PREPRINT v1.0.0 | Not peer-reviewed

The Temporal Bitmap Interpretation of Quantum Mechanics

A Parsimonious Reframing of Wave Function Dynamics as Static Structure Traversal

Murad Farzulla[1,2] 0009-0002-7164-8704

[1] *Farzulla Research*

[2] *King's College London*

December 2025

Correspondence: murad@farzulla.org

Abstract

This paper proposes the Temporal Bitmap Interpretation (TBI) of quantum mechanics, which reframes apparent wave function dynamics as static structure traversal through a four-dimensional block universe. On this view, what we perceive as quantum indeterminacy, wave function collapse, and entanglement correlations are artifacts of our epistemic position as observers traversing a determinate 4D structure. The interpretation treats wave functions not as evolving probability amplitudes but as aliased readings of a two-valued phase field (± 1)—a minimal degree of freedom sampled at insufficient temporal resolution. This framework eliminates the measurement problem without invoking observer-dependent collapse, hidden variables, or parallel universes, achieving significant ontological parsimony while remaining empirically equivalent to standard quantum mechanics. TBI naturally accommodates retrocausality, explains entanglement without nonlocality, and offers a unified account connecting Wheeler's 'it from bit,' Minkowskian eternalism, and the hypothesis that quantum phenomena emerge from undersampling. I sketch the formal mapping, propose experimental signatures, and explicitly identify where rigorous derivation remains incomplete.

Keywords: quantum mechanics, interpretation, block universe, eternalism, wave function collapse, measurement problem, digital physics, information theory, retrocausality, entanglement

Publication Metadata

DOI: 10.5281/zenodo.18091063
Version: 1.0.0
Date: December 2025
License: CC-BY-4.0

Core Claims and Open Problems

What TBI Claims:

1. The universe is a static 4D block containing a two-valued phase field $\Phi : M \to \{-1, +1\}$
2. 'Particles' are coherent regions of Φ; 'dynamics' are traversal through this static structure
3. Wave functions describe coarse-grained sampling of Φ; 'collapse' is transition to fine-grained sampling
4. Superposition is aliasing from sampling phase oscillations at insufficient temporal resolution
5. Entanglement correlations arise from structural identity in the 4D block, not nonlocal causation

What Would Constitute a Derivation:

1. Specify how Φ generates complex-valued wave functions ψ
2. Derive the Schrödinger equation from phase field structure
3. Show that sampling statistics necessarily yield $|\psi|^2$ (Born rule)
4. Demonstrate that interference patterns emerge from phase correlations

What Remains Hand-Waving:

- The Born rule correspondence is *conjectured*, not derived
- No explicit dynamics for the traversal function τ
- The matter/antimatter identification is illustrative, not mandatory
- Extension to QFT is sketched but not formalized

What Would Falsify This:

- If superposition effects *persist* at arbitrarily high measurement resolution (no approach to phase-sampling limit)
- If entanglement correlations violate structural constraints from shared 4D regions
- If any phenomenon requires genuine ontological indeterminacy incompatible with a determinate block

This interpretation is currently empirically equivalent to standard QM. The above falsification conditions are in-principle tests, not near-term experimental proposals.

Research Context

This work forms part of the Adversarial Systems Research program, which investigates stability, alignment, and friction dynamics in complex systems where competing interests generate structural conflict. The program examines how agents with divergent preferences interact within institutional constraints across multiple domains: political governance, financial markets, human cognitive development, and artificial intelligence alignment.

The Temporal Bitmap Interpretation presented here extends this framework to fundamental physics by reconceiving the apparent conflict between determinism and quantum indeterminacy. Rather than treating measurement outcomes as genuinely random events requiring special physical mechanisms, TBI proposes that apparent randomness emerges from the epistemic limitations of observers traversing a determinate structure. This dissolves the 'adversarial' relationship between quantum and classical physics by showing that the conflict was always perspectival rather than ontological.

This interpretation connects to the broader research program's investigation of how apparent conflicts between competing frameworks can be dissolved through careful analysis of the observer's epistemic position—a pattern that recurs in political legitimacy (stakeholder consent vs. technocratic efficiency), financial markets (regulatory stability vs. market innovation), and AI alignment (human preferences vs. agent objectives).

Acknowledgements

The author acknowledges the use of Claude (Anthropic) for assistance with literature review, argument refinement, and manuscript preparation. All substantive claims, theoretical frameworks, and the core interpretation are the author's own.

DOI: 10.5281/zenodo.18091063

Contents

1 Introduction: The Interpretation Problem

Nearly a century after the formalization of quantum mechanics, the interpretation problem remains unresolved. The formalism works—quantum mechanics is the most precisely confirmed theory in the history of science—but we lack consensus on what it describes. The wave function evolves deterministically according to the Schrödinger equation, yet measurement appears to induce instantaneous, probabilistic 'collapse' to definite outcomes. This duality has generated competing interpretations: Copenhagen's observer-dependent collapse (Bohr, 1928), Many Worlds' branching universes (Everett, 1957), Pilot Wave's hidden variables (Bohm, 1952), and numerous others.

