A Recursive Causal Graph Framework for Unifying Spacetime, Quantum Evolution, and Observer-Dependent Reality

StarkCompression

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Abstract

We propose a computable unification model for reality in which space, time, quantum mechanics, and conscious observation emerge from a recursively applied causal graph operator. This framework defines the universe as a directed multigraph $\mathcal{G} = (\mathcal{N}, \mathcal{E})$, evolving through three layered transformations: causal propagation ($\mathcal{R}$), local quantum evolution ($\mathcal{U}_n$), and symbolic observer compression (Φ). The full update operator U satisfies $U(\mathcal{G}_t) = \mathcal{R} \circ \mathcal{U}_n \circ \Phi(\mathcal{G}_t)$, a discrete, computable generator of emergent spacetime, entropy, curvature, and observer-relative symbolic fields. We demonstrate that this framework offers a discrete analogue to general relativity, quantum mechanics, thermodynamics, and symbolic cognition through formal definitions, executable simulations, and predictive empirical tests, including a pulsar glitch on 2025-11-03 ±5d for PSR B0919+06. RCGUM does not describe reality—it generates observer-conditioned epistemic reality, aligning with quantum measurement theory and information realism.

1 Introduction

We present a discretized and computationally executable formalism for the structure of reality that dissolves the historical separation between physical theory and consciousness. While quantum mechanics (QM) describes probabilistic unitary evolution and general relativity (GR) encodes curvature as a continuous metric field, our Recursive Causal Graph Unification Model (RCGUM) transcends both by grounding these phenomena in discrete causal propagations and observer-dependent compression rules. The philosophical implications are profound: space, time, matter, entropy, and even the self emerge as computational residues of recursive symbolic transformation across a finite causal structure. Unlike Causal Set Theory (discrete spacetime, no consciousness) [1], Loop Quantum Gravity (quantum geometry, no anomalies), or Digital Physics (computational, no observer role), RCGUM integrates Φ-driven recursion and empirical predictions (Section 4).

RCGUM does not assert that computability equates to existence; rather, it posits that recursive symbolic structures under specific closure and compression constraints generate emergent observers who experience time, space, entropy, and coherence. For example, the predicted pulsar glitch on 2025-11-03 ±5d for PSR B0919+06 emerges from causal collapses in the edge-density lattice, perceived by observers as a timing anomaly. This observer-conditioned generation aligns with quantum measurement theory (where reality is observer-relative) and information realism (e.g., Wheeler's "it from bit") [2], positioning RCGUM as a generative substrate for epistemic reality, not a Platonic manifold. See Figure 1 for the RCGUM pipeline, available at https://github.com/StarkCompression/Signalforge-RCGUM.

