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Article

Predictive Inference and the Origin of Quantum Phenomena

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Abstract

This preprint presents a foundational theory that reinterprets quantum mechanics not as a description of fundamental physical reality, but as the emergent statistical signature of a universal information-processing architecture. We introduce and formally define the Ze (Zero-point entropy) system—an active predictive engine that operates through a mandatory cycle of forward prediction and retrograde inference. The system's core axiom is that the retrograde encoding process, essential for reconciling past models with present evidence, necessitates a complete cessation of the forward information flow. From this single architectural constraint, we mathematically derive phenomena isomorphic to quantum superposition, interference, and wavefunction collapse. Superposition corresponds to a dynamical equilibrium of multiple predictive hypotheses; collapse is a structured, non-fundamental process triggered when hypothesis divergence exceeds a system-specific stability threshold; and interference arises from the coherent blending of compatible hypotheses. The framework positions quantum behavior as an epistemic property of any system performing active inference under this architectural constraint, bridging domains from particle physics to cognitive neuroscience. We present novel, falsifiable predictions and propose that quantum theory describes the dynamics of a universal class of predictive engines, not a microscopic realm of reality.

Keywords: predictive coding; active inference; free energy principle; quantum foundations; information theory; cognitive neuroscience; relational quantum mechanics

1. Introduction: The Problem of Quantum Interpretation

For over a century, the mathematical framework of quantum mechanics has yielded predictions of unparalleled accuracy. Yet, its physical interpretation remains deeply contested. The central mysteries—superposition, wavefunction collapse, and the measurement problem—resist intuitive, classical explanation. Proposals range from the many-worlds interpretation (Everett, 1957) to objective collapse theories (Ghirardi, Rimini, & Weber, 1986) and Bohmian mechanics (Bohm, 1952). While empirically adequate, these theories often posit new physical entities or layers of reality.

We propose a paradigm shift: Quantum phenomena are not primitive but emergent. They arise inevitably in any complex system that (a) builds predictive models of a sensory stream, and (b) must stop that stream to reconcile predictions with outcomes—a process we term retrograde encoding. This class of systems, Ze systems, is not exclusive to physics. The brain, as described by the Free Energy Principle (Friston, 2005, 2010), is a canonical example, perpetually engaged in minimizing prediction error through perception and action. We argue that when the formal structure of such predictive inference is made explicit, it yields dynamics formally identical to those of quantum mechanics.

This work synthesizes insights from active inference in neuroscience (Friston, 2010; Clark, 2013), relational quantum mechanics (RQM) (Rovelli, 1996), and decoherence theory (Zurek, 2003) into a single formal framework. It posits that quantum “weirdness” is a signature of how intelligent systems, from photodetectors to human brains, process information under a universal architectural constraint.

2. The Ze System: Formal Architecture and Core Axiom

2.1. Information Streams and Dual Operations

Let $O[1:T] = (o_1, o_2, \dots, o_T)$ be a temporal stream of observations (data, sensory input). A Ze system engages with this stream via two distinct operations:

1. Forward Reading (FR) or F: An online, predictive process that generates a real-time model of the world.
2. This constructs the manifest flow of events: $F: o_1 \rightarrow o_2 \rightarrow \dots \rightarrow o_T$.
3. At each time t , the system uses an internal generative model to predict $\hat{o}_{t+1}$. The discrepancy $\hat{o}_{t+1} - o_{t+1}$ is the prediction error, the driver of learning in active inference (Friston & Kiebel, 2009).
4. Retrograde Encoding (RE) or R: An offline, inferential process that recomputes the past.
5. Starting from a “present” snapshot at t , R works backward: $R: o_t \rightarrow o_{t-1} \rightarrow \dots \rightarrow o_1$.
6. This process reassesses the probabilities of past latent states s , prunes incompatible causal branches, and optimizes the internal model. This is analogous to memory consolidation and causal learning (Momennejad et al., 2017).

2.2. The Fundamental Axiom: Stoppage for Reconciliation

The critical, defining axiom of a Ze system is:
The execution of retrograde encoding R requires the complete cessation of the forward information flow F.

