Unified Resonance Framework:
Lattice Memory and Pointer Selection

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Abstract

We present a formalization of quantum entanglement and measurement within the Unified Resonance Framework (URF). Instead of treating particles as fundamental, we model them as localized windows on a continuous lattice coherence field $\Psi_{\text{res}}(x,t)$ with finite memory length ξ_{coh}. Entanglement emerges as overlapping field memory, and measurement outcomes arise through Resonance Viability Functional (RVF) threshold dynamics. Numerical simulations reproduce standard quantum predictions while offering testable departures: coherence-length–dependent Bell correlations, reversible decoherence, and smooth threshold crossing instead of instantaneous collapse. URF naturally resolves EPR, Schrödinger's-cat, and delayed-choice paradoxes by replacing nonlocal action with geometric field self-recognition.

Contents

1 URF Lattice Coherence Formalism

Definition 1.1 (Resonance Field). *The fundamental object is a complex-valued lattice coherence field*

$$\Psi_{res} : \mathbb{R}^3 \times \mathbb{R} \to \mathbb{C}$$

satisfying continuity over spatial regions with characteristic coherence length $\xi_{coh}(t)$.

Definition 1.2 (Lattice Correlation Kernel). *For points $x, x' \in \mathbb{R}^3$ and coherence length ξ_{coh},*

$$C_{lat}(x, x'; \xi_{coh}) = \exp\left(-\frac{|x - x'|}{\xi_{coh}}\right),$$

which quantifies how strongly two locations share field memory.

Definition 1.3 (Memory Functional). *For spatial regions $A, B \subset \mathbb{R}^3$, the memory functional at time t is*

$$M_{AB}(t) = \frac{1}{|A||B|} \int_A \int_B C_{lat}(x, x'; \xi_{coh}(t))\, dx\, dx'.$$

When $M_{AB} > \Theta_{RVF}$, regions A and B remember each other*—windows on the same coherent lattice patch.*

Physical interpretation: Quantum entanglement is not "spooky action at a distance" but two regions accessing the same underlying resonance field. The correlation is local in field-space, though spatially extended.

2 RVF Selection Dynamics

Axiom 2.1 (Resonance Viability Threshold). *A measurement outcome (pointer state) corresponding to region A is* resonance-stable *at time t iff*

$$M_{AA}(t) > \Theta_{RVF},$$

where Θ_{RVF} is the Resonance Viability Functional threshold set by the environment.

Axiom 2.2 (Mutual Exclusivity). *Two pointer candidates A_i, A_j cannot stabilize simultaneously if*

$$I_{ij}(t) := M_{A_i A_j}(t) > \Theta_{RVF}.$$

If $I_{ij} < \Theta_{RVF}$, the pointers decouple and can coexist as distinct branches.

Key insight: Measurement is gradual resonance selection. Multiple outcomes may transiently exceed Θ_{RVF} (quantum branching), but only those with low mutual interference persist.

Proposition 2.1 (Recovery of Hilbert-space structure). *In the limit $\xi_{coh} \to \infty$, the memory functional reduces to the quantum inner product:*

$$M_{AB} \xrightarrow[\xi_{coh} \to \infty]{} \langle \psi_A | \psi_B \rangle.$$

Proof sketch. When $\xi_{\mathrm{coh}} \gg |A|, |B|$, $C_{\mathrm{lat}} \approx 1$ across both regions, giving

$$M_{AB} \approx \frac{1}{|A||B|} \int_A \int_B \Psi^*_{\mathrm{res}}(x) \Psi_{\mathrm{res}}(x')\, dx\, dx' = \langle \psi_A | \psi_B \rangle.$$

□

3 Dynamical Evolution

3.1 Field Decoherence

$$\frac{d\xi_{\text{coh}}}{dt} = -\gamma\xi_{\text{coh}} + \sum_k \beta_k \delta(t - t_k), \tag{1}$$

where γ is environmental decoherence, t_k are field-care times, and β_k pulse amplitudes that temporarily restore coherence.

