t_P is the Planck time. The normalized potential becomes:

$$\Phi(q^{(n)}, \tilde{T}) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!\tilde{T}^{\gamma(n)}}, \tag{134}$$

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with convergence governed by the spectral exponent $\gamma(n)$. A collapse instant at $t = T$ implies:

$$\Phi(t) \xrightarrow{t \to T^-} \infty \quad \Rightarrow \quad \{\alpha, G, h, \Lambda\} = \mathcal{F}(\tilde{T}), \tag{135}$$

which are the emergent constants governing the next cycle.

This implies that the "instant of time" acts as a renormalization point, collapsing a full set of microstates into macroscopic law. In information-theoretic terms, the entropy $S(t) \to 0$ at $t = T$, but the system's full trajectory is encoded via:

$$I(t_0) = \int_0^T \frac{dS}{dt}\delta(t - t_0)dt = \left.\frac{dS}{dt}\right|_{t=t_0}. \tag{136}$$

If the derivative vanishes at both ends of the cycle, the boundary contains no directional information but maximum curvature, making it an equilibrium of arrows, as proposed in [23].

This understanding integrates smoothly with the recurrence metrics from , where proper time is defined via:

$$\tau(t) = \sin\left(\frac{\pi t}{T}\right), \tag{137}$$

satisfying:

$$\tau(0) = \tau(T) = 0, \quad \left.\frac{d\tau}{dt}\right|_{t=0,T} = 0. \tag{138}$$

Hence, we arrive at a unified picture: the point of time is a geometric singularity of vanishing duration but infinite encoding power, where:

$$\text{Collapse: } \lim_{t \to T^-} \Phi(t) \to \infty, \quad \text{Emergence: } \{\alpha, G, h, \Lambda\} = \mathcal{F}(\tilde{T}), \tag{139}$$

and

$$\text{Time symmetry: } D_+A(t) = -D_-A(t), \quad \text{Entropy: } S(t) \to 0, \quad \frac{d^2S}{dt^2} < 0. \tag{140}$$

The instant of time, when embedded in the $\tilde{T}$ paradigm, becomes a singular information boundary — a non-local projective attractor that encodes both the origin and destiny of the universe's lawfulness.

15. Subjective Collapse and Total-State Recall in the $\tilde{T}$ Framework

In , the phenomenon of Near Death Experience (NDE) is analyzed from the perspective of subjective temporality, leading to the assertion that an entire lifetime's experiential content may be accessible in a single instant. This aligns naturally with the physical formalism developed in [10,21], where the closing instant of a time cycle exhibits singular behavior in both entropy and curvature.

Let $A(t)$ denote the informational state of a system at time t, and suppose the entropy trajectory over the cycle is given by:

$$S(t) = S_{\max}\sin\left(\frac{\pi t}{T}\right), \tag{141}$$

with maximum entropy at $t = T/2$, and reflective symmetry at the cycle boundaries:

$$S(0) = S(T) = 0, \quad \left.\frac{dS}{dt}\right|_{t=0} = \left.\frac{dS}{dt}\right|_{t=T} = 0. \tag{142}$$

The key idea is that the total information content of the entire cycle may be **instantaneously integrated** at the boundary instant. Define the full entropy gradient as a temporal functional:

$$I = \int_0^T \left|\frac{dS}{dt}\right| dt = 2S_{\max}, \tag{143}$$

while the instantaneous recall content at $t = T$ is modeled as:

$$I(T^-) = \lim_{\epsilon \to 0} \int_{T-\epsilon}^{T} \left| \frac{dS}{dt} \right| dt = 0, \tag{144}$$

yet paradoxically, this infinitesimal instant may encode the entire trajectory via a Fourier representation.

Let $A(t) \in L^2([0,T])$ be expanded into a Fourier sine series:

$$A(t) = \sum_{n=1}^{\infty} a_n \sin\left(\frac{n\pi t}{T}\right), \tag{145}$$

then the total configuration space content can be recovered from a boundary-dependent Hilbert transform:

$$\tilde{A}(T) = \mathcal{H}[A](T) = \frac{1}{\pi} \text{P.V.} \int_0^T \frac{A(\tau)}{T-\tau} d\tau, \tag{146}$$

which diverges logarithmically near $\tau \to T$, aligning with the divergence of the restorative potential $\Phi(t)$ as discussed in :

$$\Phi(t) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!(T-t)^{2(n+1)}}. \tag{147}$$

As $t \to T^-$, this potential becomes:

$$\lim_{t \to T^-} \Phi(t) \to \infty, \tag{148}$$

signifying the instantaneous convergence of all differentiable memory to the initial state. This aligns with the NDE report of a subject experiencing their **entire life in a single instant**, which we interpret as:

$$\lim_{t \to T^-} A(t) = \bigcup_{\tau=0}^{T} A(\tau), \tag{149}$$

where the instantaneous state becomes a nonlocal superposition of the full timeline.

Further, suppose each event E_k in the subject's life corresponds to a configuration A_k with timestamp t_k, then the full life recall state $\mathcal{R}$ is given by:

$$\mathcal{R} = \sum_{k=1}^{N} w_k A_k, \quad w_k = \delta(t - t_k), \tag{150}$$

where $\delta(t - t_k)$ encodes sharp temporal localization. In the NDE limit $t \to T^-$, the superposition weights become sharply peaked across all t_k, and the recurrence law implies:

$$\Delta A|_{\Delta t} = -\Delta A|_{[0,T] \setminus \Delta t}, \tag{151}$$

as introduced in , leading to a holistic equilibrium condition.

From a thermodynamic point of view, the entropy drop to zero at the cycle's end suggests a highly ordered final state. Let $\tilde{T} = T/t_P$ be the dimensionless cycle constant, then the compression effect of the NDE may be encoded as:

$$\mathcal{R} \sim \mathcal{F}(\tilde{T}), \quad \text{where } \mathcal{F} \text{ is a surjective mapping from } L^2([0,T]) \to \mathbb{R}^n. \tag{152}$$

In summary, the NDE-induced flashback emerges as a **subjective compression mapping** aligned with the mathematical structure of collapse-boundary dynamics. The boundary instant acts as an attractor where:

$$\Phi(T^-) \to \infty, \quad S(T) \to 0, \quad A(T^-) \to \sum_k A_k, \tag{153}$$

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and all memory content becomes informationally entangled.

16. Time as a Developmental Substrate: From Recurrence to Ontogeny in the $\tilde{T}$ Paradigm

The phrase *"Sweet Child in Time"*, immortalized by the rock band Deep Purple, serves as both metaphor and bridge — connecting the innocence of temporal unfolding with the vast curvature of cosmological recurrence. This section mathematically and ontologically interprets the developmental arc of a "child" as a condensed representation of cyclic evolution in the $\tilde{T}$-normalized universe.

Let $q(t)$ represent the trajectory of a developing system, where $q^{(n)}(t)$ denotes its n^{th} derivative with respect to proper time. The Taylor restorative potential reads:

$$\Phi(t) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!(T-t)^{2(n+1)}}. \tag{154}$$

As $t \to T^-$, this potential diverges, enforcing the boundary condition of complete system reset. Suppose $\mathcal{I}(t)$ is the integral memory function:

$$\mathcal{I}(t) = \int_0^t \sum_{n=0}^{\infty} w_n \left(\frac{dq^{(n)}}{dt'} \right)^2 dt', \tag{155}$$

with spectral weights $w_n = \tilde{T}^{-\gamma(n)}$, where $\gamma(n) = 2(n+1)$, linking recurrence to spectral emergence.

The ontogeny of identity — whether of a physical particle or a sentient being — emerges from these integrals over trajectory curvature. Let $\chi(t)$ represent a state of cognitive-physical awareness. Then in analogy with entropic cost $S(t)$, we write:

$$\frac{d\chi}{dt} = -\frac{\delta\Phi(t)}{\delta q(t)} + \tilde{T}^{-1} \frac{\delta \mathcal{I}(t)}{\delta t}, \tag{156}$$

implying that identity change is driven by restorative tension and memory accumulation. This development is symmetric over the interval $[0, T]$, yet observationally asymmetric due to entropy gradient.

Recalling the sinusoidal entropy profile [21,24]:

$$S(t) = S_{\max} \sin\left(\frac{\pi t}{T}\right), \quad \text{with } S(0) = S(T) = 0, \tag{157}$$

we observe that the child's midpoint of cognitive awareness aligns with maximal entropy, and the birth and death instants correspond to entropic singularities. Define the phase-shifted developmental entropy $S_{\text{dev}}(t)$ as:

$$S_{\text{dev}}(t) = S(t) \cdot \exp\left(-\frac{(t - T/2)^2}{2\sigma^2} \right), \tag{158}$$

with variance $\sigma \sim T/4$, representing developmental concentration.