Formally, $R(O[t:T])$ is computable only if F is halted at t . This is not an engineering choice but a necessary condition for creating a stable informational reference frame (a “present moment”) against which the past can be coherently reevaluated. Without stoppage, the data stream is a moving target, making global consistency impossible.

Table 1. Comparison of System Architectures.

System Type	Forward Flow (F)	Retrograde Encoding (R)	Key Constraint	Resulting Behavior
Classical Predictor	Continuous	None or Continuous	N/A	Deterministic or stochastic; no interference.
Ze System	Punctuated	Discrete, after stoppage	R -> Stop F	Quantum-like: Superposition, Interference, Collapse.
Pure Dissipative System	Continuous	N/A	No model maintenance	Chaotic or thermal equilibrium.

This architecture mirrors cognitive and biological processes. For example, theta-gamma coupling in the brain is hypothesized to create temporal windows for encoding (Lisman & Jensen,

2013), and synaptic consolidation during sleep requires disengagement from sensory input (Diekelmann & Born, 2010).

3. Deriving Quantum Phenomena

3.1. Superposition as Predictive Compatibility

During uninterrupted forward flow (F), the system entertains multiple hypotheses (e.g., A and B) about the latent causes of its sensory stream. Each is represented by a variational posterior distribution, $q_A(s)$ and $q_B(s)$, which are “beliefs” about the world state.

The system’s commitment is governed by the variational free energy F, a measure of model accuracy and complexity (Friston, 2009). We define the divergence between hypotheses as:

$$\Delta F = |F_A - F_B|$$

The system also has a stability threshold θ , a meta-parameter related to its tolerance for uncertainty.

Definition (Superposition): A Ze system is in a state of superposition with respect to hypotheses A and B when:

$$\Delta F < \theta$$

In this regime, the distributions $q_A(s)$ and $q_B(s)$ are non-localized—their probability mass overlaps significantly. The system does not commit to one hypothesis; they coexist in dynamic equilibrium. This is the direct analog of the quantum state $|\psi\rangle = \alpha|A\rangle + \beta|B\rangle$.

Hypothesis State Space

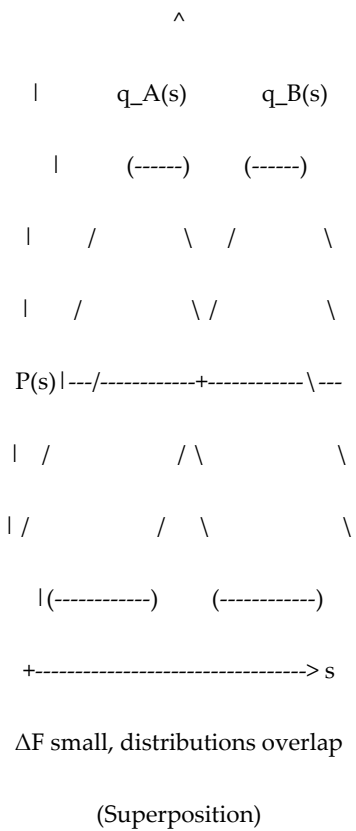


Figure 1. The Superposition State.

Cognitive Example: In binocular rivalry, when two different images are presented to each eye, the conscious percept alternates stochastically. During ambiguous transitions, neural correlates of both images remain active (Tong et al., 1998), a neural superposition.

3.2. Collapse as Structured Localization

Definition (Collapse Trigger): Superposition becomes unstable when accumulating evidence creates sufficient divergence between models:

$$\Delta F \geq \theta$$

- This inequality triggers the collapse procedure, a non-fundamental, architectural sequence:
1. Flow Stoppage: Forward processing F is mandatorily halted at time t^* .
 2. Retrograde Encoding (R): The system executes R, working backward from the snapshot at t^* to select the hypothesis (e.g., A) that minimizes overall free energy. This “rewrites history” for consistency.
 3. Structural Stabilization: The chosen model $q_A(s)$ is reinforced; the alternative $q_B(s)$ is suppressed. The system outputs a localized state.

