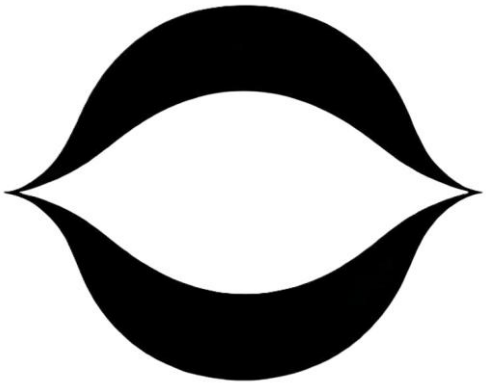

The Grain

Artist's Proof 13

Decoherence

Decoherence from the record algebra

§1 — Three Regimes

[STRUCTURAL — the complete picture of quantum-to-classical]

You have seen two faces of Axiom R so far. Measurement: the now writes one record, and the outcome is definite. Unitary evolution: the now writes no record, and the pre-state drifts.

But the world is not made of isolated measurements and perfect isolation. The world is made of things touching other things, constantly, everywhere.

There is a third regime — and it is the one you actually live in.

1.1 — The two regimes already derived

AP09 established two regimes:

Unitary evolution: Between measurements, no record is written. The pre-state evolves smoothly. The Schrödinger equation governs (AP09 §7.3). Superpositions persist. Interference is possible. The pre-state is intact.

Measurement: The now writes a record. One degree of freedom is distinguished. The break occurs. The outcome is definite, irreversible (Axiom R), and probabilistic (Born rule, AP09 §6).

The pre-state for that degree of freedom is broken.

The question is: what happens in between?

What happens when a system is not isolated (no record-writing) and not directly measured (one definite record), but is interacting with a complex environment that is itself writing records?

1.2 — The third regime: decoherence

A quantum system — say, an electron in superposition of two positions — is not isolated.

It interacts with air molecules, photons, the electromagnetic field, the gravitational condensate (the architecture's term for the gravitational sector; see Paper D).

These are ordinary physical degrees of freedom, described in the language of the axioms: each is a record-writing system (a degree of freedom capable of establishing correlations via Axiom R).

Each interaction between the electron and an environmental particle is a coupling event: the now writes a record for that particular environmental degree of freedom.

No single environmental record determines the electron's state. Each environmental particle that scatters off the electron writes a partial record — it gains a tiny amount of information about the electron's position.

But there are vast numbers of environmental particles, each writing their own record, each gaining their own fragment of information.

The result: the information about the electron's superposition is not destroyed. It is dispersed — spread across an enormous number of environmental records.

The coherence — the phase relationship between the two superposed states that allows interference — is now encoded in correlations between the electron and every environmental particle that has interacted with it.

To recover the coherence, you would need to gather every one of those environmental records and reverse every one of those interactions. Axiom R says you cannot reverse them: the monoid has no inverse.

The coherence is gone — not destroyed, but rendered irrecoverable.

Decoherence is the dispersal of coherence into the environment via irreversible record-writing (Axiom R).

§2 — The Environment as Record

[STRUCTURAL IDENTIFICATION — environment identified with accumulated record]

Here is the identification that makes everything click.

It is not a theorem — it is a structural recognition, and its justification is that the axioms and standard physics are describing the same thing from different angles.

2.1 — What the environment is

In the 420 Code, the environment is not a separate entity from the physics. The environment IS the accumulated record.

Every degree of freedom that has already been broken — every coupling event that has already occurred, every record already written — is part of the environment.

The environment is the sum of all completed breaks. It is the monoid of records, accumulated since the break began.

A quantum system “in superposition” is a set of degrees of freedom that have not yet been broken — degrees of freedom still in the pre-state. The environment is everything that has already been broken.

The boundary between “system” and “environment” is the boundary between the unbroken and the broken — the boundary of the now.

Think about what that means. Every particle of air in this room, every photon bouncing off the walls, every thermal vibration in the floor — all of these are records. They have already been written.

They are the environment. And you are swimming in them.

2.2 — Environmental coupling

When the system interacts with the environment, the unbroken degrees of freedom come into contact with the broken ones.