Each interpretation carries ontological costs. Copenhagen posits a fundamental role for observation without explaining what constitutes an 'observer' or why measurement differs from other interactions. Many Worlds proliferates universes with every quantum event, creating an ontology of staggering complexity. Pilot Wave introduces nonlocal hidden variables that must be carefully crafted to reproduce quantum statistics. Objective collapse theories (Ghirardi et al., 1986; Penrose, 1996) add new physics that remains empirically undetected.

This paper proposes an interpretation that achieves parsimony by reconceiving the problem entirely. Rather than asking 'what causes collapse?' or 'where do the other outcomes go?', I ask: what if the apparent dynamics are artifacts of our epistemic position? What if the wave function neither evolves nor collapses, but simply exists as a static structure that we traverse?

The Temporal Bitmap Interpretation (TBI) takes seriously the block universe of special relativity—the view that past, present, and future exist equally (Minkowski, 1908; Putnam, 1967; Rietdijk, 1966)—and applies it to quantum phenomena. On this view, what we call 'particles' are not point-objects moving through space but cross-sections of structures extending through time. 'Wave function collapse' is not a physical process but a sampling event: the intersection of an observer's traversal path with a point on the static structure. The apparent randomness of quantum measurement reflects which phase we happen to sample, not ontological indeterminacy.

The interpretation is called 'Temporal Bitmap' because it treats the universe as a four-dimensional phase field—a structure extended through time—where each point encodes one of two phase signs (± 1). Consciousness, on this view, is the traversal process: the sequential reading of this static structure that creates the phenomenology of time 'flowing' and events 'happening.'

2 Philosophical Foundations

2.1 The Block Universe and Eternalism

The block universe thesis holds that past, present, and future are equally real—that the universe is a four-dimensional 'block' of spacetime in which all events exist timelessly (Sider, 2001). This view follows naturally from special relativity: the relativity of simultaneity implies that there is no objective 'now,' and if the present has no privileged status, the asymmetry between past (real) and future (unreal) becomes untenable (Putnam, 1967; Rietdijk, 1966).

Eternalism—the metaphysical position that all times exist—is the natural companion to the block universe. As Sider (2001) argues, eternalism best accommodates the four-dimensional geometry of Minkowski spacetime. The distinction between 'is' (tenseless existence) and 'is now' (tensed existence) resolves the apparent contradiction: Caesar exists in the block (tenselessly), though Caesar does not exist now (tensed).

TBI extends this framework to quantum mechanics. If the future already exists in the block, then quantum 'indeterminacy' cannot be genuine ontological openness—there is nothing genuinely open if the future is already fixed. Instead, apparent indeterminacy must reflect our epistemic position: we cannot know which point on the determinate structure we will sample until we sample it.

2.2 Digital Physics and 'It from Bit'

Wheeler (1990) proposed that physical reality emerges from information: 'every it—every particle, every field of force, even the spacetime continuum itself—derives its function, its meaning, its very existence entirely. . . from the apparatus-elicited answers to yes-or-no questions, binary choices, bits.' This 'it from bit' doctrine suggests that physics is fundamentally computational, that the universe is built from information rather than matter.

Digital physics programs have developed this intuition. Fredkin (1990) proposed that the universe operates as a cellular automaton with discrete, finite states. Zuse (1969) suggested that space itself might be discrete at the Planck scale, executing computational rules. Wolfram (2002) demonstrated that simple computational rules can generate complex, physics-like behavior.

TBI takes Wheeler's metaphor seriously. The 'bits' are the ± 1 phase signs at each point of the phase field. The 'its' emerge from traversal—from the sequential reading that creates the phenomenology of matter, energy, and causation. The universe is not merely describable as information; it *is* structure, extended in four dimensions and sampled as time.

2.3 Retrocausality and Temporal Symmetry

The fundamental equations of physics are time-symmetric: they work equally well run forward or backward. Yet we observe temporal asymmetry—causes precede effects, entropy increases, we remember the past but not the future. This asymmetry is typically attributed to boundary conditions (the low-entropy Big Bang) rather than fundamental laws.

Some physicists have proposed retrocausal interpretations of quantum mechanics in which future boundary conditions influence present states (Price, 1996; Wharton, 2015; Sutherland, 2017). These approaches can explain entanglement correlations without nonlocality: if future measurements can influence past states, correlations need not be established instantaneously across space.

