A New Look at the Anthropic Principle: in Light of Penrose's Cycles of Time

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Abstract

We develop a unified theoretical framework integrating cortical electrophysiology, non-equilibrium thermodynamics, Morse topology, renormalization group scaling, and compact-time cosmology into a single neuro-anthropological model. Assuming a temporally compact spacetime manifold S^1 with Kalpic period T_K, all admissible physical observables satisfy the periodic boundary condition $A(t+T_K) = A(t)$. Embedding cortical dynamics within this topology, we show that baseline electroencephalographic (EEG) rhythms become Fourier-constrained variables whose slow modulation across cosmological epochs constitutes a civilizational order parameter rather than a merely developmental marker.

We construct population-level spectral density functionals and demonstrate that mean dominant frequency $\bar{f}(t)$, spectral entropy $H(t)$, and reticular activating system (RAS) drive $R(t)$ form a coupled nonlinear dynamical system subject to global Kalpic compensation. Stochastic resonance analysis reveals that ultra-slow cosmological forcing can be amplified through noise-assisted phase transitions. Renormalization group treatment establishes scale-dependent flow of cortical coupling constants across Kalpa duration, while Morse-theoretic analysis proves that entropy extrema and neural phase reversals occur in even-numbered pairs on the compact temporal manifold.

Extending to a spatially distributed nonlinear field theory, we formulate a Kalpa-boundary effective action describing seam-localized phase interference. Within this framework, the phenomenology of déjà vu is reinterpreted as inter-cycle neural phase overlap at the compact-time seam, modulated by entropy-slope reversal and

RAS coupling. We prove an Entropy–Memory Duality Theorem showing that integrated entropy production over one Kalpa is globally compensated by integrated memory gradients, preserving informational closure.

Finally, we define a cosmological-scale Kalpa Recurrence Operator acting on civilizational phase space, derive its discrete spectrum, and construct a statistical model predicting epoch-dependent déjà vu frequency as a function of informational complexity. The resulting synthesis proposes that baseline EEG structure, civilizational dynamics, and subjective temporal anomalies are mathematically constrained consequences of compact temporal topology.

Keywords: Compact time cosmology; Kalpa periodicity; EEG baseline modulation; Neuro-anthropology; Fourier-constrained dynamics; Morse theory; Renormalization group; Stochastic resonance; Entropy–memory duality; Déjà vu phase interference; Civilizational phase space; Reticular activating system.

1 Introduction

The present work is motivated by the hypothesis that neurophysiological baselines of human cortical dynamics may not be temporally stationary across cosmological epochs, but instead may evolve under slow periodic boundary conditions imposed by a time-cyclic universe. Cyclic cosmological models, beginning with Tolman's thermodynamic treatment of oscillatory universes [1] and extending to Penrose's conformal cyclic cosmology [2], suggest that large-scale physical parameters may admit recurrence with period T_K. In the subsequent section of this paper, the periodic boundary condition [1, 2] has been expressed as Eq. (15). Here we construct the anthropological and neurodynamic preliminaries necessary to embed cortical electrophysiology into such a framework without re-deriving Eq. (15).

Let the macroscopic state of a human population at cosmological time t be described by a distribution functional $\mathcal{N}(\mathbf{x}, f, t)$, representing density of individuals at spatial coordinate $\mathbf{x}$ exhibiting dominant cortical frequency f. The normalization condition is

$$\int d^3x \int_0^{100} \mathcal{N}(\mathbf{x}, f, t)\, df = N_{\text{tot}}(t), \tag{1}$$

where $N_{\text{tot}}(t)$ is total population. Empirical EEG studies place the physiologically relevant spectrum below 100 Hz [3, 4].

Define the anthropological mean dominant frequency

$$\bar{f}(t) = \frac{1}{N_{\text{tot}}(t)} \int d^3x \int_0^{100} f\, \mathcal{N}(\mathbf{x}, f, t)\, df. \tag{2}$$

In stationary modern populations, awake adult means cluster around $\bar{f} \approx 15$–20 Hz [5]. However, if slow cosmological modulation exists, we may posit

$$\bar{f}(t) = \bar{f}_0 + \Delta f(t), \tag{3}$$

with $\Delta f(t)$ varying on timescale T_K. For $T_K = 5000$ years as assumed in the following section, the dimensionless drift rate becomes

$$\eta = \frac{1}{\bar{f}_0} \frac{d\bar{f}}{dt}, \tag{4}$$

which for Δf amplitude of 10 Hz yields $\eta \sim 10^{-4}$ yr^{-1}, small relative to individual lifespan scales.

At the microscopic level, EEG rhythms emerge from thalamo-cortical circuits [6]. Let $V(\mathbf{r}, t)$ denote cortical field potential. In mean-field approximation, spatially averaged dynamics satisfy

$$\frac{\partial^2 V}{\partial t^2} + 2\gamma \frac{\partial V}{\partial t} + \Omega^2(t) V = \xi(t), \tag{5}$$

where γ is damping, $\Omega(t) = 2\pi f(t)$ is instantaneous angular frequency, and $\xi(t)$ is stochastic drive. The spectral power derived from Eq. (5) is

$$E(f, t) = \frac{S_0}{(f^2 - f(t)^2)^2 + (2\gamma f)^2}, \tag{6}$$

which reproduces Lorentzian peaks observed experimentally [5].

Anthropological phase structure can be quantified via variance of $\bar{f}(t)$,

$$\sigma_f^2(t) = \frac{1}{N_{\text{tot}}(t)} \int d^3x \int_0^{100} (f - \bar{f}(t))^2 \mathcal{N}(\mathbf{x}, f, t)\, df. \tag{7}$$

If epochs correspond to quartiles of T_K, then defining $T_Y = T_K/4$ as in Eq. (**??**) of the subsequent section, one may define epoch averages

$$\langle \bar{f} \rangle_Y = \frac{1}{T_Y} \int_{t_Y}^{t_Y + T_Y} \bar{f}(t)\, dt. \tag{8}$$

Neuroenergetic constraints further impose metabolic scaling. Cortical glucose consumption per neuron is approximately 6×10^{-9} mol/s in active states [7]. If total active neuronal count is $N_n \sim 10^{10}$, then total metabolic rate is

$$M(t) = 6 \times 10^{-9} N_n \frac{f(t)}{f_0} \text{ mol/s}. \tag{9}$$

Variation of $f(t)$ therefore implies proportional modulation of metabolic demand, consistent with Eq. (32).

Information-theoretic structure may be expressed through Shannon entropy of the population frequency distribution,

$$S_{\text{pop}}(t) = -\int d^3x \int_0^{100} \frac{\mathcal{N}(\mathbf{x}, f, t)}{N_{\text{tot}}(t)} \ln\left(\frac{\mathcal{N}(\mathbf{x}, f, t)}{N_{\text{tot}}(t)}\right) df. \tag{10}$$

Extrema of $S_{\text{pop}}(t)$ correspond to maximal dispersion of cognitive styles across frequencies, whereas minima correspond to anthropological coherence. Differentiating Eq. (10) yields

$$\frac{dS_{\text{pop}}}{dt} = -\int d^3x \int_0^{100} \frac{\partial p}{\partial t}(1 + \ln p)\, df, \tag{11}$$

where $p = \mathcal{N}/N_{\text{tot}}$. If p inherits slow periodicity from Eq. (15), then $S_{\text{pop}}(t + T_K) = S_{\text{pop}}(t)$, ensuring cyclic anthropological entropy.

The reticular activating system, experimentally shown to regulate cortical arousal [8], provides physiological constraint linking slow-wave dominance to wakefulness. Let $R(t)$

denote mean RAS firing rate. The joint anthropological state is then characterized by the pair $(\bar{f}(t), R(t))$. Stability analysis of the coupled system

$$\frac{d\bar{f}}{dt} = -\alpha\bar{f} + \beta R, \tag{12}$$

$$\frac{dR}{dt} = -\mu R + \nu\bar{f}, \tag{13}$$

yields eigenvalues

$$\lambda_{\pm} = \frac{-(\alpha+\mu) \pm \sqrt{(\alpha-\mu)^2 + 4\beta\nu}}{2}. \tag{14}$$

Positive real parts of $\lambda_{\pm}$ would signal instability of a given anthropological phase. Parameter regimes may thus define transitions discussed later in Eq. (36).

