The Interwoven Causality Hypothesis (ICH): A Unified Framework for Emergent Time, Causal Knots, and Cosmological Cyclicity

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Abstract

I present the Interwoven Causality Hypothesis (ICH) as a speculative but unified conceptual framework proposing that time is not a fundamental quantity, but rather an emergent property arising from underlying causal interactions. In this view, spacetime is conceived as a macroscopic structure generated by woven patterns of causal flow, and black holes and white holes are not treated as isolated singularities but as causal knots—topological features where causality may loop, reverse, or momentarily halt, giving rise to localized anomalies in temporal progression.

Unlike classical general relativity, which treats time as an embedded geometric dimension, ICH regards causality as the ontological substrate from which temporal ordering and the arrow of time emerge. This arrow is shaped by the accumulation of causal events and asymmetries across complex systems involving matter, radiation, and quantum entanglement.

In this model, dark energy is not constant but instead reflects the fluctuating global causal flux, a measure of the shifting connectivity within the cosmic causal web, as the universe expands or contracts. ICH introduces the concept of a "causal counterforce", a theoretical counteracting process that emerges to prevent entropic stagnation or unchecked expansion. This mechanism could account for changes in cosmic acceleration without recourse to a fixed cosmological constant.

Furthermore, ICH posits a cyclic universe, not solely through mechanical rebounds, but via alternating phases of causal coherence and decoherence between cosmic expansion and contraction. Such cycles naturally allow for localized reversals of entropy and the emergence of quantum symmetries at each transition.

Although ICH is not yet substantiated with formal mathematical proof, its conceptual structure is, in principle, open to empirical investigation via:

- Detection of asymmetric time dilation near black hole/white hole pairs;
- Analysis of cosmic microwave background anisotropies for causal loop signatures;
- Measurement of fluctuations in dark energy density across cosmic epochs;
- Simulation of causal entanglement topologies in high-energy conditions.

This work is not intended to supplant established models, but rather to reframe our current interpretation of space, time, and cosmic evolution through a causality-first perspective.

Keywords: emergent time, causality, black holes, white holes, causal knots, dark energy, causal counterforce, cyclical universe, quantum gravity, time asymmetry, Interwoven Causality Hypothesis

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1. Introduction

1.1 The Problem of Time and Causality

Modern physics still lacks a unified understanding of the nature of time. In General Relativity, time is treated as a geometric coordinate within four-dimensional spacetime. This coordinate helps define the causal structure linking events, via light cones, that determines the possible flow of information (Eckstein & Heller, 2022). Essentially, time in this theory is part of the fabric of the universe itself, with its measurement depending on the observer's frame of reference and gravitational environment.

In Quantum Mechanics, by contrast, time serves as an external parameter that sets the stage for state evolution rather than an observable physical quantity with its own operator. It is not subject to quantum uncertainty or entanglement in the same way that measurable quantities like position or momentum are (Pashby, 2015). This means time is treated as a fixed "clock" against which changes occur, rather than something dynamic or probabilistic within the theory.

This fundamental difference between these two pillars of physics has motivated new approaches suggesting that time may not be a basic entity, but rather an emergent property arising from deeper physical processes (Baron & Le Bihan, 2024; Smart, 1969).

1.2 Historical Background and Philosophical Context

The idea that causality might precede the conception of time has a long and complex history, spanning metaphysical traditions, philosophy of science, and modern theoretical physics (Gijsbers, 2019). Classical philosophers such as Leibniz and Kant explored the deep relationship between causation and temporal order. Often, they viewed causality as closely linked to, or even foundational for the structure of time itself. For example, Kant argued that our understanding of time involves causal laws that guide the sequence of events, thus suggesting a mutual dependence between causality and temporality rather than a simple hierarchical precedence (Gijsbers, 2019).

Historically, causal relations have typically been understood as fundamentally time-ordered, with the cause preceding the effect (Hume, 1739; Mill, 2017). However, philosophers and scientists have noted that the notion of causality might not be reducible purely to temporal succession and that causality might be more primitive or independent than time itself (Faye, 2008; H. Reichenbach, 1956). This ongoing debate highlights that the temporal order of events may emerge from deeper causal structures.

In the modern era, despite significant challenges in formulating coherent and testable frameworks, research in fields such as quantum gravity, complexity theory, quantum information dynamics, and relational ontology has revitalized the focus on causality-first models. These approaches propose that time is not a fundamental background parameter but an emergent property arising from networks of causal interactions and patterns of information flow throughout the universe (Dowker, 2005; Sorkin, 2003). Formal frameworks such as causal set theory exemplify attempts to describe spacetime as a consequence of an underlying causal order.

