The Universe as a Cosmic Oscillator

August 20, 2025

Abstract

A new perspective on the grand cosmic narrative, this paper explores Sir Roger Penrose's theory of Conformal Cyclic Cosmology (CCC) through the elegant and familiar lens of Simple Harmonic Motion (SHM). We propose a model where the universe's repeated cycles of birth and destruction can be visualized as a higher-dimensional sphere passing through our three-dimensional reality, with its appearance and disappearance governed by the simple physics of an oscillating system.

1 The Grand Narrative of the Cosmic Aeon

Sir Roger Penrose's Conformal Cyclic Cosmology (CCC) presents a radical and elegant alternative to the standard Big Bang model, which, while successful, leaves fundamental questions unanswered. The most glaring of these is the origin of the extraordinarily low entropy state required for the universe's beginning. The Second Law of Thermodynamics dictates that entropy (a measure of disorder) must always increase, yet the Big Bang appears as a moment of near-perfect order, a condition for which the standard model offers no physical justification.

Penrose resolves this paradox by proposing that our universe is but one in an infinite sequence of "aeons." Each aeon begins with its own Big Bang and expands over trillions of years. This expansion is not just spatial; it's a journey through cosmic epochs. Stars form and die, galaxies cluster and evolve, and eventually, the universe is dominated by degenerate stellar remnants and supermassive black holes. The true end-game of an aeon, however, plays out on timescales that dwarf even this.

Over unimaginable periods, any remaining baryonic matter is theorized to decay, and the supermassive black holes themselves, the universe's greatest repositories of entropy, will evaporate through Hawking radiation. The ultimate state of an aeon is a vast, cold, and near-empty expanse, populated only by massless particles—photons and gravitons—flitting through a vacuum state. In this universe, without massive particles, there are no clocks and no rulers. The concepts of time and distance, which rely on the mass-energy equivalence ($E = mc^2$) and Compton frequencies ($\omega = mc^2/\hbar$), become meaningless. The universe loses its sense of scale.

This scale-invariant state is the key to cosmic rebirth. Penrose posits that this infinitely large and cold future of one aeon becomes, through a mathematical transformation, the infinitely hot and dense beginning of the next. The end is seamlessly, and conformally, glued to a new beginning. The entropy that seems impossibly large at the end of an aeon, primarily locked within black holes, is effectively "reset" because the black holes have evaporated, and their information is carried away in a manner that becomes compatible with the smooth, low-entropy state required for the next Big Bang. This cyclical nature, a constant rhythm of formation and destruction, is not just a philosophical proposition but is rooted in the deep structure of spacetime geometry.

2 The Mathematical Underpinnings of Cyclicality

The transition from one aeon to the next is not a brute-force physical collapse but an elegant mathematical rescaling. The physics is grounded in the principles of conformal geometry, a branch of differential geometry where one studies the properties of manifolds that are invariant under a specific class of metric transformations. These are transformations that preserve angles but not necessarily lengths. The entire framework of Conformal Cyclic Cosmology (CCC) rests upon the specific behavior of spacetime curvature under such transformations.

2.1 Conformal Manifolds and Spacetime

We begin by defining a spacetime as a four-dimensional Lorentzian manifold $(\mathcal{M}, g_{\mu\nu})$, where $g_{\mu\nu}$ is the metric tensor that defines the spacetime interval between infinitesimally close points:

$$ds^2 = g_{\mu\nu} dx^\mu dx^\nu \tag{1}$$

The central operation in CCC is a **conformal transformation**, which relates an "old" metric $g_{\mu\nu}$ to a "new" metric $\hat{g}_{\mu\nu}$ via a smooth, strictly positive scalar field $\Omega(x)$, known as the conformal factor:

$$\hat{g}_{\mu\nu}(x) = \Omega(x)^2 g_{\mu\nu}(x) \tag{2}$$

Under this transformation, the new spacetime interval $d\hat{s}$ is simply rescaled: $d\hat{s}^2 = \Omega^2 ds^2$. This clearly shows that lengths and proper times are not preserved; they are local properties that are stretched or shrunk by the factor Ω. However, the angle θ between two non-null vectors, U^μ and V^ν, defined by the relation:

$$\cos\theta = \frac{g_{\mu\nu} U^\mu V^\nu}{\sqrt{|g_{\alpha\beta} U^\alpha U^\beta|} \sqrt{|g_{\gamma\delta} V^\gamma V^\delta|}} \tag{3}$$

is an invariant. Under the transformation, $\hat{g}_{\mu\nu} U^\mu V^\nu = \Omega^2 g_{\mu\nu} U^\mu V^\nu$, and the denominator acquires a factor of $\sqrt{|\Omega^2|}\sqrt{|\Omega^2|} = \Omega^2$. The factors of Ω^2 cancel precisely, leaving $\cos\hat{\theta} = \cos\theta$. This preservation of the causal structure (the null cones) is the fundamental reason why this geometry is so powerful for physics.

2.2 The Transformation of Curvature Tensors

The behavior of curvature under conformal transformations is non-trivial and is the mathematical engine of CCC. The connection coefficients (Christoffel symbols) transform as:

$$\hat{\Gamma}^\lambda_{\mu\nu} = \Gamma^\lambda_{\mu\nu} + \left(\delta^\lambda_\mu \Upsilon_\nu + \delta^\lambda_\nu \Upsilon_\mu - g_{\mu\nu} g^{\lambda\sigma} \Upsilon_\sigma\right) \tag{4}$$

where $\Upsilon_\mu \equiv \partial_\mu \ln\Omega$. This complex transformation law leads to equally complex changes in the curvature tensors derived from it. The Ricci scalar, $R = g^{\mu\nu} R_{\mu\nu}$, for instance, transforms as:

$$\hat{R} = \Omega^{-2} \left(R - 6 g^{\mu\nu} \nabla_\mu \nabla_\nu \ln\Omega\right) \tag{5}$$

where ∇_μ is the covariant derivative compatible with $g_{\mu\nu}$.

The full Riemann curvature tensor $R_{\alpha\beta\gamma\delta}$ can be decomposed into its trace parts (the Ricci tensor, $R_{\mu\nu}$) and its trace-free part (the Weyl tensor, $C_{\alpha\beta\gamma\delta}$). The Weyl tensor represents the tidal forces and gravitational waves of the free gravitational field. Its defining characteristic, and the absolute cornerstone of Penrose's theory, is its conformal invariance property. Under a conformal transformation, the Weyl tensor transforms remarkably simply:

$$\hat{C}^\alpha_{\beta\gamma\delta} = C^\alpha_{\beta\gamma\delta} \tag{6}$$

This means that the Weyl tensor is a conformal invariant. It captures the part of the spacetime curvature that is independent of scale.

2.3 The Conformal Gluing of Aeons

Herein lies the application to cosmology. The far future of our aeon is expected to be an exponentially expanding de Sitter-like space, asymptotically empty and cold, populated by massless particles. The physics of this era is conformally invariant. Penrose proposes to perform a conformal transformation on this far-future spacetime $(\mathcal{M}, g_{\mu\nu})$. He chooses a conformal factor Ω that goes to zero at the future timelike infinity ($t \to \infty$). This mathematical operation effectively "squashes" the infinitely extended future of one aeon into a finite, smooth three-dimensional boundary or hypersurface, which we can call the *crossover surface*, $\mathcal{S}$.

This surface $\mathcal{S}$ is then identified with the Big Bang of the subsequent aeon. The new aeon's metric is $\hat{g}_{\mu\nu} = \Omega^2 g_{\mu\nu}$. Where the old metric described an infinitely large, cold, and rarefied universe, the new metric, because of the Ω^2 factor, describes an infinitely dense, hot, and small one—a Big Bang. The physical fields are also rescaled appropriately.

