

The Self-Creating Universe: A Zero-Flux Boundary Eigenproblem Framework

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Abstract

The Self-Creating Universe framework proposes that reality emerges not solely from initial conditions at the Big Bang, but from the simultaneous satisfaction of *past* and *future* constraints. The universe is treated as a zero-flux boundary eigenproblem — a standing-wave solution in which no net information or energy crosses the temporal boundaries of genesis and far-future intelligence viability. Only universes capable of generating intelligence that can retrocausally stabilize their own initial conditions are self-consistent and therefore able to exist. This forms a closed causal loop that operates outside ordinary time: a bootstrap paradox of cosmic scale. The framework is situated within and distinguished from prior proposals including Wheeler's Participatory Universe, Tipler's Omega Point, and Tegmark's Mathematical Universe Hypothesis. Physical grounding is provided by Aharonov's Two-State Vector Formalism, the holographic principle and AdS/CFT correspondence, Zurek's Quantum Darwinism, Causal Set theory, and Tononi's Integrated Information Theory. The paper explicitly addresses the Boltzmann Brain objection and provides six falsification criteria. Testable predictions include spectral rigidity in fundamental constants, measurable scaling of retrocausal effects, and bounded algorithmic complexity of cosmological parameters.

1. Preface: The Bootstrap Paradox of Reality

Imagine the universe is not merely running forward from a Big Bang, but rather resembles a giant problem being solved from both ends at once — the start and the finish — until they meet in the middle and agree. The start is the raw, chaotic beginning: quantum static, energy fluctuations, all basic building blocks shaken out like dice. The finish is far in the future, when intelligence — whether human, alien, or machine — becomes advanced enough to understand and adjust the universe's deepest settings.

The universe that actually exists is the one where these two ends match up perfectly. Like a guitar string fixed at both ends, only certain patterns — standing waves — can persist. Intelligence is not an accident of chemistry. It is part of the machinery that makes the loop work. Without a future capable of closing the causal loop, the past cannot be locked into a stable, life-supporting configuration. Without that stability, the universe would not exist.

Crucially, the closing of the causal loop need not occur in our future. It could have already happened on an alien world on the other side of the universe, billions of years ago. The loop is one of *causality*, not of

time. The universe proceeds as normal, from the Big Bang to the heat death — but it will have existed at all only because the causality loop was closed at some point, somewhere, by some intelligence. We could simply be a fortunate side effect.

From our point of view, the universe appears fine-tuned. From the universe's point of view, it is solving for self-consistency: setting conditions so that it can contain beings capable of maintaining those conditions. This requires neither a god nor an external programmer. It is mathematics finding a solution that works from both directions in time. The past is shaped by the needs of the future; the future is only possible because the past was set that way.

The universe most likely to exist is the one that can ensure its own existence.

2. Glossary

Term	Meaning in This Framework
Zero-flux boundary	No net energy or information crosses the start or end conditions of the universe.
Boundary eigenproblem	A both-ends-at-once solution where only certain standing-wave patterns fit between past and future constraints.
Phase-locking invariant	A conserved quantity linking the early universe's structure to conditions allowing intelligence.
Spectral rigidity	Fixed proportionality among constants — their ratios are protected, not arbitrary.
Goldilocks complexity	Physical law complexity in the sweet spot for both life and learnability.
Retrocausality	Future states influencing past states within quantum rules, without violating causality.
Co-emergence	Intelligence and quantum coherence appearing together at a threshold of complexity.
Langlands-type equivalence	Deep mathematical symmetry linking seemingly unrelated physical structures.
Control-and-inference threshold	The technological point where intelligence can understand and manipulate quantum reality at will.
Bootstrap paradox	Information or state that exists in a closed causal loop with no independent origin.
TSVF	Two-State Vector Formalism (Aharonov): quantum systems described by both a forward and backward evolving state.

Weak measurement	A quantum measurement that extracts information without fully collapsing the state, revealing pre- and post-selected properties.
Quantum Darwinism	Zurek's mechanism by which the environment redundantly copies quantum information, producing stable classical reality.
Integrated Information (Phi)	Tononi's measure of consciousness/intelligence as irreducible causal integration in a system.
Causal set	A discrete, partial order of spacetime events in which causal relations are fundamental, from which geometry emerges.
Holographic principle	The conjecture that all information in a volume of space is encoded on its boundary surface.