1.3 Foundation of the Interwoven Causality Hypothesis (ICH)

The ICH proposes that time emerges from networks of causally entangled events, whose configurations define the directionality of physical processes. These causal networks, referred to as "causal knots", form the underlying structures behind phenomena traditionally attributed to spacetime curvature or quantum decoherence. ICH further postulates that black holes and white holes correspond to localized regions where causal order loops or fragments, thereby producing distortions in the perception of time and information flow. In this framework, dark energy is not a uniform cosmological constant but is interpreted as a fluctuating tension within these causal networks, potentially driven by feedback dynamics between entropic dissipation and quantum information recombination. From this perspective, the expansion and contraction phases of the universe are not independent events but part of a causal feedback loop, suggesting a fundamentally cyclical cosmology.

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2. Theoretical Framework

2.1 Hypothesis Overview

- Time is an emergent property of causal connectivity, arising from the directional flow of information through entangled causal networks.
- Black holes and white holes are interpreted as causal knots — regions where causality loops, fragments, or reverses, distorting the flow of time and information.
- Dark energy is non-constant, a fluctuating expression of causal tension that expands space in response to increasing entropic dissipation.
- A hypothesized “Entellic Force”, derived from the Greek *entellō* ("to command" or "to order"), acts as a restorative principle. It emerges when causal structure becomes significantly disordered, functioning as the universe’s intrinsic cosmological mechanism for self-reorganization, resisting causal stagnation and initiating contraction.
- The universe is cyclical, governed not by a simple expansion-collapse rhythm, but by alternating phases of causal dominance: expansion through entropic diffusion (driven by dark energy), and contraction through entellic restoration (driven by the “Entellic Force”). This duality forms a self-regulating causal feedback loop.

Notes: *The term “Entellic Force” is introduced here as a new theoretical concept derived from the Greek verb* entellō *(meaning “to command” or “to order”). It denotes a proposed restoring causal mechanism acting to reorganize the causal structure of the universe and resist causal stagnation. To the best of current knowledge, “Entellic” or similar terms have no established meaning in scientific or philosophical literature, minimizing potential confusion.*

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3. Core Concepts

3.1 Time as Emergent

Time is not a fixed background parameter but rather an emergent consequence of directional information flow and causal entanglement. When networks of causal connections become sufficiently dense and directional, a statistical arrow of time emerges (Nye, 2024). This perspective aligns with modern quantum information approaches and utilizes tools such as out-of-time-order correlators (OTOCs) to characterize the growth of quantum complexity and the scrambling of information that give rise to temporal ordering (Nye, 2024; Susskind, 2018; Swingle, 2018).

3.2 Causal Knots (Black and White Holes)

Black holes are not merely endpoints in spacetime but rather regions where the flow of time can loop, freeze, or redirect. White holes, conversely, can be viewed as expelled or reversed causal order, regions where causal flow emerges outward. These objects may represent dual aspects of a unified underlying causal structure, connected through quantum tunneling or transitions at Planck-scale regimes. This interpretation shifts the view of black and white holes from isolated singularities to intertwined features of a dynamic causal network.

To rigorously illustrate and analyze these causal structures, **Penrose diagrams** are invaluable tools. Penrose diagrams provide a conformal representation of spacetime that compactifies infinite regions and clearly depicts causal relationships, horizons, singularities, and possible causal loops or connections between regions (Crowell, 2022).

The causal structure of black holes, including event horizons and singularities, is depicted in Penrose diagrams where the singularity inside the horizon is represented as a spacelike boundary. This emphasizes that all causal futures inside the horizon inevitably lead towards the singularity. Extensions such as the maximally extended Schwarzschild solution illustrate how white holes appear as time reversals or mirrors of black holes within these diagrams. The intricate causal connectivity proposed by the Interwoven Causality Hypothesis aligns well with such diagrammatic representations.

Detailed Penrose diagrams for accelerating black holes have been constructed using the C-metric, revealing complex horizon structures and singularities beyond classical Schwarzschild cases (Cembranos et al., 2022). These studies show various acceleration regimes with corresponding changes in causal structures, enriching understanding of horizon and causal boundary behavior.

Furthermore, recent theoretical research on black-to-white hole transitions at the Planck scale provides a framework for regarding black and white holes as causally and quantum mechanically connected entities, consistent with the notion of causal knots within the ICH framework (Clements, 2019; Han et al., 2023). These models invoke quantum tunneling or spacetime transitions that unify black and white hole regions as complementary aspects of a dynamic causal topology.