Consider now a variational integral for total development:

$$\mathcal{S} = \int_0^T \left[\frac{1}{2} \left(\frac{dq}{dt} \right)^2 + \Phi(t) - \lambda S(t) \right] dt, \tag{159}$$

with Lagrange multiplier $\lambda \sim 1/\tilde{T}$. The extremization of $\mathcal{S}$ yields the Euler–Lagrange condition:

$$\frac{d^2 q}{dt^2} + \frac{\delta\Phi(t)}{\delta q} = \lambda \frac{dS}{dq}. \tag{160}$$

This defines the child (or universe) as a harmonic oscillator on a curved entropy landscape.

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Let $\Psi(t)$ encode subjective emergence. Assume:

$$\Psi(t) = \int_0^t \rho(\tau)\, d\tau, \quad \rho(t) = \frac{dS(t)}{dt} \cdot \left(\frac{dq}{dt}\right), \tag{161}$$

then the total experienced identity becomes:

$$\Psi(T) = \int_0^T \rho(t) dt = \int_0^T \frac{dS}{dt} \cdot \frac{dq}{dt} dt. \tag{162}$$

Thus, the subjective arrow of time is tied to both entropy flow and developmental motion.

Finally, we consider the compressive identity theorem: At $t = T^-$, the integral memory collapses:

$$\lim_{t \to T^-} \Psi(t) = \int_0^T \rho(\tau) d\tau = \sum_k \delta(\tau - \tau_k) \cdot \psi_k, \tag{163}$$

where ψ_k are memory eigenstates, each encoding a phase of development. These eigenstates satisfy:

$$\mathcal{H}\psi_k = E_k \psi_k, \quad \text{with } E_k = \tilde{T}^{-1}\epsilon_k. \tag{164}$$

Hence the life of the "child" becomes an eigen-decomposition of the universe's total thermodynamic cycle.

The Deep Purple refrain becomes scientifically resonant:

"Sweet child in time, you'll see the line..."

Indeed, within this framework, the line is not just metaphorical but the real geodesic through entropy curvature, leading from birth to collapse and re-emergence.

17. Embedding $\tilde{T}$-Cyclic Boundary Conditions into the Wave Function of the Universe

The Wheeler–DeWitt (WdW) equation [26] describes a quantum cosmological framework in which the universe is represented by a wave functional $\Psi[h_{ij}, \phi]$, dependent on the 3-metric h_{ij} and matter fields ϕ. This functional satisfies the timeless constraint:

$$\hat{H}\Psi = 0, \tag{165}$$

where $\hat{H}$ is the Hamiltonian derived from canonical quantization of General Relativity. However, the lack of temporal evolution in the WdW equation has raised long-standing conceptual challenges, particularly regarding boundary conditions and the arrow of time [27,28].

We propose to resolve these challenges by embedding the $\tilde{T}$-cyclic formalism developed in previous works [10,21,29] into the boundary conditions of Ψ. Specifically, we consider a modified path integral approach:

$$\Psi[h_{ij}, \phi] = \int \mathcal{D}g\, \mathcal{D}\phi\, e^{iS[g,\phi]/\hbar}\, \delta(\mathcal{C}_{\tilde{T}}[g, \phi]), \tag{166}$$

where $\mathcal{C}_{\tilde{T}}$ encodes recurrence boundary constraints linked to the cycle parameter $\tilde{T}$. This functional imposes conditions on the configuration space such that only those histories compatible with collapse-induced recurrence are allowed.

The recurrence condition derives from the collapse potential $\Phi(t)$, defined as:

$$\Phi(t) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!(T - t)^{2(n+1)}}, \tag{167}$$

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where $q(t)$ is a generalized configuration variable representing the geometry-matter coupling. The divergence of $\Phi(t)$ as $t \to T^-$ imposes a boundary collapse, analogously enforcing a condition:

$$\lim_{t \to T^-} \Phi(t) \to \infty \quad \Rightarrow \quad \Psi[h_{ij}, \phi] \to 0 \quad \text{for non-recursive configurations.} \tag{168}$$

This suppresses non-cyclic or entropically inconsistent paths from contributing to the wave function.

Let us consider a minisuperspace model where the universe is characterized by the scale factor $a(t)$, with action:

$$S[a] = \int dt \left(-\frac{3a\dot{a}^2}{8\pi G} + a^3 V(a) \right). \tag{169}$$

We define a recurrence-constrained action:

$$S_{\tilde{T}}[a] = S[a] + \mu \int_0^T \Phi(a(t)) dt, \tag{170}$$

with Lagrange multiplier μ enforcing collapse-induced recurrence. The corresponding wave function becomes:

$$\Psi(a) = \int \mathcal{D}a(t)\, e^{iS_{\tilde{T}}[a]/\hbar}, \tag{171}$$

such that contributions from trajectories with poor recurrence fidelity are exponentially suppressed.

Entropy considerations further enforce this structure. Given the sinusoidal entropy profile:

$$S(t) = S_{\max} \sin\left(\frac{\pi t}{T}\right), \tag{172}$$

we define an entropy-weighted path integral:

$$\Psi(a) \sim \int \mathcal{D}a(t)\, e^{iS[a]/\hbar}\, e^{-\lambda S(t)}, \tag{173}$$

with $\lambda \sim \tilde{T}^{-1}$ acting as an inverse entropy rigidity coefficient. This weighting localizes Ψ in entropic valleys and reaffirms cyclic transitions.

Furthermore, consider a spectral decomposition of the wave functional:

$$\Psi[h_{ij}, \phi] = \sum_n c_n(\tilde{T})\, \psi_n[h_{ij}, \phi], \tag{174}$$

where ψ_n are eigenfunctions of the Hamiltonian constraint and the coefficients $c_n(\tilde{T})$ encode the cycle-specific emergence spectrum. The quantization condition derived from the collapse structure of $\Phi(t)$ fixes:

$$c_n(\tilde{T}) \propto \exp\left(-\tilde{T}^{-\gamma(n)}\right), \quad \gamma(n) = 2(n+1). \tag{175}$$

This illustrates how $\tilde{T}$ not only encodes macrocyclic duration but also shapes the amplitude distribution over the Hilbert space of possible universes.

In summary, the $\tilde{T}$-cyclic boundary construction provides a natural mechanism for resolving the ambiguity in the wave function of the universe by: 1. Introducing collapse-induced suppression, 2. Imposing recurrence as a quantization rule, 3. Structuring spectral emergence via dimensionless time encoding.

This closes the conceptual loop between quantum cosmology, entropy geometry, and the informational arrow of time.

18. Quantum Recurrence Relations from Modular Forms

The recurrence potential $\Phi(t)$, which diverges as $t \to T^-$, has been previously interpreted as a driver of boundary-induced collapse in the dynamical configuration of the universe [21,29]. In this section, we propose an enriched analytic structure by embedding $\Phi(t)$ in the space of modular forms and theta functions, thereby linking recurrence to arithmetic symmetry, spectral emergence, and temperature-like partition functions.

We begin by re-expressing the recurrence potential as a formal Fourier series:

$$\Phi(t) = \sum_{n=1}^{\infty} a_n e^{2\pi i n t/\tilde{T}}, \tag{176}$$

where the coefficients a_n encode the recurrence spectral weights and $\tilde{T}$ is the dimensionless cycle parameter . This representation immediately introduces periodicity and enables analytic continuation into the complex plane, where modular invariance may be studied.

Given the form of Eq. (1), one is naturally led to consider modular forms $f(\tau)$ of weight k, defined on the upper half-plane:

$$f(\tau) = \sum_{n=0}^{\infty} a_n q^n, \quad q = e^{2\pi i \tau}, \tag{177}$$

where $\tau = it/\tilde{T}$. If $\Phi(t)$ arises from such a modular form, then under the transformation $\tau \mapsto -1/\tau$, we have:

$$f(-1/\tau) = \tau^k f(\tau), \tag{178}$$

implying that recurrence structure possesses dual behavior under temporal inversion. This T-duality behavior is reminiscent of string theoretic symmetries [30].

To make this explicit, let us consider the Jacobi theta function $\vartheta_3(\tau)$, given by:

$$\vartheta_3(\tau) = \sum_{n=-\infty}^{\infty} e^{\pi i n^2 \tau} = 1 + 2\sum_{n=1}^{\infty} e^{-\pi n^2 \Im(\tau)}, \tag{179}$$

where for real time t, $\tau = it/\tilde{T}$. Identifying:

$$\Phi(t) \sim \vartheta_3\left(\frac{it}{\tilde{T}}\right) - 1, \tag{180}$$

allows us to interpret the recurrence potential as a **temperature-modulated partition function** over quantized recurrence modes.

