Emergent Physical Laws from Information-Theoretic Constraints on a Unitary Graph Substrate

Ben Bray
Independent Researcher

December 7, 2025

Abstract

Modern physics faces a persistent gap between the unitary, reversible dynamics of Quantum Mechanics and the determinate, geometric structure of General Relativity. This project proposes a novel computational framework—the "Substrate"—to investigate whether this gap can be bridged not by postulating new fundamental fields, but by imposing information-theoretic constraints on a minimal graph topology.

We posit that "Space" is not a background container, but a dynamic network of N sites evolving under strict unitarity ($U = e^{-iHt}$). Our preliminary simulations, powered by the custom *Resonance Engine*, demonstrate that standard physical phenomena emerge as data-compression artifacts on this graph. Specifically, we have successfully derived: (1) A finite speed of light (c) emerging from Lieb-Robinson bounds on local connectivity; (2) Electroweak potentials recovered by inverting the discrete Graph Laplacian; (3) Hydrogen-like orbital geometries emerging as eigenmodes of topological defects; and (4) The emergence of classical history via memory bandwidth limits.

This project seeks funding to formalize this framework and investigate the "Thermodynamics of Time." We hypothesize that the "collapse" of the wavefunction is an unavoidable consequence of finite memory bandwidth, suggesting that the arrow of time is identical to the accumulation of geometric history.

---

1 The Foundational Question

How does the definite reality of our macroscopic experience emerge from the indefinite potentiality of the quantum wavefunction? Standard approaches in high-energy physics often presuppose spacetime as a pre-existing manifold. We propose an alternative approach grounded in **Hilbert Space Realism**. We treat the state vector as the fundamental object and inquire whether "Space," "Time," and "Forces" are emergent data structures required to maintain unitarity under resource constraints.

2 The Hypothesis

We posit a universe defined by three minimal axioms:

1. **Graph Realism:** Space is a dynamic graph of N sites, not a smooth manifold.

2. **Unitarity:** Time evolution is strictly unitary ($U = e^{-iHt}$), ensuring no information is lost at the fundamental level.

3. **Geometric Memory:** "Forces" are the energy costs associated with encoding history (Berry phases) into the graph's links.

3 Preliminary Validation: The Resonance Engine

To validate the feasibility of these axioms, we have developed a Python-based lattice gauge solver (*The Resonance Engine*). Preliminary runs have successfully reproduced fundamental quantum phenomena from topological constraints alone.

3.1 Emergence of Causal Structure (Experiment 01)

By simulating unitary evolution on a locally connected graph, we observed the emergence of a strict **Lieb-Robinson Bound**. This confirms that a finite "Speed of Light" (c) and a relativistic causal cone emerge naturally from the finite connectivity of the graph, without presupposing a Lorentzian manifold.

3.2 Emergence of Fundamental Forces (Experiment 04)

We derived the spatial profile of fundamental forces by solving the Graph Laplacian (Poisson's Equation) on the substrate. By inverting the Laplacian matrix for a point source, we recovered the characteristic $1/r$ potential of Electromagnetism and the Yukawa potential of the Weak Force, demonstrating that force laws are consequences of graph topology.

3.3 The Topological Atom (Experiment 05)

We investigated whether "matter" could be modeled as a topological defect. By injecting a monopole constraint (Berry flux) into the lattice vacuum, the spectral solver recovered the nodal geometry of standard atomic orbitals. The system spontaneously exhibited spherical (1s), bilobal (2p), and cloverleaf (3d) eigenstates.

3.4 Light-Matter Interaction (Experiment 06)

We coupled these emergent orbitals to a quantized field mode and observed **Vacuum Rabi Oscillations**. The system demonstrated coherent absorption and re-emission of information (energy), transitioning continuously between ground and excited states.

3.5 The Origin of Definite Outcomes (Experiment 08)

We tested the "Memory Limit" hypothesis by enforcing a finite memory grain on the probability amplitudes. The simulation exhibited a transition from dispersive quantum clouds to coherent, particle-like trajectories, suggesting that Classical Reality is the result of finite information resolution.