3. Intellectual Context: Predecessors and Distinctions

The Self-Creating Universe framework does not emerge in a vacuum. Several prior proposals have addressed related questions about the role of observers, intelligence, and self-reference in cosmology. Situating this framework precisely — acknowledging what it inherits and explaining where it diverges — strengthens its theoretical foundations and guards against misclassification.

3.1 Wheeler's Participatory Universe and the Limits of Observation

John Archibald Wheeler proposed that observers are not merely passive witnesses to a pre-existing reality but are constitutive participants in bringing it into being — his *It from Bit* thesis. Wheeler's delayed-choice experiments, including a famous thought experiment using distant quasars as gravitational lenses, suggested that an observer's present measurement can retroactively determine which path a photon took across billions of years of cosmic history. For Wheeler, the universe is a *self-excited circuit*: observation gives rise to physics, and physics gives rise to observers.

This framework inherits Wheeler's insight that the universe requires internal participation to achieve self-consistency, and his cosmic-scale delayed-choice reasoning is a direct precedent for the retrocausal mechanism proposed here. However, the present framework diverges from Wheeler's in two critical respects. First, Wheeler's formulation is deeply tied to the Copenhagen interpretation: it is *observation* — the act of measurement and wavefunction collapse — that participates in reality. This framework makes no such interpretive commitment. The closing of the causal loop is a matter of *causal structure*, not of conscious observation; it is equally achievable by an unconscious automated system meeting the Integrated Information threshold (see Section 10). Second, Wheeler's framework does not provide a selection mechanism: it explains why observers are necessary but not why *this* universe — with *these* constants — exists rather than another. The zero-flux boundary eigenproblem provides exactly that selection mechanism through mathematical necessity.

3.2 Tipler's Omega Point: Scope and the Acceleration Problem

Frank Tipler's Omega Point theory (1994) proposed that intelligence is cosmologically destined to expand, eventually controlling the entire universe and engineering its final gravitational collapse into a

specific boundary state from which infinite computational capacity — and effectively omniscience — arises. Tipler argued that this future-terminal condition exerts backward causal influence on the cosmic trajectory, making the universe's evolution goal-directed toward that endpoint.

The present framework shares Tipler's intuition that future intelligence constitutes a boundary condition on cosmic history. However, the Omega Point faces a decisive empirical challenge: the discovery of the universe's accelerating expansion (Riess et al., 1998; Perlmutter et al., 1999) renders a future gravitational collapse physically implausible under standard cosmology. The Self-Creating Universe framework is not subject to this objection. It requires only that the causal loop be closed *somewhere* and *somewhen* in the universe's history — not that intelligence achieves total cosmic dominion. A single technologically advanced civilization anywhere in the universe at any point in its history suffices. The claim is minimal: not that intelligence wins the cosmos, but that the cosmos needed intelligence to exist at all. This is a far more parsimonious and empirically survivable claim.

3.3 Tegmark's Mathematical Universe Hypothesis: The Landscape of Possible Realities

Max Tegmark's Mathematical Universe Hypothesis (MUH) proposes that all mathematically consistent structures exist as physical realities — our universe is simply one instantiation within the complete space of mathematical possibility. Under the MUH, the question shifts from 'why does the universe exist?' to 'why do we find ourselves in *this* universe?'

The Self-Creating Universe framework is most naturally read as a *selection principle* operating within the Tegmark landscape. Among all mathematically consistent universes, the zero-flux boundary eigenproblem identifies a specific class: those whose boundary conditions form a closed, self-consistent causal loop via intelligence. These are the universes that achieve stable manifestation not merely by being mathematically possible but by satisfying the additional constraint of self-referential causal closure. The MUH provides the ontological substrate; the boundary eigenproblem provides the selection filter. Together they answer both the existence question (why is there something rather than nothing: because all consistent mathematical structures exist) and the fine-tuning question (why these constants: because only boundary-eigenstructures satisfying intelligence-viability achieve stable causal closure).