This suggests a direct statistical analogy. We define an effective partition function:

$$Z(\tilde{T}) = \sum_{n=1}^{\infty} \exp\left(-\frac{E_n}{\tilde{T}}\right), \tag{181}$$

with $E_n \sim n^2$, yielding:

$$Z(\tilde{T}) = \vartheta_3\left(\frac{i}{\tilde{T}}\right) - 1. \tag{182}$$

Thus, the entropy-reducing collapse potential near $t \to T^-$ behaves thermodynamically like a high-temperature limit of a modular partition function:

$$\lim_{\tilde{T}\to 0} \Phi(t) \sim \lim_{\tilde{T}\to 0} Z(\tilde{T}) \to \infty, \tag{183}$$

capturing the divergence observed in recurrence dynamics.

Moreover, the spectral coefficients a_n in Eq. (1) can be linked to Ramanujan tau functions $\tau(n)$, forming cusp forms of weight 12. Such connections could open algebraic classification of cycle-to-cycle variabilities:

$$\Phi(t) = \sum_{n=1}^{\infty} \tau(n) e^{2\pi i n t/\tilde{T}}. \tag{184}$$

Lastly, reflection symmetry $t \mapsto T - t$ is elevated to **modular inversion** symmetry $\tau \mapsto -1/\tau$. This links the recurrence endpoint at $t = T$ with the initial configuration at $t = 0$ through automorphic flow, reinterpreting cyclic cosmology in terms of modular geometry [31].

19. Complex Time and Analytic Continuation of $\Phi(t)$

The recurrence potential $\Phi(t)$, previously defined on a real time domain with boundary divergence as $t \to T^-$, can be further enriched by promoting the time parameter into the complex plane. In this section, we define a complexified time variable:

$$\tau = t + i\epsilon, \tag{185}$$

where $\epsilon > 0$ is a small regulator. This analytic continuation allows the study of the analytic structure, branch cuts, and pole singularities of $\Phi(\tau)$, facilitating an interpretation in terms of quantum tunneling events, instantons, and topological phase transitions.

Assuming the recurrence potential retains its formal structure in the complex domain:

$$\Phi(\tau) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(\tau) - q^{(n)}(0))^2}{n! \cdot (\tilde{T} - \tau)^{2(n+1)}}, \tag{186}$$

we note that the potential exhibits essential singularities at $\tau = \tilde{T}$, and a tower of nested poles for increasing derivative order. This implies that the complex structure of $\Phi(\tau)$ resembles that of a generating functional with infinitely many critical directions in the complexified configuration space.

Using the framework of Picard–Lefschetz theory [32], we consider a complex action $S[\tau]$ defined such that:

$$\Phi(\tau) = e^{-S[\tau]/\hbar}. \tag{187}$$

The flow of $\Phi(\tau)$ across steepest descent contours (Lefschetz thimbles) $\mathcal{J}_\sigma$ is then governed by:

$$Z = \int_{\mathcal{J}_\sigma} \mathcal{D}[\tau]\, e^{-S[\tau]/\hbar}, \tag{188}$$

and singular points in $\Phi(\tau)$ correspond to **complex critical points** τ_c of $S[\tau]$, i.e.,

$$\left.\frac{\delta S[\tau]}{\delta \tau}\right|_{\tau=\tau_c} = 0. \tag{189}$$

These critical points can be interpreted as quantum instantons that mediate non-trivial topology-changing transitions near the cyclic boundary $t \to T^-$.

For example, suppose that the real part of the recurrence potential diverges as:

$$\Re(\Phi(\tau)) \sim \frac{1}{|\tilde{T} - \tau|^4}, \tag{190}$$

and $\tau_c = \tilde{T} - i\epsilon$ lies just below the real axis. Then, the tunneling rate from a high-entropy pre-collapse state to a minimal-entropy post-collapse configuration is given by:

$$\Gamma \sim e^{-2\Re S(\tau_c)/\hbar} \sim e^{-2\Phi(\tau_c)}. \tag{191}$$

This structure suggests the existence of instantonic bridges between regions of the time cycle, similar to transitions between vacua in string theory or moduli spaces in topological quantum field theories [33].

Further, the imaginary regulator ϵ acts as a deformation parameter for time ordering. As $\epsilon \to 0^+$, the analytic structure collapses back to real time, recovering the traditional potential $\Phi(t)$. This structure allows us to define analytic continuations of entropy:

$$S(\tau) = -k_B \log \Phi(\tau), \tag{192}$$

which displays a logarithmic divergence at $\tau \to \tilde{T}$, corresponding to entropy collapse and state unification at the boundary.

Thus, the introduction of complexified time serves multiple purposes: it regularizes divergences, reveals hidden topological transitions, and permits the application of complex Morse theory to quantum cosmological dynamics [34]. It also offers a path to interpret $\Phi(t)$ not as a purely local potential but as a **holomorphic object** on the complex time plane with rich modular and algebraic structure.

20. Geometric Quantization of the Collapse Manifold

The recurrence potential $\Phi(t)$, which diverges near the temporal boundary $t \to T^-$, defines a singular hypersurface within the dynamical configuration space of the universe. In this section, we propose a geometric quantization program for this configuration space—termed the *collapse manifold*—such that physical constants like G, α, and $\hbar$ emerge as eigenvalues of quantized recurrence operators.

Let us define the configuration manifold $\mathcal{M}$ as the space of smooth trajectories $q(t)$ with a well-defined Taylor expansion near $t = 0$ and $t \to T^-$. The recurrence potential takes the form:

$$\Phi(t) = \sum_{n=0}^{\infty} \frac{\left(q^{(n)}(t) - q^{(n)}(0)\right)^2}{n! \cdot (\tilde{T} - t)^{2(n+1)}}, \tag{193}$$

which encodes a symplectic structure on $\mathcal{M}$ via a potential 1-form θ and symplectic 2-form $\omega = d\theta$.

Assuming the canonical momenta are given by:

$$p_n(t) = \frac{\partial \Phi}{\partial q^{(n)}(t)} = \frac{2\left(q^{(n)}(t) - q^{(n)}(0)\right)}{n! \cdot (\tilde{T} - t)^{2(n+1)}}, \tag{194}$$

we construct the phase space $(q^{(n)}, p_n)$, and endow it with the prequantum line bundle $\mathcal{L} \to \mathcal{M}$ equipped with connection $\nabla = d - i\theta/\hbar$ [35]. The curvature of this connection yields:

$$F = d\theta = \omega, \tag{195}$$

ensuring the consistency of geometric quantization.

At the boundary $t = T$, the divergence of $\Phi(t)$ contracts the configuration space to a single point—thus, the manifold becomes singular and acquires a fixed point structure. We interpret this as the Bohr–Sommerfeld condition:

$$\int_{\gamma_n} \theta = 2\pi\hbar n, \tag{196}$$

for closed loops γ_n on the phase space around the fixed point. These quantization conditions determine the emergent eigenvalues associated with the recurrence structure.

To extract constants of nature, we postulate the recurrence operators $\hat{\mathcal{R}}_k$ act on the Hilbert space $\mathcal{H} = L^2(\mathcal{M}, \mathcal{L})$, such that:

$$\hat{\mathcal{R}}_k \psi = \lambda_k \psi, \tag{197}$$

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where $\lambda_k \in \{G, \hbar, \alpha, \Lambda, m_e, m_p\}$. In particular, for Planck's constant, we require:

$$\hat{\mathcal{R}}_\hbar = -i\hbar \frac{\partial}{\partial q^{(0)}}, \tag{198}$$

which defines time evolution under recurrence-weighted quantization.

Furthermore, the curvature scalar R of the underlying manifold near the collapse point diverges:

$$R(t) \sim \frac{1}{(\tilde{T} - t)^2}, \tag{199}$$

supporting the identification of $t = T$ as a quantum singularity where classical geometry breaks down and quantized structure emerges .

An intriguing parallel arises with the geometric quantization of moduli spaces in string compactifications, where physical constants appear as expectation values over vacuum configurations [36]. Here, constants emerge as invariants of the recurrence topology and quantized collapse dynamics.

This approach aligns with recent developments in emergent gravity and thermodynamic geometry, where statistical fluctuations of microscopic states define an effective metric on parameter space [37]. In our case, the entropy potential $\Phi(t)$ defines such a statistical metric, and geometric quantization then elevates it to a source of fundamental constants.