TBI naturally accommodates retrocausality because 'causality' itself is reframed. In a static block, there is no temporal becoming in which causes 'produce' effects. Instead, there are lawful patterns connecting different regions of the 4D structure. What we call 'causation' is the correlation structure of the phase field; what we call 'retrocausation' is simply attending to correlations we typically ignore. The temporal asymmetry of our experience—our sense that the past is fixed and the future open—reflects our traversal direction, not the structure of the block itself.

3 Core Postulates of TBI

The Temporal Bitmap Interpretation rests on five core postulates, each of which will be elaborated and defended in subsequent sections.

3.1 Static Ontology (P1)

Postulate 1: The universe is a static four-dimensional structure. What we perceive as 'change' is traversal through this structure, not modification of it.

This postulate extends the Minkowskian block universe to its logical conclusion. The block does not merely exist timelessly; it is causally inert. Nothing happens 'to' the block. The appearance of happening is generated by the traversal process—by consciousness (or functional analogs thereof) moving through the structure and encountering successive cross-sections as 'now.'

The static ontology has a crucial implication: the wave function does not evolve. What we interpret as Schrödinger evolution is the pattern of the wave function extended through time. The equation describes the shape of the structure, not its dynamics, just as an equation describing a helix describes its shape, not its 'motion.'

3.2 Two-Phase Sign Convention (P2)

Postulate 2: What we call 'particles' are not point-objects moving through space but cross-sections of structures extending through time, encoded as a two-valued phase field taking values ± 1.

This postulate identifies Wheeler's 'bits' with a minimal two-branch degree of freedom. At each point along its temporal extension, a particle-structure occupies one of two phase states. The ± 1 sign convention is a phase proxy—the physical instantiation might be matter/antimatter phase opposition, but the formalism requires only a two-valued oscillation between opposed phase signs.

Formally, let Φ be a four-dimensional phase field:

$$\Phi : \mathbb{R}^3 \times \mathbb{R}_t \to \{-1, +1\} \tag{1}$$

Each 'particle' is a connected region $\mathcal{P} \subset \Phi$ with coherent phase structure. The particle's trajectory through spacetime is not a worldline (one-dimensional) but a worldtube (four-dimensional), and its properties at any moment reflect the cross-section of this tube at that time.

3.3 Apparent Wave Behavior (P3)

Postulate 3: The 'wave function' emerges from sequential reading of discrete phase states. Linear traversal through alternating ± 1 states appears as oscillation to an observer embedded in the time dimension.

This postulate explains wave-particle duality. The underlying structure is discrete (two-valued phase states), but our experience of it is continuous (we traverse smoothly). The wave function is the Fourier transform of the discrete structure—or more precisely, it is how continuous traversal samples a discrete pattern.

The analogy is to digital audio. A CD encodes sound as discrete samples, yet playback produces continuous waves. The wave is not 'in' the samples; it emerges from their sequential reading. Similarly, the wave function is not 'in' the phase field; it emerges from traversal.

3.4 Measurement as Sampling (P4)

Postulate 4: 'Wave function collapse' is not a physical process but a sampling event—the intersection of an observer's traversal path with a specific point on the structure. The apparent randomness reflects which phase we intersect, not ontological indeterminacy.

This postulate dissolves the measurement problem. There is no collapse because there is nothing to collapse—the structure is already determinate. What we call 'measurement' is simply our coming to know a definite value that was always there. The Born rule probabilities reflect our uncertainty about which point we will sample, not objective chances.

The formal statement: let τ be a traversal function mapping subjective time to block-time:

$$\tau : \mathbb{R}_{\text{subjective}} \to \mathbb{R}_t \tag{2}$$

For embedded observers, τ is monotonic (we experience time 'forward'), creating the phenomenology of temporal flow. Measurement at subjective time s samples the structure at block-time $\tau(s)$, returning a determinate value.

3.5 Superposition as Aliasing (P5)

Postulate 5: Superposition occurs when the measurement interval $\Delta t_{\text{measure}}$ spans multiple phase transitions. The 'superposition' is not ontological—it is aliasing from insufficient sampling resolution.

This postulate reconceives superposition. A system is not genuinely 'in multiple states at once'; rather, our measurement averages over a temporal region containing multiple phase states. The superposition is epistemic—a reflection of our coarse-grained observation—not ontic.

The Nyquist-Shannon sampling theorem provides the formal framework. If the phase oscillation frequency is f, and we sample at rate $r < 2f$, aliasing occurs: the sampled signal does not faithfully represent the underlying structure. Superposition is the quantum mechanical signature of aliasing in time.

Interpretive Note: On the Status of Phase Encoding

The ± 1 convention is a phase sign proxy, not a claim about information bits. The specific values $\{-1, +1\}$ denote phase opposition—a two-branch degree of freedom that could be physically instantiated as matter/antimatter, peak/trough of an oscillation, or any other binary phase distinction. This is *not* digital physics in the sense of the universe being a computer processing discrete bits.