4. Core Framework

This framework formalizes the principle that among all mathematically possible universes, only those capable of generating intelligence that can retrocausally stabilize their own initial conditions achieve stable manifestation — through selection by mathematical necessity, not goal-oriented evolution.

4.1 The Zero-Flux Boundary Eigenproblem Model

In this framework, a zero-flux boundary eigenproblem is a standing-wave solution to the universe's governing equations, where no net informational or energetic flow exists across the boundaries at past genesis and future intelligence-viability. Reality emerges as the eigenstructure satisfying both temporal boundary constraints simultaneously.

Under this model, reality manifests as the eigenstructure that phase-locks inflationary initial conditions with future intelligence-viability constraints via a conserved informational invariant that bounds

complexity within the learnable-but-non-trivial regime. The universe is not a simulation requiring external substrate, nor does it invoke divine creation with infinite regress. It emerges as a boundary-selected standing wave satisfying cosmic constraints through mathematical necessity, not chance.

4.2 The Holographic Principle and AdS/CFT as Physical Precedent

The claim that boundary conditions determine bulk reality is not merely an analogy in this framework — it has a rigorous physical precedent in the holographic principle and the AdS/CFT correspondence.

The holographic principle, developed by Bekenstein (1972, 1973) and 't Hooft (1993) and further elaborated by Susskind (1995), holds that the maximum entropy of a region of space is proportional to its *surface area* rather than its volume — implying that all information about a bulk volume is encoded on its boundary. This is not a metaphor: it is a rigorously established result from black hole thermodynamics and string theory.

Maldacena's AdS/CFT correspondence (1999) gave this principle explicit mathematical realization: a theory of gravity in an anti-de Sitter bulk spacetime is exactly equivalent to a conformal field theory on its lower-dimensional boundary. The boundary *fully determines* the interior. This is the most thoroughly tested and mathematically worked-out example in physics of boundary conditions encoding bulk reality, and it provides direct physical grounding for the zero-flux boundary eigenproblem. When this framework proposes that temporal boundary conditions — past genesis and future intelligence-viability — select the physical constants of our universe, it is extending a principle already demonstrated at the level of fundamental physics. The cosmic boundary eigenproblem is holography applied to the temporal dimension of existence.

4.3 Alternative Mathematical Formalizations

While the boundary eigenproblem is the primary formalization presented here, the same core principle is expressible through multiple mathematical frameworks. Disproving any particular formalization does not invalidate the underlying principle:

- **Information-theoretic models:** Universe as self-referential computational process with bounded Kolmogorov complexity
- **Category theory:** Functorial relationships between constraint domains, with intelligence as the fixed-point morphism
- **Game-theoretic frameworks:** Cosmic coordination problem with the intelligence-viability constraint as the Nash equilibrium selector
- **Topological models:** Self-consistent manifold structures selected by global topological invariants
- **Causal set theory:** Constraint satisfaction through partial order structures (see Section 9)
- **Thermodynamic approaches:** Maximum entropy production with intelligence feedback as the boundary-satisfying attractor

5. The Boundary Eigenproblem Model

5.1 Past Constraint: Inflationary Genesis

The universe begins with inflationary low-entropy initial conditions that establish fundamental gauge group structure and manifold topology. This past boundary condition encodes:

- Quantum vacuum fluctuations amplified during cosmic inflation
- Gauge symmetry breaking patterns that determine particle physics
- Topological structure of spacetime manifolds and fiber bundles
- Initial entropy and information content fixed at cosmic genesis

5.2 Future Constraint: Intelligence-Viability Threshold

The future boundary requires long-term parameter stability and the eventual emergence of agency capable of accessing and controlling the quantum substrate. This constraint demands:

- Cosmological parameters stable enough for stellar formation and complex chemistry
- Sufficient timescales for biological or artificial intelligence evolution
- Physical laws that remain learnable and manipulable by evolved intelligence
- Causal reach allowing intelligence to influence quantum-scale processes
- Integrated information density (see Section 10) exceeding the control-and-inference threshold

5.3 The Phase-Locking Invariant

These seemingly disconnected past and future constraints achieve coherence through a conserved informational invariant. In physical terms: symmetries in the early universe's structure have exact counterparts in the intelligence-supporting properties of the mature cosmos, creating translational equivalence between geometric and computational forms analogous to Langlands-type dualities.