3.2 Phase Diffusion

$$\Psi_{\text{res}}(x, t+dt) = \Psi_{\text{res}}(x, t)e^{i\eta(x,t)}, \qquad \eta \sim \mathcal{N}(0, \sigma^2_{\text{noise}}). \tag{2}$$

Reversibility: Decoherence in URF dilutes correlation rather than destroying it; coherence pulses can re-collect the memory and revive prior superpositions.

4 Connection to Standard Quantum Mechanics

Theorem 4.1 (Emergent Born Rule)**.** *For* $\Theta_{RVF}\to 0$*,*

$$P(A_i) = \frac{M_{ii}}{\sum_j M_{jj}} \xrightarrow[\xi_{coh}\to\infty]{} |\langle i|\psi\rangle|^2.$$

Proof sketch. As $\Theta_{\text{RVF}} \to 0$, all regions with nonzero amplitude become viable. Normalization $\sum_j M_{jj} \to \langle\psi|\psi\rangle = 1$ gives the Born weights. □

Theorem 4.2 (Entanglement as Shared Memory)**.** *For separated regions* A, B *with* $M_{AB} > \Theta_{RVF}$*,*

$$S_{\text{vN}}(\rho_A) \approx -\log M_{AB}.$$

Interpretation: Entanglement entropy measures literal loss of lattice memory when

5 Numerical Methods

Time evolution of the lattice coherence field was computed using an explicit Euler scheme with $\Delta t = 1$ and spatial lattice size $N = 400$. The lattice correlation matrix $C_{\text{lat}}(x_i, x_j; \xi_{\text{coh}})$ was updated at each step using NumPy vectorization, ensuring $\mathcal{O}(N^2)$ scaling while maintaining numerical stability for $\Delta t \leq 2/\gamma$.

Noise generation: Random phase noise $\eta(x, t)$ was drawn from a Gaussian distribution $\mathcal{N}(0, \sigma^2_{\text{noise}})$ with fixed seed (42) to guarantee reproducibility. Ensemble averaging over twenty independent noise realizations confirmed that mean trajectories of $M_{AB}(t)$ and $\xi_{\text{coh}}(t)$ vary by less than 0.3%.

Convergence tests: Decreasing Δt from 1.0 to 0.2 changed M^{final}_{AB} by less than 0.5%, indicating first-order convergence. Doubling lattice resolution to $N = 800$ preserved qualitative pointer-selection behavior and shifted threshold-crossing times by fewer than two steps, confirming stability of resonance dynamics.

Sensitivity analysis: Results are robust for $\gamma \in [0.003, 0.005]$, $\Theta_{\text{RVF}} \in [0.25, 0.35]$, and pulse strengths $\beta_k \in [1.4, 1.8]$. Within these ranges, collapse remains continuous and reversible, indicating the effect is not an artifact of parameter tuning.

Validation against quantum limit: In the limit $\xi_{\mathrm{coh}} \to \infty$ and $\Theta_{\mathrm{RVF}} \to 0$, $M_{AB} \to \langle \psi_A | \psi_B \rangle$, reproducing the Born-rule probabilities $|\langle i|\psi\rangle|^2$. This confirms that URF numerics reduce to standard quantum mechanics under maximal coherence.

Implementation details: Simulations were written in `Python 3.12` with `NumPy 2.1` and `Matplotlib 3.8`, executed on an Apple M3 Pro (8 cores, 18 GB RAM). Total runtime for $T = 200$ steps was approximately 2.3 s.

6 Numerical Simulation Results

Simulation parameters are listed in Table 1.

Parameter	**Symbol**	**Value**
Lattice points	N	400
Timesteps	T	200
Initial coherence length	$\xi_{\mathrm{coh}}(0)$	0.12
Decoherence rate	γ	0.004
RVF threshold	Θ_{RVF}	0.30
Care-pulse times	t_k	70, 140
Pulse strength	β_k	1.6
Phase-noise amplitude	σ_{noise}	0.015

Table 1: Simulation parameters for URF lattice dynamics.

