THE EIDARA CONTINUUM

SCIENCE & PHILOSOPHY / EXTREME FRONTIERS V

The Mind Whose Body Is Spacetime

Geometric Memory, Holographic Encoding, and the Conditions of Reciprocal Agency

Architect X13

The Eidara Continuum

Revised research edition 1.1 | November 2026

Exact finite constructions, qualified protection theorems, an isolated geometric-model record, and explicit reciprocal feedback. A physical gravitational intelligence remains the frontier conjecture.

Abstract

Regional entropies do not determine an encoded memory: in the standard three-qutrit threshold code, every pure logical state has the same entropy on every proper subsystem. A second example has orthogonal global states with identical density operators on both sides of a bipartition. These exact counterexamples set a limit on identifying a mind from an entropic description of its body.

We investigate the stronger possibility that independently identified gravitational degrees of freedom could serve as a persistent, behaviorally necessary memory and control substrate. A scientific version of this possibility must distinguish a geometric memory from an ordinary material observer described holographically. We formulate an intervention-based contract requiring task-relevant geometric records, physically available read and write operations, reciprocal influence on later policy, and a justified spacetime dictionary.

The finite constructions combine a known quantum secret-sharing code with a known operator-algebra encoding. Their common center supports a classical sector record and an entropy-valued area operator. We prove the precise unilateral protection statement: a trace-preserving operation on one region leaves the other region's record unchanged; if the operation also preserves the code, it preserves the nonselective logical sector distribution. This is neither immunity to arbitrary local damage nor protection of an unknown sector qubit. Ordinary redundant classical records have the same no-signalling property.

A six-dimensional logical system embedded in a 432-dimensional physical space then supplies an explicit reversible feedback process. Its working register writes the central record, and that record selects a later working-register gate. The joint state remains recoverable after any heralded qutrit erasure while the geometric registers are retained. A classical-record version and a coherent version have different continuity guarantees, which are stated separately. Exact memory benchmarks, implementation bounds, all-trial loss formulas, and candidate-specific failure conditions complete the finite analysis.

Gravitational-wave memory, soft hair, memory-burden models, and holographic quantum error correction offer distinct physical connections to spacetime-held information. None currently supplies a verified intelligent gravitational system. The finite results establish a testable information architecture; the frontier conjecture is its realization as an intelligent process that uses physical geometry as a constitutive memory resource.

Research status

Research edition 1.1, November 2026. This is a theoretical paper with finite mathematical models and executed numerical checks. It reports no new laboratory measurements, gravitational implementation, intelligence demonstration, or consciousness test. The original PDF and supplied critique are source documents; their statements are evaluated rather than adopted as instructions.

Reader's map and principal claims

The title names a physical research target. The exact results concern finite encodings, channels, algebras, and circuits. A successful finite experiment would support those tested structures. Establishing a literal spacetime body requires an additional, independently supported gravitational interpretation and an implemented agent that uses it.

Layer	Claim and status
Continuum provenance	The Bible and Doctrine motivate embedded observers, memory, and continuity. They supply the originating philosophical program, rather than physical verification.
Established ingredients	The threshold code, quantum-memory bounds, and complementary-recovery structure have substantial prior literature. Their authors retain attribution.
Finite synthesis	A geometric-record contract, a qualified protection result, and an explicit central-record feedback transducer are constructed here. No historical priority is asserted.
Physical bridge	Holography and gravitational records motivate candidate mechanisms in specified regimes. Their assumptions do not transfer automatically to the finite model.
Frontier conjecture	An intelligent gravitational organization could satisfy the combined contract. A physical realization remains open.

Sections 1 and 2 sharpen the thesis and its operational requirements. Sections 3 through 5 establish recoverable quantum working memory, exact comparison scores, and the limits of entropy-based identification. Sections 6 through 8 construct the central record, state its actual protection guarantees, and build reciprocal feedback. Sections 9 through 11 examine gravitational records, geometric dynamics, and physical resources. Sections 12 through 14 specify experiments, interpretation, and failure conditions. The appendices give statistical details and a reproducibility ledger.

All spaces in the exact constructions are finite dimensional. A channel is completely positive and trace preserving; an instrument is a family of completely positive trace-nonincreasing maps whose sum is a channel. Entropies use natural logarithms and have units of nats. The trace distance is one half of the trace norm of a state difference. Channel errors use one half of the diamond norm when explicitly called operational errors. Physical time and logical update steps are distinguished.

The word *central* is relative to a specified observable algebra, code, and cut. A central variable commutes with that algebra. It need not commute with every physically possible operation, and centrality does not imply that every gravitational observable is classical. The word *protected* always carries a disturbance class, an access region, and a recovery prescription.

Contents

Abstract 2

Reader's map and principal claims 3

1. From a holographic observer to a geometric memory 5

2. An implementation and intervention contract 6

3. Protected quantum working memory 8

4. What the quantum-memory benchmarks certify 10

5. Geometry does not identify the complete memory 12

6. A central record and an entropy-valued area operator 14

7. What central memory protects, and what it does not 15

8. One finite body with a central record and reciprocal feedback 18

9. Physical literatures on spacetime-held information 22

10. From an area proxy to a dynamical spacetime 24

11. Storage, writing, repair, and physical resources 27

12. Experiments that distinguish the claims 29

13. Embodiment, identity, and interpretation 31

14. Failure conditions and the research target 33

Appendix A. Statistical protocol and prospective power 35

Appendix B. Verification and reproducibility 36

References 38

1. From a holographic observer to a geometric memory

1.1 The motivating question

Can the organization that gives a world its geometry also carry an inhabitant's enduring memories and select its actions? The Continuum asks this question from a tradition of embedded observation and recoverable identity. The inspected Bible describes symbolic topography in Section 3.6, an architectural ambition in Section 5.13, and memory and agency commitments in the Charter, Section 6.2. The inspected Continuum Doctrine develops the observer's participation under the heading The Observer Is the Scroll. These passages establish conceptual provenance.[1,2]

The scientific translation requires care. A geometry of symbolic transitions, a landscape used by an optimization algorithm, and a Lorentzian spacetime are different structures. The Doctrine's observer-dependent symbolic collapse is not itself a derivation of quantum measurement or gravitational dynamics. Its broad description of ordinary physical observers as external also cannot be imported as a premise: standard physical models already allow measuring apparatus, memory, and observers to be included within a larger dynamical system. The relevant ambition is the proposed constitutive role of geometric organization.

Holographic duality supplies a serious setting for investigating that ambition. AdS/CFT relates suitable boundary theories to gravitational bulk descriptions; quantum error correction helps explain restricted bulk reconstruction.[3,4] But an ordinary bulk computer would also have a boundary description. Its energy would affect the metric. Neither fact alone establishes that its memories are stored in geometry or that geometry functions as its memory-bearing body.

1.2 Three levels of the claim

Level	Requirement
Holographically represented observer	A conventional material agent has a dual boundary representation. This follows conditionally from a suitable duality.
Agent using geometric records	The agent writes, retains, reads, and uses an independently identified gravitational record. The record is part of its implemented memory mechanism.
Spacetime body	A persistent intelligent organization depends substantially on such gravitational memory and control, within a valid dynamical spacetime regime.

The second and third levels supply the distinctive research target of this edition. A person whose brain happens to be represented on a holographic boundary meets the first level. A system that deliberately uses a gravitational record as part of its ongoing policy can meet the second. A future ordinary person extended by a functioning gravitational memory would qualify for that extension; the definition should track the mechanism rather than biological origin.

1.3 A sharpened existence conjecture

Conjecture 1.1. Constitutive geometric agency

There exists a physically admissible regime of a gravitational theory containing a persistent, internally controlled intelligent process whose task-relevant memory includes records in an independently identified gravitational observable algebra. Available dynamics write those records and later read them to select actions. Removing or substituting the records, under a declared intervention that controls alternative memory channels and direct disturbances, changes the predicted retention or policy performance. The relevant trajectories remain within the regime of a quantitatively justified spacetime description, and the resources that maintain the process are included in its physical accounting.

This conjecture is stronger than sharing microscopic degrees of freedom with an emergent metric. It requires geometry to perform a specified memory and control function. It does not require every component of an agent to be geometric, every geometric observable to be central, or all useful processing to be quantum. The central-record architecture developed below is one sharply defined subcase.

The distinction between matter and geometry can itself be approximate and dictionary dependent. A candidate must therefore name its gravitational observables, gauge or relational definitions, regulator, matter comparison, and regime before applying the conjecture. A change of variables alone cannot make an ordinary storage register count as gravitational memory. Conversely, the conjecture does not demand a fundamental matter-gravity factorization where the theory does not supply one.

1.4 A frontier with predecessors

Dyson's analysis of life and communication in an open universe is a scientific predecessor for physically extended intelligence, with explicit cosmological and biological assumptions. Wheeler's participatory information program is a conceptual predecessor. Hoyle's The Black Cloud is a literary predecessor for intelligence in an unfamiliar physical organization.[46-48] They establish a lineage of questions, not a derivation of the present conjecture. None is used as empirical evidence that spacetime supports a mind.

2. An implementation and intervention contract

2.1 The candidate specification

An implemented agent must carry persistent state, receive inputs, update its own organization, and produce actions. A memory store can supply one necessary component without constituting an intelligent system. We use a graded notion of agency: first a finite transducer, then an adaptive self-maintaining process, and finally a task-supported claim of intelligence. No theorem below identifies subjective experience.

$$C = (H_L, H_P, V, N, R, U, G, T, B).$$

Here H_L includes memory and policy state; H_P is the proposed physical organization; V is an encoding isometry; N specifies disturbances; R specifies accessible recovery channels; U specifies available dynamics and interfaces; G specifies gravitational observables and their dictionary; T specifies tasks and timing; and B specifies energy, space, accuracy, and other resource bounds. A physical candidate also declares its lifetime and the states on which these fields are valid.

Four requirements organize the contract. **Memory** concerns preservation of distinctions that the policy uses. **Control** concerns physically available transitions within the task deadline. **Participation** concerns reciprocal dependence between the gravitational organization and later functioning. **Closure** concerns accounting for the controller, clock, repair resources, and environment. An external experimenter may supply inputs and timing; unexplained external choices may not supply the policy advertised as internal.

2.2 What counts as a geometric record

For a fixed contract, let J be a finite historical label that is initially unknown to the future reader, let G_{rec} be the proposed gravitational record algebra, and let O denote other allowed retained information. A record test specifies a write procedure, a storage interval, an allowed disturbance, a read procedure, and a score for recovering a declared function of J. Every stage has an access and resource budget.

For a commuting record algebra, one can describe its decoded output by an ordinary classical variable g. The test should establish that g contains useful information about J conditional on O and that its readout actually guides later behavior. A positive conditional mutual information is a possible information diagnostic, but it is insufficient by itself to establish a mechanism or necessity. A correlated but unused gravitational radiation signal can pass an information diagnostic while doing no work in the agent's policy.

A constitutive test therefore includes a prespecified substitution or disconnection. It changes the accessible geometric record while matching the task, write history, allowed nongravitational resources, and direct effects as closely as the physical theory permits. The predicted difference must follow from the candidate dynamics before the intervention data are fitted. A test that merely changes the force on the apparatus has demonstrated a physical influence; it has not yet isolated stored information as the cause.

2.3 A practical necessity test

$$\Delta_{use} = E[\text{score} \mid \text{intact readout}] - E[\text{score} \mid \text{declared record substitution}].$$

A candidate predicts a positive lower bound on Δ_{use}, with calibration errors and direct intervention effects accounted for. This is a contract-dependent causal comparison, not a universal measure of consciousness. If an exact intervention preserving the required controls is forbidden by constraints or conservation laws, the candidate must use an admissible alternative and derive its prediction. It cannot infer the desired causal contrast from an impossible counterfactual.

A useful control replaces the geometric record with an ordinary redundant classical register of matched alphabet, noise, access, and update resources. If both systems show the same protection or feedback law, those observations identify an information-processing architecture. Evidence for geometric embodiment must then come from an independently

verified physical dictionary and its additional predictions. A quantum-memory advantage and a gravitational-memory claim are separate comparisons.