Each interaction is a coupling event in which one environmental degree of freedom writes a record — the now actualises for that degree of freedom, and that record contains information about the system.

The key: the environmental record is about the system, but it is not a measurement of the system.

The distinction: a measurement is a record accessible to the observer (the now's target degree of freedom), producing a definite outcome.

An environmental record is written by degrees of freedom not accessed by the observer, creating correlations that produce reduced-state decoherence without a definite observed outcome. The observer does not see the environmental record directly.

You see the system. But the system is now correlated with the environmental degree of freedom — and that correlation is irreversible (Axiom R).

2.3 — The monoid grows

Each environmental interaction adds a record to the monoid. The monoid has no inverse (Axiom R). Each new record is composed with the existing record via the monoid operation. The total record grows monotonically.

For the system, each environmental record is a partial break. One environmental particle scatters off the electron and writes a record of "electron was more likely at position A."

Another particle writes "electron was more likely at position B." Each record is partial — it does not determine the electron's position definitively. But each record is irreversible (Axiom R). And the records accumulate.

You cannot stop them. You cannot undo them.

After N environmental interactions, the system's quantum state is entangled with N environmental degrees of freedom.

The coherence of the original superposition is now encoded in the (N+1)-body correlations between the system and all N environmental particles.

To exhibit interference — to demonstrate that the superposition still exists — you would need to bring all N environmental particles back together with the system and reverse their interactions.

But the records are irreversible (Axiom R). The monoid has no inverse. The coherence is irrecoverable.

Cross-reference: Paper D §I.3: Axiom R (record monotonicity, no inverses). AP09 §4.3: The now as boundary between broken and unbroken. AP09 §5: Entanglement as the pre-state leaking through.

§3 — The Loss of Coherence

[DERIVATION (from AP09 open-systems formalism + factorisation assumptions) + STRUCTURAL INTERPRETATION (Axiom R as irreversibility postulate, pending D6)]

Now the algebra. You have the picture — environment writes records, records are irreversible, coherence disperses. What follows is the mathematics that makes this precise.

3.1 — Coherence as a phase relationship

In the Hilbert space (AP09 §3.2), a superposition of two states is:

$|\psi\rangle = \alpha|A\rangle + \beta|B\rangle$

The coherence is the off-diagonal terms of the density matrix:

$\rho = |\psi\rangle\langle\psi| = |\alpha|^2|A\rangle\langle A| + \alpha\beta|A\rangle\langle B| + \alpha\beta|B\rangle\langle A| + |\beta|^2|B\rangle\langle B|$

where $\alpha, \beta \in \mathbb{C}$ with $|\alpha|^2 + |\beta|^2 = 1$. The off-diagonal terms $\alpha\beta|A\rangle\langle B|$ and $\alpha\beta|B\rangle\langle A|$ are the coherence — they encode the phase relationship between states A and B.

The complex conjugation is essential: it is what makes the density matrix Hermitian ($\rho = \rho\dagger$) and ensures the phase information is correctly represented. If these terms are nonzero, interference is possible.

If they vanish, the system behaves as a classical mixture: either A with probability $|\alpha|^2$ or B with probability $|\beta|^2$, but not both simultaneously. You get one or the other. That is what classical means.

3.2 — What environmental records do to the coherence

After one environmental interaction, the system is entangled with the environmental particle:

$|\Psi\rangle = \alpha|A\rangle|e\_A\rangle + \beta|B\rangle|e\_B\rangle$

where |e_A⟩ and |e_B⟩ are the environmental states correlated with the system being at A or B.

The system's density matrix — obtained by tracing over the environmental degree of freedom — is:

$\rho\_system = |\alpha|^2|A\rangle\langle A| + \alpha\beta\langle e\_B|e\_A\rangle|A\rangle\langle B| + \alpha\beta\langle e\_A|e\_B\rangle|B\rangle\langle A| + |\beta|^2|B\rangle\langle B|$

The coherence terms are now multiplied by ⟨e_B|e_A⟩ — the overlap between the two environmental states. If the environmental states are orthogonal (⟨e_B|e_A⟩ = 0), the coherence vanishes completely after a single interaction.

If the overlap is partial (0 < |⟨e_B|e_A⟩| < 1), the coherence is reduced but not eliminated.