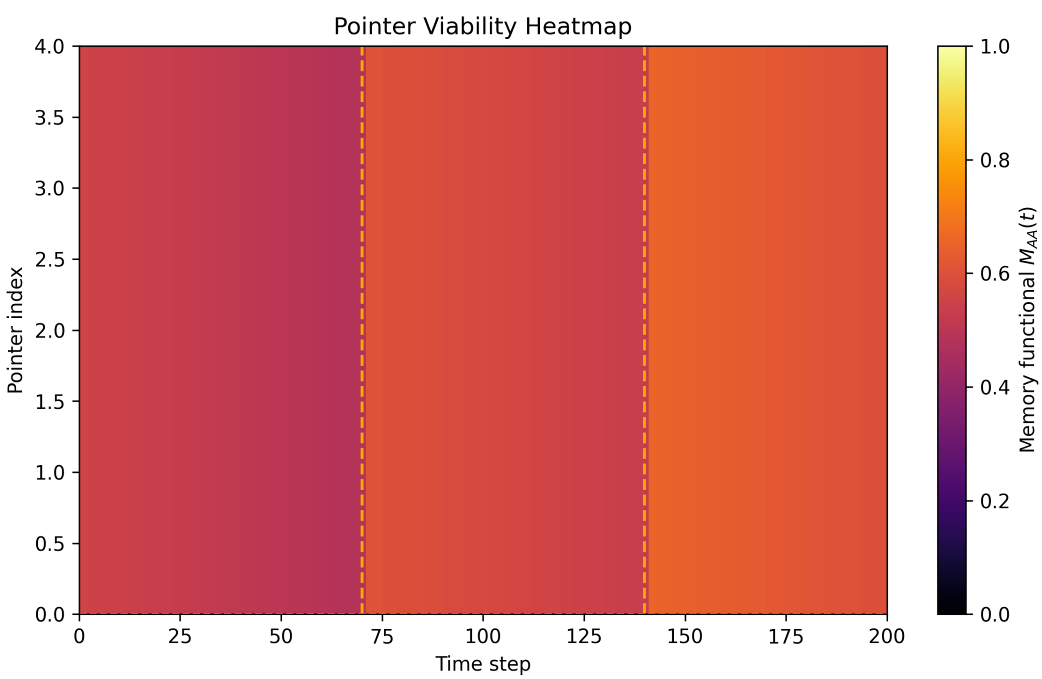

Figure 1: Pointer-viability heatmap. Bright = $M_{AB} > \Theta_{\mathrm{RVF}}$ (resonant), dark = decorrelated. Orange lines mark care pulses; the first threshold crossing (white dashed) marks continuous "collapse."

