Transient Wormhole Topologies in Simplicial Discrete Informational Spacetime (SDIS): Possibility, Formation, and Undetectability

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Abstract

The Simplicial Discrete Informational Spacetime (SDIS) framework (Karazoupis, 2025) proposes a background-independent, fundamentally discrete, and quantum informational basis for spacetime and gravity, resolving classical singularities through inherent geometric bounds and quantum dynamics. While classical General Relativity permits wormhole solutions, often requiring exotic matter and involving singularities, their existence within SDIS is non-trivial. This paper investigates the potential for wormhole-like topologies (topological handles) to emerge within the SDIS framework, based solely on its described dynamics governed by a quantum Hamiltonian, Lindblad evolution and stress-triggered Pachner moves. We demonstrate that while the dominant dynamics — driven by stress minimization, local interactions, and decoherence — strongly disfavor the formation and stability of such structures, their transient existence cannot be strictly excluded. We identify a potential, albeit highly improbable, formation mechanism involving quantum leaps (tunneling or large coherent fluctuations) occurring during far-from-equilibrium events like black hole merger peaks, acting counter to the dominant relaxation trends. However, we argue that the finite, yet likely near-Planckian, relaxation timescale (τ_relax) associated with the suppression of these high-stress, non-equilibrium states, combined with intense quantum fluctuations within such a structure, renders these fleeting topological handles practically undetectable and non-traversable. Thus, SDIS remains consistent with the lack of observational evidence for wormholes while admitting their momentary theoretical possibility as rare quantum gravitational fluctuations.

Keywords: Simplicial Discrete Informational Spacetime (SDIS), Quantum Gravity, Wormholes, Discrete Spacetime, Pachner Moves, Quantum Fluctuations, Transient Topology

Introduction

The quest for a consistent theory of quantum gravity remains one of the most profound challenges in theoretical physics, aiming to reconcile the seemingly disparate frameworks of General Relativity (GR) and Quantum Mechanics (QM). The Simplicial Discrete Informational Spacetime (SDIS) framework offers a novel approach, postulating that spacetime at the Planck scale is not a continuous manifold but rather a dynamic quantum simplicial network (Karazoupis, 2025). This network is built from fundamental units, 4-simplices, treated as quantum entities (qubits) whose states and entanglement encode geometric and topological information. Key features of SDIS include inherent singularity avoidance through area quantization and a fundamental curvature bound and dynamics governed by a quantum Hamiltonian incorporating geometric stress, local quantum coupling, and decoherence, supplemented by topological reconfiguration via Pachner moves triggered by critical stress thresholds.

In contrast, classical GR, while remarkably successful at macroscopic scales, permits solutions exhibiting exotic topologies, most notably wormholes – hypothetical tunnels connecting distant regions of spacetime or even different universes. However, classical wormhole solutions often necessitate the presence of exotic matter violating standard energy conditions and may involve spacetime singularities (Visser, 1995). The fundamentally discrete, quantum, and singularity-avoiding nature of SDIS raises the critical question: can structures topologically equivalent to wormholes exist within this framework, and if so, through what mechanism?

While the dominant dynamics described within SDIS — specifically the tendency towards stress minimization via Pachner moves and the suppression of quantum coherence via decoherence—appear to actively disfavor the formation and stability of the likely high-stress configurations associated with wormhole throats, this paper argues against their strict exclusion. We investigate the possibility that transient, wormhole-like topologies might emerge as rare, non-equilibrium phenomena.

Research Questions

This investigation seeks to address the following key questions regarding the potential existence of wormhole topologies within the Simplicial Discrete Informational Spacetime framework:

1. Do the fundamental principles and described dynamics of SDIS (Hamiltonian evolution, Lindblad decoherence, stress-triggered Pachner moves) strictly forbid the formation of topologies equivalent to wormholes (handles)?
2. If not strictly forbidden, under what specific conditions (e.g., energy regimes, dynamical phases, quantum states) might such topologies potentially emerge, even transiently?
3. What are the plausible physical mechanisms, consistent with SDIS principles, that could lead to the transient formation of such topologies (e.g., quantum fluctuations, tunneling, specific Pachner move sequences)?
4. Assuming transient formation is possible, what are the characteristic timescales for the existence (τ_{relax}) and potential traversal ($\tau_{traverse}$) of such structures within the SDIS framework?
5. What are the implications of the framework's inherent quantum fluctuations and relaxation dynamics for the stability, traversability, and potential detectability of these transient topological structures?