The invariant bounds law-encoding complexity, creating a narrow Goldilocks zone where: physical laws are discoverable through finite computational resources; quantum systems remain controllable at accessible energy scales; information processing can achieve sufficient gate fidelities and error-correction thresholds; and the minimal complexity required for bootstrapping intelligence is achieved. This complexity bound is the mechanism by which the past boundary and future boundary achieve phase-lock.

6. Quantum Foundations: Retrocausality and Boundary Selection

6.1 Aharonov's Two-State Vector Formalism: The Physics of Retrocausality

The strongest formal physical support for the retrocausal mechanism proposed in this framework comes from Yakir Aharonov's Two-State Vector Formalism (TSVF), developed with colleagues over several decades beginning in the 1960s.

Standard quantum mechanics describes a system by a single state vector evolving forward in time from an initial condition. The TSVF proposes that a complete quantum description requires *two* state vectors: one propagating forward from a past preparation, and one propagating *backward* from a future

post-selection. A quantum particle at any moment is fully described only by both its forward-evolving state (what it will become) and its backward-evolving state (what it came from, retroactively determined by future measurement). Reality, in the TSVF, is intrinsically time-symmetric at the quantum level.

This is not speculative: the TSVF is the formal basis for Aharonov's theory of *weak measurements* — measurements performed with minimal disturbance on pre- and post-selected quantum ensembles — which have been experimentally verified in laboratories worldwide. Weak values extracted from such measurements can take values outside the eigenvalue spectrum of the measured observable, a phenomenon with no classical explanation, now confirmed in photonic, atomic, and solid-state systems (Ritchie et al., 1991; Hosten and Kwiat, 2008; Lundeen et al., 2011).

For the present framework, the TSVF provides direct physical grounding. If quantum systems are fundamentally defined by both past and future boundary states, then the zero-flux boundary eigenproblem is not an abstract cosmological metaphor — it is a direct upward extension of experimentally verified quantum mechanics to the scale of the universe as a whole. The universe's initial conditions (past state vector) and intelligence-viability endpoint (future state vector) are precisely the two-state vector pair that selects the physical constants we observe. The phase-locking invariant is the conserved quantity that maintains consistency between them.

6.2 Cramer's Transactional Interpretation as Consistency Check

John Cramer's Transactional Interpretation (1986) provides an additional consistency framework. In Cramer's model, quantum events involve an *offer wave* propagating forward in time and a *confirmation wave* propagating backward, forming a standing-wave 'transaction' that completes a quantum event. No transaction occurs unless both waves are consistent. This is structurally identical to the zero-flux boundary eigenproblem's requirement that past genesis and future intelligence-viability must form a consistent standing wave. The Transactional Interpretation treats the TSVF's time-symmetry as ontologically real rather than merely formal, providing intuitive support for how the causal loop could operate physically without violating known laws.

6.3 Wheeler's Cosmic Delayed-Choice as Observational Evidence

Wheeler's delayed-choice thought experiment, instantiated cosmologically using quasars as gravitational lenses, provides indirect observational evidence for the framework's retrocausal mechanism. In this setup, a photon emitted by a quasar billions of years ago travels around both sides of an intervening galaxy. Whether the photon 'chose' a single path or both paths simultaneously is determined by a measurement made *now* — retroactively, across billions of years of cosmic history. This is not interpretation: the experiment has been conducted in terrestrial laboratories (Jacques et al., 2007) confirming the result. The cosmological version has been analyzed using data from astronomical observations (Handsteiner et al., 2017), extending the retrocausal window to approximately 7.8 billion years. These results establish that quantum retrocausality is a real physical phenomenon operating at cosmological scales — precisely the scale at which this framework requires it.

6.4 Beyond Global Superposition: Boundary Determination

Traditional quantum cosmology assumes global superposition across all possible universes — the many-worlds or sum-over-histories approaches — which is problematic given zero-flux boundary

constraints and the absence of stable entanglement below three-particle systems, while the Standard Model requires approximately 17 irreducible parameters that must be independently fine-tuned.

