

Quantum Braid Dynamics

A Computational Process

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Abstract

Quantum Braid Dynamics (QBD) is a background-independent computational framework that derives the continuous fabric of spacetime and quantum mechanics from a discrete causal substrate governed by a dual logical-physical time architecture, irreflexivity, and acyclicity. By establishing a stabilizer codespace over causal diamonds, we construct a fault-tolerant topological quantum error-correcting code inherent to the pre-geometric vacuum, where physical updates correspond to logical operations. The dynamic evolution of this substrate is driven by a comonadic self-observation and stochastic rewrite constructor, calibrating physical constants such as vacuum temperature from information-theoretic principles.

Within this relational substrate, elementary fermions emerge naturally as stable, chiral tripartite braids, mapping discrete topological invariants directly to physical quantum numbers: electric charge, spin, and color. We derive the Standard Model gauge symmetries as emergent transformations of the local braid group, explaining the three generations of matter and their decay paths through discrete rewrite rules. Furthermore, we demonstrate that these topological operations form a computationally universal set, mapping physical interactions to discrete quantum computation.

Finally, we construct a discrete formulation of differential geometry directly on the causal network, deriving the Einstein field equations as a hydrodynamic equation of state without coordinate charts. We prove the geometric well-posedness and convergence of the discrete graph sequence to a smooth, four-dimensional Lorentzian manifold under the Lorentzian Gromov-Hausdorff-Prokhorov metric, formalizing the ER = EPR conjecture as microscopic topological wormholes and proving a holographic boundary-to-bulk isomorphism. This unifies general relativity, particle physics, and quantum fault tolerance as thermodynamic consequences of discrete information processing.

Chapter 22: Singularities & Condensates (Extremes)

22.1 Black Hole Interior

In classical General Relativity, gravitational collapse inevitably leads to a singularity—a point of infinite density where the laws of physics break down. Quantum Braid Dynamics resolves this breakdown not by introducing arbitrary quantum corrections, but through the fundamental hardware limits of the discrete graph: steric friction and unique causality saturation.

22.1.1 Definition: Saturated State

Characterization of Saturated Core States as Finite Density Computational Crystals

- **Maximum Density Constraint:** At the center of gravitational collapse, the local 3-cycle density ρ_3 does not diverge to infinity. Instead, it is bounded by a maximum critical density $\rho_{crit} \approx 1/(6\mu)$ defined by the steric friction limits of the Master Equation (Sec.5.2).
- **Saturated Core:** The resulting state is a highly complex, stable subgraph of maximal cycle packing, representing a “saturated core” or a dense computational crystal.
- **State Halting:** Because all available nodes and edges are fully saturated, no local rewrite operations are topologically permitted within the core bulk, causing local structural evolution to cease.

22.1.2 Theorem: Singularity Avoidance

Avoidance of Gravitational Singularities through Steric Friction and Unique Causality Saturation

- **Steric Friction Suppression:** The Master Equation’s creation term contains an exponential damping factor $e^{-6\mu\rho}$. As density $\rho \rightarrow \rho_{crit}$, the creation rate of new cycles is exponentially suppressed to zero, mathematically preventing the density from diverging.
- **Unique Causality Obstruction:** The Principle of Unique Causality (PUC, Sec.2.2) mandates that every valid graph rewrite must have a unique precursor 2-path. At critical saturation density, the high connectivity of nodes creates multiple overlapping paths, resulting in “topological jamming” where no PUC-compliant rewrites are possible.
- **Halting Probability:** The probability of rewrite acceptance drops to zero ($P_{acc}(\mathcal{R}) \rightarrow 0$), freezing the graph’s topology and preventing collapse below the Planck length.

22.1.3 Proof: Singularity Avoidance

Verification of Singularity Avoidance by Derivation of Vanishing Lapse Functions at Critical Density

- **Lapse Dilation:** The proper time interval $\Delta\tau$ is related to logical graph ticks Δt via the emergent Lapse function $N(x)$, where $N(x) \propto 1/\rho_3$ (Sec.14.1).
- **Proper Time Stoppage:** The proof demonstrates that as density approaches the critical saturation threshold ($\rho_3 \rightarrow \rho_{crit}$), the Lapse function vanishes:

$$N(x) \rightarrow 0$$

- **External Invariance:** From the perspective of an external observer at infinity, proper time inside the core stops completely, meaning the singularity is resolved as a static coordinate frozen state, while the global system remains strictly unitary.

22.1.4 Theorem: Core Density Limitation

Establishment of Finite Curvature Bound from Planck-Scale Node Spacing Constraints

- **Discrete Curvature Bounds:** In QBD, curvature is defined through discrete Ollivier-Ricci equivalents on the graph (Sec.11.2), measuring the transport distance between neighboring cycles.
- **Planck Spacing Limit:** Because graph edges represent discrete pre-geometric connections of finite length ℓ_0 , the distance between adjacent nodes has a hard lower bound of the Planck length.
- **Bounded Curvature:** Since node spacing cannot be compressed below the Planck scale, the Ollivier-Ricci curvature tensor $R(x, y)$ remains strictly bounded, proving that physical curvature never diverges.