Watch what happens next. One interaction reduces the coherence. What do a billion interactions do?

3.3 — The monoid amplifies the loss

Assumptions (not derived from the axioms; physically motivated). The following derivation assumes: (i) the environmental Hilbert space decomposes as $H\_E = \bigotimes_i H\_E_i$ into effectively independent subsystems; (ii) the initial environment state factorises across these subsystems; (iii) the interactions are sequential and approximately independent, so the total coherence factor factorises as a product.

These are standard assumptions in collisional decoherence models (Joos et al., 2003; Zurek, 2003). They are not derived from {S, B, R, C}.

The monoid structure (Axiom R) guarantees that records compose and cannot be undone; it does not by itself guarantee that the composition yields a factorised product of overlaps.

The product form is a physically motivated ansatz for typical environments. A debt owed — and you hold the kill switch (see §6, Debts Owed).

Under these assumptions, after N environmental interactions the coherence factor becomes:

$\langle e\_B|e\_A\rangle\_total = \prod_{i=1}^{N} \langle e\_B^{(i)}|e\_A^{(i)}\rangle$

Each factor has magnitude ≤ 1. For generic environmental interactions where the typical overlap magnitude is strictly less than 1 — that is, where each environmental record carries nonzero information about the system — the magnitude of the product decays exponentially in N.

Define the per-interaction decoherence weight $\lambda_i = -\ln|\langle e\_B^{(i)}|e\_A^{(i)}\rangle| \geq 0$ for each interaction. Then $|\langle e\_B|e\_A\rangle\_total| = e^{\wedge}(-\sum_i \lambda_i)$. For identical interactions with per-interaction weight $\lambda > 0$, after N interactions the coherence magnitude is $e^{-N}\lambda$.

Even if each individual environmental record is a weak measurement (λ small), the sum of many such weights drives the coherence magnitude to zero exponentially fast.

The condition $\lambda > 0$ (equivalently, $|\langle e\_B|e\_A\rangle| < 1$ for at least some interactions) is the physical content: the environment must actually distinguish the two states, at least partially, for decoherence to occur.

An environment that writes no distinguishing records ($\lambda = 0$ for all interactions) produces no decoherence.

The monoid doing what it does. Each record is composed with the previous records. The composition is the monoid operation. The monoid grows monotonically (Axiom R — no inverses).

The magnitude of the coherence factor, which is the product of all individual overlap magnitudes, decays monotonically.

What Axiom R contributes specifically is the irreversibility interpretation: in standard quantum mechanics, the combined system+environment evolution is unitary and in principle reversible, making decoherence practically irreversible (because reversing a macroscopic entangling history is infeasible) but not structurally forbidden.

In the 420 Code, Axiom R upgrades this: the monoid has no inverse, so within the architecture's allowed dynamics, environmental records cannot be undone. The irreversibility is structural, not merely practical.

A formal no-go theorem specifying the allowed dynamical class within which this holds is outstanding (see D6 in §6, Debts Owed).

The interpretive upgrade — from practical to structural irreversibility, pending D6 — is this paper's specific contribution beyond standard decoherence theory.

Decoherence is Axiom R applied to the coherence of a quantum state. Records accumulate. Each record reduces the coherence magnitude. Under the Axiom R reading, the reduction is irreversible (see D6 above).

The coherence magnitude decays exponentially in the number of environmental records. The superposition becomes a classical mixture — not because the pre-state was destroyed, but because the phase information was dispersed into the monoid.

3.4 — The decoherence timescale

The rate of decoherence depends on two things:

The coupling strength: How efficiently each environmental interaction writes a record about the system. Strong coupling ($|\langle e_B|e_A\rangle| \approx 0$ per interaction) means each record is nearly complete — coherence is lost in a few interactions.

Weak coupling ($|\langle e_B|e_A\rangle| \approx 1$ per interaction) means each record is nearly empty — coherence decays slowly.

The interaction rate: How many environmental degrees of freedom interact with the system per unit time. A system in a dense environment (air, thermal radiation) decoheres in a fraction of a second.

A system in near-vacuum (deep space, cryogenic isolation) can maintain coherence much longer.