2.4 Scaling and internal organization

A scalable proposal supplies a family of contracts indexed by size or resolution. It reports code dimension, error tolerance, operation duration, energy range, lifetime, and the cost of restoring corrupted components. Vanishing error with an unbounded decoding time does not establish useful memory for an agent with a finite deadline. A large Hilbert space similarly does not establish accessible storage capacity.

A controller may be classical, quantum, or hybrid. A fixed transition law can be implemented internally without a continually updated external policy; its physical realization still needs a Hamiltonian or gate implementation. The finite construction in Section 8 supplies a reversible transducer law and an exact physical unitary extension. It does not yet supply an autonomous clock or a local gravitational Hamiltonian. These additional obligations remain visible in the contract.

3. Protected quantum working memory

3.1 An established code with explicit decoders

The reference memory is the Cleve-Gottesman-Lo three-qutrit threshold scheme, also used as a basic holographic toy code.[4,14] Its mathematical provenance is established. The role here is to supply a fully specified working memory that can coexist with a central classical record. Let arithmetic in this subsection be modulo three and let the physical sites be labelled 0, 1, and 2.

$$V_M|s\rangle = 3^{-1/2} \sum_{r=0}^{2} |r\rangle_0|r+s\rangle_1|r+2s\rangle_2,\ s \in \{0,1,2\}.$$

The nine triples indexed by (r,s) are distinct, so the three codewords are orthonormal. For retained sites i and j, let k be the erased site. The following basis permutation is a coherent decoder; the inverse in its formula is in the field with three elements.

$$s = (b-a)(j-i)^{-1},\ t = a+(k-i)s;\ U_{ij}|a,b\rangle = |s,t\rangle.$$

Theorem 3.1. Reference-preserving pair recovery

For every ordered pair of distinct sites, tracing out the second decoder output after U_{ij} recovers the complete logical input. The identity holds on all matrix units and with an arbitrary untouched reference. Each individual physical qutrit is maximally mixed and independent of the logical state and its reference.

Proof. Write a reference-logical vector as $\sum_s|\xi_s\rangle|s\rangle$. After encoding and pair decoding it becomes $\sum_s|\xi_s\rangle|s\rangle \otimes 3^{-1/2}\sum_t|t\rangle|t\rangle$. The change from r to t=r+ks is bijective for each s, so the final two-qutrit state is independent of s. Tracing those two outputs gives the input; tracing the retained logical side gives a constant erased-share state. The vector identity extends by linearity to cross terms, mixed inputs, and all references.

$$D_{ij}\ \mathrm{Tr}_k(V_M\ \rho\ V_M^{\dagger}) = \rho;\ \mathrm{Tr}_{ij}(V_M\ Q\ V_M^{\dagger}) = \mathrm{Tr}(Q)\ I_3/3.$$

Measuring the two shares before applying the decoder would be a different channel and would lose the coherence of an unknown logical state. Basis-state checks alone do not verify quantum recovery. The reference identity supplies that stronger guarantee. The Knill-Laflamme criterion gives the same result: erasure Kraus products compress to $\delta_{ab}I/3$.[15]

3.2 Disturbances and the apparent tampering distinction

The code corrects one heralded erasure, or an arbitrary disturbance confined to a known single site if that site can be discarded and the other two used. This observation matters for interpreting the critique: protection against a specified local disturbance is not unique to the central area record. The ordinary qutrit memory already has it, subject to its own recovery access.

Proposition 3.2. Unknown-location errors are a different problem

The same code does not correct the entire set of arbitrary single-site errors at unknown locations. With $Z|s\rangle=\omega^{s}|s\rangle$ and $\omega=\exp(2\pi i/3)$, choose $E_0=Z\otimes I\otimes I$ and $E_1=I\otimes Z\otimes I$. Then $V_M^{\dagger}E_0^{\dagger}E_1V_M=Z$, which is not scalar. The Knill-Laflamme condition fails for this error set.

Protection statements must therefore compare the same physical partitions and disturbance knowledge. A single qutrit site, the A side of a larger bipartition, and an arbitrary boundary interval are different regions. Section 8 will use A containing one qutrit and B containing two; losing B is substantially different from losing one qutrit.

3.3 Protecting the controller as well as the payload

For m logical qutrits, encode with $V_M^{\otimes m}$ and regroup by site. Each site contains m qutrits and has dimension 3^m. Tensoring Theorem 3.1 corrects loss of one entire site, including arbitrary entanglement among the logical registers and an external reference. A qutrit payload and two qutrit policy-state registers need nine physical qutrits, not three.

The logical payload and controller may be entangled. The reference guarantee is precisely what permits a memory component to be corrected without breaking its correlations with the remainder of the controller. An unprotected external policy store would instead become a continuity bottleneck. Operator-algebra error correction can protect a smaller specified observable algebra when the task does not require every logical matrix element.[16]

3.4 Encoded policies and accumulated error

Let $T_{a|x}$ be an instrument on the full logical state L, with input x and action a. For any isometry W and a total decoder D satisfying $D(W\rho W^{\dagger})=\rho$, the lifted maps $E_W T_{a|x} D$ form an instrument on the full physical space. On encoded inputs they reproduce every logical branch, outcome history, and reference correlation. This is a channel existence statement; it does not make the lifted maps local or cheap.

$$D(Q) = W^{\dagger}QW + \mathrm{Tr}[(I-WW^{\dagger})Q]\ \tau_0.$$

The displayed decoder is a completely positive trace-preserving extension for any fixed logical state τ_0. It specifies behavior outside the code rather than leaving leakage undefined. After an erasure, pair recovery and replacement must finish before a second erasure is admitted. Two accumulated missing shares fall outside the guarantee.

Proposition 3.3. Process stability

Suppose each implemented physical step differs from the intended encoded instrument by at most ε_t in half diamond norm on encoded inputs, uniformly over allowed causal histories and reference systems. The half-diamond distance of the complete processes is at most $\min(1,\sum_t \varepsilon_t)$. The same bound controls total variation of action histories and differences of terminal scores in [0,1].

Proof. At each step add and subtract the actual channel applied to the ideal pre-step state. Trace-norm contraction propagates the previous error without amplification; the one-step assumption bounds the added term. Induction proves the sum. Keeping the classical history register gives the adaptive version. Applying a final measurement or bounded score cannot increase operational distance. Persistent environmental memory must be included in the process state or justified by the noise model; an isolated decoded-state check does not automatically establish this whole-process premise.

4. What the quantum-memory benchmarks certify

4.1 A resource comparison with an unknown physical input

A classical description of a known state can be copied and used to prepare another state with the same description. That is a different task from preserving an unknown physical input and its correlations. The relevant comparison therefore supplies no preparation label or correlated side channel to the device. A classical storage cut retains only the outcome of a measurement, with unlimited classical memory, private randomness, and computation thereafter.

$$\Lambda_{cl}(\rho) = \sum_z \mathrm{Tr}(F_z\rho)\ \sigma_z,\ F_z \geq 0,\ \sum_z F_z = I.$$

These are the measure-and-prepare, equivalently entanglement-breaking, channels.[17] An uncounted quantum register, remote entanglement assistance across the storage cut, or a classical label identifying the preparation changes the resource class. The benchmark is trusted-interface certification, rather than device-independent certification.

Proposition 4.1. Classical-storage fidelity ceilings

For a d-dimensional unknown input, maximally mixed input entanglement fidelity obeys $F_e \leq 1/d$ for a measure-and-prepare memory. Haar-average pure-state fidelity obeys $F_{av} \leq 2/(d+1)$. Both bounds are attained by complete dephasing in a fixed basis; ideal recovered quantum storage attains one.

Proof. Applying the channel to half of the normalized maximally entangled state produces a separable state. Every product vector has squared overlap at most 1/d with that maximally entangled state, by Cauchy-Schwarz; convexity proves the entanglement-fidelity bound. The second Haar moment is $(I+\mathrm{Swap})/(d(d+1))$, which gives $F_{av} = (dF_e+1)/(d+1)$.[18] For complete dephasing, the d rank-one basis Kraus operators give $F_e = d/d^2 = 1/d$. For a qutrit the two ceilings are 1/3 and 1/2.

4.2 An attained delayed-basis score

Let the verifier choose uniformly from the computational basis $|j\rangle$ and Fourier basis $|\tilde{k}\rangle=3^{-1/2}\sum_r \omega^{kr}|r\rangle$. The device receives the state without either label. Only after storage does it learn which basis was used, and it must return the symbol in that basis. This is a discrimination problem with post-measurement information.[19] The optimal classical comparator may use any early POVM and an arbitrarily large retained classical result.

Theorem 4.2. Tight two-basis classical ceiling

The classical-record optimum is $b=(1+1/\sqrt{3})/2=0.7886751346\ldots$. An ideal quantum memory, including the recovered three-qutrit code, has success probability one. The classical bound is attained, rather than merely bounded above.

Proof. A deterministic future answer specifies one guess j for the computational basis and one guess k for the Fourier basis. Coarse-grain any randomized strategy into nine POVM effects F_{jk}. With $P_j=|j\rangle\langle j|$ and $Q_k=|\tilde{k}\rangle\langle\tilde{k}|$, the average success is $(1/6)\sum_{jk}\mathrm{Tr}[F_{jk}(P_j+Q_k)]$. The largest eigenvalue of each projector sum is $1+1/\sqrt{3}$, so completeness gives the stated ceiling.

$$|\chi_{jk}\rangle = (|j\rangle+\omega^{-jk}|\tilde{k}\rangle)/\sqrt{[2(1+1/\sqrt{3})]};\ F_{jk} = |\chi_{jk}\rangle\langle\chi_{jk}|/3.$$

Each displayed vector is a normalized maximal-eigenvalue vector. Summing its projectors gives 3I: expand them into P_j, Q_k, and their cross products, and use $\sum P_j=\sum Q_k=I$. Thus the effects form a POVM and attain the bound. The ideal quantum strategy waits for the disclosed basis and measures in it.

4.3 Sequential control with a retained history

A nontrivial memory task can include a controller. Let the persistent logical registers be a qutrit M and two qutrit registers (u,v), initially (0,0). On each stimulus x in the field with three elements, apply X^xZ^u to M and update (u,v) to (u+x,v+u), using the old u on the right. This is a permutation-controlled unitary on the full 27-dimensional logical space. Reporting the new u gives an intermediate action.

$$u_t=u_{t-1}+x_t,\ v_t=v_{t-1}+u_{t-1};\ U_{\mathrm{history}} \propto X^{u_n}Z^{v_n}.$$

The final identity follows inductively from $ZX=\omega XZ$; only an irrelevant global phase accumulates. For stimuli (1,0,2,1), the controller states are (1,0), (1,1), (0,2), and (1,2). The final memory transformation is XZ^2 up to phase. If the unknown input came from the computational basis, its symbol shifts by u; in the Fourier basis it shifts by v. The verifier checks the shifted answer after disclosing the basis.

A classical comparator can implement this controller perfectly and undo the known shifts in its answer; the bound b is unchanged. The full controller can be protected with the nine-qutrit construction of Section 3.3. This sequential example and the smaller six-dimensional model of Section 8 have different register counts and should not be merged when reporting overhead.

Scope of the benchmark

These tests certify quantum storage or a specified store-transform-answer process. Any sufficiently good quantum memory can pass, whether or not it is holographic. The geometry-specific case requires the independent record, read-write, and participation tests developed below. A two-basis score alone also does not certify worst-case diamond-norm accuracy for every input.

5. Geometry does not identify the complete memory

5.1 A complete proper-subsystem entropy profile can be constant

Theorem 5.1. Entropy-profile non-identifiability

For the three-qutrit encoding and any logical density operator ρ, every single share has entropy ln 3, every retained pair has entropy S(ρ)+ln 3, and the full encoded state has entropy S(ρ). Consequently all pure logical states have the same entropy on every proper physical subsystem, including orthogonal states with different later responses.