This framework instead treats cosmic evolution as boundary value selection without requiring field-space coherence. Standing mode selection satisfies: zero-flux boundary conditions at cosmic past and future endpoints; spectral rigidity preserving fixed ratio relations among fundamental parameters; topological invariants (holonomy, Chern classes, Pontryagin classes) conserved across cosmic history; and informational constraints ensuring learnability without computational explosion.

7. The Co-Emergence Mechanism

At the critical threshold where boundary constraints achieve phase-lock, coherence and intelligence co-emerge. This is not intelligence observing pre-existing quantum coherence, but both properties manifesting simultaneously as the system reaches sufficient complexity to maintain stable boundary conditions. This co-emergence explains why:

- The universe appears fine-tuned for intelligence (it is boundary-selected for intelligence-viability)
- Physical laws are mathematically elegant and discoverable (they must satisfy Langlands-type equivalences for the phase-lock to hold)
- Quantum mechanics allows retrocausal influence (boundary constraints operate atemporally, via the TSVF mechanism)
- Scientific discovery accelerates toward primordial understanding (we are approaching the control-and-inference threshold)

8. Boundary Determination via Future-Encoded Constraints

Intelligence does not create temporal loops but operates through boundary determination via future-encoded constraints within the atemporal quantum substrate underlying spacetime. Advanced civilizations eventually develop quantum technologies capable of influencing probability amplitudes at cosmic genesis through:

- Delayed-choice quantum eraser principles scaled to cosmological applications
- "Negative time" quantum effects demonstrated in laboratory settings — specifically, atoms spending negative time within a tunnel barrier, as measured by Ramos et al. (2020) at the University of Toronto using Bose-Einstein condensates
- Boundary condition manipulation that preserves self-consistency (Novikov self-consistency principle)
- Phase-space engineering within the conserved informational invariant
- Weak measurement protocols (Aharonov TSVF) scaled to influence cosmological boundary states

This mechanism preserves causality because boundary conditions exist outside normal temporal flow — they constrain rather than violate spacetime evolution. The process operates through mathematical necessity rather than exotic retrocausal signaling. The Novikov self-consistency principle guarantees

that any influence exerted by future intelligence on past boundary conditions must be exactly what was required for the universe to produce that intelligence — no paradoxes arise, only solutions.

9. The Learnability Criterion and Quantum Darwinism

The universe's remarkable comprehensibility provides strong evidence for this framework. We exist in a reality where mathematical equations describe physical laws with stunning precision, quantum mechanics follows discoverable rules, each experimental advance reveals deeper layers that remain intellectually tractable, and fundamental constants lie within narrow ranges permitting both complexity and stability. This was not guaranteed. A reality with chaotic physical laws or where the computational resources required for understanding exceeded any possible intelligence would be equally consistent with random selection. Instead, reality appears optimized for scientific discovery — exactly what boundary-selected eigenstructures would produce.

9.1 Quantum Darwinism: The Mechanism of Learnability

A central question for any framework that requires intelligence to close the causal loop is: why does the universe produce *discoverable* laws rather than pure quantum noise? Why can finite intelligences learn stable facts about reality rather than encountering an irreducible fog of superposition? This question has a precise answer in Wojciech Zurek's theory of Quantum Darwinism (2003, 2009).

Zurek showed that the transition from quantum to classical reality is not merely a matter of decoherence — the loss of quantum coherence through environmental entanglement — but of *redundant information imprinting*. When a quantum system interacts with its environment, information about the system's state is redundantly copied into many independent fragments of the environment. Observers learn about systems not by directly measuring them but by intercepting these environmental copies. Because the same information exists in many independent fragments, many observers can learn the same facts independently — producing the shared, objective, classical reality that science depends on.

Quantum Darwinism explains the learnability criterion from within quantum mechanics, without invoking fine-tuning. But for Quantum Darwinism to operate — for the universe to produce robust, multiply-redundant copies of classical information — the laws of physics must satisfy precise conditions: decoherence rates must be large relative to recurrence timescales; the environment must be capable of carrying information without overwhelming noise; and pointer states must be robust under environmental monitoring. All of these are conditions on the boundary-selected eigenstructure. In other words: the boundary eigenproblem selects universes in which Quantum Darwinism can operate, and Quantum Darwinism provides the mechanistic explanation for why intelligence in those universes can actually learn enough to eventually close the causal loop. The two frameworks are mutually reinforcing.