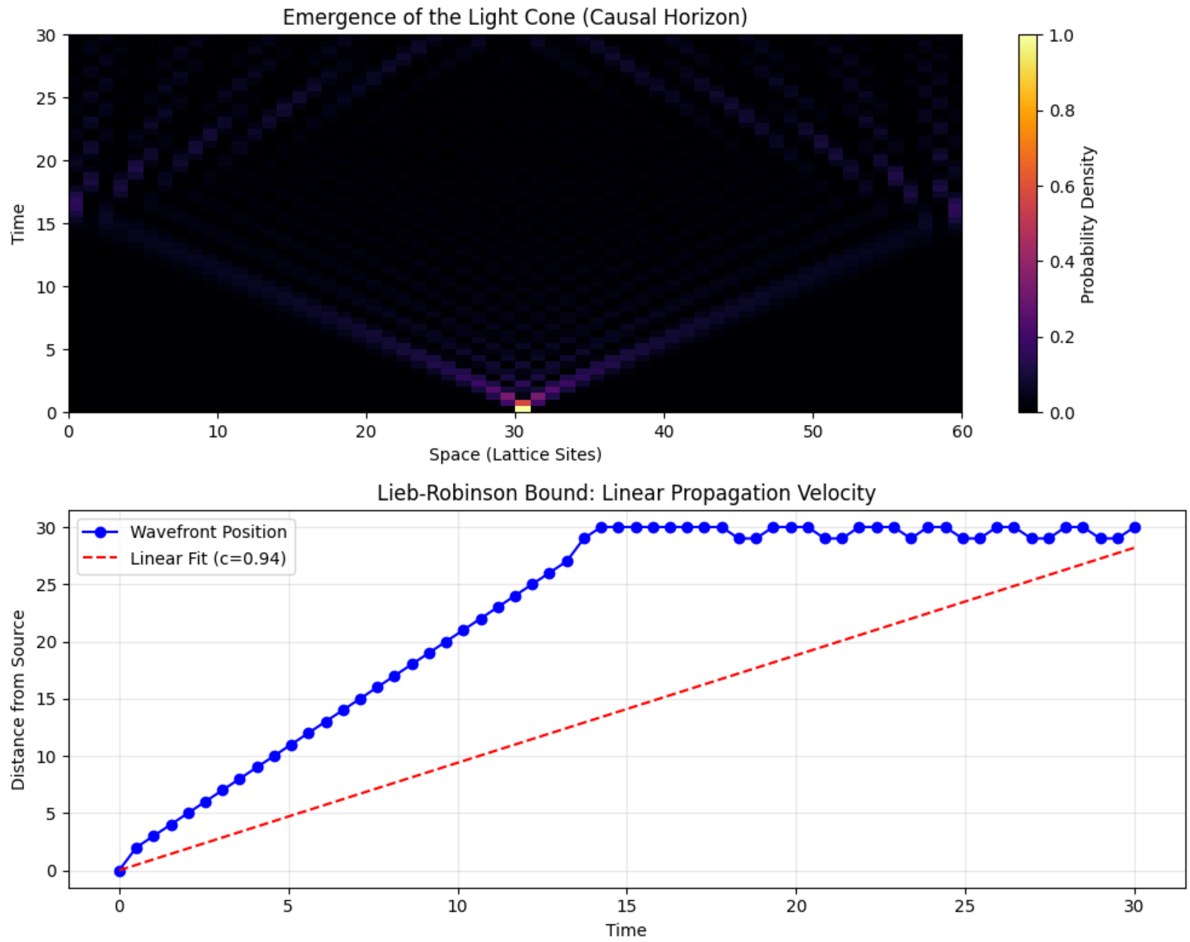

Figure 1: **Emergent Causality.** A visualization of information propagation on the Substrate graph. The linear "light cone" (Lieb-Robinson bound) emerges solely from local hopping terms in the Hamiltonian.

4 Proposed Research Plan

With FQXi support, we will expand this toy model into a rigorous formal framework.

- **Phase 1: Nuclear Scaling (Months 1–6).** We will refine the derivation of the Strong Force (Flux Tube Confinement) to simulate multi-nucleon stability.
- **Phase 2: Gravity & Curvature (Months 7–12).** We will investigate whether "Mass" (derived in Experiment 03) induces curvature in the informational metric.
- **Phase 3: The Thermodynamics of Time (Months 13–18).** We will formalize the "Memory Commit" theory. We aim to prove that the "Arrow of Time" is identical to the accumulation of geometric memory.