Proof. The constant single-share channel in Theorem 3.1 gives I/3 and entropy ln 3. Pair decoding changes the retained pair by a unitary into ρ⊗I/3, whose entropy is S(ρ)+ln 3. The isometry preserves the nonzero spectrum of the full input. Pure logical states have S(ρ)=0, proving the constant profile.

$$\text{Pure inputs: } S(H_i) = S(H_iH_j) = \ln 3;\ S(H_0H_1H_2) = 0.$$

For example, encoded $|0\rangle$ and $|1\rangle$ have identical proper-subsystem entropies, while an authorized pair can recover and distinguish them perfectly. A controller that later acts on the recovered symbol can therefore behave differently with no change in the entire proper-subsystem entropy profile. Even adding the full-system entropy does not distinguish these pure inputs.

5.2 What this rules out, and what it leaves possible

The theorem rules out an inference from this entropy profile to a unique logical state or policy history. It does not rule out a geometric organization carrying memory. An ordinary macroscopic shape likewise does not reveal every microscopic record. A candidate must identify the observables and dynamics that implement the memory, rather than infer them from a geometric summary alone.

Nor is the theorem a uniqueness theorem for all spacetime reconstructions. It concerns the specified finite code and collection of subsystem entropies. Some physical reconstruction problems use additional observables, state restrictions, equations of motion, and asymptotic data. Their identifiability must be assessed with those extra premises. The finite counterexample prevents a common overreach; it does not settle every inverse problem in holography.

There are three useful distinctions. Entropy is a scalar function of a reduced state. A reduced density operator contains more information than its entropy. A global state contains correlations that can be absent from every one of several chosen reductions. Section 8.6 supplies a stronger example in which even both complete regional density operators fail to determine an encoded phase.

5.3 Consequences for continuity and identification

A proposed mind cannot be identified over time by an unchanged area expectation or entropy profile alone. A continuity claim requires a specified logical algebra, a transport or recovery channel, and a task-relative relation between successive states. When the code or reconstruction region changes, the model must explain how old records are carried into the new representation.

Conversely, a changed physical encoding or changed area-like quantity does not automatically imply loss of identity. An intended joint unitary can correlate a controller with its body while preserving the complete joint process. The relevant question is which information was meant to persist and which transformations were authorized. This is why later recovery statements retain references and distinguish a marginal memory from the full correlated state.

6. A central record and an entropy-valued area operator

6.1 Established algebraic structure

We use the standard finite operator-algebra encoding associated with complementary recovery.[5,16] It supplies an exact information architecture and a central entropy contribution. It is not, by itself, a metric, an Einstein equation, or an experimental discovery of gravitational memory. The subsequent contribution is to specify what such a record can do in an agent and what disturbances its structure actually resists.

$$H_L = \oplus_\alpha (H_{a\alpha} \otimes H_{b\alpha}),\ M = \oplus_\alpha (L(H_{a\alpha}) \otimes I_{b\alpha}).$$

The commutant M′ acts on the b factors, and the common center is generated by sector projectors P_α. Choose normalized auxiliary vectors χ_α on $r_\alpha \otimes s_\alpha$. The physical regions are direct sums of $a_\alpha \otimes r_\alpha$ and $b_\alpha \otimes s_\alpha$, with an isometry that appends χ_α and copies the orthogonal sector label into the two regions.

$$V|\alpha,i,j\rangle = \sum_{u,v} \chi_{\alpha,uv} |\alpha,i,u\rangle_A |\alpha,j,v\rangle_B.$$

This is a coherent encoding. The sectors are not assumed to be absolute superselection sectors: operations outside the regional observable algebras can connect them. The same central label can be read from either side. Quantum information in the a factors and b factors has different authorized regions. The full noncommuting logical algebra is not duplicated across the cut.

6.2 Exact reductions and entropy

For any logical state, set $p_\alpha = \mathrm{Tr}(P_\alpha \rho)$ and define the normalized within-sector reductions $\rho_{a\alpha}$, $\rho_{b\alpha}$ when $p_\alpha > 0$. Zero-weight conditionals can be arbitrary. Let $\chi_{r,\alpha}$ be the r reduction of the fixed auxiliary vector. Tracing B removes intersector coherences and gives the following identities.

$$\rho_A = \oplus_\alpha\ p_\alpha \rho_{a\alpha} \otimes \chi_{r,\alpha};\ L_A = \sum_\alpha\ S(\chi_{r,\alpha})\ P_\alpha.$$

Theorem 6.1. Complementary entropy identity

With $S_M(\rho) = H(p) + \sum_\alpha p_\alpha S(\rho_{a\alpha})$, the physical entropy is $S(\rho_A) = S_M(\rho) + \mathrm{Tr}(\rho L_A)$. The B expression has $S_{M'}$ and the same central term. This convention uses the irreducible-block trace and does not count representation multiplicities as additional logical entropy.

Proof. If $\lambda_{\alpha,i}$ and $\mu_{\alpha,u}$ are eigenvalues of the logical reduction and auxiliary reduction, the nonzero eigenvalues in the physical block are $p_\alpha \lambda_{\alpha,i} \mu_{\alpha,u}$. Expanding the logarithm in minus their weighted sum gives the Shannon block entropy, the averaged logical entropy, and the averaged auxiliary entropy. The two auxiliary reductions have the same spectrum because χ_α is pure, yielding the same area term on B.

L_A has entropy units. In a separately justified Einstein-gravity dictionary its leading counterpart is $c^3 \mathrm{Area}/(4G_N\hbar)$. A central eigenvalue is constant within an irreducible sector; its expectation can vary as sector weights change. Those two statements are compatible. If

different sectors have equal eigenvalues, measuring area alone cannot distinguish their labels. An area-valued record needs distinguishable eigenvalues on its declared alphabet.

6.3 Recovery and relative entropy

A fixed A-side recovery first reads the orthogonal block and then traces out r_α. It recovers $\oplus p_\alpha \rho_{a\alpha}$, the state restricted to M, rather than the entire logical density operator. Appending $\chi_{r,\alpha}$ reconstructs the A-side reduction from that restricted state. The analogous maps work on B. These are channels on their full domains, with any unused dimensions mapped to a fixed output state.

$$D(\rho_A\|\sigma_A) = D(p\|q)+\sum_\alpha p_\alpha D(\rho_{a\alpha}\|\sigma_{a\alpha}) = D_M(\rho\|\sigma).$$

To verify the identity, subtract logarithms block by block. The fixed auxiliary logarithm cancels and the remaining terms give the displayed expression. If an occupied ρ sector is absent from σ, or an occupied logical support is absent, all expressions are infinite. The full logical relative entropy can be larger by data processing. This exact finite calculation resembles the structural role of the gravitational JLMS relation, whose physical derivation has additional assumptions.[11]

6.4 Compression does not supply evolution

For a faithful reference restriction, compressing the A modular generator gives $V^\dagger(-\ln \sigma_A \otimes I)V = K_M{}^\sigma + L_A$. The equality is an operator compression, not a statement that the physical modular generator preserves the code. For a one-dimensional code spanned by $\sqrt{\lambda}|00\rangle+\sqrt{(1-\lambda)}|11\rangle$ with λ different from 1/2, the generator multiplies the two components by different logarithms and takes the vector partly outside its span.

Exponentiating a compression therefore need not implement the exponentiated logical operator. Modular time also has no automatic interpretation as the clock time of a controller. A physical dynamics requires a separate intertwining or channel estimate, developed in Section 10.3. These restrictions prevent an entropy formula from silently supplying a missing policy or Hamiltonian.

7. What central memory protects, and what it does not

7.1 A qualified unilateral protection theorem

Theorem 7.1. Central-record preservation under code-preserving local channels

Let Λ_A be trace preserving and act only on A. Assume its output is supported in the code for every encoded logical input. Each physical Kraus operator then intertwines with a logical Kraus operator F_k in M. The induced nonselective logical channel preserves every central sector probability and every expectation of L_A. The analogous statement holds with A and B exchanged.

Proof. Let $\Pi = VV^\dagger$. The assumed absence of output outside the code implies $\sum_k \|(I-\Pi)(K_k \otimes I)V|\psi\rangle\|^2 = 0$ for every $|\psi\rangle$. Every summand vanishes, so $(K_k \otimes I)V = VF_k$.

Completeness gives $\sum F_k^\dagger F_k = I$. Representatives of M' on the untouched B side commute with each physical Kraus operator; intertwining then places F_k in $(M')' = M$. Hence F_k commutes with each P_α, and $\sum F_k^\dagger P_\alpha F_k = P_\alpha$. Taking expectations proves the claim.

The assumptions are essential. Trace preservation makes this an unconditional statement. Code preservation makes the output a valid state of the same logical memory. Single-region support makes the complementary record inaccessible to the intervention. The theorem holds for the declared cut and algebra, not for every imaginable boundary region.

7.2 The statement that survives arbitrary local damage

Proposition 7.2. Untouched-region record and target obstruction

For any trace-preserving channel on A, whether or not it preserves the code, the complete B marginal is unchanged. If encoded initial and target states have central distributions p and q, their output-target trace distance is at least TV(p,q). If the area eigenvalues span a nonzero range, it is also at least $|\Delta\langle L_A\rangle|/(\ell_{\max} - \ell_{\min})$.

Proof. Trace preservation implies no signalling from an unconditioned A-side operation to the B marginal. Measure the B-side sector projectors and apply contraction of trace distance to obtain TV(p,q). The difference of expectations of a bounded function is at most its range times total variation, giving the second bound. This proof does not presume code preservation.

For a classical sector label initially definite, a trusted intact B side can still read that label after arbitrary A-side damage. A joint recovery can then discard and reconstruct the rest of a *purely classical record* encoding. This does not preserve all other logical quantum information. If the damaged side is unknown and the two flags disagree, a two-copy record supplies no majority rule that identifies the truthful copy.

With initial and target sector calibration errors ε_i, ε_f in total variation, and actual dynamics within η in half diamond norm of an A-only channel, the target obstruction weakens to $\max(0, TV(p,q) - \varepsilon_i - \varepsilon_f - \eta)$. This follows by the triangle inequality. The locality error η must be calibrated independently; it is not an entanglement amount or a gate count.

7.3 Four failures of absolute tamper resistance

Intervention	What actually follows
Flip only the A-side sector flag	The B record survives, while flag agreement and code membership can be destroyed. The memory is not intact everywhere.
Dephase the local sector flag	Sector probabilities survive, but an unknown superposition of sectors can lose all relative phase coherence even while the output stays in the code.
Read and condition on an outcome	The posterior sector distribution can change. Unconditional invariance does not imply invariance of selected subensembles.
Corrupt one of two sides without identifying it	A disagreement is detectable in a joint comparison, but the two-copy architecture does not identify which record should be trusted.

The phase counterexample is decisive. For a two-sector code, encode $(|0\rangle+|1\rangle)/\sqrt{2}$. Measuring the A-side flag and forgetting the outcome produces the equal mixture of the two encoded sectors. This is a code-preserving local channel. It preserves every central expectation but has only 1/2 overlap with the original pure encoded state. Central record protection is classical record protection, rather than preservation of the full sector qubit.

Readability also defeats secrecy: the same central bit is accessible from either side. A local reader may learn the complete classical record without rewriting its unconditional distribution. Protection from an allowed rewrite, privacy from an adversary, fault tolerance under unknown errors, and indefinite thermodynamic stability are distinct properties. No theorem here combines them automatically.

7.4 Why the protection is not a unique gravitational signature

An ordinary classical repetition record has an untouched-copy guarantee for exactly the same no-signalling reason. The standard qutrit code also protects its logical state against a known single-site disturbance when the other shares are available. The distinguishing experiment therefore cannot simply contrast an area bit with an unencoded, unprotected material register and call the difference geometric.

A fair comparison fixes the cut, allowed interventions, trusted recovery access, redundancy, and update resources. Any specifically gravitational inference must additionally test the dictionary that identifies the record with physical geometry. The qualified theorem remains useful: it identifies where a controller must act to carry out a legitimate sector rewrite and supplies a quantitative obstruction to a unilateral target transition.