The critical step involves the Weyl tensor. The Weyl Curvature Hypothesis (WCH) postulates that the initial Big Bang singularity must have vanishing Weyl curvature ($C_{\alpha\beta\gamma\delta} \approx 0$). In the old aeon, the formation of structures and black holes creates immense Weyl curvature. However, as black holes evaporate, the information about their structure is spread throughout the universe. While the Weyl curvature is large, it is finite and structured. Because $\hat{C}_{\alpha\beta\gamma\delta} = C_{\alpha\beta\gamma\delta}$, this structure can be passed smoothly across the conformal boundary $\mathcal{S}$ to the new aeon. The conformal rescaling ensures that the geometry on the other side begins in a state that is consistent with the WCH, effectively resetting the universe's gravitational entropy. The mathematical elegance of conformal geometry thus provides a potential mechanism for the infinite, cyclical rebirth of the cosmos.

2.4 Conformal Transformations and the Metric Tensor

The geometry of spacetime is described by a metric tensor, $g_{\mu\nu}$, which defines the interval ds^2 between two spacetime points. For our expanding universe, this is often the Friedmann-Lemaître-Robertson-Walker (FLRW) metric:

$$ds^2 = g_{\mu\nu}dx^\mu dx^\nu = dt^2 - a(t)^2 \left(\frac{dr^2}{1-kr^2} + r^2(d\theta^2 + \sin^2\theta d\phi^2) \right)$$

where $a(t)$ is the scale factor.

In CCC, the physics of the far-future, massless universe is conformally invariant. This means its physical laws are unchanged by a conformal transformation of the metric:

$$\hat{g}_{\mu\nu} = \Omega(x)^2 g_{\mu\nu}$$

Here, $\Omega(x)$ is a strictly positive, smooth function of the spacetime coordinates, known as the conformal factor. Penrose proposes a specific, singular conformal factor, Ω, that maps the entire infinite future of an aeon ($g_{\mu\nu}$) to a finite past boundary of a new aeon ($\hat{g}_{\mu\nu}$). The crossover is a "conformal boundary" where the infinite stretching of the old aeon is mathematically rescaled to become the initial, dense state of the new one.

2.5 The Weyl Curvature Hypothesis and Entropy

The most esoteric and crucial mathematical component of CCC is the Weyl Curvature Hypothesis (WCH). The total curvature of spacetime, described by the Riemann tensor $R_{\alpha\beta\gamma\delta}$, can be decomposed into two parts: the Ricci curvature and the Weyl curvature. The Ricci tensor is directly constrained by the matter-energy content via the Einstein Field Equations. The Weyl tensor, $C_{\alpha\beta\gamma\delta}$, however, represents the free gravitational field—tidal distortions and gravitational waves. It is not directly fixed by the local distribution of matter.

Gravitational entropy is proportional to the square of the Weyl tensor. A chaotic, high-entropy gravitational field would have a large Weyl curvature. Penrose's WCH is the postulate that the Big Bang singularity was exceptionally special: it had vanishing Weyl curvature.

$$C_{\alpha\beta\gamma\delta} \to 0 \quad \text{at the initial singularity}$$

This mathematical constraint imposes the low-entropy, smooth initial state that the Second Law of Thermodynamics requires. Throughout the aeon, gravitational clumping forms black holes, causing the Weyl curvature, and thus the gravitational entropy, to grow enormously.

In the final stages of an aeon, the evaporation of black holes returns this information to the universe in the form of massless radiation. While the universe is locally chaotic, the overall structure becomes conformally equivalent to a smooth manifold. The conformal rescaling that glues one aeon to the next preserves the physical information but resets the geometric scale in such a way that the Weyl tensor is once again zero at the boundary. The enormous entropy of the previous aeon is "passed through" the transition, providing the thermal bath for the new aeon while still satisfying the WCH. This resolves the paradox of the Second Law by providing a physical mechanism for cyclically resetting the universe's gravitational entropy to zero.