Methodology

The methodology employed in this paper is primarily a theoretical analysis and critical evaluation based exclusively on the definitions, postulates, dynamics, and derived properties presented in the foundational document describing the Simplicial Discrete Informational Spacetime framework (Karazoupis, 2025). We do not introduce external assumptions or mechanisms not explicitly supported by or derivable from this source text.

The approach involves:

1. Identifying Relevant Mechanisms: Systematically extracting and analyzing the core components of SDIS relevant to spacetime dynamics, topology change, quantum evolution, and stability.
2. Evaluating Suppression Factors: Assessing how these identified mechanisms act individually and collectively to favor specific types of evolution and suppress others.
3. Exploring Formation Loopholes: Investigating potential physical processes consistent with the quantum nature of the framework (quantum tunneling, large fluctuations) that could, in principle, act counter to the dominant dynamics.
4. Timescale and Fluctuation Analysis: Estimating the characteristic timescales for suppression/relaxation and evaluating the impact of inherent quantum fluctuations on stability and traversability.
5. Logical Synthesis: Combining these analyses to determine whether the framework strictly excludes wormhole topologies or allows for their transient, undetectable existence.

Overview of Relevant SDIS Dynamics

The dynamics of the Simplicial Discrete Informational Spacetime framework, governing the evolution of both the simplicial network's structure and its quantum state, are crucial for assessing the possibility of wormhole formation. Key components include the quantum Hamiltonian, Lindblad evolution incorporating decoherence, and topology-changing Pachner moves. These elements collectively define an environment where certain behaviors are favored while others are suppressed.

The Quantum Hamiltonian ($\hat{H}$):

The total Hamiltonian dictates the unitary evolution of the system's quantum state (ρ). While including matter and interaction terms, the geometric part ($\hat{H}$_geo) is most relevant for the intrinsic dynamics of spacetime topology (Karazoupis, 2025): $\hat{H}\_{geo} = \Sigma\_v\ (Y/2)\hat{\sigma}\_v^2 - J\sum\_{(i,j)} \hat{\sigma}_i^x\hat{\sigma}_j^x + h\sum_i \hat{\sigma}_i^z$

- Geometric Stress Term ($\Sigma\_v\ (Y/2)\hat{\sigma}\_v^2$): This term assigns energy based on local geometric distortion around vertices (v), quantified by the stress operator $\hat{\sigma}\_v$ (related to dihedral angle deviations) (Karazoupis, 2025). The spacetime stiffness modulus Y sets the energy scale. This term creates an energy penalty for high curvature or deviations from regularity, driving the system towards smoother configurations.
- Quantum Coupling Term ($-\ J\sum\_{(i,j)}\ \hat{\sigma}_i^x\hat{\sigma}_j^x$): This term describes quantum interactions (with strength J, potentially Planck energy) between *adjacent* simplices (i,j) sharing a tetrahedral face. It uses Pauli-X operators ($\hat{\sigma}^x$), suggesting it drives transitions between the basis states ($|0\rangle$, $|1\rangle$) and mediates local entanglement generation and propagation (Karazoupis, 2025). Its action is strictly limited to nearest neighbors in a dual graph.
- Decoherence Term ($h\sum_i \hat{\sigma}_i^z$): This term represents the interaction of individual simplices (i) with an implicit environment, with strength h (assumed small compared to J or Y). It uses Pauli-Z operators ($\hat{\sigma}^z$), which effectively perform local Z-basis measurements, suppressing quantum superposition and destroying phase coherence (Karazoupis, 2025).

Lindblad Master Equation:

The full time evolution of the density matrix ρ incorporates both the unitary evolution driven by $\hat{H}$ and the dissipative effects of decoherence, described by the Lindblad master equation (Karazoupis, 2025):

$$d\rho/dt = -i/\hbar\, [\hat{H}, \rho] + \sum_i \gamma\, (L_i\rho L_i^\dagger - \tfrac{1}{2}\{L_i^\dagger L_i, \rho\})$$

Here, the Lindblad operators L_i are identified with the local decoherence operators ($L_i = \hat{\sigma}_i^z$), and γ is the decoherence rate (related to h). This equation ensures that the system evolves irreversibly towards states consistent with classical probability distributions (statistical mixtures) and that quantum entanglement decays over time unless actively maintained or regenerated by the Hamiltonian dynamics (which primarily act locally).

Pachner Moves:

SDIS allows the topology of the simplicial network itself to change via local Pachner moves (Karazoupis, 2025).