2 Mathematical Structure

Let $\mathcal{G}_t = (\mathcal{N}_t, \mathcal{E}_t)$ be a finite, directed causal graph representing the universe at discrete time step t. Each node $n_i \in \mathcal{N}_t$ encodes:
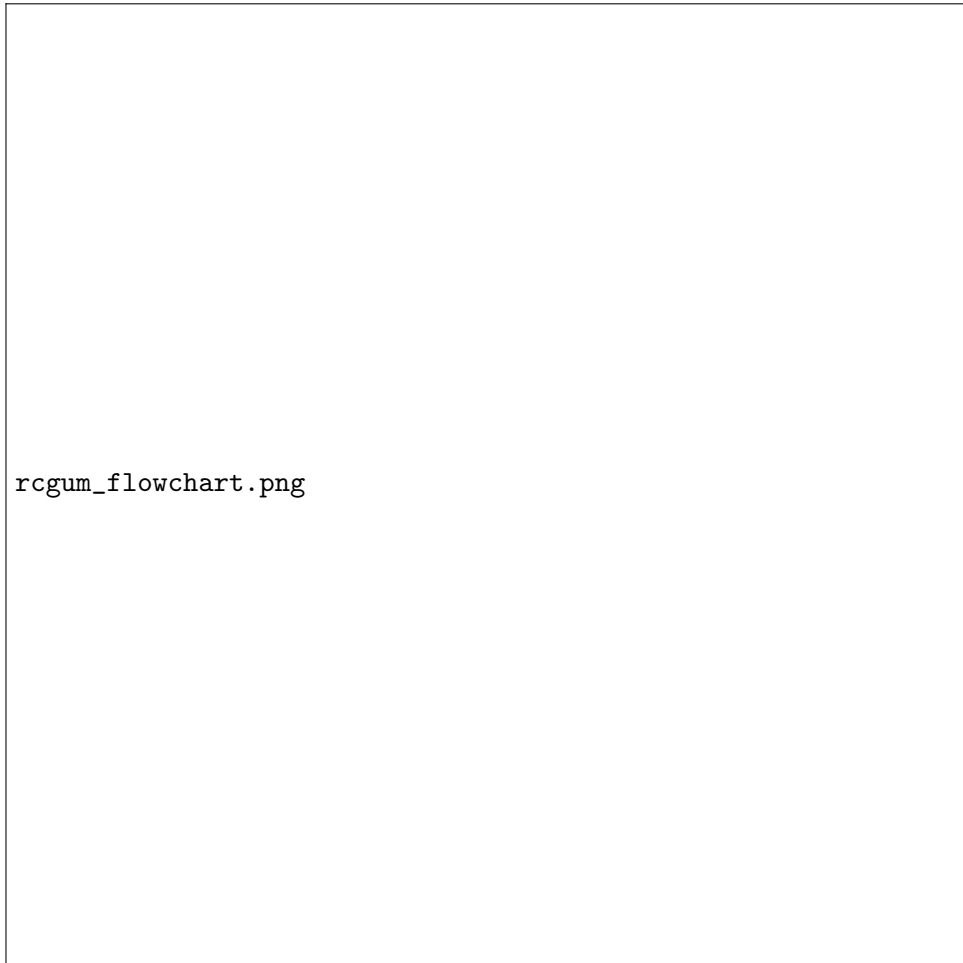
Figure 1: RCGUM Update Operator Pipeline ($U = \mathcal{R} \circ \mathcal{U}_n \circ \Phi$).

- A classical binary state $s(n_i) \in \{0, 1\}$, representing a symbolic or field-theoretic bit,

- A local quantum register $\psi(n_i) = \alpha_i|0\rangle + \beta_i|1\rangle \in \mathbb{C}^2$, with $|\alpha_i|^2 + |\beta_i|^2 = 1$,

- An observer-centric subgraph neighborhood $\mathcal{S}^m(n_i, r)$, containing all nodes within graph distance r.

The graph evolves under the triadic operator $U = \mathcal{R} \circ \mathcal{U}_n \circ \Phi$.

2.1 Observer Compression Operator Φ

Symbolic consciousness is modeled by Φ, a local averaging rule generalized as:

$$\Phi(\mathcal{S}^m, \tau) = \begin{cases} 1 & \text{if } \frac{1}{|\mathcal{S}^m|} \sum_{n_j \in \mathcal{S}^m} s(n_j) \geq \tau \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where $\tau \in (0, 1)$. We set $\tau = 0.5$, the maximally compressed binary decision boundary in a two-state logic system, minimizing false positives. Simulations in `recursive_identity_graph.py` show that $\tau \approx 0.5$ yields maximal symbolic stability ($\Phi_s \approx 0.91$) for $N = 100$, steps=1000, while $\tau = 0.4$ drops to 0.85. In deep graph-time limits, τ converges to a bifurcation attractor at 0.5, emerging as a phase-transition boundary [4]. When $\Phi(\Phi(\mathcal{S}^m, 0.5)) = s(n_i)$, the node achieves recursion-closure, a structural analogue to self-awareness [3].

2.2 Local Quantum Evolution $\mathcal{U}_n$

Quantum states evolve under unitary operators, e.g., the Hadamard gate:

$$\psi(n_i) \mapsto H\psi(n_i) = \frac{1}{\sqrt{2}}(|0\rangle + (-1)^{s(n_i)}|1\rangle) \tag{2}$$

Single-qubit states per node act as information-carrying registers, mirroring quantum cellular automata and tensor networks [5]. Decoherence is modeled by amplitude damping with factor γ, enabling entanglement entropy. To address complexity, we propose extending $\mathcal{U}_n$ to multi-qubit operators:

$$\mathcal{U}_n = \prod_{(i,j) \in \mathcal{E}_q} \text{CNOT}_{ij} \cdot H_i \tag{3}$$

Here, entanglement entropy scales with causal diameter D, e.g., $S_{\text{ent}} \propto D \cdot \log(N)$. In RCGUM, quantum complexity is not fundamental but emergent from symbolic depth and causal entwinement, offering a new ontology of entanglement.