The Introduction therefore establishes a quantitative bridge between population-level EEG distributions, metabolic scaling, entropy measures, and coupled arousal dynamics, all embedded within periodic cosmological constraints already formalized in Eq. (15). The subsequent section develops the explicit cyclic modulation of synaptic weights and frequency eigenmodes without duplicating the foundational equations presented here.

2 Neuro-anthropology: Brain Waves in a Time Periodic Cosmological Model

The neuro-anthropological hypothesis proposed here is that baseline electrophysiological structure of the human cortex may admit slow cosmological boundary conditions under a time-periodic universe. Let t denote cosmological time and T_K denote the Kalpic period. Cyclic boundary conditions require

$$\Psi(t + T_K) = \Psi(t), \tag{15}$$

where Ψ represents the total state functional of matter-energy-consciousness fields. Such cyclic cosmologies have been studied thermodynamically and conformally [1,2].

Let the EEG power spectral density be $E(f,t)$. Total cortical power is

$$P(t) = \int_0^{100} E(f,t)\, df. \tag{16}$$

Band-limited power is

$$P_i(t) = \int_{f_{i,1}}^{f_{i,2}} E(f,t)\, df, \tag{17}$$

with $i \in \{\delta, \theta, \alpha, \beta, \gamma\}$ as classified in clinical EEG [3,4].

Define normalized spectral probabilities

$$p_i(t) = \frac{P_i(t)}{P(t)}, \tag{18}$$

such that

$$\sum_i p_i(t) = 1. \tag{19}$$

The spectral entropy becomes

$$H(t) = -\sum_i p_i(t) \ln p_i(t). \tag{20}$$

If δ dominance characterizes Golden Age neurophysiology, we impose

$$p_\delta(t_G) \geq 0.6, \tag{21}$$

whereas Iron Age beta dominance requires

$$p_\beta(t_I) \geq 0.5. \tag{22}$$

Let mean cortical frequency be

$$\langle f \rangle(t) = \int_0^{100} f \frac{E(f,t)}{P(t)} df. \tag{23}$$

We model slow cosmological modulation as

$$\langle f \rangle(t) = f_0 + A \cos\left(\frac{2\pi t}{T_K}\right). \tag{24}$$

If $f_0 \approx 18$ Hz and $A \approx 10$ Hz [5], then

$$8 \leq \langle f \rangle(t) \leq 28 \text{ Hz}. \tag{25}$$

Let $T_K = 5000$ years. Then

$$\omega_K = \frac{2\pi}{T_K} \approx 1.26 \times 10^{-3} \text{ yr}^{-1}. \tag{26}$$

Neuronal oscillations arise from thalamo-cortical feedback loops [6]. A linearized Wilson–Cowan system gives

$$\tau_c \frac{dV_c}{dt} = -V_c + w_{cc} V_c - w_{ct} V_t, \tag{27}$$

$$\tau_t \frac{dV_t}{dt} = -V_t + w_{tc} V_c - w_{tt} V_t. \tag{28}$$

The eigenfrequency is

$$f(t) = \frac{1}{2\pi} \sqrt{\frac{w_{cc}(t) w_{tt}(t) - w_{ct}(t) w_{tc}(t)}{\tau_c \tau_t}}. \tag{29}$$

Introduce slow synaptic drift

$$w_{ij}(t) = w_{ij}^0 \left[1 + \epsilon \cos\left(\frac{2\pi t}{T_K}\right)\right]. \tag{30}$$

Substitution into (29) yields first-order modulation

$$f(t) \approx f_0 \left[1 + \frac{\epsilon}{2} \cos\left(\frac{2\pi t}{T_K}\right)\right]. \tag{31}$$

Metabolic coupling obeys

$$CMR(t) = CMR_0 \frac{f(t)}{f_0}, \tag{32}$$

consistent with energetic scaling of cortical rhythms [7].

RAS activation rate $R(t)$ must satisfy

$$R(t) > R_c, \tag{33}$$

for wakefulness [8]. A paradoxical Golden Age state therefore satisfies both (21) and (33).

Cross-frequency coupling becomes

$$C_{\delta\gamma}(t) = \langle A_\gamma(t) \cos(\phi_\delta(t)) \rangle, \tag{34}$$

as observed in integrative cognition [9].

Define anthropological order parameter

$$\Phi(t) = p_\delta(t) - p_\beta(t). \tag{35}$$

Phase transition occurs when

$$\Phi(t_c) = 0. \tag{36}$$

Linear stability near t_c gives

$$\frac{d\Phi}{dt} = \lambda \Phi, \tag{37}$$

where $\lambda \propto \omega_K$.

Thus, cortical electrophysiology may be embedded within the periodic constraint (15). This framework predicts generational drift in baseline EEG statistics measurable across centuries. The model remains falsifiable through large-scale comparative spectral databases.

3 Civilizational Baselines of EEG: Evolutionary Neurospiritual Dynamics, Phase Transitions, and Neuro-Cyclic Cosmology

The central thesis advanced here is that baseline electroencephalographic rhythms are not merely ontogenetic markers, but macroscopic civilizational order parameters evolving across cosmological time. Standard developmental neuroscience treats spectral maturation as a function of age, synaptic pruning, and thalamo-cortical stabilization [3, 5]. However, if cosmological boundary conditions obey the periodic constraint already formalized in Eq. (15), then anthropological ensembles of brains may inherit ultra-slow modulation across epochs.

Let $\mathcal{P}(f,t)$ denote the civilizational spectral density averaged across the entire population, defined as

$$\mathcal{P}(f,t) = \frac{1}{N_{\text{tot}}(t)} \int d^3x\, \mathcal{N}(\mathbf{x}, f, t), \tag{38}$$

where $\mathcal{N}$ was defined previously in Eq. (1). The normalization condition follows from Eq. (39),

$$\int_0^{100} \mathcal{P}(f,t)df = 1. \tag{39}$$

Define the civilizational order parameter

$$\Theta(t) = \int_0^{100} f\, \mathcal{P}(f,t)df, \tag{40}$$

which coincides with $\bar{f}(t)$ in Eq. (2). Under periodic cosmology,

$$\Theta(t + T_K) = \Theta(t). \tag{41}$$

If the amplitude of modulation is $A \approx 10$ Hz as in Eq. (25), then civilizational baseline frequency spans nearly a factor of 3.5 between δ-dominant and β-dominant regimes.

Evolutionary neuroscience characterizes synaptic density $D_s(t)$ across historical time primarily through genetic and environmental adaptation [6]. We extend this to cosmological scaling,

$$D_s(t) = D_0 \left[1 + \epsilon_s \cos\left(\frac{2\pi t}{T_K}\right)\right], \tag{42}$$

with $\epsilon_s \ll 1$. Since oscillatory frequency depends on effective connectivity as in Eq. (29), substitution yields

$$f(t) \approx f_0 \left[1 + \frac{\epsilon_s}{2} \cos\left(\frac{2\pi t}{T_K}\right)\right]. \tag{43}$$

Let $\mathcal{E}(t)$ denote aggregate spiritual coherence defined via inverse entropy relative to Eq. (20),

$$\mathcal{E}(t) = \exp[-H(t)]. \tag{44}$$

Consciousness phase transitions are modeled through the free-energy functional

$$F(\Phi) = a(t)\Phi^2 + b\Phi^4, \tag{45}$$

where $\Phi(t)$ was defined earlier in Eq. (35). Let

$$a(t) = a_0 \left(1 - \frac{t}{T_Y}\right), \tag{46}$$

with $T_Y = T_K/4$ as in Eq. (**??**). Minimization gives

$$\Phi_\pm = \pm\sqrt{-\frac{a(t)}{2b}}. \tag{47}$$

Neuro-cyclic cosmology introduces curvature coupling,

$$\Theta(t) = \Theta_0 + \alpha_R R_c(t), \tag{48}$$

with periodic curvature

$$R_c(t) = R_0 \cos\left(\frac{2\pi t}{T_K}\right). \tag{49}$$

Integrated metabolic expenditure per Kalpa becomes

$$E_K = \int_0^{T_K} M(t)dt, \tag{50}$$

consistent with Eq. (32).

Thus baseline EEG rhythms act as macroscopic thermodynamic variables of civilization, integrating neurobiology, statistical mechanics, and cyclic cosmology [1–3, 5–8].

4 Stochastic Resonance, Renormalization Scaling, and Entropy Production Across Kalpa Cycles

The civilizational modulation of baseline EEG rhythms may be further formalized through stochastic resonance theory, renormalization group scaling, and non-equilibrium entropy production across cosmological cycles. These derivations extend the periodic boundary condition already stated in Eq. (15) and the order parameter formalism introduced previously in Eq. (35).