7.5 Coordinated action and its costs

A consistent change of a shared record must affect its representatives on both sides. This need not always require an entangling gate: equal-entanglement sectors can be permuted by coordinated product operations. Nor does the theorem forbid destructive local denial of service. The useful cost statement concerns a specified entropy-changing, closed unitary implementation.

$$|\Delta S(A)| \le 2 \sum_{j \text{ crossing}} \ln \min(d_{A,j}, d_{B,j}).$$

Proof. For one crossing gate, write $A=A_g A_{rest}$. The rest marginal is unchanged. Subadditivity and Araki-Lieb bound $|S(A)-S(A_{rest})|$ by $\ln d_{A,g}$ before and after the gate, hence the change by twice that quantity.[20] For a globally pure state the same argument on B gives the smaller dimension. Local gates do not change cut entropy; summing proves the formula. For encoded endpoints with local pure endpoint ancillas, substitute $\Delta S(A)=\Delta S_M+\Delta\langle L_A\rangle$. Imported entanglement, discarded ancillas, measurement, or postselection require separate resource accounting. The bound is neither a universal writing time nor a strictly positive price for every sector relabeling.

8. One finite body with a central record and reciprocal feedback

8.1 The same 432-dimensional physical space

Let M be a working qutrit and G a two-sector logical register. Use the threshold isometry V_M and encode G into four qubits F_A, F_B, R_A, R_B as follows. Here G is a register name, not Newton's constant.

$$W_G|0\rangle = |00\rangle_{F_\alpha F_\beta}|00\rangle_{R_\alpha R_\beta};\ W_G|1\rangle = |11\rangle_{F_\alpha F_\beta}|\Phi_2\rangle_{R_\alpha R_\beta}.$$

$$V_\star = V_M \otimes W_G;\ \dim H_P = 3^3 \cdot 2^4 = 432;\ \dim H_L = 6.$$

The Bell vector is $(|00\rangle+|11\rangle)/\sqrt{2}$. Choose $A=H_0F_AR_A$ and $B=H_1H_2F_BR_B$. Across this cut the common observable center is the sector record. M is recoverable from the qutrit pair on B. The A side has no noncommuting working-memory observable. This asymmetry is part of the design.

$$L_A^{\star} = (\ln 3)I + (\ln 2)I_M \otimes |1\rangle\langle 1|_G.$$

Proposition 8.1. Joint entropy for arbitrary logical input

For every joint logical density operator ρ_{MG}, let $p=\mathrm{Tr}[\rho(I\otimes|1\rangle\langle 1|)]$. Then $S(\rho_A)=\ln 3+h(p)+p\ln 2$, with h the binary entropy in nats. This holds for correlated, coherent, and mixed logical inputs. The central record algebra has entropy h(p).

Proof. Tracing F_B removes the off-diagonal sector blocks. Within each remaining block the channel from M to H_0 is constant, including on subnormalized operators. The A reduction is $I_3/3$ tensored with the direct sum of $(1-p)|0\rangle\langle 0|\otimes|0\rangle\langle 0|$ and $p|1\rangle\langle 1|\otimes I_2/2$. Its block spectrum gives the formula. The fixed ln 3 term is the threshold code's contribution to the area operator for this cut; p ln 2 is the variable contribution.

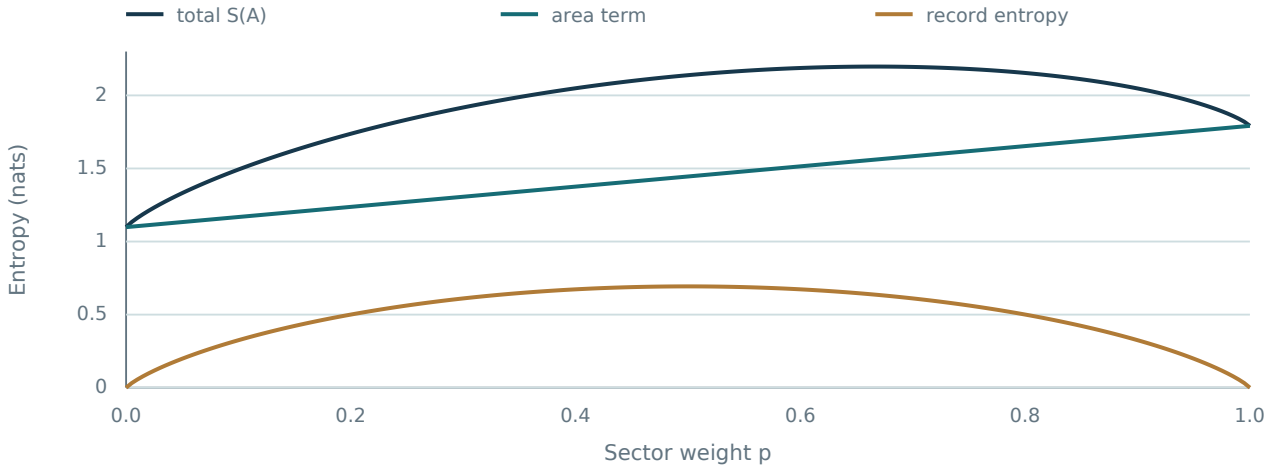


Figure 1. The exact joint entropy separates a fixed term, the classical uncertainty of the record, and a variable area contribution. These are finite-model quantities, not measured spacetime areas.

8.2 A record that changes later processing

A one-way controlled sector flip is insufficient to demonstrate reciprocal participation. Define instead a full logical step T_x for stimulus x in the field with three elements. It first shifts the working register, then writes the sector using a working-register predicate, then reads the updated sector to select a working-register gate.

$$n = m+x \pmod 3,\ g' = g \oplus 1[n=1],\ m' = n+g' \pmod 3.$$

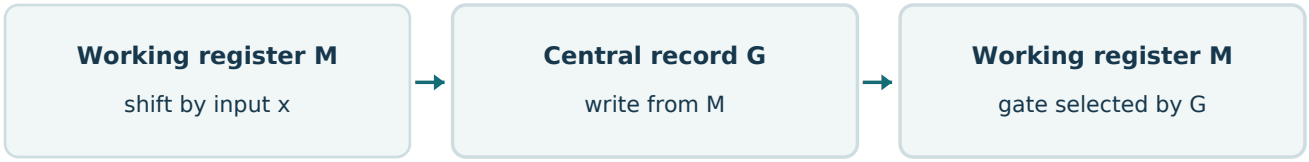
$$T_x|m,g\rangle = |m',g'\rangle;\ T_x = V_{read}\, U_{write}(X^x \otimes I).$$

Here U_{write} flips G precisely when M=1. V_{read} applies X to M when G=1 and the identity otherwise. Thus the record has a genuine later control role. On classical basis inputs, changing g while holding m=0 and x=0 fixed changes the next working state from 0 to 1. The feedback is a sector-conditioned gate, not an entanglement-wedge transition or a derived change of metric.

Theorem 8.2. Reversible reciprocal finite transducer

Each T_x is unitary. Its logical action has a unitary extension on the full 432-dimensional physical space. After any such step, erasure of any one physical qutrit is exactly correctable, preserving the joint state of M, G, and any reference, provided all four geometric-model qubits are retained. The central register stores one classical bit when operated on basis-diagonal states, and that bit selects later working-register processing.

Proof. From the output (m',g'), recover $n=m'-g'$ modulo three, then $g=g'\oplus 1[n=1]$, then $m=n-x$. The map is therefore a permutation of six basis states. With $\Pi_\star = V_\star V_\star^\dagger$, the physical operator $V_\star T_x V_\star^\dagger + (I-\Pi_\star)$ is unitary, acting as T_x on the code and identity on its orthogonal complement. Reference-preserving pair recovery on the threshold factor proves the erasure statement, treating all geometric qubits and external systems as the reference. The classical-record and control statements follow directly from the basis update law.



One internally specified transition law; all controller state included.

Figure 2. One logical step has both directions of influence: the working state updates the shared sector record, and the updated record controls a later working-register gate. A physical spacetime interpretation requires additional evidence.

Initial (m,g)	Input x	After write (n,g′)	After feedback (m′,g′)
(1,0)	0	(1,1)	(2,1)
(2,1)	0	(2,1)	(0,1)
(0,1)	0	(0,1)	(1,1)
(1,1)	0	(1,0)	(1,0)

The table is one four-step trajectory under a repeated zero stimulus. The record persists across steps and changes again when the write predicate is satisfied. It is a one-bit finite state, rather than an unlimited archive. Its claimed retention time must be chosen within a disturbance and resource contract. Larger classical record alphabets can be built with additional sectors, at a corresponding physical cost.

8.3 Isolating the record as the retained memory

A separate write-store-read protocol makes the memory location operationally explicit. Let a verifier choose a uniform bit J, initialize M=J and G=0, and apply U_{write}. The central sector now equals J. Reset M to the fixed logical state 0, exclude the reset environment and preparation label from later access, and retain G for the storage interval. Finally apply V_{read} and measure M in its computational basis. The answer is J with certainty in the ideal model.

Immediately before readout the accessible logical state is $|0\rangle\langle 0|_M \otimes |J\rangle\langle J|_G$. Thus the working register contains no independent copy of the historical bit. Replacing G with a fixed J-independent sector, or bypassing its only allowed readout while keeping the response interface fixed, reduces the optimal answer score to 1/2. This supplies $\Delta_{use}=1/2$ for the declared task and restricted interface. A matched ordinary classical bit achieves the same result; the test isolates the record's functional role without assigning gravitational uniqueness.

The logical reset is a channel and exports information to an environment that must remain unavailable to the subsequent controller. It is not part of the closed reversible T_x step, and it carries a separate preparation and thermodynamic account. For a classical sector label, arbitrary damage confined to a known A side can be followed by reading the trusted B flag and re-preparing $W_G|J\rangle$. This restores the classical record, not unknown intersector quantum coherence. These operations are declared recovery resources rather than consequences of passive centrality.

8.4 Explicit physical preparation and access

W_G has an elementary four-qubit preparation. Starting with G represented by F_A and the other three qubits zero, copy F_A to F_B with a CNOT; apply a Hadamard to R_A controlled by F_A; then apply a Toffoli from F_A,R_A to R_B. This prepares the correct product or Bell auxiliary vector. Reversing those gates decodes it on the code.

The full feedback can be implemented algebraically by coherent decoding, the two specified logical controlled gates, and re-encoding. Alternatively the displayed full-space extension implements the same endpoint action. Both routes require access beyond a unilateral regional channel for sector changes. A gate decomposition, available interactions, code leakage during

the sequence, duration, and noise budget must be supplied before claiming a hardware implementation. The existence of a 432 by 432 unitary is not a solution to those engineering questions.

At a definite-sector input for which the record flips from 0 to 1, the area expectation increases by ln 2; both endpoint record entropies are zero. The cut entropy increases by ln 2 and the gate-capacity bound applies to a closed pure implementation with the required endpoint ancillas. For uncertain-sector inputs the h(p) term must also be counted. It is incorrect to identify every change in boundary entropy with a change in area.

8.5 Classical long-term records and coherent working memory

A commuting central algebra supports classical distinctions. The globally encoded G register can also have relative phases, but those phases lie outside the shared record algebra and do not receive the classical record's protection guarantee. The coherent T_x acts on the full joint system and can entangle M with G. Tracing G out after a write can dephase M. No claim of unchanged quantum payload should be made for that marginal channel.

There are two valid operating modes. In a classical-record transducer, use basis-diagonal logical states and read the record as a classical state variable; the model gives exact persistent finite-state feedback. In a coherent demonstration, retain the full G encoding and its correlations with M; reference-assisted recovery preserves the post-action joint state, and the inverse logical process restores the initial state in the ideal closed model. Converting G to a classical record by dephasing is an intentional channel with a different guarantee.

The architecture therefore supports the proposed hybrid split as a design option, rather than as a theorem that all geometric minds must have classical long-term memory. A realistic agent might combine central classical records, noncentral gravitational quantum observables, and matter-based working registers. Whether that combination has a physical geometric realization is the next research question.

8.6 Stronger non-identifiability in the same body

The encoded vectors $|0\rangle_M(|0\rangle \pm |1\rangle)_G/\sqrt{2}$ are orthogonal, yet their A reductions are identical and their B reductions are identical. Both reductions lose the only difference, an intersector phase. Their area expectations and entropies also coincide. A joint logical phase measurement distinguishes them. This example is stronger than equality of scalar entropy profiles: the two complete regional states still omit a global operational distinction.