The core thesis of TBI does not depend on this particular encoding. What is essential is the **sampling hypothesis**: that quantum mechanical phenomena—superposition, collapse, entanglement—may arise from measuring a determinate underlying structure at insufficient temporal resolution. The two-valued phase field provides a minimal, concrete instantiation of this idea. Alternative encodings (continuous phase $e^{i\theta}$, higher-dimensional states, etc.) could serve the same explanatory role.

The framework should be understood as a **hypothesis about the relationship between measurement and underlying structure**, not a definitive claim about the fundamental alphabet of physics. We propose a mapping, identify necessary assumptions, and acknowledge where derivation remains incomplete.

4 Formal Structure

4.1 The Phase Field

Let Φ be a four-dimensional phase field defined over Minkowski spacetime M:

$$\Phi : M \to \{-1, +1\} \tag{3}$$

The field assigns to each spacetime point a phase sign. This is the fundamental ontology: spacetime plus a two-valued degree of freedom. All else—particles, fields, forces—is derived.

A 'particle' $\mathcal{P}$ is defined as a connected region of Φ satisfying coherence conditions:

1. *Phase coherence*: the ± 1 values within $\mathcal{P}$ exhibit regular oscillation patterns.
2. *Boundary coherence*: the boundary $\partial\mathcal{P}$ is well-defined across time.
3. *Conservation*: certain integral properties of $\mathcal{P}$ are preserved across spacelike slices.

The 'mass' of a particle corresponds to the oscillation frequency of its phase states. Higher-frequency oscillation = higher mass. This provides a digital-physics gloss on the de Broglie relation: $m = h\omega/(2\pi c^2)$, where ω is now interpreted as the literal frequency of phase alternation.

4.2 Traversal Dynamics

An observer O is characterized by a traversal function τ_O:

$$\tau_O : \mathbb{R} \to M \tag{4}$$

This function maps the observer's subjective time parameter to spacetime points. The observer's 'experience' at subjective time s is the value $\Phi(\tau_O(s))$—or more precisely, a coarse-grained average over a neighborhood of $\tau_O(s)$.

The subjective experience of 'time flowing' is the monotonicity of τ_O in the time direction. The subjective experience of 'locality' is the continuity of τ_O in the space directions. The subjective experience of 'measurement' is the restriction of averaging to smaller neighborhoods, approaching point-sampling in the limit.

4.3 The Born Rule: A Proposed Mapping

What we propose: Consider a region R of the phase field containing values that oscillate with frequency f. An observer sampling R at rate $r < 2f$ will experience aliasing. The probability of observing phase $+1$ versus -1 depends on the duty cycle of the oscillation within R.

The conjectured correspondence: Let $\psi(x)$ be the complex wave function standardly associated with a quantum system. TBI proposes that $|\psi(x)|^2$ corresponds to the proportion of one phase state in the temporal extension of the structure at spatial location x. On this view, the Born rule probabilities are not fundamental chances but frequencies-in-time, analogous to how a biased coin's probability reflects its physical asymmetry.

The complex phase of $\psi(x)$ would encode the timing of oscillations: systems with aligned phases (constructive interference) have correlated oscillations; systems with opposed phases (destructive interference) have anti-correlated oscillations that cancel upon averaging.

What remains hand-waving: This sketch does not yet constitute a derivation. A rigorous account would need to: (1) specify how the phase field Φ generates the complex-valued ψ; (2) derive the Schrödinger equation from phase field dynamics; (3) show that sampling statistics necessarily yield $|\psi|^2$. These constitute the primary open mathematical problems for TBI.

4.4 Entanglement as Structural Identity

The deepest puzzle of quantum mechanics is entanglement: distant particles exhibit correlated measurement outcomes that cannot be explained by local hidden variables (Bell, 1964). Standard interpretations must posit either nonlocality (spooky action at distance) or many worlds (correlations within branches) or retrocausality.

TBI offers a simpler solution: entangled particles are not two objects mysteriously correlated; they are the same object intersected at different points.

In the 4D block, what we call an 'entangled pair' is a single structure $\mathcal{P}$ with a branching topology. The two 'particles' are cross-sections of $\mathcal{P}$ at different spatial locations but connected through time. Measuring one 'particle' and finding correlation with another is just reading two points on the same phase structure.

Formally, if particles A and B are entangled, then:

$$\mathcal{P}_A \cap \mathcal{P}_B \neq \emptyset \text{ in } \Phi \tag{5}$$

The intersection occurs in the temporal dimension: the 'two' particles share a common past region of the phase field. The correlations are not established 'at measurement' (requiring nonlocality) but are intrinsic to the structure's geometry.

4.5 Antimatter and Annihilation

On TBI, matter and antimatter are not different substances but different phases: $+1$ and -1. What we call 'pair creation' is the spawning of a structure with alternating phases; what we call 'annihilation' is destructive interference when both phases are sampled simultaneously.