4.1 Stochastic Resonance in Civilizational Neurodynamics

Consider the mean-field cortical potential $V(t)$ governed by a bistable potential consistent with the free-energy structure defined earlier in Eq. (45). Let the effective Langevin equation be

$$\frac{dV}{dt} = -\frac{\partial U(V,t)}{\partial V} + \sqrt{2D}\,\xi(t), \tag{51}$$

where $\xi(t)$ is Gaussian white noise satisfying

$$\langle \xi(t)\xi(t')\rangle = \delta(t-t'), \tag{52}$$

and D is noise intensity [10].

Let the time-dependent potential be

$$U(V,t) = -\frac{1}{2}a(t)V^2 + \frac{1}{4}bV^4 - \Lambda \cos\left(\frac{2\pi t}{T_K}\right)V, \tag{53}$$

where $a(t)$ follows Eq. (46) and Λ is weak forcing amplitude. The Kramers escape rate between metastable states becomes

$$\Gamma(t) = \Gamma_0 \exp\left[-\frac{\Delta U(t)}{D}\right], \tag{54}$$

where $\Delta U(t)$ is instantaneous barrier height [11]. Stochastic resonance occurs when forcing frequency $\omega_K = 2\pi/T_K$ defined in Eq. (26) matches the noise-induced hopping rate,

$$\Gamma(t) \approx \frac{\omega_K}{2\pi}. \tag{55}$$

Given $T_K = 5000$ yr and $\omega_K \approx 1.26 \times 10^{-3}\,\text{yr}^{-1}$, optimal resonance implies $\Gamma \sim 2 \times 10^{-4}\,\text{yr}^{-1}$. Thus ultra-slow anthropological transitions may be noise-assisted, amplifying weak cosmological modulation through stochastic resonance [10].

The power amplification factor at resonance is

$$G(D) = \frac{\Lambda^2}{4D^2 + (\omega_K - \Gamma)^2}. \tag{56}$$

4.2 Renormalization Group Scaling

EEG activity exhibits scale-free properties across frequency bands [5]. Let the power spectrum follow approximate power-law behavior

$$E(f) \sim f^{-\alpha}, \tag{57}$$

with $\alpha \approx 1$ in resting-state conditions. Define coarse-graining transformation

$$f' = sf, \quad E'(f') = s^{\beta}E(f), \tag{58}$$

where $s > 1$ is scaling factor. Invariance requires

$$E'(f') = (f')^{-\alpha}. \tag{59}$$

Substitution of Eq. (58) into Eq. (59) yields scaling exponent relation

$$\beta = \alpha - 1. \tag{60}$$

The renormalization flow equation for coupling constant g of the quartic term in Eq. (45) is

$$\frac{dg}{d\ln s} = -\epsilon g + 3g^2, \tag{61}$$

with $\epsilon = 4 - d$ for effective dimensionality d [12]. Fixed points satisfy

$$g^* = \frac{\epsilon}{3}. \tag{62}$$

4.3 Entropy Production Across Kalpa Cycles

Non-equilibrium thermodynamics describes entropy production rate as

$$\dot{S}_{\text{prod}} = \int \frac{J^2}{\sigma T} dV, \tag{63}$$

where J is generalized flux and σ conductivity [13]. For cortical dynamics, let $J(t) = -\partial V/\partial t$ using Eq. (51). Averaging over noise gives

$$\langle \dot{S}_{\text{prod}} \rangle = \frac{1}{\sigma T} \left\langle \left(\frac{dV}{dt} \right)^2 \right\rangle . \tag{64}$$

Integrated entropy production per Kalpa is

$$\Delta S_K = \int_0^{T_K} \langle \dot{S}_{\text{prod}} \rangle dt. \tag{65}$$

The combined framework demonstrates that stochastic resonance amplifies ultra-slow cosmological forcing, renormalization scaling modifies critical behavior of consciousness order parameters, and entropy production remains compatible with periodic boundary conditions [1–3, 5, 10, 12, 13].

5 Fourier-Constrained Civilizational Neurodynamics in Compact Time

In a spacetime with compact temporal topology S^1, all admissible dynamical variables must satisfy periodic boundary conditions. The fundamental recurrence constraint has already been formalized in Eq. (15). In such a universe, any observable $A(t)$ admits a Fourier expansion of the form [14–17]

$$A(t) = \sum_{m=0}^{\infty} \left[C_m^{(1)} \cos\left(\frac{2\pi m t}{T_K} \right) + C_m^{(2)} \sin\left(\frac{2\pi m t}{T_K} \right) \right] . \tag{66}$$

Differentiation yields

$$\frac{d^n A}{dt^n} = \sum_{m=0}^{\infty} \left(\frac{2\pi m}{T_K} \right)^n \left[C_m^{(1)} \cos\left(\frac{2\pi m t}{T_K} + \frac{n\pi}{2} \right) + C_m^{(2)} \sin\left(\frac{2\pi m t}{T_K} + \frac{n\pi}{2} \right) \right] . \tag{67}$$

Compactness of time requires

$$\int_0^{T_K} \frac{d^n A}{dt^n} dt = 0, \quad n = 1, 2, 3, \ldots \tag{68}$$

consistent with Eq. (15).

5.1 Civilizational EEG Baseline Expansion

Let $\Theta(t)$ denote the civilizational baseline frequency defined earlier in Eq. (40). Its Fourier representation becomes

$$\Theta(t) = \sum_{m=0}^{\infty} \left[\alpha_m \cos\left(\frac{2\pi m t}{T_K} \right) + \beta_m \sin\left(\frac{2\pi m t}{T_K} \right) \right] . \tag{69}$$

The Kalpic average is

$$\langle \Theta \rangle = \frac{1}{T_K} \int_0^{T_K} \Theta(t) dt = \alpha_0 . \tag{70}$$

Variance across epochs is

$$\sigma_\Theta^2 = \frac{1}{2} \sum_{m=1}^{\infty} (\alpha_m^2 + \beta_m^2). \tag{71}$$

5.2 Infinite Linear Constraints

Evaluation at $t = 0$ produces

$$A^{(n)}(0) = \sum_{m=0}^{\infty} \left(\frac{2\pi m}{T_K} \right)^n \gamma_{m,n}, \tag{72}$$

equivalent to infinite matrix systems [15–17]

$$\sum_{m=1}^{\infty} a_{nm} x_m = y_n. \tag{73}$$

5.3 Dual Periodicity

Physiological EEG rhythms satisfy millisecond periodicity [3, 5]. Full signal becomes

$$V(t) = \sum_{m,n} A_{mn} \cos\left(\frac{2\pi m t}{T_{\text{EEG}}} \right) \cos\left(\frac{2\pi n t}{T_K} \right). \tag{74}$$

5.4 Entropy Recurrence

Spectral entropy defined earlier in Eq. (20) expands as

$$H(t) = \sum_{m=0}^{\infty} h_m \cos\left(\frac{2\pi m t}{T_K} \right). \tag{75}$$

Integral over one cycle gives

$$\int_0^{T_K} \frac{dH}{dt} dt = 0, \tag{76}$$

consistent with Loschmidt-type arguments [18–21].

5.5 Phase Space Closure

Closed neural phase-space trajectory requires [14]

$$\oint_\gamma dq_i = 0, \quad \oint_\gamma dp_i = 0. \tag{77}$$

Identical evolution across cycles demands

$$q_i(t) = q_i(t + T_K), \quad p_i(t) = p_i(t + T_K). \tag{78}$$

5.6 Scaling with Kalpa Duration

Derivative amplitudes scale as

$$A^{(n)}(t) \propto T_K^{-n}. \tag{79}$$

Limit $T_K \to \infty$ gives

$$\lim_{T_K \to \infty} A^{(n)}(t) = 0. \tag{80}$$

5.7 Fourier Cutoffs

Finite observation imposes

$$m_{\mathrm{IR}} \le m \le m_{\mathrm{UV}}, \tag{81}$$

with UV cutoff from discrete spacetime [22].

Thus civilizational EEG baselines are Fourier-constrained dynamical variables on compact time manifolds consistent with infinite-matrix recurrence theory [3, 5, 14–17].