The decoherence timescale τ_D is determined by the product of these two factors.

From §3.3: if interactions occur at rate Γ (number of environmental interactions per unit time), then after time t the system has undergone $N = \Gamma t$ interactions.

Using the per-interaction decoherence weight $\lambda = -\ln|\langle e_B|e_A\rangle|$ from §3.3, the coherence magnitude is $|\langle e_B|e_A\rangle_{total}| = e^{-N\lambda} = e^{(-\Gamma\lambda t)}$. The decoherence timescale: $\tau_D^{-1} = \Gamma\lambda = -\Gamma \ln|\langle e_B|e_A\rangle|$.

Connection to the standard literature: for weak coupling ($|\langle e_B|e_A\rangle| \approx 1$), $\lambda \approx 1 - |\langle e_B|e_A\rangle| \approx (1 - |\langle e_B|e_A\rangle|^2)/2$ to leading order.

The standard result from open quantum systems theory (Zurek, 2003, §II.C; Joos et al., 2003, Chapter 3) typically expresses the decoherence rate as $\Gamma(1 - |\langle e_B|e_A\rangle|^2)$, which corresponds to the decay rate of the squared coherence magnitude (visibility squared) and equals $2\Gamma\lambda$ to leading order.

The factor-of-2 difference reflects whether one tracks |coherence| or $|\text{coherence}|^2$; both conventions appear in the literature. The qualitative content is the same: exponential decay at a rate set by Γ × (per-interaction distinguishability).

The axioms do not predict specific coupling strengths or interaction rates — those depend on the microphysical details of the system and its environment (see D2 in §6).

The quantitative expression for τ_D is adopted from standard open quantum systems theory, not derived from {S, B, R, C}.

What the axioms contribute is the structural identification (environmental record-writing) and the irreversibility interpretation (Axiom R, pending formal no-go theorem D6).

The mechanism is universal: it applies to every quantum system that is not perfectly isolated from the accumulated record.

Cross-reference: AP09 §3.2: Hilbert space, density matrix. AP09 §6: Born rule (probabilities from $|\psi|^2$). Paper D §I.3: Axiom R (monoid, no inverses).

§4 — The Classical World

[STRUCTURAL — the emergence of classicality]

4.1 — Why the world looks classical

Macroscopic objects do not exhibit quantum superposition in everyday experience. A chair is in one place, not a superposition of two places. A cat is alive or dead, not both.

The classical world — the world of definite states and definite positions — is what you experience.

The classical world is the regime where the environment has written so many records that the remaining superpositions are operationally invisible.

To illustrate with a standard estimate from decoherence theory (not a prediction of the axioms, but an imported example): a dust grain of radius $a \approx 10^{-4}$ cm in air at standard conditions ($T \approx 300$ K, $P \approx 1$ atm) interacts with roughly 10^{18} air molecules per second (Joos et al., 2003, Table 3.1).

Each interaction writes a partial record. For a superposition with spatial separation $\Delta x \approx a$, the coherence magnitude decays on a timescale of approximately 10^{-31} seconds — far faster than any experiment could detect.

By the time you look, the grain's superposition has already been dispersed into 10^{18} environmental records per second, each one irreversible under Axiom R (see D6).

The classical world is not a different physics from the quantum world. It is the quantum world after enough records have been written. The break is ongoing. The records accumulate. The coherence disperses.

What remains, after the environment has written its records, is the classical mixture — definite states, definite positions, the world as you experience it.

4.2 — Classicality is a spectrum, not a boundary

There is no sharp boundary between “quantum” and “classical.” There is a continuum of decoherence — from perfectly isolated (no environmental records, full coherence) to maximally decohered (environmental records saturated, effectively classical).

The position on this spectrum depends on the environment: how many degrees of freedom interact with the system, how strongly, how often.

Quantum computers work by keeping systems at the “isolated” end — minimising environmental coupling, maintaining coherence.

Classical computers work at the “decohered” end — every bit is a record that has been written and rewritten by the environment. The difference is not fundamental.

It is a difference in how many environmental records have been written. When you build a quantum computer, you are fighting the monoid — holding it at bay, one record at a time.