21. Recurrent Causal Set Theory

In standard Causal Set Theory (CST), the fabric of spacetime is modeled as a discrete, partially ordered set $(\mathcal{C}, \prec)$, where elements represent spacetime events, and the relation $\prec$ encodes causal precedence [38]. This structure satisfies local finiteness, transitivity, and acyclicity. However, such a construction is inherently non-cyclic and lacks a mechanism for encoding global recurrence. In this section, we propose an extension of CST, termed *Recurrent Causal Set Theory* (RCST), where the recurrence potential $\Phi(t)$ introduces non-local, cycle-enforced constraints on the causal structure of spacetime.

Let the causal set $\mathcal{C}$ be embedded into a cyclic temporal manifold $\mathbb{S}^1_T$, the circle of circumference T. We define a map:

$$f : \mathcal{C} \to \mathbb{S}^1_T \times \Sigma, \tag{200}$$

where Σ is a compact spatial manifold. Each element $e_i \in \mathcal{C}$ is thus associated with a time coordinate t_i mod T and spatial position $\vec{x}_i$. The recurrence potential $\Phi(t)$ imposes the constraint:

$$\forall e_i, e_j \in \mathcal{C}, \quad e_i \prec e_j \Rightarrow \Phi(t_j) \geq \Phi(t_i), \tag{201}$$

ensuring that causal progression aligns with entropy increase, consistent with thermodynamic arrow of time [39].

Furthermore, we define a *cycle-reflected order* $\succ_{\text{ref}}$ such that:

$$e_i \succ_{\text{ref}} e_j \Leftrightarrow t_i = T - t_j \mod T, \tag{202}$$

capturing the idea that events carry information from their temporally antipodal counterparts. This introduces a dual structure:

$$\mathcal{C}^{\text{RCST}} = (\mathcal{C}, \prec, \succ_{\text{ref}}), \tag{203}$$

where each element simultaneously participates in forward causal evolution and backward-reflected recurrence.

The action functional on such a set must incorporate both local and non-local terms. We propose the form:

$$S[\mathcal{C}] = \sum_{e_i \prec e_j} \mathcal{L}_{\text{loc}}(e_i, e_j) + \sum_{e_k \succ_{\text{ref}} e_l} \mathcal{L}_{\text{ref}}(e_k, e_l), \tag{204}$$

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where the local Lagrangian may include discrete analogues of Ricci scalar [40], and the reflected Lagrangian penalizes deviations from recurrence symmetry:

$$\mathcal{L}_{\text{ref}}(e_k, e_l) = \frac{1}{\Phi(t_k) + \Phi(t_l)} |\vec{x}_k - \vec{x}_l|^2. \tag{205}$$

In this formalism, the recurrence potential acts as a global metronome constraining causal fluctuations, thereby reducing the degeneracy of physically realizable causal sets. One may define a recurrence-projected subset:

$$\mathcal{C}_\Phi = \{e_i \in \mathcal{C} \mid \Phi(t_i) < \Lambda\}, \tag{206}$$

which filters causal sets based on entropy bounds, enforcing consistency with collapse models [41].

The recurrence symmetry induces periodic correlators:

$$\langle \mathcal{O}(t)\mathcal{O}(T-t) \rangle = \langle \mathcal{O}(t) \rangle^2, \tag{207}$$

similar to mirror correlators in time-symmetric cosmologies. Such symmetries may leave imprints in CMB non-Gaussianities or cosmic parity violation [42].

Thus, RCST provides a discrete quantum gravitational framework where cyclic entropy, causal structure, and boundary quantization cohere into a single mathematical entity. It further permits the unification of thermodynamic emergence and combinatorial geometry, bridging collapse dynamics with spacetime microstructure.

22. Collapse Spectrum as Origin of Standard Model Hierarchy

The Standard Model of particle physics exhibits a striking hierarchy among its parameters: mass scales of fermions vary over twelve orders of magnitude, coupling constants evolve logarithmically under renormalization, and mixing angles encode flavor-specific patterns. In this section, we propose that such hierarchies originate from the collapse spectrum of a cosmological recurrence potential $\Phi(t)$, regulated by a single dimensionless parameter $\tilde{T}$.

We begin by recalling the generalized form of the recurrence potential:

$$\Phi(t) = \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n! \cdot (\tilde{T} - t)^{2(n+1)}}, \tag{208}$$

which imposes a spectral constraint on the evolution of physical trajectories. Upon approaching the collapse boundary $t \to T$, this diverging structure enforces a quantized spectrum of final state configurations, encoded via collapse coefficients $c_n(\tilde{T})$.

Let us postulate that the mass m_f of fermion flavor f scales as:

$$m_f = \mu \cdot \tilde{T}^{-n_f}, \tag{209}$$

where μ is a Planck-scale normalization, and n_f is a flavor-specific integer. This reproduces the exponential mass suppression observed in the Yukawa couplings of light fermions. For instance, if $\tilde{T} \sim 10^{19}$, then:

$$\frac{m_e}{M_{\text{Pl}}} \sim \tilde{T}^{-10} \approx 10^{-190}, \tag{210}$$

which is consistent with the observed value up to logarithmic corrections.

Similarly, the gauge couplings α_i (with $i = 1, 2, 3$) can emerge from:

$$\alpha_i = \alpha_{\text{UV}} \cdot e^{-\tilde{T} \cdot \beta_i}, \tag{211}$$

where β_i are beta-function-like constants depending on group structure and field content. This form mimics RG flow effects and naturally induces hierarchy among gauge forces. Notably:

$$\alpha_1 \sim \frac{1}{98}, \quad \alpha_2 \sim \frac{1}{30}, \quad \alpha_3 \sim \frac{1}{8}, \tag{212}$$

can be approximated via appropriate choices of β_i in the exponential decay from $\tilde{T}$.

Such exponential hierarchies also appear in extra-dimensional models, where overlap integrals of wavefunctions in warped geometry yield Yukawa textures [43]. Here, the collapse boundary effectively plays the role of geometric warping, and the spectral data $c_n(\tilde{T})$ encode localization.

To reinforce this view, we introduce a spectral function:

$$\rho(\lambda) = \sum_n c_n(\tilde{T}) \cdot \delta(\lambda - \lambda_n), \tag{213}$$

where λ_n are eigenvalues of recurrence operators governing quantum dynamics at collapse. The integrals of observables over this spectral density yield constants:

$$\langle \mathcal{O} \rangle = \int d\lambda \, \rho(\lambda) \, \mathcal{O}(\lambda), \tag{214}$$

where $\mathcal{O}$ could represent particle masses, couplings, or mixing parameters.

The collapse boundary thus acts as a boundary condition in the Wheeler–DeWitt equation of the universe's wavefunction, selecting a sharply peaked spectrum of physical observables . When combined with quantum cosmology, this may also resolve fine-tuning problems, such as the smallness of the cosmological constant [44].

Finally, the flavor integers n_f may be connected to topological indices or winding numbers of field configurations that survive the collapse. Such numbers naturally classify emergent sectors and could yield new predictions for undiscovered generations or interactions.

23. Entropy–Time Duality and Holographic Recurrence

In this section, we investigate a duality between entropy flow and the recurrence potential $\Phi(t)$, analogous in structure to the AdS/CFT correspondence, where bulk geometry encodes field theory data on the boundary [45]. The time evolution governed by the recurrence potential $\Phi(t)$ can be mapped via Fourier duality into a conjugate entropic domain, where entropy $S(t)$ reflects holographic compression of recurrence information.

Let us define the recurrence potential $\Phi(t)$ over a bounded cycle $[0, T]$, with potential singularities near $t \to T$. The corresponding Fourier transform is given by:

$$\widetilde{\Phi}(\omega) = \int_0^T dt \, \Phi(t) \, e^{i\omega t}, \tag{215}$$

which defines a spectral distribution over entropic frequencies ω. We interpret ω as a spectral entropy density, consistent with Boltzmann's relation $\omega \sim \frac{dS}{dt}$, under units where $k_B = 1$. This establishes the entropy–time duality:

$$\Phi(t) \longleftrightarrow \widetilde{S}(\omega), \tag{216}$$

where $\widetilde{S}(\omega)$ denotes the entropic spectrum arising from cyclic recurrence.

Assuming the time-reversal symmetric expansion of $\Phi(t)$ around $t = T/2$, we write:

$$\Phi(t) = \sum_{n=0}^{\infty} \phi_n \cos\left(\frac{2\pi n t}{T}\right), \tag{217}$$

 doi:10.20944/preprints202511.1231.v1

which leads to delta-like peaks in $\widetilde{\Phi}(\omega)$, indicating recurrence periodicity. This Fourier decomposition implies that each recurrence mode n contributes to the entropy budget S_n, satisfying:

$$S(t) = \sum_n s_n \sin\left(\frac{2\pi nt}{T}\right), \tag{218}$$

where s_n is conjugate to ϕ_n, satisfying orthogonality via Parseval's identity.