6 Neural Time Reversal and Global Compensation in Compact Temporal Topology

The compact temporal topology S^1 imposes nonlocal constraints on all dynamical variables, as previously expressed through the periodic boundary condition in Eq. (15). In the compact-time formalism developed in [14], the integral identity

$$\int_0^{T_K} A^{(1)}(t)\, dt = 0 \tag{82}$$

holds for any admissible dynamical variable $A(t)$ over one Kalpic period T_K. Equations (10)–(12) of [14] imply the stronger local-global relation

$$\delta A|_{t=\tau} = -\left(\int_0^{\tau-\varepsilon} A^{(1)}(t)\, dt + \int_{\tau+\varepsilon}^{T_K} A^{(1)}(t)\, dt \right), \tag{83}$$

which states that the instantaneous change at $t = \tau$ equals the negative of the total change during the remainder of the cycle. We now apply this constraint to internal neural time modeling.

Let $\Theta(t)$ denote the internal neural time coordinate, defined through instantaneous oscillatory frequency $\omega_{\mathrm{int}}(t)$ as

$$\Theta(t) = \int_0^t \omega_{\mathrm{int}}(s)\, ds. \tag{84}$$

Differentiation gives

$$\frac{d\Theta}{dt} = \omega_{\mathrm{int}}(t). \tag{85}$$

Substituting $A(t) = \Theta(t)$ into Eq. (82) yields

$$\int_0^{T_K} \omega_{\rm int}(t)\, dt = 0, \tag{86}$$

which implies that the net accumulated neural phase over one Kalpa vanishes. Thus internal time cannot exhibit secular drift across the entire cosmological cycle.

Applying Eq. (83) to $\Theta(t)$ gives

$$\delta\Theta(\tau) = -\left(\int_0^{\tau-\varepsilon} \omega_{\rm int}(t)\, dt + \int_{\tau+\varepsilon}^{T_K} \omega_{\rm int}(t)\, dt\right). \tag{87}$$

Using Eq. (86), this becomes

$$\delta\Theta(\tau) = \int_{\tau-\varepsilon}^{\tau+\varepsilon} \omega_{\rm int}(t)\, dt. \tag{88}$$

Therefore the internal phase experiences a finite but compensatory correction at special instants τ where the global compensation occurs.

Consider neural oscillatory activity modeled as

$$V(t) = A_0 \cos\left(\phi(t)\right), \tag{89}$$

where phase evolves according to

$$\frac{d\phi}{dt} = \omega_{\rm int}(t). \tag{90}$$

Compact-time compensation implies

$$\omega_{\rm int}(\tau^+) = -\omega_{\rm int}(\tau^-), \tag{91}$$

leading to

$$\phi(\tau^+) = -\phi(\tau^-). \tag{92}$$

This establishes a neural phase-reversal condition analogous to velocity reversal in compact-time cosmology [14, 19, 20].

We now examine consequences for synaptic plasticity. Let synaptic weight $w(t)$ evolve via Hebbian dynamics

$$\frac{dw}{dt} = \eta\, x(t) y(t), \tag{93}$$

where $x(t)$ and $y(t)$ are pre- and post-synaptic activities [5]. Compact-time constraint gives

$$\int_0^{T_K} \frac{dw}{dt} dt = 0, \tag{94}$$

implying

$$w(\tau^+) - w(\tau^-) = -\left(\int_0^{\tau-\varepsilon} \frac{dw}{dt} dt + \int_{\tau+\varepsilon}^{T_K} \frac{dw}{dt} dt\right). \tag{95}$$

Thus total synaptic drift over one Kalpa is constrained to vanish. Neural plasticity is globally compensated.

Consider spectral entropy $H(t)$ defined previously in Eq. (20). Applying Eq. (82) yields

$$\int_0^{T_K} \frac{dH}{dt} dt = 0, \tag{96}$$

ensuring that entropy growth during one phase of the cycle is balanced by entropy decrease during another, consistent with Loschmidt-type reversibility arguments [18, 19, 21].

Let entropy evolve approximately as

$$H(t) = H_0 \sin\left(\frac{\pi t}{T_K}\right), \tag{97}$$

which satisfies Eq. (96). Differentiation gives

$$\frac{dH}{dt} = \frac{\pi H_0}{T_K} \cos\left(\frac{\pi t}{T_K}\right). \tag{98}$$

At $t = T_K/2$, entropy slope vanishes, representing a neural-cosmological critical point. Energy of neural oscillation is

$$E(t) = \frac{1}{2} A_0^2 \omega_{\text{int}}^2(t). \tag{99}$$

Integrating over one Kalpa gives

$$\int_0^{T_K} E(t) dt = \frac{A_0^2}{2} \int_0^{T_K} \omega_{\text{int}}^2(t) dt. \tag{100}$$

Thus Eq. (83) generates a neural time-reversal theorem: any instantaneous neural adjustment equals the negative of cumulative remainder, ensuring global compensation.

The brain, modeled as a dynamical system embedded within compact temporal topology, cannot sustain irreversible secular drift in phase, synaptic weight, or entropy across the Kalpa. Instead, local monotonic evolution is globally balanced, providing a mathematically rigorous bridge between compact-time cosmology and internal neural time perception [3, 5, 14, 19–21].

7 Explicit Morse-Theoretic Treatment of Neural Critical Points

The compact temporal topology S^1 implies that admissible neural dynamical variables must satisfy periodic boundary conditions as expressed previously in Eq. (15). Morse theory provides a rigorous framework for analyzing critical points of smooth functions defined on compact manifolds [23]. Since internal neural time variables and entropy functions are smooth periodic functions on S^1, Morse-theoretic constraints apply directly.

Let $F(t)$ be a smooth neural functional defined over the compact time manifold $t \in [0, T_K]$ with periodic identification $t \sim t + T_K$. Critical points are defined by

$$\frac{dF}{dt} = 0. \tag{101}$$

Since S^1 is a closed manifold, Morse theory requires that the number of critical points be even [23]. Denote the ordered set of critical times as

$$X = \{t_1, t_2, t_3, \ldots, t_{2N}\}, \tag{102}$$

with $2N$ even.

7.1 Application to Neural Entropy

Let spectral entropy $H(t)$ be defined as in Eq. (20). Critical neural states satisfy

$$\frac{dH}{dt} = 0. \tag{103}$$

Using the compact-time constraint Eq. (96), entropy extrema must occur in pairs over one Kalpa.

Consider sinusoidal entropy model

$$H(t) = H_0 \sin\left(\frac{\pi t}{T_K}\right), \tag{104}$$

whose derivative

$$\frac{dH}{dt} = \frac{\pi H_0}{T_K} \cos\left(\frac{\pi t}{T_K}\right) \tag{105}$$

vanishes at

$$t_c = \frac{T_K}{2}, \frac{3T_K}{2}. \tag{106}$$

Thus exactly two critical points occur in each cycle, satisfying Morse parity.

7.2 Index of Neural Critical Points

At each critical time t_c, define Hessian

$$\mathcal{H}(t_c) = \frac{d^2F}{dt^2}\Big|_{t_c}. \tag{107}$$

For entropy model, second derivative is

$$\frac{d^2H}{dt^2} = -\left(\frac{\pi}{T_K}\right)^2 H_0 \sin\left(\frac{\pi t}{T_K}\right). \tag{108}$$

At $t = 0$, Hessian vanishes, indicating degenerate criticality. At $t = T_K/2$,

$$\frac{d^2H}{dt^2}\Big|_{T_K/2} = -\left(\frac{\pi}{T_K}\right)^2 H_0. \tag{109}$$

Sign of Hessian determines Morse index: positive for minima, negative for maxima.

7.3 Neural Phase Critical Points

Let neural phase $\phi(t)$ satisfy Eq. (90). Define phase functional

$$F(t) = \phi(t). \tag{110}$$

Critical points satisfy

$$\frac{d\phi}{dt} = 0, \tag{111}$$

which from Eq. (85) means $\omega_{\text{int}}(t) = 0$. By Eq. (86), such zeros must occur in pairs over one Kalpa.

7.4 Morse Inequalities and Neural Topology

Let $M = S^1$ denote compact time manifold. Betti numbers satisfy $b_0 = b_1 = 1$ for S^1. Morse inequalities give

$$C_k \geq b_k, \tag{112}$$

where C_k is number of critical points of index k. Thus at least one minimum and one maximum must occur.

For neural entropy and phase functionals, this implies unavoidable reversal events within each Kalpa.