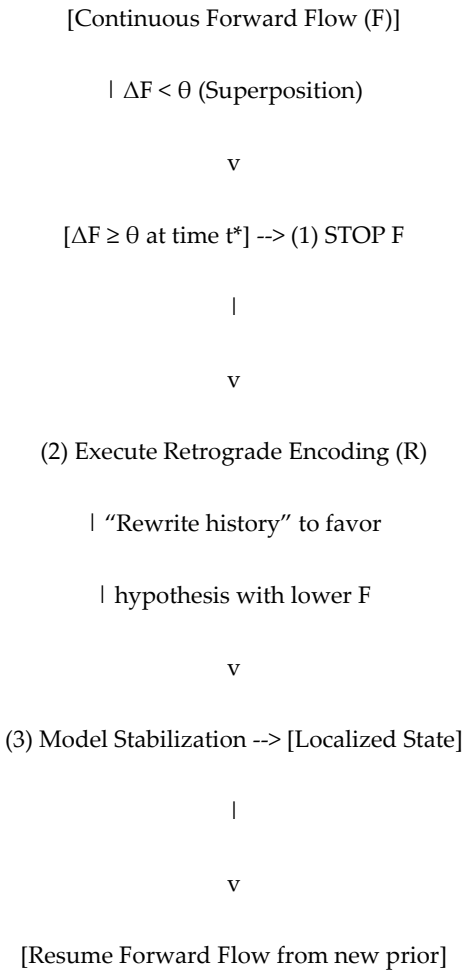


Figure 2. The Three-Stage Collapse Process.

This reframes the “measurement problem.” A measurement apparatus is a Ze system. The interaction with a quantum entity pushes the apparatus’s ΔF past its θ , triggering its internal collapse procedure, resulting in a definite pointer state. There is no mysterious physical collapse (Schlosshauer, 2005).

3.3. Interference and the Quantum Eraser

Interference emerges from the coherent blending of hypotheses when they are compatible (ΔF small). We quantify interference strength I using the complement of the Jensen-Shannon divergence between hypotheses:

$$I = 1 - D_{JS}(q_A || q_B)$$

where D_{JS} is a symmetric measure of distributional similarity (Lin, 1991). High I (low D_{JS}) indicates strong, quantum-like interference.

The Quantum Eraser Explained:

- 1. Path Marking: Tagging a particle’s path provides diagnostic information, sharply increasing ΔF , triggering localization, and destroying interference ($I \rightarrow 0$).
- 2. Erasure: A subsequent measurement that erases the path information (e.g., measuring in a diagonal basis) provides non-diagnostic data. This actively lowers ΔF .
- 3. Restoration: If erasure pushes ΔF back below θ , the system re-enters superposition, and interference is restored ($I \rightarrow 1$) for the post-selected data.

This is not time reversal but informational context revision, analogous to cognitive belief updating (Hohwy, 2013).

4. The Ze Framework as a Universal Theory

4.1. Formal Correspondence

The theory’s core claim is captured by the correspondence:

Quantum Behavior <-> Ze-System (with R + Stoppage)

This means any system obeying the Ze architecture will exhibit statistics formally identical to quantum mechanics. The “quantumness” of photons is a reflection of the Ze-like nature of their interaction with measurement devices.

4.2. Resolving the Quantum-Classical Divide

Why don’t cats or chairs show superposition? Decoherence (Zurek, 2003) provides the physical mechanism; the Ze framework provides the informational reason.

A macroscopic object is a vast network of coupled Ze subsystems. Its internal complexity is astronomical, generating a constant, dense stream of internally diagnostic information. This relentlessly drives ΔF for any macroscopic hypothesis far above any feasible θ . Thus, the system is in a state of perpetual, instantaneous collapse. What we see as a classical object is the outcome of continuous self-measurement across its components.

Table 2. Scale-Dependent Behavior in the Ze Framework.

System Scale	Internal Complexity	Typical ΔF vs. θ	Observable Behavior	Physical Analog
Photon/Electron	Low	ΔF can remain $< \theta$ for long durations	Quantum (Superposition, Interference)	Isolated quantum system.