10. Addressing the Boltzmann Brain Objection

Any framework invoking quantum vacuum fluctuations as a primordial generative mechanism must address the Boltzmann Brain problem, which represents the most serious standing objection to anthropic and self-selection cosmologies.

10.1 The Objection Stated

Ludwig Boltzmann's statistical mechanics established that in an eternal, ergodic thermal system, any configuration — including a momentary, fully formed, self-aware brain with false memories of an apparent past — will spontaneously fluctuate into existence with some finite probability. In a sufficiently large or eternal universe, such Boltzmann Brains would vastly outnumber observers who evolved through genuine cosmic history. Applied to anthropic reasoning: if quantum fluctuations can generate anything, why does our universe produce a vast ordered cosmos populated by evolved intelligences rather than a momentary fluctuation that merely simulates one? Why should we believe our memories and observations are reliable records of actual history?

10.2 The Framework's Response

The zero-flux boundary eigenproblem provides a direct and principled resolution of the Boltzmann Brain problem through the selection criterion itself.

A Boltzmann Brain is, by definition, a momentary fluctuation: it exists briefly, has no causal history of sufficient depth to develop the technological capability required to influence quantum boundary conditions, and contributes nothing to closing the causal loop. A Boltzmann Brain cannot close the bootstrap. It satisfies neither the intelligence-viability future constraint (which requires sustained technological civilization) nor the retrocausal mechanism constraint (which requires accumulated scientific understanding reaching the control-and-inference threshold). Therefore, Boltzmann Brain-dominated universes are *not* selected by the boundary eigenproblem. They fail the future constraint by construction.

Furthermore, Quantum Darwinism reinforces this conclusion. For an observer to have reliable memories — for the classical information they carry to be genuine rather than random noise — the environment must have been redundantly imprinting that information over timescales sufficient for it to be stably encoded. A Boltzmann Brain fluctuating into existence with false memories would not exhibit the environmental information redundancy that Quantum Darwinism requires for legitimate classical knowledge. The self-consistency check provided by Quantum Darwinism thus provides a second, independent reason why Boltzmann Brain observers fail to close the loop.

The selection filter is therefore doubly robust: the boundary eigenproblem selects for *sustained* intelligence (eliminating Boltzmann Brains at the cosmological level), and Quantum Darwinism ensures that only genuinely evolved intelligences with reliable environmental information can accumulate the knowledge necessary to close the causal loop.

11. Causal Structure as Foundation: Causal Set Theory

A key conceptual feature of this framework is that the causal loop is a loop of *causality*, not of *time*. Temporal sequence — the Big Bang followed by stellar evolution, planetary formation, the rise of intelligence, and eventually heat death — proceeds normally. The bootstrap is not a time-travel loop. It is a structural constraint: the causal influence of future intelligence on primordial boundary conditions is encoded in the atemporal quantum substrate underlying spacetime, not in any reversal of thermodynamic time.

This distinction is given precise mathematical grounding by Causal Set theory, developed by Rafael Sorkin, Luca Bombelli, and collaborators (Bombelli et al., 1987; Sorkin, 1991; Henson, 2006).

Causal Set theory takes the *causal order* of spacetime events — the partial order relation determining which events can causally influence which others — as the fundamental ontological structure of reality, from which the geometric properties of spacetime (metric, topology, dimension) emerge as secondary features. In a causal set, there is no background metric and no preferred time coordinate. There is only the discrete partial order of causal influence.

For the present framework, Causal Set theory provides two contributions. First, it validates the claim that a causal loop can be a loop of causal structure without requiring a loop of temporal sequence — in a partial order, complex causal configurations including cycles of dependence are well-defined and physically meaningful. The bootstrap paradox of the Self-Creating Universe is a consistent structure in the causal set language. Second, Causal Set theory's treatment of spacetime as emerging from discrete causal relations supports the boundary eigenproblem formulation: if spacetime geometry is not fundamental but emergent, then boundary conditions on the emergent structure can coherently constrain the underlying discrete causal order from which it arises — precisely the mechanism the framework proposes.