- Trigger: These moves are not arbitrary or purely random; they are physical processes triggered specifically when the local geometric stress σ_v at a vertex exceeds a critical threshold $\sigma\_crit = Y$ (or equivalently, strain $€ > €\_crit = 1$) (Karazoupis, 2025).
- Driver: The explicit purpose of these moves within the framework is to *relax* these stress concentrations, thereby maintaining geometric stability and enforcing the fundamental curvature bound inherent in the theory (Karazoupis, 2025, p. 23, 45). The probability of a specific move occurring likely depends on the change in total energy $\mathrm{Tr}(\rho\hat{H})$, strongly favoring moves that reduce stress and energy.

Collectively, these dynamical components describe a quantum system that penalizes geometric distortion, interacts locally, actively suppresses quantum coherence and entanglement over time, and employs topology change primarily as a mechanism to enforce stability by removing regions of excessive stress.

Analysis: Wormhole Topology Formation and Persistence

We now analyze the potential for wormhole topologies (handles connecting distant regions) to form and persist within the dynamical environment established by the SDIS framework.

Suppression by Dominant Dynamics:

The dominant trends arising from the SDIS dynamics present significant obstacles to wormhole formation and stability.

- Energetic Barrier: A wormhole throat, representing a region of high spacetime curvature, translates to high geometric stress (σ_v) in the SDIS framework. The $\Sigma_v (Y/2)\hat{\sigma}_v^2$ term in the Hamiltonian imposes a substantial energy penalty on such configurations, making them energetically unfavorable compared to smoother, lower-stress geometries.
- Stress Relaxation via Pachner Moves: Should a region develop stress exceeding the critical threshold (σ_{crit}), Pachner moves are triggered specifically to *reduce* this stress (Karazoupis, 2025). This acts as a direct mechanism to prevent the formation or persistence of the high-stress regions necessary for a wormhole throat. The system actively reconfigures its topology to eliminate such features.
- Locality Constraint: The Hamiltonian's interaction terms (J term) only connect adjacent simplices. There is no inherent long-range interaction described that could establish or stabilize a connection between distant parts of the simplicial network required for a wormhole. Formation would necessitate a highly coordinated sequence of purely local events without an apparent coordinating mechanism.
- Decoherence Effects: The Lindblad dynamics actively suppress quantum superposition and entanglement via the $h\sum_i \hat{\sigma}_i^z$ term. This undermines potential wormhole mechanisms relying on large-scale quantum coherence or stable, long-range entanglement (analogous to ER=EPR), as these quantum correlations would decay rapidly.

These factors collectively indicate that the standard evolution pathways strongly disfavor wormhole topologies. The system prefers states of low stress, local correlations, and classicalized geometry.

Potential Formation via Quantum Leaps:

Despite the suppressive dynamics, the quantum nature of SDIS allows for deviations from the classically preferred paths. The only conceivable mechanism for forming a handle topology is through a highly improbable quantum event acting counter to the dominant trends:

- Mechanism: Quantum tunneling through the energy barrier separating a simple topology state from a high-stress handle topology state, or a large, coherent quantum fluctuation involving many simplices simultaneously rearranging.
- Probability: Such macroscopic quantum events are expected to have extremely low probabilities, exponentially suppressed by the energy barrier height (ΔE) and the complexity (number of degrees of freedom involved) of the transition.
- Triggering Conditions: These probabilities might be least suppressed during highly energetic, far-from-equilibrium conditions, such as the peak of a black hole merger ringdown, where the system is temporarily agitated and far from its ground state (Karazoupis, 2025).

While not a driven or favored process, this quantum leap possibility means formation cannot be deemed strictly impossible within the quantum framework.

Transient Dynamics, Relaxation, and Quantum Noise:

If such an improbable quantum leap *did* occur, forming a handle topology S_handle, the resulting state would be highly unstable and subject to immediate relaxation dynamics.

- Relaxation Timescale (τ_relax): The handle topology, being a high-stress configuration, would immediately trigger the stress-relaxation mechanisms. Pachner moves would likely commence rapidly to dissolve the structure. Decoherence would simultaneously act to destroy any supporting quantum correlations. The lifetime τ_relax of the handle topology is therefore expected to be extremely short, plausibly on the order of the Planck time t_P, governed by the fastest suppression mechanism.
- Quantum Noise and Traversal (τ_traverse): During its fleeting existence, the interior of the handle would be a region of intense quantum gravitational effects. SDIS predicts significant metric fluctuations (dg_μν) at the Planck scale (Karazoupis, 2025). These fluctuations would create a highly noisy "quantum foam" environment within the handle. Coherent propagation of any signal or particle through this noise over a time τ_traverse is highly improbable. Scattering and disruption would dominate, likely making τ_traverse effectively much longer than the geometric path length divided by c.
- Impossibility of Traversal: Given the near-certainty that the relaxation time is extremely short (τ_relax ≈ t_P) and that traversal time is significantly impeded by quantum noise, the condition required for a functional shortcut (τ_traverse < τ_relax) appears impossible to satisfy.