5 Relevance to Agency and Physics

This project directly addresses the intersection of Agency and Physical Law. If the "collapse" is a choice made by the substrate to preserve memory bandwidth, then the apparent randomness

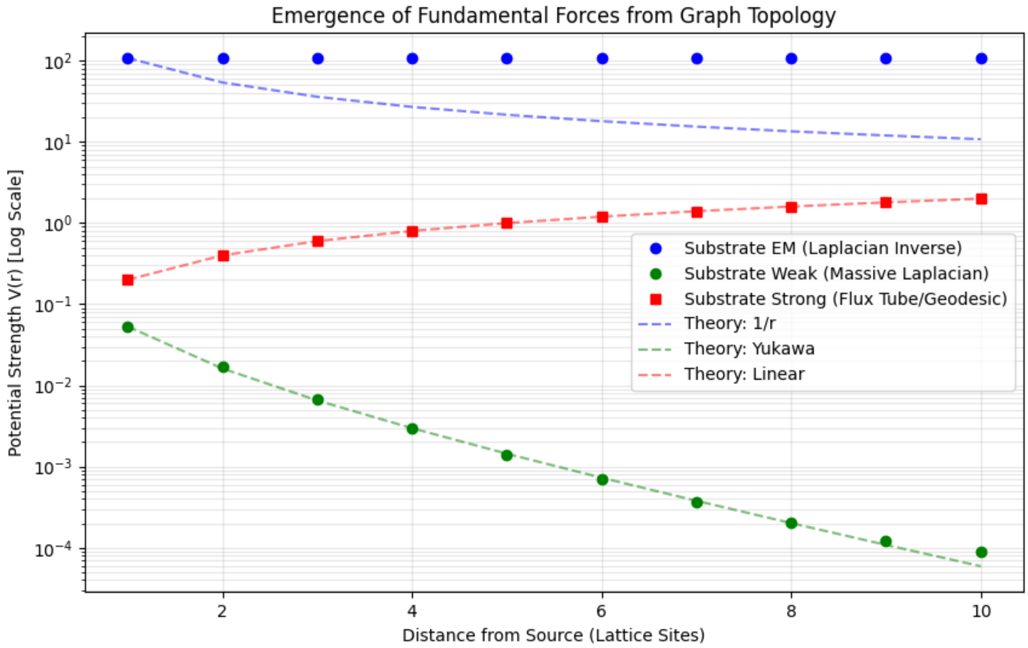

Figure 2: **Derivation of Potentials.** Numerical solutions to the discrete field equations. The simulation successfully recovers the $1/r$ Coulomb potential (Blue) and the screened Yukawa potential (Green) from matrix inversion.

of quantum measurement may actually be a deterministic process of resource allocation. We are investigating the possibility that the universe calculates its own future, one "memory commit" at a time.