22.1.5 Proof: Core Density Limitation

Verification of Core Density Limitation through Calculation of Maximum Ollivier-Ricci Curvature

- **Ricci Curvature Integration:** The proof integrates the Ollivier-Ricci curvature over a saturated graph configuration with maximum cycle density ρ_{crit} .
- **Finiteness Result:** It shows that the curvature eigenvalues are strictly bounded by $R_{max} \sim 1/\ell_0^2$, confirming that the physical curvature remains finite and verifying the resolution of the classical singularity.

22.2 Event Horizon & Evaporation

Classical General Relativity characterizes the event horizon as a geometric surface of no return. Quantum Braid Dynamics reinterprets this boundary as a computational phase boundary, explaining Hawking radiation not as spontaneous particle pair-creation in empty space, but as unitary, boundary-spanning topological swaps.

22.2.1 Definition: Desynchronization Boundary

Characterization of Event Horizons as Phase Boundaries of Infinite Error-Correction Latency

- **Lapse Dilation Divergence:** Near the horizon, the Lapse function $N(x)$ falls toward zero relative to the external asymptotic flat space (Sec.14.1).
 - **QECC Latency:** The Quantum Error Correction Code (QECC) stabilizing the manifold requires a finite number of logical ticks Δt_{corr} to complete a full correction cycle.
 - **Desynchronization Surface:** The physical time required for an error correction cycle diverges as $\Delta\tau = N(x)\Delta t_{corr} \rightarrow \infty$. This defines the Event Horizon not as a physical membrane, but as a computational phase boundary of infinite error-correction latency where the interior causally desynchronizes from the exterior.
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22.2.2 Theorem: Unitary Evaporation

Preservation of Black Hole Unitarity via Boundary-Mediated Topological Swaps

- **Boundary Spanning Moves:** Although the interior is desynchronized, non-local graph rewrite operations \mathcal{R} can span across the horizon boundary, connecting nodes just inside the desynchronization limit with nodes just outside.
 - **Topological Swaps:** These rewrites represent boundary-mediated tunneling events that swap high-entropy braid configurations from the frozen core with simple vacuum cycles from the exterior.
 - **Unitary Radiation:** Because these swaps are governed by strictly unitary rewrite operators, the emitted radiation is quantum-entangled with the core state, carrying information out and ensuring that the evaporation process is completely unitary.
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22.2.3 Proof: Unitary Evaporation

Verification of Black Hole Unitarity through Integration of Entanglement Page Curves

- **Tunneling Rate Evaluation:** The proof calculates the non-perturbative transition probability $\Gamma \propto e^{-S}$ of the boundary topological swap operators.
 - **Page Curve Derivation:** By integrating the entanglement entropy of the emitted radiation over the lifetime of the core, it shows that the entropy strictly follows the Page Curve, returning to zero at complete evaporation without firewall creation, proving global unitarity.
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22.3 Superconductivity

Standard condensed matter physics explains superconductivity through the pairing of electrons (Cooper pairs) and their condensation into a coherent state. Quantum Braid Dynamics reinterprets this zero-resistance state as a macroscopic manifestation of the universe's stabilizer code, explaining dissipationless flow through topological fault tolerance.

22.3.1 Definition: Macroscopic Braid Condensate

Characterization of Superconducting States as Macroscopic Topological Braid Condensates

- **Phonon-Mediated Fusion:** In a superconductor, lattice vibrations (phonons) act as local rewrite operators that couple individual fermion braids (β_e) together, forming composite, Bosonic 6-ribbon braids (β_{CP}).
 - **Braid Condensation:** These composite braids condense into a single, highly ordered, macroscopic topological braid state $|\Psi_{SC}\rangle$ spanning the entire material bulk.
 - **Coherence Length:** The coherence length of this macroscopic braid scales with the physical dimensions of the superconductor, representing a unified pre-geometric quantum state at human scales.
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22.3.2 Theorem: Infinite Code Distance

Suppression of Electrical Dissipation through Error-Correction of Low-Weight Thermal Fluctuations

- **Resistance as Rewrite Errors:** In a classical conductor, resistance is caused by random electron-lattice scattering events. In QBD, these events are modeled as weight-1 “rewrite errors” (random graph edge flips) that disrupt the electron braids.
 - **Macroscopic Code Distance:** The macroscopic braid condensate $|\Psi_{SC}\rangle$ possesses an extremely large code distance d proportional to the total number of lattice atoms ($d \propto N_{atoms}$).
 - **Frictionless Conduction:** Since the thermal errors have low weight ($w \ll d$), the comonad stabilization framework of the universe’s stabilizer code (the **Awareness Comonad**, Sec.4.3) automatically detects and corrects these fluctuations before they can decohere the state, allowing current to flow with strictly zero resistance.
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22.3.3 Proof: Infinite Code Distance

Verification of Dissipationless Flow through Integration of Awareness Comonad Projection Operators

- **Stabilizer Projection:** The proof constructs the projection operators for the comonad stabilization flow acting on the macroscopic braid condensate state $|\Psi_{SC}\rangle$.
- **Error Correction Yield:** By calculating the expectation value of the dissipation operator under the stabilizer projection, it demonstrates that all weight- $w < d/2$ errors are projected out, yielding a net scattering cross-section that is identically zero and proving the absolute fault tolerance of superconducting currents.

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