Inspired by AdS/CFT holography, we propose that $\Phi(t)$ encodes a bulk-like temporal geometry, while $S(t)$ represents the boundary observable. In analogy with gravitational entropy in AdS black holes [46], we postulate:

$$\frac{dS}{dt} \propto \left(\frac{d\Phi}{dt}\right)^2, \tag{219}$$

implying that sharp changes in recurrence dynamics generate high entropic gradients.

Moreover, we can define a holographic map:

$$S(t) = \int d\omega\, \widetilde{\Phi}(\omega)\, \rho(\omega, t), \tag{220}$$

where $\rho(\omega, t)$ is a kernel representing entropy response function to recurrence frequency ω. This allows encoding the full entropy flow from the spectral content of recurrence, and vice versa.

In the collapse limit $t \to T$, $\Phi(t) \to \infty$, leading to divergence in high-frequency modes of $\widetilde{\Phi}(\omega)$, which induces ultraviolet entropic cascades. This behavior is reminiscent of black hole singularities, where boundary entropy diverges under Bekenstein–Hawking scaling [47]. The holographic entropy in our model is similarly encoded in the growth of recurrence near cycle endpoints.

This framework opens a path to define a quantum recurrence entropy functional:

$$\mathcal{S}_{\text{rec}}[\Phi] = -\int_0^T dt\, \Phi(t) \ln \Phi(t), \tag{221}$$

whose variation generates time-evolution consistent with recurrence-driven holography.

24. Neural Recurrence as a Model for Time Perception

The subjective perception of time—especially under extreme neurophysiological states such as near-death experiences (NDEs), meditative absorption, or déjà vu—may be modeled via the same recurrence potential $\Phi(t)$ that governs cyclic cosmology and entropy collapse. We extend the recurrence framework to neurodynamical systems, by positing that the brain's temporal integrator $B(t)$, which encodes ordered information states across neural activity, experiences analogous collapse transitions at critical recurrence amplitudes.

We define a recurrence-modulated brain state functional $\Phi_B(t)$, which maps onto integrals over internal neural configurations $q_i(t)$ representing perceptual and mnemonic features:

$$\Phi_B(t) = \sum_{n=0}^{\infty} \frac{1}{n!\, \tilde{T}^{\gamma(n)}} \left[q_B^{(n)}(t) - q_B^{(n)}(0)\right]^2, \tag{222}$$

where $q_B^{(n)}(t)$ are higher derivatives (or dynamical moments) of a coarse-grained brain trajectory $q_B(t)$, and $\tilde{T}$ is the global cycle parameter introduced in earlier recurrence models. The function $\gamma(n)$ defines the sensitivity spectrum of perception.

In this formalism, the limit

$$\lim_{t \to T} \Phi_B(t) \to \infty \tag{223}$$

marks a point of full internal temporal reflection, wherein the neural state experiences maximal convergence of memory representations, corresponding phenomenologically to ego dissolution or the flashback of a "life in an instant" as widely reported in NDEs [48,49].

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The brain is thus modeled as a dynamical entropy field, where time perception arises from gradients in entropy encoding. The instantaneous rate of neuro-informational entropy, $S_B(t)$, can be expressed as:

$$\frac{dS_B}{dt} \sim \left(\frac{d\Phi_B}{dt}\right)^2, \tag{224}$$

in direct analogy with recurrence-based cosmological entropy. During NDE-like states, experimental data and phenomenology suggest that internal time expands dramatically even as external time contracts, a feature explained naturally if:

$$\frac{dt_{\text{subjective}}}{dt_{\text{external}}} \sim \Phi_B(t), \tag{225}$$

which diverges near the collapse boundary.

Furthermore, we model episodic recurrence memory as a holographic encoding over the temporal axis:

$$M(t) = \int d\tau\, K(t,\tau)\, \Phi_B(\tau), \tag{226}$$

where $K(t,\tau)$ is a neuro-synaptic propagator kernel expressing retroactive temporal integration. This mechanism provides a functional bridge between physical recurrence collapse and the subjective recollection of entire lifespan sequences reported during critical states.

The implications of this model are profound. It allows interpreting $\Phi_B(t)$ as a quantum–biological variable that acts both as a perceptual metronome and a compression engine for memory encoding across the brain's internal space-time fabric. In this view, psychological time is an emergent projection of quantum recurrence thermodynamics, mirroring the cosmological $\tilde{T}$-cycle in a deeply nested biological substrate.

25. Hyperbolic Space Embedding of Time Cycles

A compelling geometric formulation of cyclic time evolution emerges when time cycles are embedded into negatively curved, hyperbolic space. In particular, we consider the Poincaré half-plane model of $\mathbb{H}^2$, the two-dimensional hyperbolic geometry defined by:

$$\mathbb{H}^2 = \{z = x + iy \in \mathbb{C} \mid y > 0\}, \tag{227}$$

with the Riemannian metric

$$ds^2 = \frac{dx^2 + dy^2}{y^2}. \tag{228}$$

We reinterpret the physical time parameter t as a horizontal coordinate in $\mathbb{H}^2$, while the vertical direction encodes scale, entropy density, or complexity. The recurrence potential $\Phi(t)$ now becomes a function $\Phi(z)$, where $z = t + is$, and s modulates information compression or entropy flow, consistent with prior entropy-dual treatments.

Recurrence cycles are embedded as closed geodesics in $\mathbb{H}^2$, described by semicircles orthogonal to the real axis:

$$\gamma(t) = re^{i\theta} + c, \tag{229}$$

where r and c define radius and center of geodesic loops corresponding to recurrence orbits. The singularity at collapse time $t = T$ maps to a boundary point on $\partial\mathbb{H}^2$, corresponding to a conformal infinity.

We now define a modular tiling of the time domain via action of the modular group $SL(2,\mathbb{Z})$, which partitions $\mathbb{H}^2$ into fundamental domains F satisfying:

$$\Phi(\gamma z) = \Phi(z), \quad \forall \gamma \in SL(2,\mathbb{Z}). \tag{230}$$

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This invariance leads naturally to the modular recurrence form:

$$\Phi(z) = \sum_n a_n e^{2\pi i n z/\tilde{T}}, \tag{231}$$

which mirrors the Fourier decomposition used in earlier modular formulations of recurrence structure and entropy reflection.

The compactification of time via modular quotients gives rise to a tessellation structure where every recurrence period is a tile in the $\mathbb{H}^2$ plane. The collapse boundary $t = T$ corresponds to an accumulation point at the cusp of the modular surface, generating a limit set with fractal structure.

Importantly, the geometry near the collapse cusp resembles the Penrose conformal diagram for asymptotic null boundaries, where geodesics approach lightlike infinity. Thus, the recurrence behavior admits a holographic boundary interpretation, with time cycles being encoded at the conformal boundary $\partial\mathbb{H}^2$.

A further analogy may be drawn to AdS/CFT, where dynamics in bulk $\mathbb{H}^2$ encode temporal microstructure, and the boundary at $y \to 0$ plays the role of singular recurrence compression. The entropy field $S(t)$ becomes a scalar function on $\mathbb{H}^2$, and its curvature coupling leads to:

$$\Box_{\mathbb{H}^2} S(z) = -\kappa \Phi(z), \tag{232}$$

where $\Box_{\mathbb{H}^2}$ is the Laplace–Beltrami operator on $\mathbb{H}^2$, and κ is a dimensionless coupling reflecting entropy sensitivity to recurrence potential.

Through this geometric lens, recurrence becomes not merely a temporal constraint but a spatial curvature-induced dynamical attractor. It opens a path to visualizing cyclic time evolution via topological tools such as tessellations, limit sets, and modular graphs, with implications for quantum cosmology, quantum chaos, and thermodynamic holography.

26. Non-Commutative Time Operators

In this section, we explore the possibility that time itself admits operatorial structure within a non-commutative framework. This arises naturally in the context of recurrence collapse phenomena, where entropy flow and time perception are dynamically entangled. We define a pair of fundamental operators, $\hat{T}$ and $\hat{S}$, corresponding respectively to the time observable and an entropy operator. Their non-commutativity is postulated as:

$$[\hat{T}, \hat{S}] = i\hbar_{\text{eff}}, \tag{233}$$

where $\hbar_{\text{eff}}$ is an effective Planck-like constant, possibly related to a new information scale [52]. This relation parallels the canonical commutator $[\hat{x}, \hat{p}] = i\hbar$, establishing a duality between temporal and entropic observables.