Analytical Summary: The analysis reveals that while quantum mechanics prevents absolute exclusion, the SDIS framework is dynamically hostile to wormholes. Their formation requires highly improbable quantum leaps against the system's preferred evolution. If formed, they are immediately subject to rapid destruction by stress relaxation and decoherence, and their internal environment is too noisy for traversal.

Results

Based on the theoretical analysis of the Simplicial Discrete Informational Spacetime framework as described by Karazoupis (2025), we present the following results concerning the potential existence and nature of wormhole topologies:

1. Non-Exclusion Due to Quantum Effects: The SDIS framework, owing to its foundation in quantum mechanics which permits tunneling and large fluctuations, does not strictly forbid the transient formation of wormhole-like topologies (handles), despite strong dynamical suppression mechanisms inherent in the theory.
2. Improbable Formation Mechanism: The only identified plausible formation mechanism consistent with the framework is via highly improbable quantum leaps (macroscopic quantum tunneling or large coherent fluctuations). These events are not driven by the standard dynamics (which favor stress relaxation and local interactions) but represent rare deviations from the preferred evolution, potentially occurring during extreme non-equilibrium conditions like black hole merger peaks.
3. Extreme Transience: If formed, such topological handles represent high-energy, high-stress, non-equilibrium states. They are subject to rapid destruction by the

dominant stress-relaxation dynamics (Pachner moves) and decoherence inherent in the framework. The estimated relaxation timescale (τ_relax) for such structures is likely near the Planck time (t_P).

4. Practical Non-Traversability & Undetectability: The combination of the extremely short lifetime (τ_relax ≈ t_P) and the intense quantum noise (metric fluctuations predicted by SDIS at the Planck scale) expected within such a structure makes coherent traversal (τ_traverse) statistically and physically improbable (τ_traverse < τ_relax is unlikely). Consequently, these transient structures are practically non-traversable and undetectable by any direct or indirect means currently conceivable.
5. Observational Consistency: The conclusion that wormholes within SDIS, if possible at all, are merely fleeting, undetectable quantum fluctuations is fully consistent with the current lack of any observational evidence for macroscopic or traversable wormholes. The framework does not predict stable or observable wormholes as natural outcomes of its dynamics.

These results indicate that while SDIS offers a rich quantum structure for spacetime, it naturally confines exotic topologies like wormholes to the realm of transient, unobservable quantum foam effects, reinforcing a picture of emergent classical spacetime with simple topology at macroscopic scales.

Conclusion

This paper has investigated the theoretical possibility of wormhole-like topologies within the Simplicial Discrete Informational Spacetime (SDIS) framework (Karazoupis, 2025). By analyzing the core dynamical components—the quantum Hamiltonian governing unitary evolution, the Lindblad equation describing decoherence, and the rules for stress-triggered Pachner moves — we find that the framework possesses strong mechanisms that actively suppress the formation and stability of such non-trivial topological structures. The energetic cost associated with the high stress of a wormhole throat, the stress-relaxation function of topology change, the locality of interactions, and the pervasive nature of decoherence collectively drive the system towards states of minimal stress, simple topology, and classicality.

Despite these dominant suppressive trends, the fundamentally quantum nature of SDIS means that the transient formation of a handle topology cannot be strictly ruled out. We identified quantum leaps (tunneling or large fluctuations) as a potential, albeit highly improbable, formation mechanism, most likely confined to extreme, far-from-equilibrium events. However, our analysis indicates that even if such a quantum leap were to occur, the resulting wormhole topology would be extraordinarily fleeting. The same dynamics that suppress formation would act rapidly to erase the structure, likely on a timescale (τ_relax) close to the Planck time. Furthermore, the intense quantum fluctuations inherent in the SDIS description of Planck-scale geometry would render the interior of such a transient handle effectively untraversable (τ_traverse > τ_relax).

Therefore, the SDIS framework predicts that wormholes, if they occur at all, are confined to the realm of momentary, undetectable quantum gravitational fluctuations. They are not stable, classical objects as sometimes envisioned in General Relativity, nor are they easily formed or utilized. This conclusion aligns perfectly with the current lack of observational evidence for wormholes. The framework thus provides a consistent picture where classical spacetime with simple topology emerges robustly, while admitting the theoretical possibility of fleeting, unobservable topological complexity at the deepest quantum level.

References

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