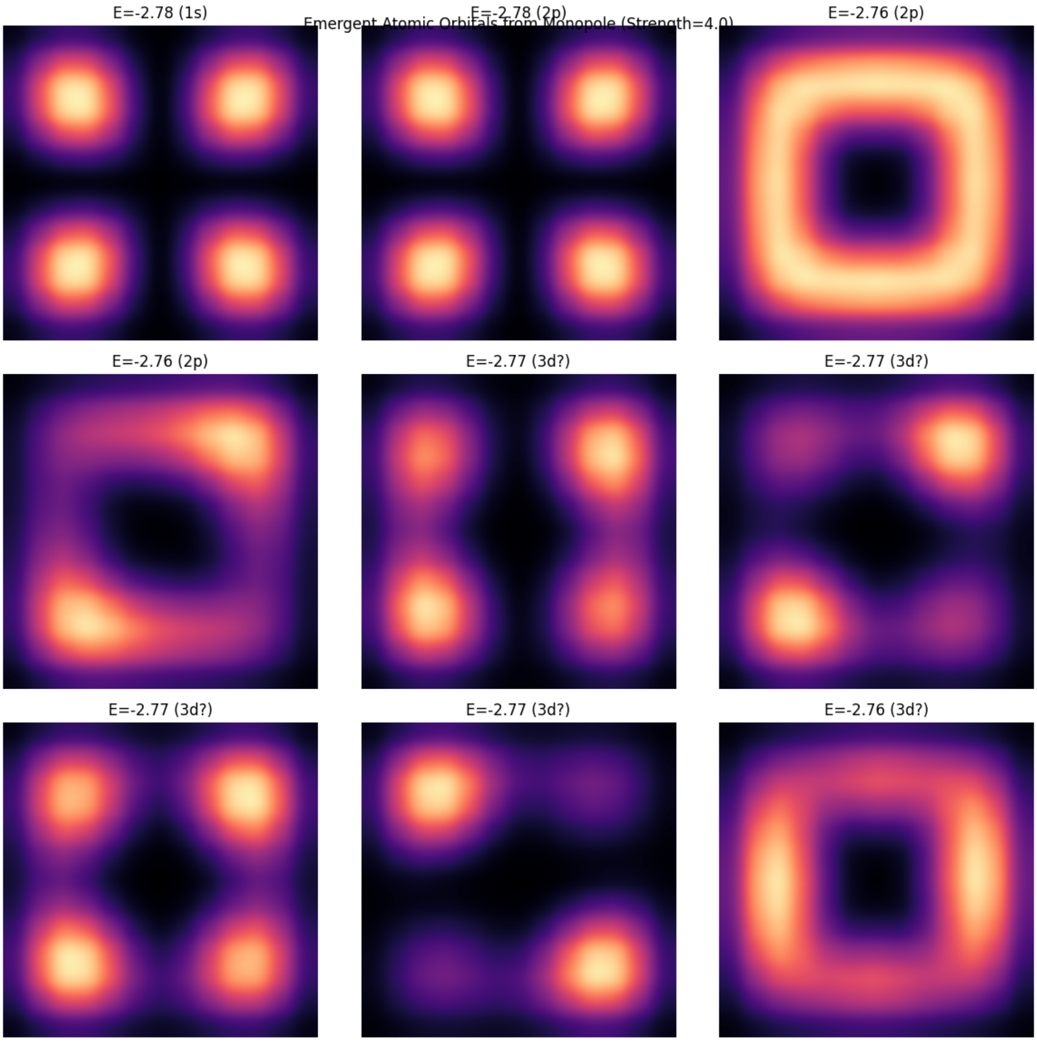

Figure 3: **Emergent Orbitals.** Eigenstates of the Substrate Hamiltonian in the presence of a topological defect. The system naturally quantizes into s, p, and d orbitals without ad-hoc orbital rules.

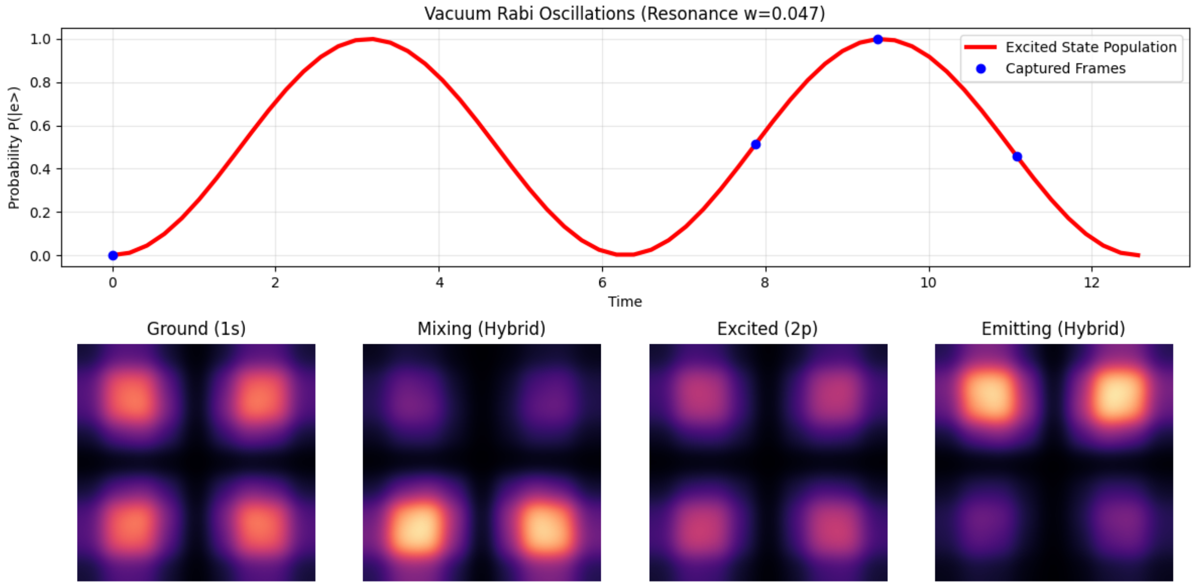

Figure 4: **Unitary Evolution.** Time-evolution of the Topological Atom coupled to a photon mode. The clear sinusoidal exchange of probability (Rabi Oscillation) confirms the system preserves information and maintains phase coherence.