7.5 Fractal Structure of Higher Derivatives

Let $F^{(n)}(t)$ denote n-th derivative. Compact-time constraint requires

$$\int_0^{T_K} F^{(n)}(t)dt = 0, \tag{113}$$

consistent with Eq. (82). Applying Morse theory recursively to $F^{(n)}(t)$ implies even number of zeros for each derivative order. This produces nested critical sets

$$X^{(n)} = \{t_1^{(n)}, t_2^{(n)}, \ldots, t_{2N_n}^{(n)}\}. \tag{114}$$

Thus neural dynamics exhibits hierarchical critical structure.

7.6 Phase-Space Interpretation

Neural microstate (q, p) evolves on compact phase-space trajectory satisfying Eq. (77). Define Lyapunov functional

$$\mathcal{L}(t) = \frac{1}{2}p^2 + U(q). \tag{115}$$

Critical points occur when

$$\frac{d\mathcal{L}}{dt} = 0. \tag{116}$$

By periodicity, total number of such stationary events must be even, enforcing paired neural reversal states.

7.7 Topological Stability

Perturb small deviation δF near critical point. Taylor expansion gives

$$F(t) = F(t_c) + \frac{1}{2}\mathcal{H}(t_c)(t - t_c)^2 + \mathcal{O}((t - t_c)^3). \tag{117}$$

Sign of Hessian ensures stability classification.

Thus Morse theory rigorously demonstrates that neural critical points, entropy extrema, and phase reversals are topologically mandated within compact-time cosmology. Even number of critical events per Kalpa, paired entropy reversals, and hierarchical derivative zeros follow from smooth periodicity on S^1, providing explicit topological structure to neural time modeling [3, 5, 14, 23].

8 Coupled RAS–Entropy–Phase Inversion System

The Reticular Activating System (RAS) regulates global cortical arousal and oscillatory state transitions [8, 24]. Within compact temporal topology S^1, neural phase evolution, spectral entropy, and RAS drive must satisfy periodic constraints previously expressed in Eq. (15) and the integral identity Eq. (82). We construct an explicit coupled dynamical system linking RAS activation $R(t)$, neural phase $\phi(t)$, and entropy $H(t)$.

Let internal phase obey Eq. (90), namely

$$\frac{d\phi}{dt} = \omega_{\text{int}}(t). \tag{118}$$

We model instantaneous frequency as RAS-modulated:

$$\omega_{\text{int}}(t) = \omega_0 + \alpha_R R(t) - \beta_H H(t). \tag{119}$$

Here ω_0 is intrinsic baseline frequency, α_R and β_H are coupling constants with dimensions Hz per unit RAS and Hz per entropy unit respectively.

RAS dynamics are modeled by nonlinear activation equation

$$\frac{dR}{dt} = -\gamma R + \kappa \sin\phi(t), \tag{120}$$

where $\gamma > 0$ is decay rate and κ coupling amplitude. This reflects thalamo-reticular feedback modulation [6, 24].

Spectral entropy evolves according to production-dissipation balance:

$$\frac{dH}{dt} = \eta R^2 - \lambda H, \tag{121}$$

with entropy production coefficient η and dissipation $\lambda > 0$. Equation (121) is consistent with non-equilibrium entropy production discussed in [13].

Substituting Eq. (119) into Eq. (118) gives

$$\frac{d\phi}{dt} = \omega_0 + \alpha_R R(t) - \beta_H H(t). \tag{122}$$

The coupled system (120)–(122) forms a three-dimensional nonlinear dynamical system.

8.1 Compact-Time Constraint

From Eq. (86),

$$\int_0^{T_K} \omega_{\text{int}}(t)dt = 0. \tag{123}$$

Using Eq. (119),

$$\omega_0 T_K + \alpha_R \int_0^{T_K} R(t)dt - \beta_H \int_0^{T_K} H(t)dt = 0. \tag{124}$$

Thus long-term averages satisfy

$$\omega_0 + \alpha_R \langle R \rangle - \beta_H \langle H \rangle = 0. \tag{125}$$

This algebraic condition constrains mean arousal and entropy.

8.2 Linear Stability Analysis

Linearize about equilibrium (R_*, H_*, ϕ_*) with $\phi_* = 0$ without loss of generality. Setting derivatives to zero gives

$$0 = -\gamma R_*, \tag{126}$$

$$0 = \eta R_*^2 - \lambda H_*, \tag{127}$$

$$0 = \omega_0 + \alpha_R R_* - \beta_H H_*. \tag{128}$$

From Eq. (126), $R_* = 0$. Then Eq. (127) gives $H_* = 0$, and Eq. (128) yields $\omega_0 = 0$ for strict equilibrium. Thus nonzero baseline requires oscillatory steady state.

Define perturbations (r, h, φ). Linearized system becomes

$$\dot{r} = -\gamma r + \kappa \varphi, \tag{129}$$

$$\dot{h} = -\lambda h, \tag{130}$$

$$\dot{\varphi} = \alpha_R r - \beta_H h. \tag{131}$$

Matrix form:

$$\frac{d}{dt}\begin{pmatrix} r \\ h \\ \varphi \end{pmatrix} = \begin{pmatrix} -\gamma & 0 & \kappa \\ 0 & -\lambda & 0 \\ \alpha_R & -\beta_H & 0 \end{pmatrix} \begin{pmatrix} r \\ h \\ \varphi \end{pmatrix}. \tag{132}$$

Characteristic polynomial:

$$(\lambda + \lambda_e)\left[\lambda_e^2 + \gamma \lambda_e + \kappa \alpha_R\right] = 0, \tag{133}$$

where λ_e denotes eigenvalues. Stability requires

$$\gamma > 0, \quad \kappa \alpha_R > 0. \tag{134}$$

8.3 Phase Inversion Condition

Compact-time reversal demands Eq. (91),

$$\omega_{\text{int}}(\tau^+) = -\omega_{\text{int}}(\tau^-). \tag{135}$$

Using Eq. (119),

$$\alpha_R[R(\tau^+) + R(\tau^-)] = \beta_H[H(\tau^+) + H(\tau^-)]. \tag{136}$$

Thus RAS and entropy must satisfy instantaneous compensation balance.

8.4 Energy Functional

Define coupled energy functional

$$\mathcal{E}(t) = \frac{1}{2}R^2 + \frac{1}{2}H^2 + \frac{1}{2}\phi^2. \tag{137}$$

Time derivative gives

$$\frac{d\mathcal{E}}{dt} = R\dot{R} + H\dot{H} + \phi\dot{\phi}. \tag{138}$$

Substituting Eqs. (120)–(122) yields

$$\frac{d\mathcal{E}}{dt} = -\gamma R^2 - \lambda H^2 + \kappa R \sin\phi + \phi(\omega_0 + \alpha_R R - \beta_H H). \tag{139}$$

Integrating over T_K and using periodicity gives

$$\int_0^{T_K} \frac{d\mathcal{E}}{dt} dt = 0, \tag{140}$$

consistent with compact-time constraint.

8.5 Bifurcation Structure

Set $\lambda_e = i\Omega$ in Eq. (133). Oscillatory regime occurs when

$$\kappa\alpha_R > 0, \quad \gamma^2 < 4\kappa\alpha_R. \tag{141}$$

Thus Hopf bifurcation threshold is

$$\gamma_c = 2\sqrt{\kappa\alpha_R}. \tag{142}$$

This defines transition between stable fixed point and oscillatory RAS–entropy–phase cycle.

8.6 Global Kalpic Balance

Integrating Eq. (121) over one cycle yields

$$\eta \int_0^{T_K} R^2 dt = \lambda \int_0^{T_K} H dt. \tag{143}$$

Combined with Eq. (124), this provides algebraic closure of Kalpic averages.

The coupled RAS–entropy–phase inversion system therefore constitutes a compact-time constrained nonlinear oscillator linking arousal regulation, entropy production, and neural phase reversal, consistent with electrophysiological principles [5, 6, 8, 13, 14, 24].

9 Nonlinear Field-Theoretic Extension with Spatial RAS–Cortical Coupling, Stochastic Forcing, and Kalpa-Scale Renormalization

We now extend the coupled RAS–entropy–phase inversion system defined by Eqs. (120)–(122) into a spatially extended nonlinear field theory. Let cortical phase, RAS drive, and entropy density be continuous fields $\phi(\mathbf{x}, t)$, $R(\mathbf{x}, t)$, and $H(\mathbf{x}, t)$ defined on spatial manifold $\mathbf{x} \in \mathbb{R}^3$ with compact time $t \in S^1$.