The 'energy release' in annihilation is the consequence of forcing opposed phases into superposition at observation. When a measurement samples both $+1$ and -1 states (because a particle and antiparticle are co-located), the result is neither—instead, the sampling process produces a different kind of excitation (photons) that encodes the structural information in a phase-symmetric way.

The baryon asymmetry problem—why is there more matter than antimatter?—receives a novel framing. On TBI, the question is: why does our traversal direction favor one phase over the other? The answer may lie in the initial conditions of the block: the Big Bang boundary preferentially contains one phase sign, and our traversal direction was set by thermodynamic gradients emerging from that boundary.

5 Derived Consequences

5.1 Dissolution of the Measurement Problem

The measurement problem asks: what physical process causes wave function collapse, and why does it occur upon 'measurement' but not other interactions? TBI dissolves this problem by denying its presuppositions.

On TBI, there is no collapse because the wave function never existed as a physical entity that could collapse. The wave function is a mathematical description of the phase field's structure as it appears to coarse-grained observation. 'Collapse' is the transition from coarse-grained to fine-grained sampling—from averaging over a temporal region to (approximately) point-sampling.

This dissolves the problem rather than solving it. We do not need to explain what 'observers' are or why they trigger collapse, because observation is not a special physical process—it is simply the traversal/sampling that all physical systems do. The asymmetry between measured and unmeasured systems is epistemic (we know the result) not ontic (the system changed).

5.2 Compatibility with Special Relativity

A major advantage of TBI is its natural compatibility with special relativity. The block universe is the geometric structure required by SR; TBI adds only the phase field Φ and the traversal interpretation.

The Lorentz transformations apply to the block as usual. Different inertial observers slice the block differently, but all agree on the invariant structure of Φ. The phase values $\{-1, +1\}$ are Lorentz-invariant; only the appearance of oscillation frequency changes with reference frame, in accordance with time dilation.

Crucially, TBI explains nonlocal correlations without superluminal signaling. Entangled particles are structurally identical in the block; measuring one reveals information about the other because they are the same structure. No signal passes between them because there is nothing to pass—the correlation is geometric, not causal.

5.3 Natural Retrocausality

TBI naturally accommodates retrocausal phenomena. Since the block is static and contains all times, there is no fundamental distinction between 'past-to-future' and 'future-to-past' correlations. Both are simply patterns in the 4D structure.

The transactional interpretation of quantum mechanics (Cramer, 1986) posits 'offer waves' traveling forward in time and 'confirmation waves' traveling backward, with transactions forming between them. TBI provides a natural ontology for this: the 'waves' are not traveling at all but are static structures, and the 'transaction' is the intersection of these structures in the block.

Wheeler's delayed-choice experiment (Wheeler, 1978) and its extensions (Jacques et al., 2007) appear to show that future measurements affect past behavior. On TBI, this is unsurprising: the 'past' and 'future' are equally real and constrain each other. The past is not 'already happened' in a way that precludes future influence; both are fixed points in a static structure.

6 Comparison with Other Interpretations

To evaluate TBI's merits, we compare it to major competing interpretations on several criteria: ontological parsimony, explanatory power, compatibility with relativity, and treatment of the measurement problem.

TBI's primary advantage is parsimony. It requires no new physics (unlike objective collapse), no extra universes (unlike Many Worlds), no nonlocal hidden variables (unlike Pilot Wave), and no undefined notion of 'observer' (unlike Copenhagen). It requires only the block universe—already implied by special relativity—plus a two-valued phase field and the reinterpretation of wave function dynamics as traversal.

7 Objections and Replies

7.1 The Traversal Problem

Objection: If the block is static, what explains the traversal? Isn't 'traversal through the block' just a restatement of time passing, smuggling in the very temporal becoming that the block universe was supposed to eliminate?

Reply: The traversal is not a process occurring 'in time'—that would indeed be circular. Rather, traversal is a structural feature of certain patterns in the block: those patterns we identify as conscious observers. An observer-pattern extended through time contains, at each temporal slice, representational states that encode the content of 'earlier' slices. This structural property—that later stages represent earlier stages—constitutes memory and the experience of temporal flow, without requiring anything to 'move' through the block.

Consider the analogy of a novel. A novel is a static structure (a sequence of symbols), yet reading it generates the experience of narrative flow, of events 'happening.' The flow is real as experience without the symbols changing. Similarly, the block is static, but the structural relationships within it constitute experiences of temporal flow for embedded patterns.