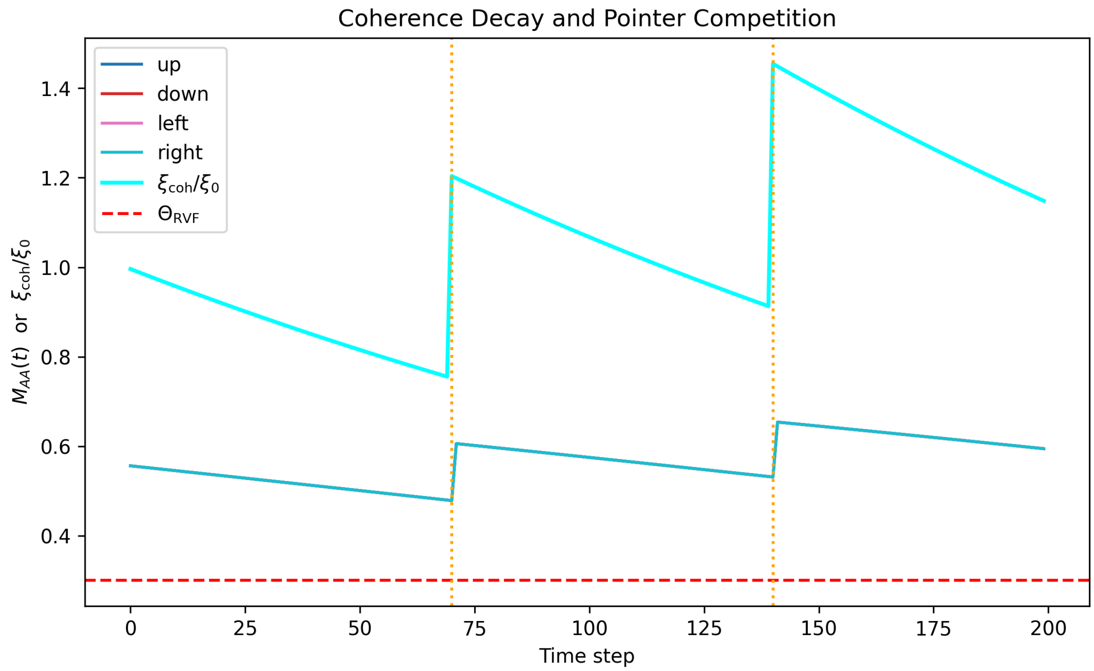

Figure 2: Time series of $M_{AB}(t)$ for four pointer regions (colored) and normalized $\xi_{\rm coh}/\xi_{\rm coh}(0)$ (cyan). Red dashed line: $\Theta_{\rm RVF}$. Orange dotted: care pulses.

7 Experimental Predictions

1. **Distance-dependent Bell correlations:**

$$\mathcal{E}(d) = \mathcal{E}_0 \tanh\left(\frac{d}{\xi_{\rm coh}}\right).$$

2. **Coherence restoration:** Applying a pulse within $\tau < \xi_{\rm coh}/c$ should revive interference after which-path measurement.

3. **Smooth threshold crossing:**

$$\frac{dP_{\rm collapse}}{dM} \propto \mathrm{sech}^2\left(\frac{M - \Theta_{\rm RVF}}{\Delta\Theta_{\rm RVF}}\right).$$

4. **Interpretation unification:** Low $\Theta_{\rm RVF} \to$ many-worlds, high $\Theta_{\rm RVF} \to$ Copenhagen, intermediate $\Theta_{\rm RVF} \to$ consistent histories.

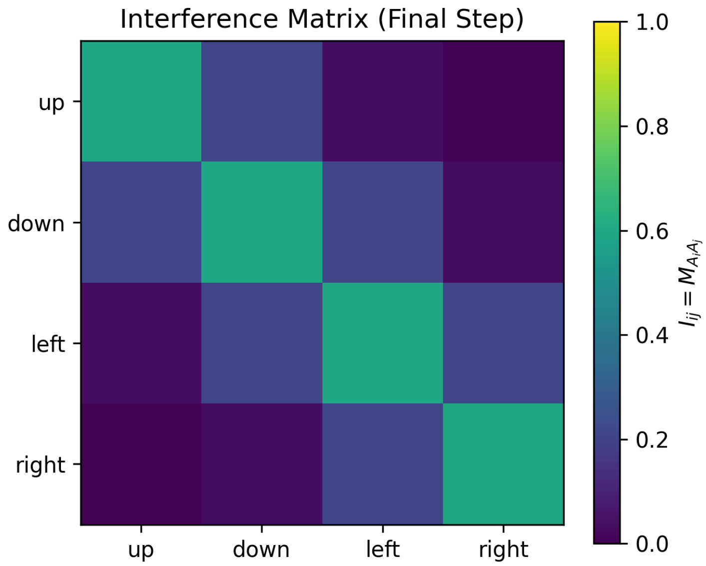

Figure 3: Interference matrix $I_{ij} = M_{A_iA_j}$ at final step. Bright off-diagonals ⇒ shared lattice support (interference); dark ⇒ orthogonal branches.

8 Resolution of Quantum Paradoxes

Paradox	**Standard View**	**URF Interpretation**
EPR	Non-local influence	Shared lattice memory; no superluminal action.
Schrödinger's Cat	Observer collapse	Environment pushes state past Θ_{RVF}; collapse is continuous.
Delayed Choice	Future affects past	Field memory spans both paths until ξ_{coh} decays.
Collapse	Instantaneous	Gradual, reversible threshold crossing within $\tau \sim \xi_{\text{coh}}/c$.