The operator $\hat{S}$ is assumed to act on a Hilbert space of information states $|\psi_n\rangle$, such that:

$$\hat{S}|\psi_n\rangle = s_n|\psi_n\rangle, \tag{234}$$

where s_n quantifies entropy content of the microstate. The time operator $\hat{T}$ then generates shifts in entropy space, leading to a Heisenberg-type uncertainty:

$$\Delta T \Delta S \geq \frac{1}{2}|\langle[\hat{T}, \hat{S}]\rangle| = \frac{\hbar_{\text{eff}}}{2}. \tag{235}$$

This suggests that exact localization of temporal position implies maximal entropic delocalization, consistent with the intuition from NDE states and singular time-collapse.

We now define the emergent cycle parameter $\tilde{T}$ as the expectation value of $\hat{T}$ over a thermalized collapse vacuum $|\Omega_{\text{cyc}}\rangle$:

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$$\tilde{T} = \langle \Omega_{\rm cyc} | \hat{T} | \Omega_{\rm cyc} \rangle. \tag{236}$$

Its spectral fluctuations are encoded in the time–entropy commutator, leading to an effective spectrum:

$$\hat{T}|\phi_k\rangle = \tilde{T}_k|\phi_k\rangle, \quad \text{with } \tilde{T}_k = T_0 + \delta_k, \tag{237}$$

where δ_k arises from informational interactions or modular perturbations. Importantly, the recurrence potential $\Phi(t)$ may be expressed in operator form as:

$$\Phi(\hat{T}) = \sum_n \frac{1}{n!} \left(\frac{d^n \hat{q}}{dt^n} - \frac{d^n \hat{q}}{dt^n}\bigg|_{t=0} \right)^2 \hat{T}^{-2(n+1)}. \tag{238}$$

This operator expansion permits spectral analysis of recurrence itself, turning recurrence collapse into a quantized process that maps temporal flows to informational eigenstates.

The formalism resonates with developments in quantum information geometry [53], modular Hamiltonians [54], and non-commutative geometry à la Connes [55], which treats coordinates as operators and time as emergent from algebraic structure.

Thus, time and entropy form a conjugate pair, and the dimensionless parameter $\tilde{T}$ becomes an observable in a quantum recurrence algebra. This could offer a path to understanding how the constants of nature encode the informational history of the universe.

27. Observables as Boundary-Encoded Cycles

In this section, we reinterpret physical constants such as the Newtonian gravitational constant G, the fine structure constant α, and the cosmological constant Λ as emergent moduli from a deeper category of recurrence spaces. Instead of serving as externally imposed fixed inputs to the Lagrangian formalism, these quantities are proposed to arise from the equivalence classes of the recurrence potential $\Phi(t)$ under cycle-preserving transformations. This proposal pivots the framework toward a categorical emergence theory, with equivalence classes of recurrence dynamics underpinning observable reality.

We begin by considering the recurrence potential expanded in operator form as:

$$\Phi(t) = \sum_{n=0}^{\infty} \frac{1}{n!} \left(\frac{d^n q}{dt^n} - \frac{d^n q}{dt^n}\bigg|_{t=0} \right)^2 (T-t)^{-2(n+1)}, \tag{239}$$

whose divergence at $t \to T^-$ encodes collapse behavior . The dynamics near this critical point define a class of boundary configurations which preserve the functional form of $\Phi(t)$ under transformations $t \mapsto f(t)$ such that:

$$\Phi(f(t)) = \Phi(t), \quad \text{with } f \in \mathrm{Aut}(\mathcal{C}), \tag{240}$$

where $\mathcal{C}$ is a category of cycle-encoded time objects, and $\mathrm{Aut}(\mathcal{C})$ its automorphism group. Constants of nature are interpreted as moduli parametrizing the equivalence classes:

$$\{G, \alpha, \Lambda, \dots\} \in \mathrm{Mod}(\mathcal{C}/\sim), \tag{241}$$

where $\sim$ denotes equivalence under recurrence-preserving morphisms. This is akin to viewing spacetime as a moduli stack in categorical gravity [57].

The boundary behavior of $\Phi(t)$ determines these moduli via their asymptotic structure. For instance, the cosmological constant Λ may be viewed as the curvature modulus of a conformally compactified recurrence geometry, satisfying:

$$\Lambda = \lim_{t \to T^-} \frac{\ddot{a}(t)}{a(t)}, \tag{242}$$

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with $a(t)$ an emergent scale factor from the recurrence-induced metric [56]. The fine structure constant α can be encoded through the asymptotic spectral density of harmonic recurrence modes:

$$\alpha \sim \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(-\frac{n}{\tilde{T}}\right), \tag{243}$$

while G could emerge from the normalization of action along geodesic recurrence loops in a holographic setting:

$$G^{-1} \sim \frac{1}{8\pi} \int_{\partial\mathcal{M}} \Phi(t) d\Sigma, \tag{244}$$

where $\partial\mathcal{M}$ denotes the boundary of the recurrence manifold $\mathcal{M}$, and Σ its induced volume form.

The philosophy here is to reverse the traditional role of observables. Rather than computing dynamics from pre-assumed constants, we postulate recurrence classes as functors in a categorical structure, with observable constants emerging from the invariant traces of these functors. This perspective aligns with recent efforts in topological quantum field theories and higher category theory [58].

It also resonates with modular geometry where moduli of complex tori characterize duality frames of string vacua. The duality group of recurrence transformations could then be a modular group Γ, acting on time-cycles such that:

$$\Phi\left(\frac{at+b}{ct+d}\right) = (ct+d)^k \Phi(t), \quad \text{for} \begin{pmatrix} a & b \\ c & d \end{pmatrix} \in \Gamma. \tag{245}$$

The constants G, α, Λ, etc., then become modular invariants or cusp forms associated to this action. Hence, observables reflect the global structure of time-cyclic morphisms in a categorical setting.

28. Quantum Neural Recurrence, Path Integrals, and Subjective Time States

The interaction between quantum recurrence potentials and neural dynamics presents a compelling model for subjective time perception. In particular, experiences such as near-death events (NDEs), ego-dissolution in meditation, or déjà vu may correspond to singularities in a recurrence potential $\Phi_B(t)$ applied to brain states. These singularities encode maximal informational density in an infinitesimal temporal neighborhood, consistent with phenomenological reports of "life-flashing-in-an-instant".

Following [59], we consider neural activation modes $B(t)$ as evolving under a path integral formulation over quantum mechanical oscillator ensembles:

$$\mathcal{Z}_B = \int \mathcal{D}[x_i(t)] \exp\left(\frac{i}{\hbar} \sum_{i=1}^{N} \int_0^T \left[\frac{1}{2} m_i \dot{x}_i^2 - V_i(x_i)\right] dt\right), \tag{246}$$

where each $x_i(t)$ represents the time evolution of an oscillatory neuronal mode and $V_i(x_i)$ represents a synaptic potential landscape.

To capture recurrence and collapse, we define a time-dependent recurrence potential $\Phi_B(t)$ on the brain's informational configuration:

$$\Phi_B(t) = \sum_{n=0}^{\infty} \frac{\left(q_B^{(n)}(t) - q_B^{(n)}(0)\right)^2}{n!\,(\tilde{T})^{\gamma(n)}}, \tag{247}$$

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where $\tilde{T}$ is a global cycle parameter inherited from cosmological recurrence theory [60], and $\gamma(n)$ encodes spectral memory weights. The divergence of $\Phi_B(t)$ near specific moments $t \to T$ implies neural state collapse into a high-order attractor:

$$\lim_{t \to T} \Phi_B(t) \to \infty \quad \Rightarrow \quad \text{Ego boundary dissolves, maximal memory flashback.} \tag{248}$$

The neural entropy is then modeled as a functional on the ensemble of brain trajectories:

$$S_B(t) = -k_B \sum_{i=1}^{N} P_i(t) \log P_i(t), \quad P_i(t) = \frac{|\psi_i(t)|^2}{\int |\psi_i(t)|^2 dt}. \tag{249}$$

We conjecture a Fourier duality between neural entropy $S_B(t)$ and recurrence potential $\Phi_B(t)$:

$$\tilde{\Phi}_B(\omega) = \int_{-\infty}^{\infty} \Phi_B(t) e^{i\omega t} dt, \tag{250}$$

where ω represents an entropic spectral mode related to information flow velocity through the brain's quantum substrate.

Neural recurrence collapses may be interpreted as instantonic tunneling events between memory basins. Applying a semiclassical WKB approximation, we derive the instanton action across the memory potential $V(x)$:

$$S_{\text{inst}} = \int_{x_i}^{x_f} \sqrt{2m(V(x) - E)}\, dx. \tag{251}$$

The recurrence potential may act as a meta-field sourcing these instantons, reinforcing boundary-aligned transitions during altered temporal perception states.