7.2 Empirical Equivalence

Objection: If TBI makes the same predictions as standard quantum mechanics, what reason is there to prefer it? Isn't it merely a reinter-

Interpretation	Ontological Cost	Measurement	Entanglement
Copenhagen	Observer-dependent collapse	Unexplained	Nonlocal
Many Worlds	Infinite universes	Branching	Branch correlations
Pilot Wave	Nonlocal hidden variables	Deterministic	Nonlocal guidance
Objective Collapse	New physics (GRW/Penrose)	Physical collapse	Collapse-induced
TBI	**Block + phase field**	**Sampling**	**Structural identity**

Table 1: Comparison of quantum mechanical interpretations

pretation with no empirical content?

Reply: First, empirical equivalence is not a defect—all viable interpretations must be empirically equivalent to standard QM in the confirmed domain. The question is which interpretation is theoretically preferable on grounds of parsimony, explanatory power, and compatibility with other physics.

Second, TBI may not be strictly empirically equivalent. Section 8 proposes experiments that could distinguish TBI from alternatives. If measurement is sampling of a determinate structure, certain patterns should emerge at high temporal resolution that would not appear on collapse interpretations.

7.3 Free Will and Fatalism

Objection: If the future already exists in the block, aren't we fatally committed to fatalism? Doesn't TBI eliminate free will and moral responsibility?

Reply: This objection conflates determinism with fatalism. Determinism is the thesis that states evolve according to laws; fatalism is the thesis that our actions don't matter. The block universe is compatible with compatibilist free will: our choices are real patterns in the block, causally efficacious in the sense that they are nodes in the correlation structure.

More importantly, TBI does not change the phenomenology of choice. From within the block, embedded observers experience deliberation, choice, and action just as they would on any interpretation. The metaphysics of the block does not reach down to phenomenology in a way that eliminates agency.

7.4 Why Two-Valued?

Objection: Why should the fundamental field be two-valued? This seems arbitrary. And why identify the phases with matter and antimatter?

Reply: The ± 1 phase field is the minimal nontrivial structure—a single degree of freedom that can oscillate. A field taking only one value would be structureless. A field taking two values is the simplest structure capable of exhibiting periodic behavior. This is consistent with Wheeler's 'it from bit' and with the information-theoretic foundations of physics (Lloyd, 2006).

Critically, the ± 1 values are a *sign convention*, not a claim that the universe processes digital bits. The physical instantiation could be matter/antimatter phase opposition, peak/trough of a wave, or any other two-branch degree of freedom. CPT symmetry motivates the matter/antimatter correspondence: matter and antimatter are related by charge conjugation, parity inversion, and time reversal. On TBI, time reversal swaps the direction of traversal, which swaps the apparent phase sign. This naturally identifies matter/antimatter with phase opposition, but the core formalism would survive alternative identifications.

7.5 Quantum Field Theory

Objection: You've discussed particle quantum mechanics, but modern physics uses quantum field theory. Can TBI extend to QFT?

Reply: The extension is natural. In QFT, particles are excitations of underlying fields. On TBI, the phase field Φ is the fundamental field; 'particles' are coherent excitation patterns in Φ. Field operators create and annihilate patterns; the vacuum is the ground-state configuration of Φ (perhaps alternating ± 1 at the Planck scale, appearing smooth at larger scales).

The renormalization program in QFT can be understood as the systematic relationship between fine-grained Φ-structure and coarse-grained observations. Divergences arise when we pretend the field is continuous; renormalization is the correction for discrete underlying structure.

8 Experimental Signatures

Although TBI is designed to reproduce standard quantum predictions, it suggests experimental directions that could provide distinguishing evidence.

8.1 High-Frequency Sampling Effects

If superposition is aliasing from insufficient temporal resolution, sufficiently fast measurements should reduce apparent superposition. This predicts that as measurement technology improves, we should observe transitions from superposition to determinate states at timescales approaching the phase oscillation frequency.

The relevant timescale is presumably Planckian ($\sim 10^{-43}$ seconds), far beyond current technology. However, intermediate effects might be detectable: systematic deviations from Born rule probabilities at the fastest achievable measurement rates could indicate approach to the sampling limit.

8.2 Entanglement Geometry

If entangled particles are the same structure at different intersection points, their correlations should exhibit geometric regularities reflecting the 4D topology. Specifically, the 'amount' of entanglement should correlate with the size of the shared region in the block.

This suggests experiments varying the preparation history of entangled pairs while measuring correlation strength. Pairs with longer shared histories (more intersection in the block) should show stronger correlations than minimally-prepared pairs.

8.3 Retrocausal Signatures

TBI predicts that future boundary conditions influence present states. This is consistent with delayed-choice experiments, but stronger tests are possible. The 'two-state vector formalism' (Aharonov and Vaidman, 1990) already incorporates both past and future boundary conditions; TBI provides its natural interpretation.

Experiments probing weak values and post-selection could provide evidence. On TBI, weak values are not mysterious—they reflect the structure of the block as constrained by both initial and final conditions.