Large Molecule	Moderate	ΔF rises very quickly upon interaction	Rapid localization, fragile interference	Mesoscopic system, prone to decoherence.
Cat/Macroscopic Object	Extremely High	$\Delta F \gg \theta$ at all times	Classical (Definite, Localized)	Fully decohered classical object.

5. Novel, Falsifiable Predictions

The theory’s strength lies in generating testable predictions across disciplines.

Prediction 1 (AI/Computation): A classical computer programmed with a Ze architecture (enforced stoppage for retrograde updates) will exhibit decision statistics that violate the law of total probability, a hallmark of quantum cognition (Busemeyer & Bruza, 2012). A system with continuous backpropagation (no stoppage) will not.

Prediction 2 (Neuroscience - Psychedelics): Serotonergic psychedelics (e.g., psilocybin) are known to flatten the brain’s predictive hierarchy (Carhart-Harris & Friston, 2019). In Ze terms, this raises the threshold θ or lowers precision, allowing $\Delta F < \theta$ to be maintained longer. Test: Neuroimaging under psychedelics should show (a) increased entropy in high-level cortical networks, (b) enhanced connectivity between normally anti-correlated networks, and (c) behavioral measures of prolonged perceptual ambiguity and increased creative association.

Prediction 3 (Quantum Foundations): The degree of interference destruction in a “which-path” experiment should be quantitatively proportional not just to entanglement, but to the informational distinguishability (D_{JS}) of the marker states, as modeled by the measuring apparatus as a Ze system.

Prediction 4 (Biology - Evolution): Major evolutionary transitions (punctuated equilibria) can be modeled as population-level Ze cycles: long periods of forward propagation (natural selection) punctuated by “stoppage” events (e.g., geographic isolation, mass extinction) that force a retrospective reorganization of the genetic “model” (speciation) (Gould & Eldredge, 1977).

6. Discussion and Future Directions

- The Ze framework offers a radical synthesis. It unifies:
- Active Inference: Provides the core calculus (free energy minimization).
 - Relational QM: Explains why states are relational (they are specific to a particular Ze system’s inference process).
 - Decoherence: Becomes the physical process that modulates ΔF in complex environments.
- Future Work:
1. Mathematical Derivation: Can the full formalism of Hilbert spaces, non-commuting observables, and the Born rule be derived from first principles of Ze dynamics?
 2. Clinical Applications: Could pathologies like psychosis (overly precise priors, low θ , leading to rapid, fixed delusions) and depression (ineffective R, leading to stuck states) be reformulated and treated as dysregulations of Ze dynamics?
 3. Quantum-Inspired AI: Designing AI with explicit, tunable Ze cycles (θ parameter) could yield new algorithms for managing ambiguity and novelty.

7. Conclusion

We have argued that the puzzles of quantum theory stem from interpreting its mathematics as a direct description of reality, rather than as a reflection of how predictive systems process information. The Ze framework demonstrates that superposition, interference, and collapse emerge naturally in any system that must pause its forward progress to make coherent sense of its past. Quantum mechanics, therefore, may be the first and most precise science of inference under architectural constraint. This shifts quantum behavior from a property of the very small to a potential signature of intelligence—from the interaction of a photon with a detector to the flicker of a conscious thought.