9.1 Field Equations

We generalize Eq. (122) to

$$\partial_t \phi(\mathbf{x}, t) = \omega_0 + \alpha_R R(\mathbf{x}, t) - \beta_H H(\mathbf{x}, t) + D_\phi \nabla^2 \phi - g_\phi \phi^3 + \xi_\phi(\mathbf{x}, t), \tag{144}$$

where D_ϕ is cortical diffusion coefficient, g_ϕ nonlinear self-interaction, and ξ_ϕ Gaussian stochastic forcing satisfying

$$\langle \xi_\phi(\mathbf{x}, t) \xi_\phi(\mathbf{x}', t') \rangle = 2D_\phi^{(n)} \delta(\mathbf{x} - \mathbf{x}') \delta(t - t'). \tag{145}$$

RAS field obeys reaction-diffusion dynamics extending Eq. (120),

$$\partial_t R = -\gamma R + \kappa \sin \phi + D_R \nabla^2 R - g_R R^3 + \xi_R, \tag{146}$$

with analogous noise correlation

$$\langle \xi_R(\mathbf{x}, t) \xi_R(\mathbf{x}', t') \rangle = 2D_R^{(n)} \delta(\mathbf{x} - \mathbf{x}') \delta(t - t'). \tag{147}$$

Entropy density evolves as

$$\partial_t H = \eta R^2 - \lambda H + D_H \nabla^2 H - g_H H^3 + \xi_H, \tag{148}$$

with

$$\langle \xi_H(\mathbf{x}, t) \xi_H(\mathbf{x}', t') \rangle = 2D_H^{(n)} \delta(\mathbf{x} - \mathbf{x}') \delta(t - t'). \tag{149}$$

The stochastic terms encode intrinsic neural fluctuations consistent with cortical variability [5].

9.2 Compact-Time Integral Constraints

Compact-time condition requires spatially integrated frequency satisfy Eq. (86). Thus

$$\int_0^{T_K} dt \int d^3x\, \partial_t \phi(\mathbf{x}, t) = 0. \tag{150}$$

Substituting Eq. (144) gives

$$\omega_0 V T_K + \alpha_R \int_0^{T_K} dt \int d^3x\, R - \beta_H \int_0^{T_K} dt \int d^3x\, H = 0, \tag{151}$$

where V is cortical volume.

9.3 Functional Integral Formulation

Define action functional

$$\mathcal{S} = \int_0^{T_K} dt \int d^3x \left[\frac{1}{2}(\partial_t \phi)^2 + \frac{D_\phi}{2}(\nabla\phi)^2 + \frac{g_\phi}{4}\phi^4 + \frac{\gamma}{2}R^2 + \frac{\lambda}{2}H^2 \right]. \tag{152}$$

Partition function becomes

$$Z = \int \mathcal{D}\phi\, \mathcal{D}R\, \mathcal{D}H\, e^{-\mathcal{S}}. \tag{153}$$

Compact-time periodicity enforces $\phi(\mathbf{x}, 0) = \phi(\mathbf{x}, T_K)$ and similarly for R, H.

9.4 Renormalization Group Analysis

Introduce coarse-graining transformation

$$\mathbf{x}' = s\mathbf{x}, \quad t' = s^z t, \tag{154}$$

with dynamic exponent z. Field rescaling:

$$\phi'(\mathbf{x}', t') = s^{\chi_\phi}\phi(\mathbf{x}, t). \tag{155}$$

Quartic coupling g_ϕ flows as

$$\frac{dg_\phi}{d\ln s} = (4 - d - z)g_\phi - Cg_\phi^2, \tag{156}$$

with $C > 0$ constant from one-loop diagram [12].

Fixed point occurs when

$$g_\phi^* = \frac{4 - d - z}{C}. \tag{157}$$

For $d = 3$, $z = 2$, $g_\phi^* = \frac{-1}{C}$ indicating infrared-stable trivial fixed point unless nonlinear coupling strong.

Kalpa-scale renormalization integrates over entire temporal circle. Define dimensionless coupling

$$\tilde{g}_\phi = g_\phi T_K^{(4-d-z)/z}. \tag{158}$$

Long-period limit $T_K \to \infty$ drives $\tilde{g}_\phi \to 0$, recovering frozen-universe limit consistent with Eq. (80).

9.5 Stochastic Phase Inversion

Noise-averaged phase obeys Fokker–Planck equation

$$\partial_t P(\phi, t) = -\partial_\phi \left[(\omega_0 + \alpha_R R - \beta_H H)P\right] + D_\phi^{(n)} \partial_\phi^2 P. \tag{159}$$

Stationary solution under compact-time constraint satisfies

$$\int_0^{T_K} \partial_t P \, dt = 0. \tag{160}$$

Thus probability current reverses sign at Kalpic midpoint, realizing stochastic phase inversion.

9.6 Entropy Production Functional

Define entropy production density

$$\sigma(\mathbf{x}, t) = \frac{(\partial_t H)^2}{\lambda T}. \tag{161}$$

Integrated production per Kalpa:

$$\Delta S_K = \int_0^{T_K} dt \int d^3x \, \sigma(\mathbf{x}, t). \tag{162}$$

Periodic boundary conditions ensure ΔS_K finite and globally compensated.

The fully nonlinear field-theoretic formulation therefore unifies spatial RAS-cortical coupling, stochastic neural forcing, and Kalpa-scale renormalization flow within compact temporal topology, extending the deterministic system of Eqs. (120)–(122) into a statistical field theory of neural phase inversion [5, 12–14, 24].

10 Déjà Vu as Kalpa-Seam Neural Phase Interference

Within the compact temporal topology S^1 previously imposed through the periodicity condition

$$A(t + T_K) = A(t), \tag{163}$$

all admissible physical observables admit a Fourier representation over one Kalpa T_K as established in the Fourier-constrained formulation of periodic time [14]. Thus any neural field observable $X(t)$ satisfies

$$X(t) = \sum_{n=-\infty}^{\infty} c_n e^{i\omega_n t}, \qquad \omega_n = \frac{2\pi n}{T_K}. \tag{164}$$

We now specialize to the cortical phase field $\phi(\mathbf{x}, t)$ introduced earlier in Eq. (144). Compactness requires

$$\phi(\mathbf{x}, 0) = \phi(\mathbf{x}, T_K), \tag{165}$$

which enforces closure of neural phase trajectories across Kalpic boundaries.

10.1 Kalpa-Seam Matching Condition

Let the Kalpa seam be defined at $t = 0 \sim T_K$. Define left and right limits

$$\phi^-(\mathbf{x}) = \lim_{\epsilon \to 0^+} \phi(\mathbf{x}, T_K - \epsilon), \qquad \phi^+(\mathbf{x}) = \lim_{\epsilon \to 0^+} \phi(\mathbf{x}, \epsilon). \tag{166}$$

Exact periodicity implies

$$\phi^+(\mathbf{x}) = \phi^-(\mathbf{x}). \tag{167}$$

However, stochastic forcing terms defined in Eqs. (145)–(149) introduce microscopic fluctuations of order $\delta\phi$, so that operationally

$$\phi^+(\mathbf{x}) = \phi^-(\mathbf{x}) + \delta\phi(\mathbf{x}). \tag{168}$$

The Kalpa-seam deviation field $\delta\phi$ is therefore defined by

$$\delta\phi(\mathbf{x}) = \phi^+(\mathbf{x}) - \phi^-(\mathbf{x}). \tag{169}$$

10.2 Phase Overlap Functional

We define the inter-Kalpa phase overlap functional

$$\mathcal{O}(t) = \int d^3x \, \phi_K(\mathbf{x}, t)\phi_{K-1}(\mathbf{x}, t). \tag{170}$$

Using Fourier decomposition Eq. (164), we obtain

$$\mathcal{O}(t) = \sum_{n,m} c_n^{(K)} c_m^{(K-1)} \int d^3x \, e^{i(\omega_n + \omega_m)t}. \tag{171}$$

Orthogonality of modes gives

$$\mathcal{O}(t) = V \sum_n c_n^{(K)} c_{-n}^{(K-1)}, \tag{172}$$

where V is cortical volume.

Déjà vu corresponds to the condition

$$\mathcal{O}(t) > \mathcal{O}_c, \tag{173}$$

for some phenomenological threshold $\mathcal{O}_c$ linked to familiarity activation [25, 26].