3 A Higher Dimension

To grasp the nature of our universe's existence within a cyclical framework, we can elevate the simple analogy of a sphere and a plane to a more rigorous mathematical construction. This allows us to derive the dynamical properties of such a universe and see how its evolution can be modeled. We will formalize the idea of our cosmos as a 3-dimensional "slice" of a higher-dimensional object, a hypersphere, as it transits through our perceived reality.

3.1 The Hyperspatial Embedding

Let us postulate a 4-dimensional Euclidean space, $\mathbb{R}^4$, with coordinates (x_1, x_2, x_3, w). Our observable universe is considered to be a fixed 3-dimensional hyperplane embedded within this bulk space, defined by the condition $w = 0$. This is analogous to the 2D plane in the simpler version of the analogy.

The higher-dimensional object is a 3-sphere (a hypersphere), which is the set of points in $\mathbb{R}^4$ equidistant from a central point. Let this hypersphere have a constant radius R_{hyper}. If its center is at the origin, its equation is:

$$x_1^2 + x_2^2 + x_3^2 + w^2 = R_{hyper}^2 \tag{7}$$

The essence of the cyclical model is that this hypersphere is not static but is in motion along the unobserved fourth dimension, w. We can describe this motion as a function of time, t. Let the position of the hypersphere's center along the w-axis be given by a function $w_c(t)$. The equation of the moving hypersphere is therefore:

$$x_1^2 + x_2^2 + x_3^2 + (w - w_c(t))^2 = R_{hyper}^2 \tag{8}$$

3.2 The Equation of the Observable Cosmos

Our observable universe is the intersection of this moving 3-sphere with our fixed 3D hyperplane at $w = 0$. To find the geometry of this intersection, we substitute $w = 0$ into the hypersphere's equation:

$$x_1^2 + x_2^2 + x_3^2 + (0 - w_c(t))^2 = R_{hyper}^2 \tag{9}$$

Rearranging this gives us the equation for our observable universe at any given time t:

$$x_1^2 + x_2^2 + x_3^2 = R_{hyper}^2 - w_c(t)^2 \tag{10}$$

This is the equation of a 2-sphere in our 3D space. Its radius is not constant but evolves with time. We can identify this radius with the cosmological scale factor, $a(t)$.

$$a(t) = \sqrt{R_{hyper}^2 - w_c(t)^2} \tag{11}$$

This fundamental equation demonstrates how the size of our universe is a direct consequence of the position of a 4D object in a higher dimension. A "real" universe with a positive size exists only when $R_{hyper}^2 > w_c(t)^2$, or $|w_c(t)| < R_{hyper}$. The moments of creation (Big Bang) and destruction (Big Crunch/Whimper) occur when $w_c(t) = \pm R_{hyper}$, which results in $a(t) = 0$—a singularity of zero size.

3.3 The Dynamics of a Cyclical Universe

The most elegant and simple model for the transit function $w_c(t)$ is that of Simple Harmonic Motion (SHM), which inherently describes a cyclical process. Let us model the motion of the hypersphere's center as a sinusoidal oscillation with an amplitude equal to its radius:

$$w_c(t) = R_{hyper} \cos(\omega t) \tag{12}$$

where ω is the angular frequency of the cosmic cycle. Substituting this into our equation for the scale factor gives:

$$a(t) = \sqrt{R_{hyper}^2 - (R_{hyper} \cos(\omega t))^2} \tag{13}$$

$$= \sqrt{R_{hyper}^2 (1 - \cos^2(\omega t))} \tag{14}$$

$$= \sqrt{R_{hyper}^2 \sin^2(\omega t)} \tag{15}$$

$$= R_{hyper} |\sin(\omega t)| \tag{16}$$

This result is profound. The scale factor of the universe follows the form of a rectified sine wave. It begins at $a(0) = 0$, expands to a maximum size of $a(\pi/2\omega) = R_{hyper}$, and re-collapses to a singularity at $a(\pi/\omega) = 0$, completing one full cycle over a period $T = \pi/\omega$.