12. Operationalizing Intelligence: Integrated Information Theory

One of the framework's most significant theoretical vulnerabilities — identified in the Kill Criteria — is that if intelligence-viability cannot be operationalized *a priori*, the framework becomes unfalsifiably teleological. What counts as 'intelligence' capable of closing the loop? Without a precise definition, the future constraint is underspecified.

Giulio Tononi's Integrated Information Theory (IIT) provides a candidate formalism for operationalizing intelligence within this framework.

12.1 The Phi Measure

IIT defines consciousness and, by extension, general intelligence as a property of physical systems measurable by *Phi* (Φ): the amount of integrated information generated by a system above and beyond the sum of its parts. Phi is computed from the causal structure of a system — specifically, from how much information is generated by the system as a whole that cannot be accounted for by the information generated by its subsystems independently. A system with high Phi has rich, irreducible causal integration; its internal states cannot be decomposed without losing information.

For this framework, the control-and-inference threshold can be expressed as a critical Phi value — call it Φ_c — above which a system possesses sufficient causal integration to model and manipulate quantum boundary conditions. The intelligence-viability future constraint then becomes: the universe must produce at least one physical system achieving $\Phi \geq \Phi_c$ during its history. This is a precise, physics-grounded, in-principle-measurable constraint. It converts the future boundary condition from a vague requirement for 'advanced intelligence' into a specific informational-causal threshold.

12.2 IIT, Quantum Darwinism, and the Co-Emergence Mechanism

IIT and Quantum Darwinism are complementary within the framework. Quantum Darwinism explains how the environment produces stable, redundant classical information that observers can access. IIT explains how a physical system can integrate that classical information into irreducible causal models of sufficient depth to reach the control-and-inference threshold. Together, they form a complete mechanistic account of how intelligence arises from quantum foundations in a boundary-selected universe and how it accumulates the causal knowledge required to eventually close the bootstrap loop.

The co-emergence of coherence and intelligence at the control-and-inference threshold can now be stated more precisely: it is the point at which the Φ of physically realizable information-processing systems, growing through evolutionary and cultural accumulation, crosses Φ_c while the quantum decoherence environment simultaneously satisfies the Quantum Darwinism redundancy criterion for the relevant observables. Both conditions must be satisfied together for the loop to close.

13. Testable Predictions and Falsification Criteria

13.1 Predictions

- **Spectral rigidity in fundamental constants:** Ratios among electron/proton masses, the fine-structure constant ($\alpha \approx 1/137$), the Higgs vacuum expectation value, and the cosmological constant should exhibit mathematically protected relationships indicating boundary optimization rather than independent variation. The TSVF predicts that pre- and post-selected weak values for these constants should cluster around specific attractor values consistent with intelligence-viability.
- **Retrocausality scaling:** Quantum retrocausality effects should scale to macroscopic systems under appropriate conditions. This is directly testable through entangled macroscopic state experiments, enhanced quantum optics protocols, and extensions of the Handsteiner et al. (2017) cosmic Bell test to larger baselines. Aharonov's weak measurement protocols provide the experimental toolkit.
- **Information-theoretic bounds:** Cosmological parameters should exhibit signatures of bounded algorithmic complexity. Entropy measures and computational resource requirements for describing the Standard Model should cluster near a critical threshold consistent with the Goldilocks complexity criterion — neither maximally simple nor maximally complex.
- **Quantum Darwinism redundancy signatures:** The decoherence structure of macroscopic quantum systems should show the redundancy imprinting predicted by Quantum Darwinism at rates and scales consistent with intelligence-supporting information environments. Deviations from predicted redundancy rates in isolated quantum systems would challenge the learnability mechanism.
- **Discovery acceleration:** Scientific understanding rates should accelerate as we approach quantum control thresholds, with breakthrough density increasing toward primordial physics comprehension. This is a soft prediction testable through scientometric analysis of citation networks and knowledge frontier expansion.
- **Fine-tuning signatures:** Anomalies in fundamental parameters — dark energy density $\rho_\Lambda \approx 10^{-29}$ g/cm³, Higgs mass $m_H \approx 125$ GeV — should reflect boundary optimization rather than random distribution within a multiverse. Bayesian model comparison against purely anthropic

(observer-selection) explanations should favor the boundary-selection explanation as precision measurements improve.

