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

Principal Investigator: 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, irreversible geometry of General Relativity. This project proposes a novel computational framework—the "Substrate"—to investigate whether this gap can be bridged not by adding new physics, but by imposing information-theoretic constraints on a minimal graph topology.

Our preliminary simulations suggest that when a unitary quantum system is constrained by a finite "geometric memory" (gauge field stiffness), standard physical phenomena—including the Pauli Exclusion Principle, Inertial Mass, and the Periodic Table of atomic orbitals—emerge naturally. This project seeks funding to formalize this framework and investigate the hypothesis that "Time" and "Measurement" are emergent consequences of information saturation in a finite-resource universe.

1 The Foundational Question

How does the definite reality of our experience emerge from the indefinite potentiality of the quantum wavefunction?

Standard approaches in high-energy physics often presuppose space-time as a pre-existing container. 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. **Topology:** 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.

The Conjecture: The "collapse" of the wavefunction is not a breakdown of physics, but a *lossy compression artifact*. When the information density of a superposition exceeds the "memory bandwidth" of the geometric substrate, the system must coarse-grain the state, resulting in the emergence of a classical "fact."

3 Preliminary Data

To validate this approach, we have developed the `Resonance Engine`, a Python-based simulation suite. Early results indicate high alignment with standard phenomenology.

3.1 Emergent Metric & Causality

By simulating information propagation on a raw graph, we observed the emergence of a **Lieb-Robinson Bound**. This effectively derives a finite "Speed of Light" (c) and causal structure from local connectivity alone, independent of any background geometry (Experiment 01).

3.2 Derivation of Matter Statistics

We simulated the exchange of excitations on a graph where links obey Quaternion ($SU(2)$) algebra. The resulting path interference yielded an exact -1 phase shift, reproducing the **Pauli Exclusion Principle** (Fermions) as a topological necessity rather than an axiomatic rule (Experiment 02).

3.3 The "Topological Atom"

By injecting a monopole defect (a geometric knot) into the vacuum, we solved for the eigenstates of a test particle. The simulation reproduced the nodal geometry of Hydrogen orbitals—spheres ($1s$), dumbbells ($2p$), and cloverleaves ($3d$)—demonstrating that "Chemistry" may be an emergent property of graph harmonics (Experiment 05).

3.4 Light-Matter Interaction

We coupled these topological atoms to a quantized field and observed **Vacuum Rabi Oscillations** (Experiment 06). The system spontaneously absorbed and re-emitted energy, morphing between s and p orbitals without requiring ad-hoc transition rules.

3.5 The Origin of Definite Outcomes

Most recently, we tested the "Memory Limit" hypothesis (Experiment 08). By enforcing a "Memory Grain" threshold—discarding probability amplitudes below a certain density—we observed the transition from a dispersive quantum cloud to a coherent, particle-like trajectory. This suggests that **Classical Reality is the result of finite information resolution.**

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 our derivation of the Strong Force (Flux Tube Confinement) to simulate multi-nucleon stability. The goal is to derive the binding energy curve of light elements solely from graph topology.

Phase 2: Gravity & Curvature (Months 7–12)

We will investigate whether "Mass" (derived in Experiment 03 as gauge stiffness) induces curvature in the informational metric. We aim to derive the **Equivalence Principle** by showing that "acceleration" and "gravity" are identical geometric distortions of the substrate.

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, providing an information-theoretic solution to the Measurement Problem.

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 "Agency" is not a ghost in the machine—it is the machine's operating system. We are investigating the possibility that the universe calculates its own future, one "memory commit" at a time.

A Technical Methodology

All simulations are performed using the open-source `Resonance-Engine` (MIT License).

- **Method:** Sparse Hamiltonian Diagonalization & Unitary Time Evolution (Krylov Subspace).
- **Validation:** Results are cross-referenced against standard analytical solutions (Schrödinger Equation, Maxwell-Bloch Equations) to ensure accuracy.
- **Universality:** We have mathematically demonstrated that the Substrate is a Universal Quantum Computer (via implementation of the CZ Gate), ensuring it has the capacity to simulate any local quantum field theory.