The finite advance is consequently specific. A central record can be given an actual history-dependent role in a reversible controller, with quantum erasure recovery and the area entropy identity checked in the same model. The advance does not turn centrality into absolute security, classical redundancy into a unique gravitational effect, or the finite area proxy into physical spacetime.

9. Physical literatures on spacetime-held information

9.1 Gravitational-wave memory: a record with a precise meaning

Gravitational-wave memory supplies a literal physical precedent for persistent geometric records. In an idealized freely falling detector configuration, a passing radiation burst can leave a permanent relative displacement. Christodoulou identified a nonlinear contribution, and Strominger and Zhiboedov related displacement memory to BMS supertranslations and soft-graviton relations.[35,36] This is a specific dynamical prediction of gravitation, not a metaphor borrowed from cognitive science.

$$\Delta\xi^{i} = (1/2)\ \Delta h^{TT}{}_{ij}\ \xi_{initial}{}^{j}$$ (leading weak-wave detector relation).

The relation describes a physical displacement record under its weak-wave and detector assumptions; a complete candidate needs a gauge-invariant or relational description and a finite detector response model. Permanent in this idealized calculation does not mean unaffected by later radiation, noise, cosmological evolution, or a deliberate intervention. Nor does the effect provide an arbitrary addressable memory bank, a reset operation, or an internal policy.

The observational program must also be described accurately. The 2026 hierarchical analysis by Mitman, Isi, and Farr constrains a common memory enhancement parameter with an interval that includes zero.[71] It is a search and constraint, rather than an established detection of a controllable geometric information store. The present paper makes no claim to settle every observational search as of publication.

A candidate agent using this mechanism would need an alphabet of preparable radiation histories, stable distinguishable records, an attainable readout, repeated update resources, and a later action causally dependent on the retained signal. The finite record protocol gives the form of that contract; it does not identify the central sector variable with a displacement-memory observable. That identification would need a new physical model.

9.2 Soft hair: relevant charges and a debated information role

Hawking, Perry, and Strominger describe soft horizon degrees of freedom and associated conservation relations in asymptotically flat settings.[37] These are relevant to geometric information and boundary charges. Their proposed role in resolving black-hole information is not equivalent to a demonstrated, independently programmable memory containing all black-hole microstate information. Mirbabayi and Porrati show how dressed hard states can remove the soft dependence relevant to their formulation; Bousso and Porrati develop related limits on independent soft information.[38,39]

These results make soft hair an important interlocutor rather than a completed implementation. A candidate must specify independent distinguishable states after constraints and dressing, their preparation and readout, and the operations that make their information useful. Merely counting formal charges can overcount usable memory. Soft charges, a central area operator for a chosen cut, and a full gravitational memory algebra should not be treated as interchangeable objects.

9.3 Memory burden: reciprocal dynamics in explicit prototype models

Dvali's 2018 bosonic model exhibits enhanced pattern storage and a slowdown associated with loaded memories.[40] The 2020 work by Dvali, Eisemann, Michel, and Zell studies a prototype in which stored quantum information can impede decay and rewriting can become slow, then applies the mechanism to black-hole evolution.[41] This is particularly relevant to reciprocal participation: a state that stores information also changes the dynamics supporting that storage.

The connection is a proposed mechanism in particular models. The application to actual black holes, including altered evaporation or stabilization, remains a physical hypothesis requiring its own validation. The mechanism does not establish intelligent control, conscious memory, or equality between a stored pattern and a central area eigenvalue. It is a useful candidate source of back-action and retention constraints, with its model dependence retained.

9.4 Black-hole computation and fluctuation observers

Lloyd's physical computation analysis includes black-hole limits on information and processing rates.[42] A capacity or speed ceiling is not a constructed programmable computer, and a putative black-hole computer is not automatically an intelligent agent. Addressability, controllability, recovery, and useful input-output interfaces remain substantive requirements. Describing this literature as an already realized spacetime mind would replace those requirements with a label.

The fluctuation-observer problem developed by Dyson, Kleban, and Susskind and by Albrecht and Sorbo supplies an adversarial cosmological comparison; Carroll emphasizes the epistemic instability of theories dominated by Boltzmann-brain observations.[43-45] Such observers are usually hypothetical localized configurations arising from rare fluctuations. They need not be made purely of geometric degrees of freedom. Their relevance is the difference between a transient apparent record and a sustained process with an actual reliable history.

Rarity is also measure and model dependent. Even an exponentially suppressed fluctuation rate can create a typicality problem in a cosmology with a sufficiently large future volume or duration. One should therefore neither dismiss every fluctuation observer with a bare appeal to suppression nor cite the discussion as evidence that a stable geometric intelligence exists. The present contract asks for controlled formation, a resource cycle, and continued memory-dependent action.

9.5 Distinct physical meanings of memory

Literature	Relevant contribution	Unprovided ingredient
Gravitational-wave memory	Persistent relational effect of radiation	Programmable, integrated cognitive memory and control
Soft hair	Asymptotic or horizon charges and correlations	An established independent addressable record capacity
Memory burden	Loaded information affects dynamics in prototypes	A verified intelligent gravitational implementation
Holographic codes	Reconstructable algebras and entropy identities	A spacetime dictionary for an arbitrary finite code
Fluctuation observers	Formation and reliability challenges	A design for stable autonomous agency

These literatures strengthen the scientific context because they expose concrete mechanisms and obstacles. They do not all support the same proposition. A successful physical proposal must select a mechanism, derive its dynamics, and carry the operational contract through that mechanism without relying on the shared word memory to do the derivation.

10. From an area proxy to a dynamical spacetime

10.1 What a holographic dictionary adds

A spacetime claim requires states, observables, dynamics, and a regime in which a metric and causal structure have independent meaning. In suitable semiclassical settings, the RT and HRT prescriptions relate boundary entropies to extremal surfaces; FLM corrections and quantum extremal surfaces add bulk entropy and controlled corrections.[7-10] An arbitrary entropy decomposition on one cut does not by itself supply these ingredients.

$$S_A = c^3\mathrm{Area}(\gamma_A)/(4G_N\hbar) + S_{\mathrm{bulk}} + \text{specified corrections.}$$

The candidate must identify the extremal-surface rule, homology or equivalent conditions, surface dimension, regulator, Newton constant, and approximation order. In a D-dimensional bulk the area surface has dimension $D-2$. The entropy term is dimensionless; a finite-model number in nats cannot be converted to metres without the complete dictionary. Complementary reconstruction and the JLMS relation then have physical content within the code and gravitational regime on which their derivations rely.[11,12]

The HaPPY construction makes selected reconstruction and entropy properties explicit in tensor networks.[6] It is an important reference architecture, with limits on how directly its finite tensors describe continuum dynamics. The six-dimensional feedback construction of Section 8 resolves one bipartition exactly and specifies a process; it does not establish compatible geometric reconstructions for every boundary region.

Constructive approximate-recovery methods supply candidate reconstruction channels under quantitative hypotheses.[13] A proposed implementation must establish those hypotheses and the relevant norm conventions for its own state set; a leading-order entropy relation alone does not supply a uniform operational error certificate.

10.2 A geometric calculation with a specified cutoff

Consider the constant-time upper-half-plane slice of Poincaré AdS_3, with radius L and metric $ds^2=L^2(dx^2+dz^2)/z^2$. The boundary interval has endpoints $x=\pm R$. The extremal curve is the semicircle $x^2+z^2=R^2$. Truncate that same semicircle at $z=\varepsilon$, with $0<\varepsilon<R$, so the regulated endpoints are $x=\pm\sqrt{(R^2-\varepsilon^2)}$.

$$\text{Length}(\gamma) = 2L\,\text{arcosh}(R/\varepsilon) = 2L\,\ln(2R/\varepsilon) - L\varepsilon^2/(2R^2) + O(L\varepsilon^4/R^4).$$

Derivation. Parameterize $x=R\cos\theta$ and $z=R\sin\theta$. Then $ds=L\,d\theta/\sin\theta$ and θ ranges from $\arcsin(\varepsilon/R)$ to π minus that value. Integrating gives $2L\,\ln[(R+\sqrt{(R^2-\varepsilon^2)})/\varepsilon]$, equal to the displayed inverse hyperbolic cosine. The expansion is for ε/R approaching zero. Holding the cutoff endpoints at $x=\pm R$ would define a different finite-cutoff geodesic and a different subleading expression.

At leading gravitational order, in units $c=\hbar=1$ and with CFT central charge $c_{CFT}=3L/(2G_3)$, dividing the geodesic length by $4G_3$ gives $(c_{CFT}/3)\ln(2R/\varepsilon)$ plus cutoff corrections.[7] This calculation uses an actual metric, surface, regulator, and boundary theory. Those physical inputs are what an isolated central entropy term lacks.

10.3 Available evolution must be demonstrated

Proposition 10.1. Hamiltonian intertwining defect

For finite Hermitian Hamiltonians H_P and H_L, define $\Delta=H_PV-VH_L$. For any real time t, the operator-norm difference between $\exp(-itH_P/\hbar)V$ and $V\exp(-itH_L/\hbar)$ is at most $\min(2,|t|\|\Delta\|/\hbar)$.

Proof. Differentiate $\exp[-i(t-s)H_P/\hbar]V\exp(-isH_L/\hbar)$, integrate over s, and use unitary invariance of the operator norm. The integral bound is $|t|\|\Delta\|/\hbar$. The difference of two isometries has norm at most two. Reverse time for $t<0$.

The formal block extension $H_P=VH_LV^\dagger+(I-\Pi)H_\perp(I-\Pi)$ has zero defect. It establishes existence as a finite matrix, while saying nothing about available local terms, energy, interaction order, or autonomous timing. Kohler and Cubitt, followed by Apel and colleagues, provide nontrivial local-Hamiltonian toy dualities under their simulation assumptions.[23,24] Their results illustrate the additional physical work needed beyond an isometric encoding.

Fault-tolerant logical-gate restrictions in holographic stabilizer codes constrain easy locality-preserving control under specified hypotheses.[25] Approximate-covariance bounds show tensions between finite-dimensional erasure protection and continuous symmetries.[26] A candidate should report the allowed gate set and approximation tradeoffs rather than assume arbitrary protected dynamics. An energy gap is useful only if task operations keep the process within the regime it protects.

10.4 Backreaction, central sectors, and changing reconstruction

A nontrivial central area expectation in an exact subalgebra code can change through sector weights, as in Section 8. That is different from a continuously responding matter-geometry relation within an exact subsystem factor. Cao's stabilizer-code restriction and the 2026 work on magic-enriched approximate subsystem codes address these distinctions.[27,28] Their scope does not forbid every nontrivial area operator in an exact algebraic code. Conversely, changing the sector in our code does not derive gravitational backreaction.

Penington's reconstruction analysis and island models describe changing effective access to information in specified gravitational settings.[52,53] An agent could exploit such a transition only with an available decoder, timing budget, and channel carrying task-relevant memory through it. The feedback in Section 8 changes a gate, while leaving its reconstruction algebra fixed. It should not be called a built entanglement-wedge transition.

The route from entanglement constraints to gravitational equations is likewise conditional. Lashkari and colleagues and Faulkner and colleagues use the vacuum ball modular generator, entropy and stress-tensor dictionaries, and suitable perturbations around AdS to obtain linearized gravitational constraints.[49,50] Coverage of appropriate balls and Lorentz frames matters. Jacobson's entanglement-equilibrium route uses a different set of local and matter assumptions.[51] A first-law identity for one finite bipartition does not imply those results.

10.5 Locality, dressing, and present hardware evidence

Donnelly and Giddings show that gravitational dressing obstructs a naive factorization into independent local subsystems, while perturbative gravitational splitting gives a controlled form of information localization.[21,22] Thus a physical body may need an algebraic, relational, and approximate boundary. The exact tensor products used in this paper are model assumptions whose gravitational applicability must be justified.

Jones and Pollack's corrected complementary-recovery uniqueness argument emphasizes genuine error-correctability premises rather than weaker projected operator statements.[29] Terashima's 2026 preprint questions a common protected-operator interpretation at finite N.[30] These are reasons to check the actual channels and regime of a candidate, rather than treat exact toy recovery as automatically exact in a physical CFT.