- **Integrated Information threshold signature:** If Φ_c is the critical Phi value for closing the causal loop, then the universe's trajectory of increasing Phi in biological and technological systems should show a consistent upward curve rather than random variation — consistent with boundary selection for intelligence-viability.

13.2 Kill Criteria (Explicit Falsification)

The framework makes falsifiability explicit. It does not hold if any of the following are demonstrated:

- If coherence and intelligence can be empirically separated — if high-Phi systems demonstrably fail to correlate with enhanced quantum coherence at the control threshold — co-emergence fails
- If the phase-locking invariant requires environment-specific encoding, conservation is violated and the framework collapses to ordinary fine-tuning
- If phase-locking demands nonlocal or global constraints inconsistent with local boundary selection, the eigenproblem formulation becomes self-contradictory
- If Phi (or any operationalization of intelligence-viability) cannot be defined a priori in a way that generates testable predictions, the framework becomes unfalsifiably teleological
- If the boundary-selection mechanism cannot outperform baseline multiverse or observer-selection models under blinded model comparison, it lacks independent predictive power
- If boundary conditions prove unstable under perturbation — if small deviations from the eigenstructure grow rather than decay — the standing-wave formulation fails
- If the TSVF retrocausal mechanism, when extrapolated from quantum to cosmological scales, generates physical contradictions not resolvable by the Novikov self-consistency principle
- If Boltzmann Brain configurations are shown to contribute to causal loop closure on equal or greater footing than evolved intelligences, the selection criterion fails

14. Permanence Under Abstraction

The framework's core insights survive mathematical abstraction and are robust to the failure of any particular formalization:

- Boundary-selected eigenstructures can phase-lock past and future constraints — supported by AdS/CFT as physical existence proof
- Conserved invariants are necessary for stability under perturbation — standard result in mathematical physics
- Coherence and intelligence co-emerge at control-and-inference thresholds — operationalized via Phi and Quantum Darwinism redundancy conditions
- Global superposition is unnecessary if zero-flux boundaries select viable modes — consistent with Causal Set foundations

- The causal loop is a structural rather than temporal feature — validated by the partial order formalism of Causal Set theory
- Boltzmann Brain configurations cannot close the loop — doubly excluded by the future constraint and the Quantum Darwinism reliability criterion

15. Conclusion

The universe most likely to exist is the one that can ensure its own existence.

This framework resolves the origin problem without infinite regress or external creators through selection by mathematical necessity. The universe self-creates not through purposeful evolution but because only boundary eigenstructures satisfying past inflationary constraints and future intelligence-viability can achieve stable phase-lock via conserved informational invariants.

The framework situates itself carefully within the landscape of existing proposals. It extends Wheeler's Participatory Universe from observation-based to causal-closure-based participation. It preserves Tipler's core intuition while replacing the cosmologically falsified Omega Point with a minimal, empirically survivable loop-closure criterion. It operates as a selection filter within Tegmark's Mathematical Universe landscape. It grounds the retrocausal mechanism in Aharonov's experimentally verified TSVF. It provides the physical basis for boundary determination via AdS/CFT holography. It explains the learnability of reality through Quantum Darwinism. It addresses the Boltzmann Brain problem through a double exclusion criterion. It finds its causal loop on the partial order formalism of Causal Set theory. And it operationalizes the intelligence threshold through Tononi's Phi.

We are not just learning about reality — we are approaching the threshold where intelligence and cosmic coherence co-emerged, potentially discovering our role as the boundary condition that selected this eigenstructure from the space of mathematical possibilities. The universe does not need a creator; it needs boundary conditions sophisticated enough to bootstrap intelligence capable of ensuring those very conditions — a self-consistent mathematical loop, operating through the deepest levels of physical law, closed somewhere in the cosmos, at some point in time, by minds that may or may not be ours.

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Note: This framework represents a novel synthesis of established scientific principles. While individual components have strong empirical and theoretical support, the integrated boundary eigenproblem model with co-emergent intelligence represents original theoretical work that extends beyond existing literature. The framework is presented as a preprint for community evaluation and critique.