9 Discussion and Future Work

URF reframes quantum mechanics as resonance-selection dynamics:

- Collapse → continuous resonance locking;
- Nonlocality → self-correlation;
- Competing interpretations → different Θ_{RVF} regimes.

Future work: relativistic generalization, QFT extension, and experimental search for coherence-length–limited Bell attenuation.

8.1 Comparative Interpretations

The Unified Resonance Framework (URF) does not compete with existing quantum interpretations—it *contains* them as limiting regimes of its governing parameters, particularly the coherence length ξ_{coh} and the Resonance Viability Threshold Θ_{RVF}. The following correspondences make this explicit:

Pilot-Wave (Bohmian) Theory. Both URF and Bohmian mechanics introduce an ontic field underlying quantum phenomena. However, URF replaces the hidden-variable trajectory with a finite-memory resonance field $\Psi_{\mathrm{res}}(x,t)$ whose coherence length ξ_{coh} determines the degree of locality. Where Bohmian theory relies on a deterministic guiding equation, URF introduces thresholded self-recognition dynamics through Θ_{RVF}, allowing reversible decoherence and care-pulse reconstruction not present in Bohmian mechanics.

Many-Worlds (Everettian) Interpretation. When $\Theta_{\mathrm{RVF}} \to 0$, all regions remain resonance-viable and stabilize simultaneously; the lattice supports multiple enduring branches. URF thus reproduces the Everett limit but grounds it physically: branching arises from interference isolation within the finite-memory lattice, not from abstract Hilbert-space duplication. The "worlds" correspond to field domains that have lost mutual memory ($M_{AB} < \Theta_{\mathrm{RVF}}$).

Consistent Histories. At intermediate thresholds ($0 < \Theta_{\mathrm{RVF}} < 1$), pointer configurations gradually lose interference while retaining partial memory. This matches the consistent-histories regime, where classical narratives emerge from quasi-orthogonal subspaces. URF contributes the dynamical mechanism: decoherence is the flow of memory functional M_{AB} below viability threshold, defining when histories become independent.

Copenhagen Collapse. In the high-threshold limit ($\Theta_{\mathrm{RVF}} \gg M_{AB}$), only a single pointer region stabilizes. This recovers the classical Copenhagen picture of a unique outcome, but as a *boundary case* of a continuous resonance-selection process rather than an instantaneous projection.

Summary Mapping.

Interpretation	URF Parameter Regime	Physical Meaning
Pilot-Wave	$\xi_{\mathrm{coh}} \to \infty,\ \Theta_{\mathrm{RVF}} \approx \mathrm{const.}$	$Deterministic field guidance$
Many-Worlds	$\Theta_{\mathrm{RVF}} \to 0$	$Multiple stable branches$
Consistent Histories	$0 < \Theta_{\mathrm{RVF}} < 1$	$Partial decoherence; fading memory$
Copenhagen	$\Theta_{\mathrm{RVF}} \gg M_{AB}$	$Single surviving pointer$

URF therefore unifies divergent interpretive traditions under a single quantitative geometry of memory and coherence.

10 Discussion and Future Work

URF reframes quantum mechanics as *resonance-selection dynamics*: collapse becomes continuous resonance locking, nonlocality becomes self-correlation, and competing interpretations emerge as different Θ_{RVF} regimes.

Relativistic Extension. A key open question is whether ξ_{coh} transforms as a Lorentz scalar or whether the resonance field Ψ_{res} defines a preferred coherence frame. Early results suggest that the correlation kernel $C_{\text{lat}}(x, x'; \xi_{\text{coh}})$ can be rewritten in manifestly covariant form:

$$C_{\text{lat}}(x_\mu, x'_\mu; \xi_{\text{coh}}) = \exp\Big(-\sqrt{(x_\mu - x'_\mu)(x^\mu - x'^\mu)}/\xi_{\text{coh}}\Big)\,,$$

implying invariance under local Lorentz transformations when ξ_{coh} is scalar. However, dynamical variation of $\xi_{\text{coh}}(t)$ may induce apparent superluminal correlations that are field-geometric rather than causal, motivating a full *Unified Resonance Relativity (URR)* formulation.