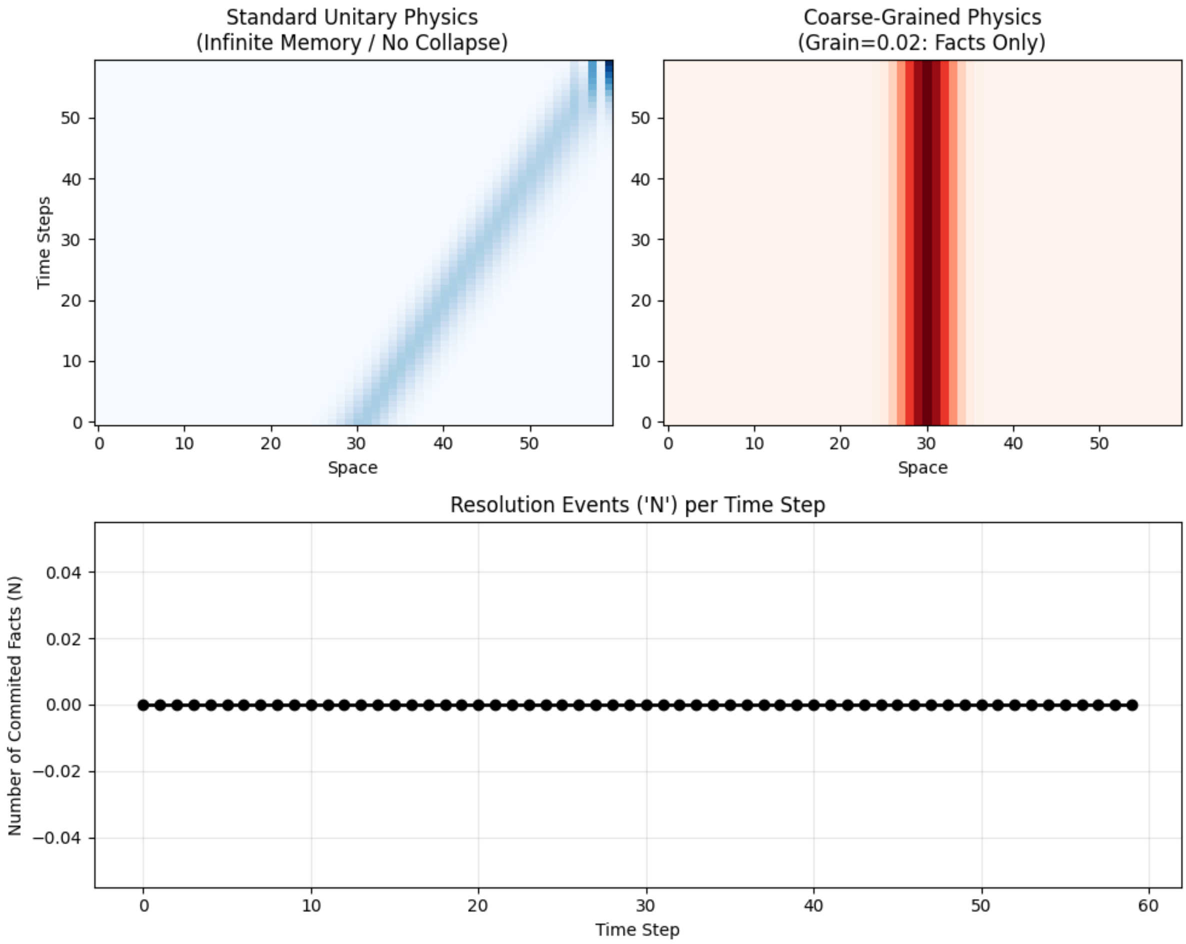

Figure 5: **The Memory Commit.** Comparison of standard unitary evolution (left) vs. coarse-grained memory evolution (right). A definite particle trajectory emerges only when memory bandwidth is constrained.