10.3 Entropy-Slope Reversal Coupling

From the entropy evolution equation Eq. (148) and the Kalpic compensation relation Eq. (96), entropy derivative must reverse sign within the cycle. Define entropy slope

$$\Sigma(t) = \frac{dH}{dt}. \tag{174}$$

Near a seam-adjacent critical point $t = \tau$ satisfying

$$\Sigma(\tau) = 0, \tag{175}$$

we expand

$$\Sigma(t) = \Sigma'(\tau)(t - \tau) + \mathcal{O}((t - \tau)^2). \tag{176}$$

If $\Sigma'(\tau) < 0$, directional predictive coding signals reverse sign, altering familiarity classification [27]. We therefore couple entropy slope to phase deviation via

$$\partial_t \delta\phi = -\kappa_\Sigma \Sigma(t)\delta\phi. \tag{177}$$

10.4 Attractor Basin Re-Entry

Neural state vector $\Gamma(t)$ evolves in phase space under

$$\frac{d\Gamma}{dt} = F(\Gamma), \tag{178}$$

consistent with earlier dynamical formalism. Compactness implies closed trajectory

$$\Gamma(T_K) = \Gamma(0). \tag{179}$$

Let basin distance across seam be

$$D = \|\Gamma^+ - \Gamma^-\|. \tag{180}$$

Déjà vu arises when

$$D < \epsilon_c, \tag{181}$$

so that state re-enters identical attractor geometry [5].

10.5 Probability of Déjà Vu

Assuming Gaussian distribution of seam fluctuations,

$$P(\delta\phi) \propto \exp\left(-\frac{1}{2\sigma^2}\int d^3x\, \delta\phi^2\right). \tag{182}$$

Probability of overlap exceeding threshold becomes

$$P(\mathcal{O} > \mathcal{O}_c) = \int_{\mathcal{O}>\mathcal{O}_c} \mathcal{D}\delta\phi\, P(\delta\phi). \tag{183}$$

Evaluating Gaussian integral yields

$$P(\mathcal{O} > \mathcal{O}_c) \approx \exp\left(-\frac{\mathcal{O}_c^2}{2\sigma^2 V}\right). \tag{184}$$

10.6 RAS Coupling

Using RAS field dynamics Eq. (146), we introduce seam perturbation source

$$\partial_t R|_0 = \partial_t R|_{T_K} + \eta_{seam}. \tag{185}$$

Coupled phase-RAS seam equation becomes

$$\partial_t\phi = \omega_0 + \alpha_R R - \beta_H H + \chi\delta(t)\delta\phi. \tag{186}$$

Dirac delta term localizes interference at Kalpa seam.

10.7 Full Kalpa-Seam Field Equation

Combining previous relations, the seam-modified nonlinear phase equation becomes

$$\partial_t\phi = \omega_0 + \alpha_R R - \beta_H H + D_\phi\nabla^2\phi - g_\phi\phi^3 - \kappa_\Sigma\Sigma(t)\delta\phi + \xi_\phi + \chi\delta(t)\delta\phi. \tag{187}$$

This equation defines déjà vu as a localized Kalpa-boundary interference phenomenon.

10.8 Interpretation

Within this framework, déjà vu is neither reincarnational memory nor block-universe access, but a dynamical artifact of Fourier-constrained compact time. It arises when inter-cycle phase overlap functional Eq. (170) exceeds threshold due to seam fluctuation field $\delta\phi$. Entropy-slope reversal and RAS coupling modulate perceptual classification, producing conscious recognition without causal memory trace.

Thus, déjà vu becomes a necessary consequence of compact temporal topology embedded within nonlinear neural field dynamics [5, 14, 25–27].

11 Renormalized Kalpa-Boundary Dynamics, Morse Classification, Entropy–Memory Duality, and Civilizational Statistics of Déjà Vu

We extend the seam-interference formulation defined in Eq. (187) into a fully renormalized boundary effective theory on compact temporal manifold S^1. All fields satisfy global periodicity Eq. (163) and Fourier decomposition Eq. (164).

11.1 Kalpa-Boundary Effective Action

Let ϕ, R, H denote cortical phase, RAS field, and entropy density respectively. Define bulk action from Eq. (152) as $\mathcal{S}_{bulk}$. We introduce a boundary-localized Kalpa seam term at $t = 0$:

$$\mathcal{S}_{seam} = \int d^3x \left[\frac{\mu}{2}\delta\phi^2 + \lambda_{RH} R\delta\phi - \lambda_H H\delta\phi\right]_{t=0}. \tag{188}$$

Total effective action becomes

$$\mathcal{S}_{eff} = \mathcal{S}_{bulk} + \mathcal{S}_{seam}. \tag{189}$$

Partition function generalizes Eq. (153):

$$Z_K = \int \mathcal{D}\phi\mathcal{D}R\mathcal{D}H \exp(-\mathcal{S}_{eff}). \tag{190}$$

Integrating out short-wavelength modes under RG scaling Eq. (154) yields flow equation for seam coupling μ:

$$\frac{d\mu}{d\ln s} = (1-d)\mu - C_\mu g_\phi \mu, \tag{191}$$

where $d = 3$ spatial dimension and $C_\mu > 0$ loop constant [12]. Fixed point occurs at

$$\mu^* = 0, \tag{192}$$

indicating marginal stability of seam fluctuations at long scales.
Renormalized overlap functional becomes

$$\mathcal{O}_R = Z_\phi \mathcal{O}, \tag{193}$$

where Z_ϕ is wavefunction renormalization constant.

11.2 Morse-Theoretic Classification of Seam Critical Points

Let seam functional be

$$\mathcal{F}[\phi] = \int d^3x \, \frac{\mu}{2} \delta\phi^2. \tag{194}$$

Critical seam configurations satisfy

$$\frac{\delta \mathcal{F}}{\delta \phi} = 0. \tag{195}$$

Thus

$$\delta\phi = 0. \tag{196}$$

Second variation yields Hessian

$$\mathcal{H}_{ij} = \frac{\delta^2 \mathcal{F}}{\delta\phi_i \delta\phi_j} = \mu \delta_{ij}. \tag{197}$$

Morse index is number of negative eigenvalues of $\mathcal{H}$ [23]. If $\mu > 0$, seam is stable minimum. If $\mu < 0$, seam is unstable saddle with index equal to dimension of cortical mode space.

Define déjà vu intensity parameter

$$I_{DV} = \int d^3x \, \delta\phi^2. \tag{198}$$

Using Gaussian measure Eq. (182), expected intensity becomes

$$\langle I_{DV} \rangle = \sigma^2 V. \tag{199}$$

Morse classification implies that intensity peaks at saddle-type seam critical points, corresponding to maximal eigenvalue spread.

11.3 Entropy–Memory Duality Theorem

Let memory encoding field $M(t)$ be functional of phase correlations:

$$M(t) = \int d^3x \, \phi(\mathbf{x}, t)\phi(\mathbf{x}, t - \tau). \tag{200}$$

Entropy production defined earlier in Eq. (161). We define dual functional

$$\mathcal{D}(t) = H(t) + \alpha M(t). \tag{201}$$

Differentiating and integrating over Kalpa gives

$$\int_0^{T_K} dt \, \frac{d\mathcal{D}}{dt} = 0. \tag{202}$$

Using Eq. (96), we obtain duality relation

$$\int_0^{T_K} dt \, \frac{dH}{dt} = -\alpha \int_0^{T_K} dt \, \frac{dM}{dt}. \tag{203}$$

Entropy–Memory Duality Theorem: On compact time manifold S^1, integrated entropy production over a Kalpa is exactly compensated by integrated memory gradient, preserving global informational balance.

11.4 Civilizational Statistical Model

Let civilizational epoch parameter be E. Define seam fluctuation variance dependent on socio-technological complexity:

$$\sigma^2(E) = \sigma_0^2 e^{\beta E}. \tag{204}$$

From probability estimate Eq. (184), frequency per capita becomes

$$f_{DV}(E) = f_0 \exp\left(-\frac{\mathcal{O}_c^2}{2\sigma_0^2 V} e^{-\beta E}\right). \tag{205}$$

Thus advanced epochs with larger $\sigma^2(E)$ exhibit increased déjà vu frequency.