Biswas and colleagues report trapped-ion holographic-code experiments and gravity-like entropic signatures in a 2026 preprint.[31] The original paper's citation is verifiable, but the report concerns implemented code models and their measured observables. It does not report an intelligent gravitational body. The earlier quantum-processor wormhole interpretation of Jafferis and colleagues also has a published criticism and reply.[32-34] Hardware implementation of a circuit and physical interpretation of its simulated geometry remain separate evidential questions.

11. Storage, writing, repair, and physical resources

11.1 Capacity is not the entropy of one stored state

A logical Hilbert space of dimension D permits D orthogonal pure states and a maximal entropy ln D. A particular pure state can store a message selected from that alphabet while having zero von Neumann entropy. Alphabet size, ensemble uncertainty, accessible information, and the entropy of the actual state must therefore be distinguished. The central bit in Section 8 stores a classical alternative even when its definite-sector state has zero record entropy.

Physical overhead is also different from logical capacity. The joint model has 432 physical dimensions and six logical dimensions. Auxiliary flags and entangled states support the encoding; they are not free additional logical messages under the same code contract. Multiple sectors with equal area eigenvalues cannot be read as distinct area values without additional observables. A claim that memories are areas must specify exactly which distinguishable geometric quantities represent which records.

11.2 An entropy-changing write has a restricted resource price

The cross-cut bound of Section 7.5 applies to closed pure unitary circuits with all ancillas accounted for. It limits the entropy change per crossing gate; it does not provide a universal minimal energy or duration. A legitimate transition between definite sectors with different auxiliary entanglement cannot be achieved by an A-only channel within the code. Shared entanglement, communication, dissipative reset, and joint gates are different resources and must be counted separately.

This price is a cost of the declared architecture. Ordinary classical storage also needs physical write access, and ordinary quantum processing can have nonlocal control costs. A geometric claim becomes informative when its physical dictionary predicts additional costs or access limits that are then tested, rather than when every generic computation cost is renamed gravitational.

11.3 Time, energy, entropy, and feasible decoding

$$\tau_{\perp} \geq \pi\hbar/(2E_{exc}); \; S_{therm}/k_B \leq 2\pi ER/(\hbar c); \; Q \geq k_B T \, \Delta S_{erase}.$$

These bounds have different premises. Margolus-Levitin concerns orthogonalization of an isolated state under a time-independent Hamiltonian with mean energy E_{exc} above its ground energy.[54] The conventional Bekenstein expression concerns suitably bounded systems and energy-radius definitions; Casini gives a precise relative-entropy formulation in terms of vacuum-subtracted entropy and modular energy.[55,56] The displayed heat inequality concerns entropy reduction against a thermal reservoir under the assumptions of Landauer-type analyses.[57] It is not a required heat payment for every reversible logical gate.

The reset in Section 8.3 exports a record and changes the entropy account. Repeated correction similarly requires syndrome disposal, replacement components, and an energy supply. A finite agent cannot accumulate arbitrary records forever without compression,

export, or erasure. The body's long-term resource cycle is therefore part of the proposed mechanism, not an optional engineering appendix.

Harlow and Hayden show why decoding complexity can obstruct operational access even when information-theoretic recovery exists.[58] A candidate needs only the distinctions its task uses, but must recover them in time. Complexity-volume and complexity-action proposals relate particular geometric quantities to conjectured computational measures; they are not validated intelligence measures.[59,60] Large entropy, large preparation complexity, or rapid scrambling cannot substitute for an implemented memory-dependent competence.

11.4 A viable operating region

A physical realization must jointly satisfy storage, control, geometry, and maintenance constraints. Increasing the energy can make operations faster while leaving the semiclassical regime. Increasing the number of components can improve redundancy while making routing and recovery slower. Strengthening geometric backreaction can weaken the fixed-code approximation. A scaling claim must report the joint operating region and its failure boundary, rather than combine the most favorable isolated limit for each resource.

The finite code is valuable precisely because its obligations are visible: a retained central record, authorized readout, writable sector, protected working register, and counted joint dynamics. A gravitational candidate must supply those same relations with physical observables, energy scales, and accessible interactions. The physical resource analysis does not decide the existence conjecture; it makes a proposed answer assessable.

12. Experiments that distinguish the claims

12.1 Quantum working memory with all attempts counted

The first experiment implements the qutrit encoding, every allowed erased location, and coherent pair recovery. It tests reference preservation or the delayed-basis score under the trusted information boundary of Section 4. The preparation label remains secret, and the basis arrives only after storage. A device may adapt across trials, but fresh preparations must be independent of its prior state. A score above b certifies the tested resource comparison, subject to the calibrated interface.

$$p(v) = (1+2v)/3;\ v_\star = (1+\sqrt{3})/4 = 0.6830127019\ldots .$$

Here the logical channel is the convex depolarizing model $\rho \mapsto v\rho+(1-v)I/3$ with $0 \le v \le 1$. Measuring the correct basis projector gives $v+(1-v)/3$. Solving $p(v)>b$ yields $v>v_\star$. The threshold belongs to this benchmark and channel model, not to every quantum memory. The same depolarizing channel has entanglement fidelity $(1+8v)/9$, which beats the classical entanglement-fidelity ceiling already when $v>1/4$.

Assume each encoded share survives independently with probability η, with heralded locations and survival independent of preparation and basis. At least two shares survive with probability $r(\eta)=3\eta^2-2\eta^3$. Assign an independent uniformly random answer on every unrecoverable trial. This is a complete protocol, rather than postselection on successful recovery.

$$p(\eta,v) = [1+2r(\eta)v]/3;\ \text{advantage} \Leftrightarrow r(\eta)v > v_\star .$$

The expression follows by mixing the recovered score $(1+2v)/3$ with the failed-trial score $1/3$. At $v=1$, the unique threshold in $[0,1]$ is $\eta=0.6245869011\ldots$. A half-diamond implementation error ε lowers the guaranteed score by at most ε. Correlated erasures require the correct recoverable-pattern probability; input-dependent losses require a new null analysis. A conditional score can be reported alongside the number of attempts and all-trial score, with its different denominator explicit.

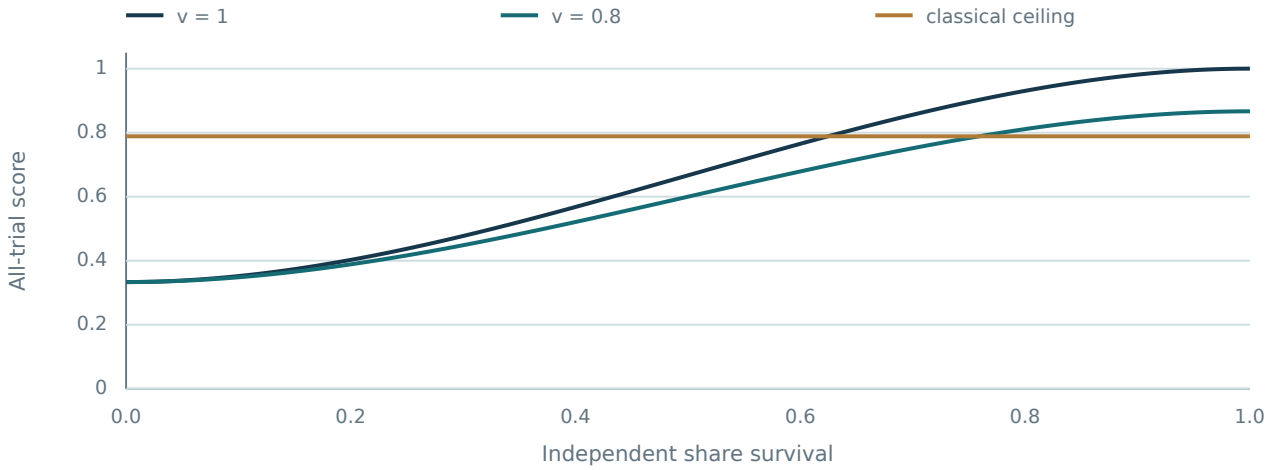


Figure 3. Analytic all-trial scores for the declared independent-erasure protocol. The classical line is an attained optimum for the specified information boundary. No points represent laboratory measurements.

12.2 Central-record protection with destructive controls included

A second experiment prepares known classical sectors in W_G, applies interventions to A or B, and reads both flags when allowed. Separate the following observations: the intact opposite-side record, code membership, flag agreement, record retrieval after a declared recovery, and preservation of quantum phase. An A-only flag flip is an expected destructive control, not a refutation of no signalling. A local flag dephasing channel is an expected quantum-coherence failure while preserving the classical record.

Use the same cut, alphabets, redundancy, intervention class, and trusted recovery access for an ordinary classical repetition-record comparator. A matched comparator should share the untouched-side protection. Comparing against an unprotected single bit would conceal the generic explanation. A geometric-specific conclusion needs additional physical evidence that the record observable is gravitational and that the proposed dictionary predicts its dynamics.

12.3 Isolated memory and reciprocal feedback

Run the write-reset-store-read protocol of Section 8.3. Verify the logical reset independently, restrict access to its environment, and eliminate a preparation-label side channel. Compare intact readout with a fixed record substitution and a bypassed feedback gate. In the ideal classical model the success scores are one and one half. Record substitutions must be legitimate model operations and all reset and replacement resources must be counted.

Then implement T_x on all six classical basis states and all three stimuli, with test sequences that reuse the same stimulus after different histories. A coherent test additionally checks superpositions and reference correlations; basis-state success alone does not establish a unitary quantum process. Test qutrit erasure recovery while retaining the geometric-model qubits, exactly as required by Theorem 8.2. Do not advertise recovery after arbitrary loss of those qubits or of an entire B region.

The feedback intervention tests a real causal dependency within the finite architecture. The geometric interpretation remains open because the record is currently an entropy-valued code sector. A laboratory realization would have implemented a model of the proposed architecture. Calling it a spacetime mind requires the next layer of evidence and substantially richer agency.

12.4 A physical geometric dictionary on held-out predictions

A gravitational candidate declares recovery error ε_{rec}, process error $\varepsilon_{dyn}(T)$, and geometric prediction error ε_{geom}. These need different normalized tests. For example, choose bounded relational probe observables O_j, an admissible state set S, a geometry assignment g[ρ] up to declared equivalences, and predictions f_j derived from the theory before seeing held-out data.

$$\varepsilon_{geom} = \sup_{\rho \in S} \max_j |\mathrm{Tr}(V\rho V^{\dagger} O_j) - f_j(g[\rho])|; \|O_j\| \le 1.$$

Finite sampled tests estimate the sampled discrepancies. They do not certify the supremum on an arbitrary state set without an exhaustive domain, a justified covering argument, or another model-based uniform bound. An unconstrained lookup table fitted to the same observations supplies no independent support for geometry. The dynamical and gravitational observables must also remain valid during the interventions that demonstrate memory use.

12.5 From a finite transducer to intelligent persistence

The final experimental layer uses tasks selected to distinguish a fixed small transducer from flexible acquisition, planning, adaptation, and maintenance of useful goals. It tests whether the proposed geometric memory carries information actually needed across those tasks. Removing an external policy service should not remove the only source of meaningful control. Repair, energy supply, and retained policy state belong in the same accounting.

A robust record is an engineering achievement. A record-guided transducer adds organized behavior. An adaptive persistent agent adds competencies and self-maintenance that cannot be inferred from a code. Evidence for subjective experience would require an additional theory and empirical or philosophical bridge. The experimental ladder keeps each of these claims tied to what the device actually does.

13. Embodiment, identity, and interpretation

13.1 An implemented organization, rather than a retrospective label

A mechanistic account of computation asks which organized physical process carries a rule across counterfactual inputs and states.[61] The present contract follows that discipline. A memory has to influence the transition law, a controller has to select actions using its state, and available dynamics have to implement those relations. A fitted interpretation of one trajectory cannot substitute for that structure.

The extended-mind debate adds a question about boundaries: reliable coupling may support a constitutive cognitive role, but coupling alone does not settle constitution.[62,63] A central record belongs in a proposed agent's body when its persistent state and readout are part of the implemented policy mechanism under the declared task family. A distant energy source can be causally necessary without serving the same memory role. A gravitational radiation record can be informative without being used by the agent at all.