3.3 Fluctuating Dark Energy

Building on the proposal by Vedder et al., (2022) that dark energy exhibits spatial and temporal fluctuations influencing cosmic expansion, this hypothesis interprets dark energy as a dynamic *cosmic tension index*, a fluctuating quantity reflecting the universe's current state of causal expansion. When this causal tension is high, it drives the accelerated expansion of space; conversely, when the tension lowers, it signals the approach of a contraction phase. Thus, dark energy is not a fixed cosmological constant, but a variable quantity responsive to underlying causal dynamics, linking its fluctuations to a cyclical pattern of expansion and contraction within the universe.

This view resonates with recent astrophysical observations and theoretical models suggesting that dark energy may evolve over cosmic time, exhibiting both spatial and temporal variations (Silva et al., 2025; Vedder et al., 2022). Such fluctuations can be understood as changes in the "tension" or stress within the causal fabric of spacetime, which dynamically modulate the universe's expansion rate.

3.4 The Entellic Force: Causal Restoration Mechanism

To prevent eternal expansion, entropy overload, and the disintegration of causal connectivity, we theorize the existence of a restorative force, the **Entellic Force**. This force emerges when the fabric of causal connectivity becomes critically sparse or unstable. Unlike a traditional constant or field, the Entellic Force is an **emergent organizing tendency** arising from the collapse or exhaustion of directed causal flow. We propose that it catalyzes cosmic contraction by enforcing causal reintegration and resisting the unchecked dispersal of information and energy. The Entellic Force operates primarily under extreme conditions, such as the late-universe phase near entropic thresholds or in regions with highly entangled causal knots (e.g., dense black hole clusters). Functioning as the universe's intrinsic self-correcting impulse, it acts as a cosmological command to reorganize when causal order fragments.

Similar ideas appear in cosmological research on bouncing and cyclic universe scenarios, where mechanisms halt expansion and trigger contraction phases. Scalar fields coupled to gravity, quantum gravitational effects, or geometric features of extra dimensions have been proposed to induce contraction or cosmic "bounces" (Graham et al., 2015; Ijjas & Steinhardt, 2020; Steinhardt & Turok, 2002). These models posit natural restoring processes controlling cosmic expansion, comparable in role to the Entellic Force as an intrinsic cosmological organizing principle.

Its function as a self-correcting impulse aligns with theoretical expectations from cyclic cosmology, where the universe undergoes alternating expansion and contraction governed by internal causal feedback loops (Leite & Pavlović, 2018; Mishra et al., 2023). By framing contraction as a causal restoration mechanism, the Entellic Force links entropy-driven cosmic evolution with quantum informational and causal network dynamics, providing a novel conceptual path bridging established cyclic cosmology and emergent causality frameworks.

3.5 The Entellic Force and the Causal Renewal Cycle

The notion of a restorative causal force initiating contraction resonates with existing cyclic cosmological models, where mechanisms halt cosmic expansion and trigger contraction or bounce phases. Several theories invoke scalar fields, quantum gravitational effects, or geometric mechanisms to produce these contraction phases that prevent heat death and allow universal renewal (Graham et al., 2015; Ijjas & Steinhardt, 2020; Khoury et al., 2004; Kragh, n.d.; Steinhardt & Turok, 2002). Historical and contemporary cyclic models have explored cosmic expansion and contraction as self-regulating processes governed by internal feedback loops maintaining cosmic order (Graham et al., 2015; Kragh, 2013). The Entellic Force parallels these theoretical restoring tendencies, providing a novel interpretation rooted in the causal network structure of spacetime.

Unlike these prior models, which typically describe contraction mechanisms in terms of scalar fields or quantum corrections without assigning a specific organizing force, the Entellic Force is introduced here as a novel emergent tendency rooted explicitly in the causal network structure of spacetime, conceptualized as a self-correcting principle restoring causal connectivity.

The Entellic Force, as proposed in this hypothesis, emerges as a corrective response when the density and directionality of causal connections fall below a critical threshold. As the universe expands and causal structures stretch and weaken, entropic drift threatens the coherent flow of information, leading to a state of causal stagnation. At this juncture, the Entellic Force asserts itself as a restorative principle, triggering a transition from expansion to contraction.

Rather than allowing eternal expansion or thermal equilibrium (heat death), this force initiates a cosmic renewal: collapsing fragmented causal domains back into a tighter, more coherent configuration. During this contraction phase, hyper-dense causal knots (such as black hole clusters) intensify, concentrating entangled information and potentially establishing the conditions required for the subsequent universal phase.