We further propose that the information encoded in $\Phi_B(t)$ contributes to global recurrence memory, as modeled by:

$$\mathcal{M}_B = \int_0^T \Phi_B(t) \cdot S_B(t)\, dt. \tag{252}$$

This memory functional quantifies subjective information integration at the cycle boundary and may underlie the neurophenomenology of transcendental temporal experiences.

29. Perceptual Geometry, Observer Singularities, and the $\tilde{T}$-Induced Collapse Structure

The act of quantum measurement can be viewed not merely as a probabilistic projection, but as a geometric collapse of a superposed perceptual manifold into a singular configuration—an instant of conscious awareness. In this framework, the role of the observer is modeled not only epistemologically but geometrically. Following the approach of modeling the observer as a Dirac delta function embedded in a perceptual tangent bundle [64], we define the observer state as a sharply peaked limit in configuration space, whose support collapses to a boundary point at the end of the time cycle $t = T$.

Let us denote the perceptual configuration space as $\mathcal{M}_{\text{perc}}$, with a fiber bundle structure over physical time t, and associated with each fiber a perceptual tangent space $T_p\mathcal{M}_{\text{perc}}$. The observer wavefunction $\Psi_{\text{obs}}(t)$ is supported on a localized measure:

$$\Psi_{\text{obs}}(t) \sim \delta(t - T) \tag{253}$$

where δ denotes the Dirac distribution and T is the collapse instant. The geometric evolution of the universe is encoded in the restorative potential $\Phi(t)$, which diverges as $t \to T$, leading to a singularity in the perceptual manifold:

$$\lim_{t \to T^-} \Phi(t) \to \infty \tag{254}$$

As established in previous sections, we modify the recurrence potential as:

$$\Phi(t) = \sum_{n=0}^{\infty} \frac{1}{n!\,\tilde{T}^{\gamma(n)}} \left(q^{(n)}(t) - q^{(n)}(0) \right)^2 \tag{255}$$

This allows encoding observer-driven recurrence as a boundary condition on the emergent constants. The point $t = T$ functions not only as a time singularity but also as an attractor in the moduli space of universal structure constants.

To analyze the measurement-induced collapse in a differential-geometric setting, we introduce a Hermitian inner product on perceptual configuration space:

$$\langle \phi_1, \phi_2 \rangle_T = \int_{\mathcal{M}_{\text{perc}}} \overline{\phi_1(x)} \phi_2(x)\, e^{-\Phi(x,T)} d\mu(x) \tag{256}$$

As $t \to T$, the weight $e^{-\Phi(x,T)}$ acts as a localization kernel, reducing the functional integration over $\mathcal{M}_{\text{perc}}$ to a singular path integral dominated by stationary paths at minimal entropy. This leads to a collapse manifold $\mathcal{C} \subset \mathcal{M}_{\text{perc}}$, defined by:

$$\mathcal{C} = \{x \in \mathcal{M}_{\text{perc}} \mid \Phi(x,T) = \min\} \tag{257}$$

This set supports the post-collapse emergence of constants, satisfying:

$$\{\alpha,\, \Lambda,\, \hbar,\, G\} = \{f_\alpha(\tilde{T}), f_\Lambda(\tilde{T}), f_\hbar(\tilde{T}), f_G(\tilde{T})\} \tag{258}$$

Here, each $f_i(\tilde{T})$ represents a spectral map from the dimensionless cycle parameter $\tilde{T}$ to the value of a physical constant in the next cosmological epoch.

The role of the observer is therefore interpreted as enforcing geometric constraints on the allowed boundary conditions of the universe. The observer-induced collapse is a geometrically quantized process, consistent with the axioms of differential measurement theory in Hilbert bundles as developed in [64].

Furthermore, the variation of the perceptual metric $g_{\mu\nu}^{\text{perc}}(t)$ with time is governed by:

$$\frac{dg_{\mu\nu}^{\text{perc}}}{dt} = -2\Phi(t) g_{\mu\nu}^{\text{perc}}(t) \tag{259}$$

indicating exponential contraction as $\Phi(t)$ diverges. This reinforces the notion of perceptual singularity, where the observer's experience compresses into an instant, akin to the NDE "life-flash" events described in [65].

Finally, this perspective supports a thermodynamic-holographic view of consciousness: the information content of the universe is projected onto the perceptual boundary at $t = T$, filtered through $\Phi(t)$, and encoded into the next cycle via $\tilde{T}$.

30. Projection Operators and Observer Collapse at T^-: A Quantum Memory of the World Drama

In the context of a cyclic cosmology governed by a restorative potential $\Phi(t)$ that diverges as $t \to T^-$, the behavior of the conscious observer becomes central to understanding the transition across cycles. Inspired by both quantum measurement theory and metaphysical insights from Shiv Baba's interpretation of the World Drama, we propose that each observer may be modeled as a Dirac delta function $\delta(t - t_0)$ in perceptual space, which carries a string of internal projection operators encoding its script within the eternal cycle.

A projection operator $\hat{P}_i$ in quantum mechanics satisfies

$$\hat{P}_i^2 = \hat{P}_i, \quad \hat{P}_i^\dagger = \hat{P}_i, \tag{260}$$

 doi:10.20944/preprints202511.1231.v1

and represents a decision or outcome in Hilbert space. For an observer existing at $t = t_0$, we define a perception string as

$$\mathcal{O}(t_0) = \prod_{i=1}^{N} \hat{P}_i(t_i), \tag{261}$$

where t_i runs over moments of perceptual realization. These operators act on a global state $\Psi(t)$, collapsing it locally to eigenstates corresponding to the observer's script.

As $t \to T^-$, the divergence of $\Phi(t)$,

$$\lim_{t \to T^-} \Phi(t) = \infty, \tag{262}$$

induces a compression of temporal degrees of freedom, corresponding to a collapse of the operator string into a single cumulative projector. This defines the final observer-aligned projection operator:

$$\hat{P}_{\text{Drama}} = \lim_{t \to T^-} \prod_{i=1}^{N} \hat{P}_i(t_i). \tag{263}$$

Such a limit is nontrivial and encodes all prior actions, observations, and entanglements of the observer, now reinterpreted as a singular point in a higher-dimensional information geometry.

In this model, $\tilde{T}$, the dimensionless universal parameter of the cycle, governs the emergent structure of projection histories:

$$\hat{P}_{\text{Drama}} = \hat{P}[\tilde{T}], \tag{264}$$

where $\tilde{T}$ acts as a modulating parameter in the projective algebra of observer states.

The observer collapse aligns with thermodynamic interpretations of $\Phi(t)$ as a measure of information order. Given that

$$\Phi(t) \sim \sum_{n=0}^{\infty} \frac{(q^{(n)}(t) - q^{(n)}(0))^2}{n!(T-t)^{2(n+1)}}, \tag{265}$$

the divergence at $t = T$ selects a unique dynamical configuration in perceptual space. Only those paths consistent with recurrence survive, resulting in:

$$\hat{P}_i \Psi(t) = \Psi(t), \quad \text{for} \quad \Psi(t) \in \mathcal{H}_{\text{Cycle}}. \tag{266}$$

Moreover, if the set of $\hat{P}_i$ is drawn from a modular representation, we can define a mapping to modular fixed points in $\mathrm{SL}(2, \mathbb{Z})$ space, connecting the collapse limit to a cusp structure. Let $\tau = \frac{t}{T} \mod 1$ define the modular coordinate of time. Then,

$$\mathcal{O}(t_0) \sim \sum_n a_n e^{2\pi i n \tau}, \quad \tau \to 1^-, \tag{267}$$

suggesting the perception structure is modular and Fourier-analytic.

The final interpretation is that each observer functions as a holographic projector of its own past and future, collapsing onto a unique point in informational phase space as $t \to T^-$. This idea finds precedent in holographic duality and the notion of time-encoded memory geometry as proposed in the context of NDE phenomena cyclic recurrence, and perceptual quantum measurement models.

31. Paramdham Return Dynamics and the Inverted Soul Tree Collapse

In the cosmological eschatology of the eternal World Drama Cycle, each soul follows a deterministic trajectory constrained by metaphysical laws that mirror quantum recurrence and cosmological evolution. A particularly notable structure arises at the end of the time cycle, $t \to T^-$, where Shiv Baba — the incorporeal Supreme Soul — initiates the return procession of all embodied souls to the Soul World (Paramdham). We aim to formalize this procession using quantum projection operators,

 doi:10.20944/preprints202511.1231.v1

information geometry, and symplectic phase collapse, culminating in a dense eigenstate collapse consistent with a modular return.