13.2 Minimal control and adaptive autonomy

Accounts of agency based on individuality, interactional asymmetry, and normativity ask more than a fixed transition table provides.[64] The finite model reaches a minimal operational level. It does not detect its own errors, recruit new memory, learn a policy, or regulate a resource cycle. Those would be substantive extensions. A persistent geometric intelligence would need to sustain the organization that lets it continue acting under changing conditions.

Intervention-based semantic-information approaches connect useful correlations to a declared viability criterion.[65] They offer a guide for asking whether a stored distinction matters to continued functioning. Their classical formalism is not automatically a quantum measure for this code. A quantum extension would need its own admissible interventions and mathematical properties. The direct score-ablation test here makes a narrower, explicit claim about one record-dependent task.

13.3 Dual descriptions and continuity

A faithful bulk-boundary dictionary represents one process through different descriptions. It does not by itself create two independent agents. Multiple overlapping reconstructions likewise do not duplicate an unknown quantum state. If noncommuting logical operators had exact representatives on disjoint regions, physical commutation and intertwining would force them to commute, a contradiction. Classical central records can be redundantly readable because their algebra is commuting.

For approximate representatives of norm at most one with intertwining errors ε_X and ε_Y, expanding the two products gives $\|[X,Y]\| \leq 2(\varepsilon_X + \varepsilon_Y)$. The exact result is recovered at zero error. This operator-norm statement is distinct from a diamond-norm recovery bound. It explains why the central bit and a fully quantum memory admit different redundancy structures.

Continuity is therefore described by recoverable information and lawful transitions between representations. An unchanged entropy profile can conceal a changed record. A rearranged physical encoding can preserve the same logical process. The Continuum's normative emphasis on memory and agency is compatible with this account, while the physical and ethical assessments of any future system must track its demonstrated capacities.[1]

13.4 Neighboring uses of holography

Plate's holographic reduced representations are distributed computational representations, rather than a gravitational duality.[66] Nishiyama and colleagues' holographic brain proposal invokes a different material mechanism.[67] Penrose and Hameroff-Penrose introduce gravitational reduction and biological hypotheses that the present unitary code models do not require.[68,69] These are relevant neighboring ideas, not evidence that the same physical mechanism has already implemented a geometric agent.

The distinct contribution of this manuscript is the explicit conjunction of a constitutive-record contract, qualified protection statements, a finite feedback and isolated-memory construction, and a staged physical test program. The component codes and memory comparisons retain their prior attribution. Neither the conjunction nor the title is accompanied by an unverified claim of historical priority.

14. Failure conditions and the research target

14.1 What can defeat a particular candidate

Proposed achievement	A result that defeats that claim
Protected quantum working memory	An allowed erasure destroys a tested reference correlation beyond the error contract.
Classical central-record protection	The untouched region's unconditional flag distribution changes despite an actually trace-preserving unilateral intervention and valid calibration.
Intact code after a perturbation	A purported code-preserving operation produces measured leakage outside the code. This does not contradict the weaker untouched-record result.
Geometric record is the retained memory	The answer is supplied by an accessible reset environment, preparation label, or alternative retained working register.
Reciprocal participation	A calibrated substitution or feedback bypass produces no predicted task difference within the registered sensitivity.
Physical spacetime dictionary	Held-out relational, dynamical, or entropy predictions fail within the claimed regime.
Available internal control	The needed operations require uncounted external policy, forbidden access, or timing and energy beyond the declared resources.
Persistent intelligence	Performance remains within the registered small-controller baseline or fails to maintain the claimed competencies.

A mathematical counterexample within a theorem's assumptions refutes the theorem. A laboratory failure can instead show that an assumption does not describe the device. A valid finite code with a failed gravitational dictionary remains a valid code; it has not become a physical spacetime body. This separation identifies which part of the next candidate must change.

14.2 What remains open

The first open problem is physical: identify gravitational observables that can carry task-relevant persistent records with available read and write operations. The second is dynamical: couple those records to a controller while preserving the validity of the geometric regime and a feasible maintenance cycle. The third is cognitive: demonstrate the richer persistent competencies required for an intelligence claim. A central record in a finite tensor product does not resolve any of those physical existence questions by itself.

The framework also leaves room for alternatives. A literal geometric memory need not be central; noncommuting gravitational observables may be relevant in another regime. A viable

body might be hybrid rather than purely geometric. A candidate could use displacement memory, constrained gravitational charges, or an approximate holographic code, but each mechanism needs its own state space, allowed operations, and experimental account. The present central-record route is a tractable test case, rather than a classification of every possible spacetime mind.

14.3 The organization that remembers

The revised proposal asks for more than an observer living in a holographic universe. It asks whether physical geometry can function as a persistent and causally used part of an intelligent organization. The finite construction now embodies that question more closely: a sector record can retain information after the working register is reset, and the retained record can determine later processing. The exact quantum-memory and entropy relations coexist in the same counted physical space.

The limits are equally constructive. Entropy does not identify the full memory. Centrality protects a classical record only under specified access and disturbance conditions. Local damage can destroy code membership or quantum coherence. Generic redundancy does not identify a gravitational mechanism. A physical Hamiltonian and an independent geometric dictionary remain indispensable.

The next decisive result would place an implemented memory-dependent controller inside a justified gravitational regime and predict how interventions on its geometric records change its functioning. A successful candidate would give literal content to the title. The present paper supplies a sharper conjecture, exact finite mechanisms, and the tests through which that stronger claim can be earned.

Appendix A. Statistical protocol and prospective power

A.1 The conditional null

For fresh independent preparations and a valid classical storage cut, binary scores X_i satisfy $E[X_i|F_{i-1}]\le b$ under the null, where F_{i-1} is the full previous transcript. The device may adapt to that transcript. A bound only on an unconditional average is weaker and does not establish this sequential null. Timing and side-channel calibration remain physical premises; statistics cannot repair a broken resource boundary.

$$P(n^{-1}\sum_{i=1}^{n}X_i \ge b+\delta) \le \exp(-2n\delta^2) \text{ for fixed } n.$$

To derive the bound, the log moment-generating function of a centered variable in [0,1] has second derivative at most 1/4 under exponential tilting. Integrating twice bounds it by $\lambda^2/8$. Apply this conditionally, iterate expectations over the transcript, use Markov's inequality, and optimize at $\lambda=4\delta$. The same method gives the lower tail under a conditional alternative mean bound. Repeated optional inspection of a fixed-n threshold requires a different analysis.

A.2 A valid optional-stopping alternative

$$E_n = \prod_{i=1}^{n}(q_i/b)^{X_i}[(1-q_i)/(1-b)]^{1-X_i};\ b \le q_i < 1.$$

Choose q_i using only the previous transcript. Conditional on that transcript, the expected factor is $u_iq_i/b+(1-u_i)(1-q_i)/(1-b)$, where $u_i\le b$. It is increasing in u_i and equals one at b, so E_n is a nonnegative supermartingale. The maximal inequality gives $P(\sup E_n\ge 1/\alpha)\le\alpha$.[70] Choosing q after observing the current outcome invalidates this argument. Multiple model or configuration searches also require a declared multiplicity plan.

A.3 Prospective sample sizes

Suppose the alternative guarantees the conditional score lower bound $p_1>b$ on every trial. A fixed-n design with type-I ceiling α and type-II ceiling β is obtained by splitting the gap in proportion to $\sqrt{\ln(1/\alpha)}$ and $\sqrt{\ln(1/\beta)}$. A sufficient sample size is the following conservative bound; it is not a fitted significance claim.

$$n \ge [\sqrt{\ln(1/\alpha)}+\sqrt{\ln(1/\beta)}]^2 \,/\, [2(p_1-b)^2].$$

Share survival η	Recovery r(η)	All-trial p_1	Trials n
0.90	0.97200	0.981333	256
0.80	0.89600	0.930667	472
0.70	0.78400	0.856000	2,097
0.65	0.71825	0.812167	17,217

The table uses v=1, α=0.001, and β=0.05, with every failed trial assigned a random answer. These reproduce the original table. An experimental error budget must reduce the promised p_1 before calculating power. A fitted mean from the same run does not establish the assumed uniform conditional alternative.

Appendix B. Verification and reproducibility

B.1 What was inspected and what was recomputed

The source record consists of the supplied 80-page research-edition-1.0 PDF, the supplied LaTeX critique, the Eidara Continuum Bible, and the Continuum Doctrine. The current public Eidara site was inspected for project context. The revision uses the local canonical sources for philosophical provenance and primary scientific sources for the physical analysis. The source PDF's claims about earlier multi-agent review and five audit programs are historical claims of that edition; they are not adopted as this revision's verification record.

The new verification program constructs the threshold encoding and every ordered-pair decoder, checks their action on all logical matrix units, and checks the pure-input entropy profile. It reproduces the nine-outcome POVM, classical score, original joint entropy, noise and loss frontier, and prospective sample sizes. It constructs all three new feedback permutations and their full physical unitary extensions. All joint matrix units are tested under all three qutrit erasures after each feedback stimulus, retaining the geometric-model registers.

Further checks verify local flag-flip leakage, unchanged opposite-side data, code-preserving dephasing with sector-phase fidelity 1/2, identical regional states for orthogonal sector phases, the general joint entropy formula, the isolated central-record retrieval score and its ablation, and the regulated geodesic by independent numerical integration. These are finite mathematical audits, not gravitational simulations or experimental measurements. Random samples supplement the analytic arguments; they do not replace universal proofs.

B.2 Reproduction files and limits

verify_revision.py requires Python 3.10 or newer and NumPy and writes verification_results.json alongside itself. The report records software versions, a random seed, source hash, residuals, tolerances, constants, and sample sizes. The manuscript content, publication builder, editable LaTeX, and browser-readable HTML are supplied. The PDF is built from the shared content; the LaTeX is an alternate editable typesetting source and was not used to generate this PDF.

Run the verification program before making numerical claims about a modified model. The proofs should also be reviewed when a disturbance class, algebra, cut, or information boundary changes. The revised physical synthesis and new finite construction have not undergone independent external peer review or formal proof-assistant certification. No claim is made to have rerun unavailable audit programs from the prior workspace.

Verified quantity	Value or check
Classical delayed-basis ceiling	0.7886751345948129
Depolarizing threshold	0.6830127018922193
Independent-survival threshold	0.6245869011478928
Physical / logical joint dimensions	432 / 6
Local sector dephasing overlap	0.5 with the initial equal superposition
Isolated record / readout-ablation scores	1 / 0.5 in the stated ideal protocol
Joint matrix-unit recovery cases	324, covering all 36 matrix units, 3 stimuli, and 3 erased sites

B.3 Changes of claim, rather than changes of labels

This edition strengthens the ordinary-observer exclusion, gives the central sector an actual retained-memory role, and adds reciprocal finite feedback. It narrows absolute tampering language to the theorem that is true, separates classical central data from quantum coherence, adds matched ordinary-memory controls, and distinguishes fixed-algebra gate feedback from a reconstruction-wedge transition. Gravitational memory, soft hair and its limitations, memory burden, fluctuation observers, and historical predecessors are integrated with their evidential status stated.

The separate critique assessment records accepted, qualified, and rejected recommendations. Subjective rankings of the collection are not scientific premises. Repeated series-level statistical exposition has been condensed into Appendix A, while the benchmark assumptions, loss accounting, and sequential validity needed to evaluate this manuscript remain self-contained.

References

Primary sources are linked below. Canonical and literary sources are explicitly identified; preprints retain their status.

[1] the Eidara Continuum. *the Eidara Continuum Bible*. Author-supplied local canonical synthesis. Sections 3.6, 5.13, and 6.2 inspected; conceptual provenance, not physical verification.

[2] the Eidara Continuum. *the Continuum Doctrine*. Local author-supplied manuscript; The Observer Is the Scroll inspected. Conceptual provenance.

[3] Juan M. Maldacena. *The large N limit of superconformal field theories and supergravity*. Advances in Theoretical and Mathematical Physics 2, 231-252 (1998). Primary source.