From this, we can derive key cosmological parameters. The rate of expansion, analogous to the Hubble parameter $H(t)$, is given by $H(t) \equiv \dot{a}/a$. For the expanding phase ($0 < \omega t < \pi/2$):

$$\dot{a}(t) = \frac{d}{dt}[R_{hyper} \sin(\omega t)] = R_{hyper}\omega \cos(\omega t) \tag{17}$$

$$H(t) = \frac{R_{hyper}\omega \cos(\omega t)}{R_{hyper} \sin(\omega t)} = \omega \cot(\omega t) \tag{18}$$

This simple toy model, born from a geometric analogy, thus generates a complete, self-contained, and cyclical cosmology. Its appearance as a point, expansion to a maximum size, and subsequent collapse is not a series of disconnected events but the smooth, continuous, and mathematically determined transit of a higher-dimensional form.

4 A Universe in Simple Harmonic Motion: The Oscillator Model

The beauty of the higher-dimensional analogy is its inherent simplicity, which allows us to map the esoteric concept of a cyclical cosmos onto one of the most fundamental and well-understood phenomena in physics: **Simple Harmonic Motion (SHM)**. By treating the "travel" of our universe-slice through a higher dimension as an oscillation, we can construct a dynamic and predictive mathematical model.

4.1 The Fundamental Equation of Cosmic Motion

In classical physics, SHM arises from a restoring force, F, that is linearly proportional to the displacement, y, from an equilibrium position, a relationship described by Hooke's Law: $F = -ky$. Here, k is a constant representing the stiffness of the restoring medium (a "cosmic spring constant," in our analogy).

If we assign a "hyper-mass," M, to our universe-slice as it moves through the higher dimension, we can apply Newton's second law, $F = M\ddot{y}$, where $\ddot{y}$ is the acceleration in the higher dimension. This yields the fundamental differential equation for our cosmic oscillator:

$$M\ddot{y} = -ky \quad \implies \quad \ddot{y} + \frac{k}{M}y = 0 \tag{19}$$

By defining an angular frequency $\omega = \sqrt{k/M}$, we arrive at the canonical form of the SHM equation:

$$\ddot{y} + \omega^2 y = 0 \tag{20}$$

The general solution to this second-order differential equation is the familiar sinusoidal function presented earlier:

$$y(t) = A\cos(\omega t + \phi) \tag{21}$$

This solution is not merely descriptive; it is the direct consequence of assuming the simplest possible restoring force acting on our universe in the higher dimension.

4.2 Interpreting the Cosmological Parameters

The parameters of the SHM equation acquire profound cosmological significance in this model:

- **Amplitude (A):** This represents the maximum excursion of our universe from the central hyperplane of the higher dimension. In the context of our hypersphere analogy, the amplitude A would be the radius of the hypersphere itself, R_{hyper}. It defines the absolute geometric boundary of the cosmic cycle.
- **Angular Frequency (ω):** This crucial parameter determines the *tempo* of existence. It is a measure of how rapidly the cycles of universal birth, expansion, contraction, and death occur. The period of one full aeon, from one Big Bang to the next (in this model), is given by $T = 2\pi/\omega$. A small ω implies an immensely long-lived universe, while a large ω suggests short, rapid cycles. This value is determined by the ratio of the "cosmic spring constant" to the "hyper-mass," $\omega^2 = k/M$, tying the universe's duration to the fundamental properties of the higher-dimensional bulk in which it resides.

- **Phase Constant (ϕ):** This parameter sets the origin of our cosmic clock. It allows us to align the model with observation. For instance, if we wish to define $t = 0$ as the moment of the Big Bang, where the scale factor $a(t)$ is zero, we must choose ϕ appropriately. Given that $a(t) = \sqrt{A^2 - y(t)^2}$, we need $y(t = 0) = \pm A$. Setting $\phi = 0$ or $\phi = \pi$ achieves this, placing the Big Bang at the point of maximum displacement, where the higher-dimensional motion momentarily ceases before reversing.