9 Connections to Consciousness

TBI has implications for philosophy of mind. If consciousness is the traversal process—the sequential sampling of the block that creates the phenomenology of time—then several traditional problems receive new framings.

9.1 The Unity of Consciousness

The 'binding problem' asks how diverse neural processes give rise to unified conscious experience. On TBI, the unity is structural: a conscious observer is a coherent pattern in the block, and its coherence across time is what constitutes the unity of experience. The pattern at each moment represents (and is connected to) the pattern at adjacent moments, creating the experience of a persisting self.

9.2 The Passage of Time

The experience of time 'passing' is notoriously difficult to explain on block universe views. TBI offers a solution: passage is what traversal feels like from inside. The block does not change, but embedded observer-patterns have structural properties that constitute the experience of change—memories of 'past' states, anticipations of 'future' states, and a sense of presentness at each moment.

9.3 Free Will Revisited

On TBI, free will is reframed as the structural property of observer-patterns that their future states depend on their deliberative states. A choice is 'free' in the relevant sense if the agent-pattern's deliberation is a genuine node in the correlation structure—if removing it would change the downstream pattern.

This is compatibilist, but in a new key: rather than locating freedom in the absence of external constraint, TBI locates it in the positive contribution of deliberation to the block's structure.

10 Conclusion

The Temporal Bitmap Interpretation offers a parsimonious, unified framework for understanding quantum mechanics. By taking seriously the block universe of special relativity and extending it with a two-valued phase field, TBI dissolves the measurement problem, explains entanglement without nonlocality, and naturally accommodates retrocausality.

The core insight is that apparent dynamics can emerge from static structure through traversal. What we call 'wave function evolution' is the shape of the wave function extended through time; what we call 'collapse' is the transition from coarse to fine sampling; what we call 'entanglement' is structural identity in the 4D block.

TBI is not merely a reinterpretation but a research program. It suggests experimental directions (high-frequency sampling, entanglement geometry, retrocausal signatures) and theoretical extensions (QFT, gravity, consciousness). Its parsimony recommends it on theoretical grounds; its predictions offer the possibility of empirical support.

Most importantly, TBI takes Wheeler's vision seriously: the universe is structure, physically extended and experientially traversed. The 'bits' are the ± 1 phase signs; the 'its' emerge from the reading. Physics is not the study of matter in motion but the study of structure in spacetime—and consciousness is what structure feels like from inside.

Methods

This theoretical paper was developed using philosophical analysis and conceptual synthesis. Claude (Anthropic), a large language model, assisted with literature review, argument refinement, and manuscript preparation. All substantive claims, theoretical frameworks, and the core interpretation are the author's own. The author takes full responsibility for the content.

A A Minimal Toy Model: Aliasing and Interference

This appendix provides a minimal mathematical demonstration of the aliasing intuition underlying TBI. The goal is not to derive quantum mechanics but to show that interference-like phenomena can emerge from undersampling a discrete oscillatory structure.

A.1 Setup: Oscillatory Microstate

Consider a microstate $s(t)$ oscillating between $+1$ and -1 at frequency ω:

$$s(t) = \operatorname{sgn}(\cos(\omega t)) \in \{-1, +1\} \tag{6}$$

Alternatively, for smoother analysis, consider a complex phase:

$$s(t) = e^{i\omega t} \tag{7}$$

A.2 Measurement as Coarse-Grained Averaging

Define a measurement as averaging over a temporal window Δt:

$$\langle s \rangle_{\Delta t} = \frac{1}{\Delta t} \int_{t_0}^{t_0+\Delta t} s(t')\, dt' \tag{8}$$

For the complex phase:

$$\langle s \rangle_{\Delta t} = \frac{1}{\Delta t} \int_{t_0}^{t_0+\Delta t} e^{i\omega t'}\, dt' = e^{i\omega(t_0+\Delta t/2)} \cdot \operatorname{sinc}\left(\frac{\omega \Delta t}{2}\right) \tag{9}$$

When $\omega\Delta t \gg 2\pi$ (measurement window spans many oscillations), $\langle s \rangle \approx 0$. When $\omega\Delta t \ll 2\pi$ (fine sampling), $\langle s \rangle \approx e^{i\omega t_0}$ (phase-resolved).

A.3 Two Oscillators and Interference

Now consider two oscillators with identical frequency but relative phase ϕ:

$$s_1(t) = e^{i\omega t} \tag{10}$$

$$s_2(t) = e^{i(\omega t+\phi)} \tag{11}$$

Their superposition is $s_{\text{tot}}(t) = s_1(t) + s_2(t)$. The coarse-grained intensity:

$$I = |\langle s_{\text{tot}} \rangle_{\Delta t}|^2 = |\langle s_1 \rangle + \langle s_2 \rangle|^2 \tag{12}$$

Expanding:

$$I = |\langle s_1 \rangle|^2 + |\langle s_2 \rangle|^2 + 2\,\mathrm{Re}\left(\langle s_1 \rangle^* \langle s_2 \rangle\right) \tag{13}$$

The cross-term $2\,\mathrm{Re}(\langle s_1 \rangle^* \langle s_2 \rangle)$ is an **interference term** that depends on the relative phase ϕ. For $\phi = 0$ (constructive): $I = 4|\langle s \rangle|^2$. For $\phi = \pi$ (destructive): $I = 0$.