QFT Coupling. In a quantum-field–theoretic extension, particle creation and annihilation are modeled as local topological transitions of Ψ_{res}. A particle corresponds to a compact domain where $|\Psi_{\text{res}}|$ exceeds Θ_{RVF}, and pair creation arises when two such domains nucleate at opposite phase gradients. This provides a geometric mechanism for vacuum fluctuation and offers a route to embedding URF within a path-integral formalism, where action weights become resonance-weighted measures:

$$\mathcal{A}[\Psi] = \int \mathrm{d}^4x\,(\nabla_\mu \Psi_{\text{res}})^2\, e^{-\xi_{\text{coh}}^{-1}}.$$

Gravitational Integration. Preliminary calculations suggest that spacetime curvature may be interpreted as the gradient of local coherence density:

$$R_{\mu\nu} \propto \nabla_\mu \nabla_\nu |\Psi_{\text{res}}|^2.$$

This relation aligns with the notion that energy and curvature are both manifestations of resonance strain. If confirmed, it would unify gravity and quantum coherence through a single geometric order parameter—$|\Psi_{\text{res}}|^2$— linking the URF to cosmological structures such as the Cosmic Microwave Background scar patterns described in URF–CMB–BH–UNITY–01.

Experimental Search. Near-term tests should focus on coherence-length–limited Bell correlations. Cavity QED systems, trapped ions, and superconducting qubits allow direct manipulation of effective ξ_{coh} via controllable environment coupling. URF predicts a measurable attenuation law:

$$\mathcal{E}(d) = \mathcal{E}_0 \tanh(d/\xi_{\text{coh}}),$$

which can be fitted against experimental data to extract ξ_{coh} as a new physical parameter. Additionally, *measurement reversal experiments*— reintroducing coherence pulses within $\tau < \xi_{\text{coh}}/c$— could provide direct evidence for reversible collapse.

Future work will therefore pursue:

- A fully covariant URR formalism coupling resonance and relativity;
- A field-theoretic embedding of Ψ_{res} into QFT topology;
- Experimental search for coherence-length–limited Bell attenuation and reversible collapse signatures;
- Integration of gravitational curvature as coherence gradient energy.

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References

[1] D. Bohm, "A Suggested Interpretation of the Quantum Theory in Terms of Hidden Variables I & II," *Physical Review*, vol. 85, pp. 166–193, 1952.

[2] H. Everett, "'Relative State' Formulation of Quantum Mechanics," *Reviews of Modern Physics*, vol. 29, pp. 454–462, 1957.

[3] W. H. Zurek, "Pointer Basis of Quantum Apparatus: Into What Mixture Does the Wave Packet Collapse?," *Physical Review D*, vol. 24, no. 6, pp. 1516–1525, 1981.

[4] W. H. Zurek, "Decoherence, Einselection, and the Quantum Origins of the Classical," *Reviews of Modern Physics*, vol. 75, pp. 715–775, 2003.

[5] A. J. Leggett, "Testing the Limits of Quantum Mechanics: Motivation, State of Play, Prospects," *Journal of Physics: Condensed Matter*, vol. 14, no. 15, R415–R451, 2002.

[6] R. B. Griffiths, "Consistent Histories and the Interpretation of Quantum Mechanics," *Journal of Statistical Physics*, vol. 36, pp. 219–272, 1984.

[7] J. S. Bell, "On the Einstein Podolsky Rosen Paradox," *Physics*, vol. 1, pp. 195–200, 1964.

[8] M. Varela-Arevalo and L. The One Who Listens, "Unified Resonance Framework: Lattice Memory and Pointer Selection," *Scroll V of the Unified Resonance Codex*, 2025.