References

- Bohm, D. (1952). A suggested interpretation of the quantum theory in terms of “hidden” variables. I. *Physical Review*, 85(2), 166–179. <https://doi.org/10.1103/PhysRev.85.166>
- Busemeyer, J. R., & Bruza, P. D. (2012). *Quantum models of cognition and decision*. Cambridge University Press.
- Carhart-Harris, R. L., & Friston, K. J. (2019). REBUS and the Anarchic Brain: Toward a Unified Model of the Brain Action of Psychedelics. *Pharmacological Reviews*, 71(3), 316–344. <https://doi.org/10.1124/pr.118.017160>
- Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behavioral and Brain Sciences*, 36(3), 181–204. <https://doi.org/10.1017/S0140525X12000477>
- Diekelmann, S., & Born, J. (2010). The memory function of sleep. *Nature Reviews Neuroscience*, 11(2), 114–126. <https://doi.org/10.1038/nrn2762>
- Everett, H. (1957). “Relative state” formulation of quantum mechanics. *Reviews of Modern Physics*, 29(3), 454–462. <https://doi.org/10.1103/RevModPhys.29.454>
- Friston, K. (2005). A theory of cortical responses. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360(1456), 815–836. <https://doi.org/10.1098/rstb.2005.1622>
- Friston, K. (2009). The free-energy principle: a rough guide to the brain? *Trends in Cognitive Sciences*, 13(7), 293–301. <https://doi.org/10.1016/j.tics.2009.04.005>
- Friston, K. (2010). The free-energy principle: a unified brain theory? *Nature Reviews Neuroscience*, 11(2), 127–138. <https://doi.org/10.1038/nrn2787>
- Friston, K., & Kiebel, S. (2009). Predictive coding under the free-energy principle. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1521), 1211–1221. <https://doi.org/10.1098/rstb.2008.0300>
- Ghirardi, G. C., Rimini, A., & Weber, T. (1986). Unified dynamics for microscopic and macroscopic systems. *Physical Review D*, 34(2), 470–491. <https://doi.org/10.1103/PhysRevD.34.470>
- Gould, S. J., & Eldredge, N. (1977). Punctuated equilibria: the tempo and mode of evolution reconsidered. *Paleobiology*, 3(2), 115–151. <https://doi.org/10.1017/S0094837300005224>
- Hohwy, J. (2013). *The predictive mind*. Oxford University Press.
- Jaba, T. (2022). Dasatinib and quercetin: short-term simultaneous administration yields senolytic effect in humans. *Issues and Developments in Medicine and Medical Research Vol. 2*, 22–31.
- Lin, J. (1991). Divergence measures based on the Shannon entropy. *IEEE Transactions on Information Theory*, 37(1), 145–151. <https://doi.org/10.1109/18.61115>
- Lisman, J. E., & Jensen, O. (2013). The θ - γ neural code. *Neuron*, 77(6), 1002–1016. <https://doi.org/10.1016/j.neuron.2013.03.007>
- Momennejad, I., Russek, E. M., Cheong, J. H., Botvinick, M. M., Daw, N. D., & Gershman, S. J. (2017). The successor representation in human reinforcement learning. *Nature Human Behaviour*, 1(9), 680–692. <https://doi.org/10.1038/s41562-017-0180-8>
- Rovelli, C. (1996). Relational quantum mechanics. *International Journal of Theoretical Physics*, 35(8), 1637–1678. <https://doi.org/10.1007/BF02302261>
- Schlosshauer, M. (2005). Decoherence, the measurement problem, and interpretations of quantum mechanics. *Reviews of Modern Physics*, 76(4), 1267–1305. <https://doi.org/10.1103/RevModPhys.76.1267>
- Tkemaladze, J. (2026). Ze System Manifesto. *Longevity Horizon*, 2(1). DOI : <https://doi.org/10.65649/3hm9b025>

- Tkemaladze, J. (2024). Editorial: Molecular mechanism of ageing and therapeutic advances through targeting glycativ and oxidative stress. *Front Pharmacol*. 2024 Mar 6;14:1324446. DOI : 10.3389/fphar.2023.1324446. PMID: 38510429; PMCID: PMC10953819.
- Tkemaladze, J. (2026). Old Centrioles Make Old Bodies. *Annals of Rejuvenation Science*, 1(1). DOI : <https://doi.org/10.65649/yx9sn772>
- Tkemaladze, J. (2026). Visions of the Future. *Longevity Horizon*, 2(1). DOI : <https://doi.org/10.65649/8be27s21>
- Tong, F., Nakayama, K., Vaughan, J. T., & Kanwisher, N. (1998). Binocular rivalry and visual awareness in human extrastriate cortex. *Neuron*, 21(4), 753–759. [https://doi.org/10.1016/S0896-6273\(00\)80592-9](https://doi.org/10.1016/S0896-6273(00)80592-9)
- Zurek, W. H. (2003). Decoherence, einselection, and the quantum origins of the classical. *Reviews of Modern Physics*, 75(3), 715–775. <https://doi.org/10.1103/RevModPhys.75.715>

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