A.4 Gesture Toward $|\psi|^2$

On TBI, $\psi(x)$ would encode the phase structure of Φ at location x. The Born rule $|\psi|^2$ would correspond to the time-averaged proportion of one phase sign in the temporal extension.

Conjecture: If we define

$$\psi(x) \sim \langle \Phi(x,t) \rangle_{\Delta t} \tag{14}$$

then $|\psi|^2$ would give the coarse-grained intensity, and interference between paths would emerge from phase correlations in Φ.

What this does not show: This toy model demonstrates that interference-like terms *can* emerge from phase averaging, but it does not derive the specific form of the Schrödinger equation or prove that $|\psi|^2$ *must* give measurement probabilities. These remain open problems for TBI.

A.5 Summary

This minimal example illustrates the core intuition:

- Discrete phase oscillations (± 1 or $e^{i\theta}$) underlie the structure
- Coarse-grained measurement averages over oscillation cycles
- Interference emerges from relative phase between components
- $|\psi|^2$ could correspond to time-averaged intensity

A rigorous derivation would need to specify the exact relationship between Φ and ψ, derive the evolution equation, and prove the Born rule follows from sampling statistics. This appendix shows only that the approach is not obviously incoherent.

References

Aharonov, Y. and Vaidman, L. (1990). Properties of a quantum system during the time interval between two measurements. *Physical Review A*, 41(1):11–20.

Bell, J. S. (1964). On the Einstein Podolsky Rosen paradox. *Physics Physique Fizika*, 1(3):195–200.

Bohm, D. (1952). A suggested interpretation of the quantum theory in terms of 'hidden' variables. *Physical Review*, 85(2):166–179.

Bohr, N. (1928). The quantum postulate and the recent development of atomic theory. *Nature*, 121:580–590.

Cramer, J. G. (1986). The transactional interpretation of quantum mechanics. *Reviews of Modern Physics*, 58(3):647–687.

Everett, H. (1957). 'Relative state' formulation of quantum mechanics. *Reviews of Modern Physics*, 29(3):454–462.

Fredkin, E. (1990). Digital mechanics. *Physica D: Nonlinear Phenomena*, 45(1-3):254–270.

Ghirardi, G. C., Rimini, A., and Weber, T. (1986). Unified dynamics for microscopic and macroscopic systems. *Physical Review D*, 34(2):470–491.

Jacques, V., Wu, E., Grosshans, F., Treussart, F., Grangier, P., Aspect, A., and Roch, J.-F. (2007). Experimental realization of Wheeler's delayed-choice gedanken experiment. *Science*, 315(5814):966–968.

Lloyd, S. (2006). *Programming the Universe: A Quantum Computer Scientist Takes on the Cosmos*. Knopf.

Minkowski, H. (1908). Space and time. Address at the 80th Assembly of German Natural Scientists and Physicians, Cologne.

Penrose, R. (1996). On gravity's role in quantum state reduction. *General Relativity and Gravitation*, 28(5):581–600.

Price, H. (1996). *Time's Arrow and Archimedes' Point: New Directions for the Physics of Time*. Oxford University Press.

Putnam, H. (1967). Time and physical geometry. *The Journal of Philosophy*, 64(8):240–247.

Rietdijk, C. W. (1966). A rigorous proof of determinism derived from the special theory of relativity. *Philosophy of Science*, 33(4):341–344.

Sider, T. (2001). *Four-Dimensionalism: An Ontology of Persistence and Time*. Oxford University Press.

Sutherland, R. I. (2017). How retrocausality helps. *AIP Conference Proceedings*, 1841(1):020001.

Wharton, K. (2015). The universe is not a computer. In Aguirre, A., Foster, B., and Merali, Z., editors, *Questioning the Foundations of Physics*, pages 177–189. Springer.

Wheeler, J. A. (1978). The 'past' and the 'delayed-choice' double-slit experiment. In Marlow, A. R., editor, *Mathematical Foundations of Quantum Theory*, pages 9–48. Academic Press.

Wheeler, J. A. (1990). Information, physics, quantum: The search for links. In Zurek, W. H., editor, *Complexity, Entropy, and the Physics of Information*, pages 3–28. Addison-Wesley.

Wolfram, S. (2002). *A New Kind of Science*. Wolfram Media.

Zuse, K. (1969). *Rechnender Raum*. Friedrich Vieweg & Sohn.