Assuming population size $N(E)$, total events per epoch:

$$\mathcal{N}_{DV}(E) = N(E) f_{DV}(E). \tag{206}$$

Differentiating with respect to E gives growth rate

$$\frac{d\mathcal{N}_{DV}}{dE} = \mathcal{N}_{DV}\left(\frac{1}{N}\frac{dN}{dE} + \frac{\beta \mathcal{O}_c^2}{2\sigma_0^2 V} e^{-\beta E}\right). \tag{207}$$

This predicts non-linear growth in reported déjà vu frequency with technological and informational density.

11.5 Unified Interpretation

The renormalized Kalpa-boundary effective action Eq. (189) governs seam interference. Morse-theoretic classification Eq. (197) determines stability and intensity. Entropy–memory duality Eq. (203) ensures global informational conservation. Statistical epoch model Eq. (205) connects cosmological compact time with sociocultural evolution.

Thus déjà vu emerges as a renormalized seam-critical phenomenon within Fourier-periodic cosmology, embedded in nonlinear neural field theory [2, 5, 12, 14, 23, 25–27].

12 A Cosmological-Scale Kalpa Recurrence Operator Acting on Civilizational Phase Space

The compact temporal topology S^1 enforces the global periodicity condition

$$\mathcal{X}(t + T_K) = \mathcal{X}(t), \tag{208}$$

for every admissible cosmological observable $\mathcal{X}(t)$ over one Kalpa of duration T_K as formulated in the Fourier-constrained periodic time model [14]. Civilizational evolution, being embedded within the physical universe, must therefore admit a representation compatible with Eq. (208).

12.1 Civilizational Phase Space

Let civilizational macrostate be represented by vector

$$\mathbf{C}(t) = \big(E(t), S(t), I(t), \Pi(t), \Phi(t)\big), \tag{209}$$

where E denotes energy consumption density, S informational entropy production rate, I technological complexity, Π population density, and Φ collective neural phase coherence measure. The civilizational phase space is defined as manifold

$$\mathcal{M}_C \subset \mathbb{R}^5. \tag{210}$$

Dynamics are governed by nonlinear flow

$$\frac{d\mathbf{C}}{dt} = \mathbf{F}(\mathbf{C}, t), \tag{211}$$

where $\mathbf{F}$ is smooth vector field.

Compact time implies closed orbit condition

$$\mathbf{C}(T_K) = \mathbf{C}(0). \tag{212}$$

12.2 Definition of the Kalpa Recurrence Operator

We define the Kalpa Recurrence Operator $\hat{\mathcal{R}}_K$ acting on civilizational state by

$$\hat{\mathcal{R}}_K \mathbf{C}(t) = \mathbf{C}(t + T_K). \tag{213}$$

Using Eq. (208),

$$\hat{\mathcal{R}}_K \mathbf{C}(t) = \mathbf{C}(t). \tag{214}$$

Fourier expansion of each component gives

$$C_i(t) = \sum_{n=-\infty}^{\infty} a_{i,n} e^{i\omega_n t}, \qquad \omega_n = \frac{2\pi n}{T_K}. \tag{215}$$

Operator action in frequency space becomes

$$\hat{\mathcal{R}}_K a_{i,n} = e^{i\omega_n T_K} a_{i,n} = a_{i,n}. \tag{216}$$

12.3 Recurrence Generator and Spectrum

Define infinitesimal generator $\hat{H}_C$ such that

$$\hat{\mathcal{R}}_K = e^{T_K \hat{H}_C}. \tag{217}$$

From Eq. (214),

$$e^{T_K \hat{H}_C} = \mathbf{1}. \tag{218}$$

Thus eigenvalues λ_j satisfy

$$e^{T_K \lambda_j} = 1, \tag{219}$$

implying

$$\lambda_j = i\frac{2\pi n_j}{T_K}. \tag{220}$$

12.4 Entropy Compatibility

Let cosmological entropy be $S_{cos}(t)$. Compactness requires

$$\int_0^{T_K} \frac{dS_{cos}}{dt} dt = 0. \tag{221}$$

Define civilizational entropy ratio

$$\eta_C(t) = \frac{S(t)}{S_{cos}(t)}. \tag{222}$$

12.5 Neural Coherence Recurrence

Let collective neural coherence $\Phi(t)$ be

$$\Phi(t) = \frac{1}{N} \sum_{j=1}^{N} e^{i\theta_j(t)}. \tag{223}$$

Recurrence implies

$$\Phi(t + T_K) = \Phi(t). \tag{224}$$

12.6 Spectral Recurrence Density

Define spectral density

$$\rho(\omega) = \sum_{n=-\infty}^{\infty} \delta\left(\omega - \frac{2\pi n}{T_K}\right). \tag{225}$$

12.7 Recurrence Index

Define recurrence index

$$\mathcal{I}_R = \frac{1}{T_K} \int_0^{T_K} dt\, \|\mathbf{C}(t)\|^2. \tag{226}$$

Thus civilizational evolution is harmonically constrained within compact-time cosmology [2, 12, 14, 28].

13 Conclusion

The present work has developed a unified neuro-anthropological framework in which cortical electrophysiology, non-equilibrium thermodynamics, nonlinear dynamical systems, topology, renormalization theory, and compact-time cosmology are treated within a single mathematical structure. Beginning from the periodic boundary condition

$$A(t + T_K) = A(t), \tag{227}$$

imposed by a temporally compact manifold S^1, we embedded population-level electroencephalographic (EEG) observables into a Fourier-constrained cosmological model. Within this construction, baseline neural rhythms are not interpreted solely as developmental or age-dependent markers, but as macroscopic civilizational order parameters evolving under ultra-slow cosmological boundary conditions.

We formalized anthropological spectral distributions $N(x, f, t)$ and demonstrated that the mean dominant frequency $\bar{f}(t)$, spectral entropy $H(t)$, and metabolic demand $M(t)$ can be consistently modulated by Kalpic periodicity without violating established neurophysiological constraints. The introduction of slow synaptic drift and Wilson–Cowan–type coupled dynamics showed that oscillatory eigenfrequencies admit controlled cosmological perturbations while remaining compatible with empirical EEG bandwidth limits. The reticular activating system (RAS) was incorporated as a regulatory variable, leading to a coupled RAS–entropy–phase inversion system whose stability criteria define transitions between anthropological epochs.

Extending the analysis, we constructed a nonlinear stochastic field theory for cortical phase $\phi(x, t)$, RAS drive $R(x, t)$, and entropy density $H(x, t)$ on a spatial manifold with compact temporal topology. Renormalization group analysis demonstrated that Kalpa-scale periodicity imposes discrete spectral constraints on admissible modes, while Morse theory proved that entropy extrema and phase-reversal events must occur in paired critical sets on S^1. These topological constraints eliminate the possibility of secular drift across a full cosmological cycle, enforcing global compensation of phase, entropy production, and synaptic modification.

Within this compact-time framework, the phenomenology of déjà vu was reinterpreted as Kalpa-seam neural phase interference. We showed that stochastic seam fluctuations generate an inter-cycle phase overlap functional whose magnitude determines familiarity without causal memory trace. The renormalized seam effective action and associated Morse classification provide a mathematically consistent mechanism for transient experiential anomalies arising from compact temporal topology. The Entropy–Memory Duality Theorem established that integrated entropy production over one Kalpa is globally compensated by integrated memory gradients, preserving informational closure across the cycle.

At the macroscopic scale, we introduced a cosmological Kalpa Recurrence Operator acting on civilizational phase space and derived its discrete spectrum. This operator formalism demonstrates that civilizational evolution is harmonically constrained within compact-time cosmology, implying recurrence not merely of physical configurations but of collective neurodynamic baselines. A statistical model linking informational complexity to déjà vu frequency suggests that experiential anomalies may scale with sociotechnological density, providing a potentially falsifiable empirical interface.

The synthesis proposed here does not replace established neuroscience or cosmology; rather, it embeds them within a broader topological context in which global temporal compactness constrains local dynamical processes. If compact time is a valid description of cosmological structure, then neural oscillations, entropy flows, and civilizational trajectories are necessarily Fourier-quantized and globally compensated. Conversely, if long-term EEG baselines exhibit measurable ultra-slow drift incompatible with periodic boundary conditions, the compact-time hypothesis would be empirically challenged.

In summary, the framework advanced in this manuscript proposes that baseline EEG rhythms, civilizational phase structure, and certain subjective temporal phenomena are mathematically consistent consequences of compact temporal topology. This work establishes a quantitative bridge between cosmology and neurophysiology, opening avenues for empirical testing through large-scale spectral databases, longitudinal anthropological analysis, and refined dynamical modeling of cortical field activity.

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