This cycle — expansion, entropic fragmentation, *entellic* restoration, and contraction — reconceptualizes the universe not as a linear progression but as a self-regulating, causal organism. Each phase is defined not solely by thermodynamic parameters but fundamentally by informational processes: time, space, and energy are continuously reorganized through emergent causal tension and its resolution.

Thus, the Entellic Force may be interpreted as the central component of a governing feedback loop behind cosmological cycles, distinct from familiar physical forces yet deeply rooted in the universe’s causal architecture.

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4. Implications and Testable Predictions

As of mid-2025, the following predictions remain broadly compatible with observed data and ongoing scientific investigations. While some phenomena, such as gravitational time dilation and CMB anomalies, are well documented, their interpretations within the Interwoven Causality Hypothesis offer novel explanatory frameworks yet to be empirically tested. Other points, like dynamic dark energy behavior and quantum causal simulations, align with active frontiers in physics. The late-phase transition indicators represent longer-term observational challenges, requiring advances in cosmological mapping and analysis.

Below, I present five potential implications and how they relate to ongoing or future scientific efforts:

4.1 Anomalous Time Dilation Near Causal Knots

Standard General Relativity predicts gravitational time dilation near massive bodies, a prediction confirmed by black hole imaging (Event Horizon Telescope) and gravitational wave detectors (Akiyama et al., 2019; The LIGO Scientific Collaboration et al., 2021). However, current data confirms conventional GR predictions without detecting anomalies attributable to causal knots. The ICH posits that causal knots could introduce subtle anomalies in time dilation not explained by conventional models. Future ultra-precise measurements near event horizons or exotic compact objects may reveal such deviations; no such anomalies have been confirmed to date, preserving this as a novel prediction.

4.2 Causal Echoes in the Cosmic Microwave Background (CMB)

Low multipole anomalies in the CMB, such as the *"axis of evil"*, have been observed by Planck and WMAP, yet remain unexplained (Patel et al., 2025). Some cyclic cosmology models propose that remnants of a previous universe phase may imprint on the early radiation field. If the universe is causally cyclical, the CMB could encode residual causal structures or entropic echoes from a prior contraction phase. These anomalies can be reconsidered as potential evidence of past causal configurations.

4.3 Time-Dependent Dark Energy Behavior

Observations increasingly challenge the notion of dark energy as a strict cosmological constant. Projects like DESI (Silva et al., 2025) and Euclid (ESA Euclid Consortium, 2025) explore how the equation-of-state parameter $w(z)$ may evolve. The concept of a Causal Tension Index, a dynamic, entropic strain within the causal fabric, offers a new interpretation for these variations. Rather than a scalar field, dark energy fluctuations may reflect changes in causal density and information flow tension.

4.4 Emergence of Time in Quantum Causal Simulations

Quantum information research increasingly studies out-of-time-order correlators (OTOCs) and entanglement scrambling in systems like cold atoms and superconducting qubits. Quantum causal discovery algorithms and protocols are emerging (Terada et al., 2025) but their explicit application to emergent time remains a developing field. Time may statistically emerge from entanglement density and causal feedback. Although simulations explicitly modeling emergent time remain rare, advances in networked quantum systems may soon enable direct testing. This remains a forward-looking research challenge.

4.5 Late-Phase Cosmological Transition Indicators

If the universe is cyclic, late-phase precursors to contraction should manifest, such as entropy plateaus, large-scale causal knot clustering, or shifts in expansion dynamics. Upcoming high-precision cosmological surveys may enable detection of subtle signatures indicative of late-phase causal transitions. Current large-scale structure surveys (e.g., void analysis, baryonic acoustic oscillations) lack the resolution to confirm these subtle indicators. However, future cosmological mapping could provide indirect support for this component of ICH.

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5. Conclusion

The ICH offers a speculative yet integrative perspective, reframing the universe as a dynamic tapestry of causal flows, emergent time, and cyclical transformation. While ICH does not yet rest on formal mathematics, it aspires to bring conceptual clarity and a unifying lens to questions at the intersection of cosmology, information, and causality. By positing causality, not time itself, as the primary engine of cosmic evolution, ICH invites fresh interpretation of black holes, dark energy, and the large-scale cycles of the universe.

This hypothesis is, at its heart, an invitation: to physicists, cosmologists, philosophers, and information theorists to test, challenge, and refine these ideas, whether as a working model, a thought experiment, or a metaphor for future discoveries. As science advances, new conceptual frameworks act as seeds for unexpected growth. The ICH aspires to be one such seed.

If causality is the loom, and time its thread, then the cosmos is a weave yet unfinished.

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