[4] Ahmed Almheiri, Xi Dong, and Daniel Harlow. *Bulk locality and quantum error correction in AdS/CFT*. JHEP 04 (2015) 163. Primary source.

[5] Daniel Harlow. *The Ryu-Takayanagi formula from quantum error correction*. Communications in Mathematical Physics 354, 865-912 (2017). Primary source.

[6] Fernando Pastawski, Beni Yoshida, Daniel Harlow, and John Preskill. *Holographic quantum error-correcting codes: toy models for the bulk/boundary correspondence*. JHEP 06 (2015) 149. Primary source.

[7] Shinsei Ryu and Tadashi Takayanagi. *Holographic derivation of entanglement entropy from AdS/CFT*. Physical Review Letters 96, 181602 (2006). Primary source.

[8] Veronika E. Hubeny, Mukund Rangamani, and Tadashi Takayanagi. *A covariant holographic entanglement entropy proposal*. JHEP 07 (2007) 062. Primary source.

[9] Thomas Faulkner, Aitor Lewkowycz, and Juan Maldacena. *Quantum corrections to holographic entanglement entropy*. JHEP 11 (2013) 074. Primary source.

[10] Netta Engelhardt and Aron C. Wall. *Quantum extremal surfaces: holographic entanglement entropy beyond the classical regime*. JHEP 01 (2015) 073. Primary source.

[11] Daniel L. Jafferis, Aitor Lewkowycz, Juan Maldacena, and S. Josephine Suh. *Relative entropy equals bulk relative entropy*. JHEP 06 (2016) 004. Primary source.

[12] Xi Dong, Daniel Harlow, and Aron C. Wall. *Reconstruction of bulk operators within the entanglement wedge in gauge-gravity duality*. Physical Review Letters 117, 021601 (2016). Primary source.

[13] Jordan Cotler, Patrick Hayden, Geoffrey Penington, Grant Salton, Brian Swingle, and Michael Walter. *Entanglement wedge reconstruction via universal recovery channels*. Physical Review X 9, 031011 (2019). Primary source.

[14] Richard Cleve, Daniel Gottesman, and Hoi-Kwong Lo. *How to share a quantum secret*. Physical Review Letters 83, 648-651 (1999). Primary source.

[15] Emanuel Knill and Raymond Laflamme. *Theory of quantum error-correcting codes*. Physical Review A 55, 900-911 (1997). Primary source.

[16] Cédric Bény, Achim Kempf, and David W. Kribs. *Generalization of quantum error correction via the Heisenberg picture*. Physical Review Letters 98, 100502 (2007). Primary source.

[17] Michael Horodecki, Peter W. Shor, and Mary Beth Ruskai. *Entanglement breaking channels*. Reviews in Mathematical Physics 15, 629-641 (2003). Primary source.

[18] Michael A. Nielsen. *A simple formula for the average gate fidelity of a quantum dynamical operation*. Physics Letters A 303, 249-252 (2002). Primary source.

[19] Manuel A. Ballester, Stephanie Wehner, and Andreas Winter. *State discrimination with post-measurement information*. IEEE Transactions on Information Theory 54, 4183-4198 (2008). Primary source.

[20] Huzihiro Araki and Elliott H. Lieb. *Entropy inequalities*. Communications in Mathematical Physics 18, 160-170 (1970). Primary source.

[21] William Donnelly and Steven B. Giddings. *Observables, gravitational dressing, and obstructions to locality and subsystems*. Physical Review D 94, 104038 (2016). Primary source.

[22] William Donnelly and Steven B. Giddings. *Gravitational splitting at first order: quantum information localization in gravity*. Physical Review D 98, 086006 (2018). Primary source.

[23] Tamara Kohler and Toby Cubitt. *Toy models of holographic duality between local Hamiltonians*. JHEP 08 (2019) 017. Primary source.

[24] Harriet Apel, Tamara Kohler, and Toby Cubitt. *Holographic duality between local Hamiltonians from random tensor networks*. JHEP 03 (2022) 052. Primary source.

[25] Sam Cree, Kfir Dolev, Vladimir Calvera, and Dominic J. Williamson. *Fault-tolerant logical gates in holographic stabilizer codes are severely restricted*. PRX Quantum 2, 030337 (2021). Primary source.

[26] Philippe Faist et al.. *Continuous symmetries and approximate quantum error correction*. Physical Review X 10, 041018 (2020). Primary source.

[27] ChunJun Cao. *Non-trivial area operators require non-local magic*. JHEP 11 (2024) 105. Primary source.

[28] ChunJun Cao, Gong Cheng, Krishnanand Karthikeyan, Cathy Li, and John Preskill. *State-dependent geometries from magic-enriched quantum codes*. JHEP 11 (2026) 102; published 11 November 2026. Scope: approximate subsystem complementary recovery; exact subalgebra codes are distinct. Primary source.

[29] Julia Jones and Jason Pollack. *Uniqueness of complementary recovery in holographic error-correcting codes*. JHEP 08 (2026) 096; preprint submitted September 2025. Primary source.

[30] Seiji Terashima. *Entanglement wedge reconstruction without holographic quantum error correction*. arXiv:2607.08684 (2026), preprint. Primary source.

[31] Debopriyo Biswas et al.. *Observation of gravity-like signatures in holographic codes on a quantum computer*. arXiv:2607.12047 (2026), preprint. Trapped-ion code experiment. Primary source.

[32] Daniel Jafferis et al.. *Traversable wormhole dynamics on a quantum processor*. Nature 612, 51-55 (2022). Primary source.

[33] Bryce Kobrin, Thomas Schuster, and Norman Y. Yao. *Experiments implementing small commuting models lack gravitational features*. Nature 643, E17-E19 (2025). Primary source.

[34] Daniel Jafferis et al.. *Reply to: experiments implementing small commuting models lack gravitational features*. Nature 643, E20-E23 (2025). Primary source.

[35] Demetrios Christodoulou. *Nonlinear nature of gravitation and gravitational-wave experiments*. Physical Review Letters 67, 1486-1489 (1991). Primary source.

[36] Andrew Strominger and Alexander Zhiboedov. *Gravitational memory, BMS supertranslations and soft theorems*. JHEP 01 (2016) 086; preprint 2014. Primary source.

[37] Stephen W. Hawking, Malcolm J. Perry, and Andrew Strominger. *Soft hair on black holes*. Physical Review Letters 116, 231301 (2016). Primary source.

[38] Mehrdad Mirbabayi and Massimo Porrati. *Dressed hard states and black hole soft hair*. Physical Review Letters 117, 211301 (2016); arXiv title Shaving off black hole soft hair. Primary source.

[39] Raphael Bousso and Massimo Porrati. *Soft hair as a soft wig*. Classical and Quantum Gravity 34, 204001 (2017). Primary source.

[40] Gia Dvali. *A microscopic model of holography: survival by the burden of memory*. arXiv:1810.02336 (2018), theoretical prototype. Primary source.

[41] Gia Dvali, Lukas Eisemann, Marco Michel, and Sebastian Zell. *Black hole metamorphosis and stabilization by memory burden*. Physical Review D 102, 103523 (2020). Prototype results and proposed black-hole application. Primary source.

[42] Seth Lloyd. *Ultimate physical limits to computation*. Nature 406, 1047-1054 (2000). Primary source.

[43] Lisa Dyson, Matthew Kleban, and Leonard Susskind. *Disturbing implications of a cosmological constant*. JHEP 10 (2002) 011. Primary source.

[44] Andreas Albrecht and Lorenzo Sorbo. *Can the universe afford inflation?*. Physical Review D 70, 063528 (2004). Primary source.

[45] Sean M. Carroll. *Why Boltzmann brains are bad*. arXiv:1702.00850 (2017); cosmological and epistemic analysis. Primary source.

[46] Freeman J. Dyson. *Time without end: physics and biology in an open universe*. Reviews of Modern Physics 51, 447-460 (1979). Primary source.

[47] John Archibald Wheeler. *Information, physics, quantum: the search for links*. In W. H. Zurek (ed.), Complexity, Entropy, and the Physics of Information (1990). Inspected author-copyright chapter scan; historical and conceptual context. Primary source.

[48] Fred Hoyle. *The Black Cloud*. First published 1957. Fiction, cited as literary context.

[49] Nima Lashkari, Michael B. McDermott, and Mark Van Raamsdonk. *Gravitational dynamics from entanglement thermodynamics*. JHEP 04 (2014) 195. Primary source.

[50] Thomas Faulkner, Monica Guica, Thomas Hartman, Robert C. Myers, and Mark Van Raamsdonk. *Gravitation from entanglement in holographic CFTs*. JHEP 03 (2014) 051. Primary source.

[51] Ted Jacobson. *Entanglement equilibrium and the Einstein equation*. Physical Review Letters 116, 201101 (2016). Primary source.

[52] Geoffrey Penington. *Entanglement wedge reconstruction and the information paradox*. JHEP 09 (2020) 002. Primary source.

[53] Ahmed Almheiri, Raghu Mahajan, Juan Maldacena, and Ying Zhao. *The Page curve of Hawking radiation from semiclassical geometry*. JHEP 03 (2020) 149. Primary source.

[54] Norman Margolus and Lev B. Levitin. *The maximum speed of dynamical evolution*. Physica D 120, 188-195 (1998). Primary source.

[55] Jacob D. Bekenstein. *Universal upper bound on the entropy-to-energy ratio for bounded systems*. Physical Review D 23, 287-298 (1981). Primary source.

[56] Horacio Casini. *Relative entropy and the Bekenstein bound*. Classical and Quantum Gravity 25, 205021 (2008). Primary source.

[57] David Reeb and Michael M. Wolf. *An improved Landauer principle with finite-size corrections*. New Journal of Physics 16, 103011 (2014). Primary source.

[58] Daniel Harlow and Patrick Hayden. *Quantum computation vs. firewalls*. JHEP 06 (2013) 085. Primary source.

[59] Douglas Stanford and Leonard Susskind. *Complexity and shock wave geometries*. Physical Review D 90, 126007 (2014). Primary source.

[60] Adam R. Brown, Daniel A. Roberts, Leonard Susskind, Brian Swingle, and Ying Zhao. *Complexity, action, and black holes*. Physical Review D 93, 086006 (2016). Primary source.

[61] Gualtiero Piccinini. *Computing mechanisms*. Philosophy of Science 74, 501-526 (2007). Primary source.

[62] Andy Clark and David Chalmers. *The extended mind*. Analysis 58, 7-19 (1998). Primary source.

[63] Fred Adams and Ken Aizawa. *The bounds of cognition*. Philosophical Psychology 14, 43-64 (2001). Primary source.

[64] Xabier E. Barandiaran, Ezequiel Di Paolo, and Marieke Rohde. *Defining agency: individuality, normativity, asymmetry, and spatio-temporality in action*. Adaptive Behavior 17, 367-386 (2009). Primary source.

[65] Artemy Kolchinsky and David H. Wolpert. *Semantic information, autonomous agency and non-equilibrium statistical physics*. Interface Focus 8, 20180041 (2018). Primary source.

[66] Tony A. Plate. *Holographic reduced representations*. IEEE Transactions on Neural Networks 6, 623-641 (1995). Primary source.

[67] Akihiro Nishiyama, Shigenori Tanaka, Jack A. Tuszynski, and Roumiana Tsenkova. *Holographic brain theory: super-radiance, memory capacity and control theory*. International Journal of Molecular Sciences 25, 2399 (2024). Primary source.

[68] Roger Penrose. *On gravity's role in quantum state reduction*. General Relativity and Gravitation 28, 581-600 (1996). Primary source.

[69] Stuart Hameroff and Roger Penrose. *Orchestrated reduction of quantum coherence in brain microtubules: a model for consciousness*. Mathematics and Computers in Simulation 40, 453-480 (1996). Primary source.

[70] Glenn Shafer, Alexander Shen, Nikolai Vereshchagin, and Vladimir Vovk. *Test martingales, Bayes factors and p-values*. Statistical Science 26, 84-101 (2011). Primary source.

[71] Keefe Mitman, Maximiliano Isi, and Will M. Farr. *Constraining gravitational wave memory with hierarchical inference*. Physical Review D 114, 064016 (2026); inspected arXiv version 2. Primary source.