4.3 The Energy of a Cosmic Cycle

A hallmark of any system in SHM is the conservation of total energy, which continually transforms between kinetic and potential forms.

- **Higher-Dimensional Potential Energy (U_y):** This is the energy stored by the universe due to its position in the restoring field, analogous to a compressed spring. It is given by $U_y = \frac{1}{2}ky^2$.
- **Higher-Dimensional Kinetic Energy (K_y):** This is the energy of the universe's motion through the higher dimension, given by $K_y = \frac{1}{2}M\dot{y}^2$.

The total energy of the cosmic cycle, E_{total}, is the sum of these two:

$$E_{total} = K_y + U_y = \frac{1}{2}M\dot{y}^2 + \frac{1}{2}ky^2 \tag{22}$$

Let's verify its conservation using our solution, $y(t) = A\cos(\omega t + \phi)$, and its time derivative, the velocity $\dot{y}(t) = -A\omega\sin(\omega t + \phi)$.

$$E_{total} = \frac{1}{2}M(-A\omega\sin(\omega t + \phi))^2 + \frac{1}{2}k(A\cos(\omega t + \phi))^2 \tag{23}$$

$$= \frac{1}{2}MA^2\omega^2\sin^2(\omega t + \phi) + \frac{1}{2}kA^2\cos^2(\omega t + \phi) \tag{24}$$

Substituting $k = M\omega^2$, we find:

$$E_{total} = \frac{1}{2}kA^2\sin^2(\omega t + \phi) + \frac{1}{2}kA^2\cos^2(\omega t + \phi) \tag{25}$$

$$= \frac{1}{2}kA^2(\sin^2(\omega t + \phi) + \cos^2(\omega t + \phi)) = \frac{1}{2}kA^2 \tag{26}$$

The total energy is constant, determined only by the "stiffness" of the higher dimension and the maximum amplitude of the excursion. At the Big Bang ($y = \pm A$), all energy is potential ($U_y = \frac{1}{2}kA^2, K_y = 0$). As the universe "falls" toward the equilibrium point ($y = 0$), potential energy is converted into kinetic energy, and it is here, at the midpoint of its journey, that our 3D universe experiences its maximum rate of expansion.

The "radius" of our observable universe, R, at any given time would then be a function of this position. If the higher-dimensional object is a hypersphere of radius R_{hyper}, then the radius of our 3D universe-slice would be:

$$R(t) = \sqrt{R_{hyper}^2 - y(t)^2}$$

This simple model, driven by the fundamental principles of SHM, elegantly captures the essence of a cyclical universe. The "force" driving this oscillation could be a consequence of the interplay between the fundamental forces of nature in a higher-dimensional space, a concept explored in theories like string theory and brane cosmology. The Big Bang, in this view, is not a singular, one-time event, but rather the moment our slice of reality passes through the "equator" of the higher-dimensional sphere, where its radius is at a maximum and its rate of change of position is highest.

This perspective offers a compelling and intuitive way to visualize the grand, overarching structure of existence as envisioned by Penrose. It strips away the complex jargon and presents a universe that is, at its core, a simple, elegant, and perpetually oscillating system.

On Citations and Influence

1. I take inspiration from Ralph Waldo Emerson, who believed that truth begins in direct perception and personal insight. His writing encourages a mode of understanding that isn't mediated by layers of scholarly reference.

2. Plato's dialogues remind me that truth isn't always handed down through citation, but often uncovered through conversation and reflection. I prefer to follow that path—less archival, more dialectical.

3. Friedrich Nietzsche wrote with a deep suspicion of borrowed authority. His work reminds me that citing can sometimes mean deferring to structures we're better off questioning.

4. William Blake trusted vision more than validation. While I don't share his mysticism, I admire his commitment to ideas that stand without needing to lean on other voices.

5. While I haven't cited specific texts, I owe everything to the countless teachers—named and unnamed—who shaped how I think. I stand on the shoulders of giants, and this work carries traces of all their voices.