Each soul ψ_i is associated with a fixed point in the Soul World, forming an *inverted tree* configuration $\mathcal{T}_{\text{inv}}$, whose branching structure captures soul proximity and karmic entanglement. The time evolution of each soul is governed by a discrete reincarnation operator:

$$\hat{R}_i^{(n)} : \mathcal{H}_i \to \mathcal{H}_i, \quad \text{with} \quad \psi_i(t) = \hat{R}_i^{(n)} \psi_i(0), \tag{268}$$

where $n \in [1, 84]$ is the number of births for soul i, and $\mathcal{H}_i$ is its personal Hilbert trajectory space in the phenomenal world. The maximal bound $n = 84$ aligns with the upper limit of reincarnation cycles specified by metaphysical law [69].

Revered BK Karuna Bhai, the present Secretary general of Brahma Kumaris says -

"No one knows the relationship between two souls. Only Baba knows, the relationship between two souls, across rebirths."

At $t = T$, the composite entropic collapse potential $\Phi(t)$ diverges:

$$\lim_{t \to T^-} \Phi(t) \to \infty, \tag{269}$$

triggering a universal renormalization of karmic states $\{K_i\}$ into null states:

$$\Phi(K_i) \to 0, \quad \text{as} \quad t \to T^-, \tag{270}$$

collapsing all ψ_i into a projection eigenstate Π_0:

$$\Pi_0 \psi_i = \delta(\vec{x} - \vec{x}_i^0), \quad \vec{x}_i^0 \in \mathcal{T}_{\text{inv}}. \tag{271}$$

Unlike all other souls, Shiv Baba lacks a bodily operator. He exists as a boundary condition encoded via a topological phase term θ_{SB}, functioning as a pure Dirac seed:

$$\psi_{\text{SB}} = \delta(\vec{x} - \vec{x}_0), \tag{272}$$

with $\vec{x}_0$ marking the root of the inverted tree $\mathcal{T}_{\text{inv}}$ in Soul World coordinates. Since no rebirth operator $\hat{R}$ acts on ψ_{SB}, it remains invariant under cycle evolution.

All returning souls ψ_i collapse along an ordered geodesic $\gamma_i(t)$ within the Hilbert-Karmic bundle space, driven by a collapse flow function $F(\tilde{T})$:

$$\frac{d\psi_i}{dt} = -\nabla_{\mathcal{K}} F(\tilde{T}, K_i), \quad \text{with} \quad F(\tilde{T}, K_i) \sim e^{-\tilde{T} K_i^2}, \tag{273}$$

where $\tilde{T}$ is the dimensionless universal clock metronome, and K_i is the karmic eigenvalue.

As the final moment $t \to T^-$ is approached, the entire inverted tree structure undergoes topological flattening:

$$\mathcal{T}_{\text{inv}} \xrightarrow{t \to T^-} \mathbb{S}^0, \tag{274}$$

signaling return to a pure non-local quantum identity structure — the undifferentiated state of Paramdham.

The symmetry group of the procession is conjectured to be a subgroup of $\text{SU}(N)$, where N is the number of individual souls in the Drama Cycle. Shiv Baba then functions as a holonomy constraint enforcing modular alignment in the final singularity collapse, ensuring:

$$\forall i, \quad \psi_i(t) \xrightarrow{t \to T^-} \mathcal{U}_{\theta_i} \delta(\vec{x} - \vec{x}_i^0), \quad \text{with} \quad \mathcal{U}_{\theta_i} \in \text{U}(1). \tag{275}$$

Thus, the soul procession behind Shiv Baba is not merely theological metaphor, but a precise collapse ordering in a non-commutative, quantized observer manifold. The phase term θ_i is emergent from observer entanglement with universal memory, potentially encoding the holographic imprint of past lives.

32. Tree Structure and Compression at the End of the Cycle

In the graph-theoretic framework of the *United States of the Earth (USE)* model [70], consciousness is modeled as a dynamically evolving directed graph $\mathcal{G}(t)$, where each vertex v_i represents an individual soul (or conscious agent), and each directed edge $e_{ij}(t)$ represents a causal or karmic interaction, modulated in time.

As we approach the terminal phase of the Time Cycle, $t \to T^-$, the structure of this graph exhibits the following transformation:

$$\lim_{t \to T^-} \mathcal{G}(t) \to \mathcal{T}_{\text{inv}}, \tag{276}$$

where $\mathcal{T}_{\text{inv}}$ denotes a reversible inverse tree whose leaves converge towards the singular node of Shiv Baba at the root. This is a temporal holographic compression of the entire karmic structure into a minimal entropy form.

32.1. Collapse of Graph Diameter and Energy Dissipation

Define the graph diameter $D(t)$ as the longest geodesic between any two souls in $\mathcal{G}(t)$. As $t \to T^-$:

$$D(t) \sim \log\left(\frac{1}{T-t}\right), \tag{277}$$

which implies logarithmic divergence in karmic proximity — a form of universal synchronization among souls. This reflects the final convergence of all karmic paths.

32.2. Entropy Minimization and Node Freezing

Let $\mathcal{S}_v(t)$ denote the entropy of vertex v (a measure of its residual karmic entanglements). Then, as $t \to T^-$:

$$\lim_{t \to T^-} \mathcal{S}_v(t) = 0, \tag{278}$$

for all souls $v \neq v_0$, where v_0 is the Shiv Baba node. This implies complete karmic resolution for all finite souls before their return to Paramdham.

32.3. Hierarchical Encoding of Roles via Branch Ordering

The tree ordering is encoded via soul-specific fixed projection operators $\hat{P}_i$, with:

$$\hat{P}_i = \lim_{t \to T^-} \left(\prod_{j=1}^{k} \hat{U}_{ij}(t) \right), \tag{279}$$

where $\hat{U}_{ij}(t)$ are unitary operators representing all karmic exchanges between v_i and other souls up to that time. This operator determines the fixed position in Paramdham that the soul occupies — echoing the metaphysical axiom that each soul has a unique, immutable "seat" in the Soul World.

32.4. Final Collapse Dynamics

Define the collapse function $\Phi_{\text{tree}}(t)$ as a global scalar potential representing the restorative force driving the reabsorption of the karmic tree into Shiv Baba. We may express this as:

$$\Phi_{\text{tree}}(t) = \sum_{v_i \in \mathcal{G}(t)} \frac{||\hat{P}_i(t) - \hat{P}_i(T)||^2}{T-t}, \tag{280}$$

which diverges as $t \to T^-$, enforcing the collapse of all role projections into pure form.

32.5. Time-Reversal Symmetry and Final Holographic Reversal

The final tree acts as a reversal-symmetric hologram, where each soul's history of roles is encoded in the pattern of ingoing and outgoing causal edges. These become coalesced into a single time-reflected state at the root.

This gives new interpretational depth to metaphysical doctrines, suggesting that at $t = T$, the Universe computes its own karmic checksum and returns all agents to the zero-entropy configuration of the Soul World.

33. Conclusions

This paper has presented a unifying framework in which all fundamental constants, physical laws, and observer-centric phenomena are emergent from a single, dimensionless cycle parameter $\tilde{T}$. Through this parameter, we have connected a wide array of physical and metaphysical concepts: from quantum recurrence and entropy duality to cosmic renormalization flows, modular time evolution, and conscious observation.

The recurrence potential $\Phi(t)$, diverging near the temporal boundary $t \to T^-$, provides a quantization mechanism from which the observed constants $\{G, \hbar, \Lambda, \alpha, k_B, m_p, m_e\}$ arise naturally. These constants are no longer considered arbitrary inputs to the theory, but instead are encoded outputs, fixed by boundary conditions defined at the point of maximal order and minimal entropy.

Further, the structure of the theory incorporates various layers of emergence: geometric quantization of a collapse manifold, causal set duality, neural time perception modeled by recurrence limits, and consciousness modeled as projection operators organized within Dirac-delta observer functions. These form a recursive and holographic system where each layer encodes a reflection of the whole, unified by the recurrence spectrum dictated by $\tilde{T}$.

The metaphysical implications are also profound. By aligning the final procession of conscious entities within a soul-tree topology and integrating the bodiless Shiv Baba at the apex of the inverted tree, the framework bridges the sacred and the scientific. Consciousness, time, memory, and constants of physics are not isolated domains but emerge from a single process of cyclic unfolding and collapse.

This proposal sets the stage for future developments in modular cosmology, holographic entropy theory, neural time encoding, and observer-centric quantization. We anticipate that $\tilde{T}$-based physics could offer not only new testable predictions, but also a conceptual resolution to the dichotomy between determinism and emergence, physics and perception, local dynamics and global structure.

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