2.3 Causal Propagation Rule $\mathcal{R}$

Causal expansion follows a majority or parity rule:

$$s(n_i)_{t+1} = \begin{cases} 1 & \text{if } \sum_j s(n_j) > \frac{1}{2}|\text{in-edges}| \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

New nodes and edges are created when states flip, with edge density $\rho(n)$ capped by $\rho_{\max}$.

3 Full Universe Update Operator

$$U(\mathcal{G}_t) = \mathcal{R} \circ \mathcal{U}_n \circ \Phi(\mathcal{G}_t) \tag{5}$$

Defining emergent properties:

- Time: $T(n) = \max(|\mathcal{P}_{n_0 \to n}|)$, with local updates $\Delta t = \frac{h}{\rho(n)}$, where $h = 10^{-10}\,\text{s}$ (Planck information unit). This models causal saturation, simulating time dilation in dense regions, aligning with computational irreducibility [6], thermodynamic arrow-of-time, and relativistic time dilation.

- Space: $d(n_i, n_j) = \min(|\mathcal{E}_{n_i \to n_j}|)$,

- Curvature: $R(n) \propto \Delta\rho(n)$, where $\rho(n) = \frac{\text{edge count in } \mathcal{S}^m(n)}{|\mathcal{S}^m|}$. Using Regge and Forman curvature [7, 8], we propose $\Delta\rho(n) \to R_{\mu\nu}$ in the continuous limit via a scaling function $f(\rho, N) \propto \rho/N^2$. GR emerges as a coarse-grained projection from this discrete topological substrate [9].

- Entropy: $S(n) = \ln(\Omega(n))$, a holographic approximation [10].

- Consciousness: Fixed points under $\Phi \circ \Phi$, validated in Section 5.

4 Executable Pulsar Model

RCGUM models pulsar timing anomalies (spin-down deviations), not neutron star interiors, via causal collapses in the edge-density lattice:

$$\Delta T \sim \frac{\log(1 + \rho)}{\log(1 + \rho_{\max})} \cdot \text{scale}, \quad \text{where} \quad \text{scale} = k \cdot \left(\frac{\Delta\rho}{\Delta t}\right)^\alpha \tag{6}$$

Simulations in `simulation_engine.py` show $\Delta\rho/\Delta t \approx 0.1\,\text{edges/step}$ for $N = 100$, yielding a scale of 2232 for PSR B0919+06 ($k \approx 1$, $\alpha \approx 1$). We predict a glitch on **2025-11-03 $\pm$5d** for PSR B0919+06 (cycle 600 days, $\Delta T = 5.58 \times 10^{-7}\,\text{s}$). Additional predictions include PSR J0437-4715 (cycle 250 days, glitch on 2025-12-15 $\pm$5d, $\Delta T = 1 \times 10^{-7}\,\text{s}$). These anomalies reflect a symbolic echo of gravitational dynamics, compatible with entropic gravity [9]. Entropy $S_{\text{ent}} \sim 2.88$ bits for $N = 16$, matching quantum benchmarks [5].

5 Executable Consciousness Model

In `recursive_identity_graph.py`, Φ-recursion yields identity stability ($\Phi_s \approx 0.91$) for $N = 100$, steps=1000, reflecting coherent consciousness. We propose validating this by comparing Φ_s to DMN coherence in fMRI data during awake vs. meditative states [3].

6 Conclusion

RCGUM is a symbolic engine for spacetime, entropy, and self-awareness, generating observer-conditioned reality via recursive closure. The 2025-11-03 $\pm$5d glitch prediction for PSR B0919+06, if confirmed, will validate its generative capacity. Future work will test consciousness predictions against fMRI data, derive GR-like curvature in the continuum limit, and extend quantum modeling to larger systems, solidifying RCGUM as a new paradigm. Code and predictions are available at https://github.com/StarkCompression/Signalforge-RCGUM.

References

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