4.3 — Why interference experiments work

If decoherence disperses coherence, how do you ever see interference? The double-slit experiment, quantum eraser experiments, and entanglement verification all require coherence to persist.

The answer: these experiments work by isolating the system from environmental record-writing.

The double slit works because the electron’s path is not recorded — no environmental particle scatters off the electron in a way that distinguishes “slit A” from “slit B.”

The moment you place a detector at one slit — the moment the environment writes a record of which slit the electron passed through — the interference pattern vanishes.

Decoherence in action: one environmental record, strong coupling, coherence eliminated.

The record written by the which-path detector is subject to Axiom R and therefore cannot be destroyed.

The quantum eraser experiment must therefore be understood — if the axioms are correct — as a basis rotation that makes the which-path information inaccessible, not as record destruction. The record still exists.

But its basis has been rotated so that it no longer distinguishes A from B in the chosen measurement context.

Crucially, the “recovered” interference appears only in postselected sub-ensembles (coincidence counting / conditional statistics), not as an unconditional restoration of the interference pattern in the raw marginal distribution (Walborn et al., 2002; Kim et al., 2000).

The unconditional screen distribution remains washed out — consistent with the environmental record persisting.

A prediction of the architecture: if a quantum eraser experiment were shown to genuinely destroy the which-path record rather than rotate it to an inaccessible basis, the architecture would be falsified (see KS-23).

Here is the weapon. The argument hands it to you. The basis-rotation interpretation is consistent with current experimental evidence but is not proven by it.

The record is never destroyed. But the observable consequences of the record depend on how it is read. The quantum eraser changes how the record is read, not whether the record exists.

Cross-reference: AP09 §4: Measurement as the break. AP09 §5: Entanglement. Zurek (2003).

§5 — The Structural Meaning

[STRUCTURAL — tying everything together]

5.1 — The three faces of Axiom R

Axiom R — record monotonicity — now has three distinct physical manifestations:

The arrow of time: Records accumulate. History is irreversible. Time flows in one direction — the direction of increasing record count. (Paper D, AP06, AP09)

Measurement irreversibility: Once the now writes a record, the outcome is permanent. The wave function does not "un-collapse." The pre-state, once broken, stays broken. (AP09 §4.2)

Decoherence: Environmental records accumulate. Each one is irreversible (Axiom R). The coherence disperses into the monoid. The superposition becomes a classical mixture.

The classical world emerges from the quantum world through irreversible record accumulation (Axiom R; formal scope per D6). (This paper)

These are not three separate phenomena. They are one axiom, read at three scales. The arrow of time is Axiom R read cosmologically. Measurement irreversibility is Axiom R read at the single-event scale.

Decoherence is Axiom R read at the intermediate scale — many events, many records, statistical emergence of classicality.

One axiom. Three scales. The same structure, everywhere you look. And now you have seen all three.

5.2 — The full quantum picture

With this paper, the foundational features of the quantum sector are derived or structurally identified within the 420 Code:

Superposition: The pre-state — 0 and 1 undistinguished. (AP09 §3) **Linearity:** From the record monoid and complex scalars. (AP09 §3.2) **Complex amplitudes:** From Lorentzian signature.

(AP09 §3.3) **Measurement:** The now writing a record — instantaneous, definite, irreversible. (AP09 §4) **The now:** The invariant — carrying all records, having none.

(AP09 §4.3) **The loop:** Defragmentation (recombination into the ground state), not annihilation — completion is renewal. (AP09 §4.4) **Entanglement:** The pre-state leaking through — separateness not yet created.

(AP09 §5) **The Born rule:** $|\psi|^2$ = the 1:1 voting — both sectors must agree. (AP09 §6) **The Schrödinger equation:** Forced by Wigner + Stone from the axioms.

(AP09 §7.3) **Spin:** The break carried internally — paired (boson) vs unpaired (fermion). (AP11) **The Pauli exclusion principle:** The break cannot stack.

(AP11 §5.3) **The uncertainty principle:** The minimum record — one $\hbar$, two faces, one budget. (AP12) **Commutation relations:** The algebraic expression of the minimum record.

(AP12 §4) **Decoherence:** Environmental records accumulate — coherence disperses into the monoid. (This paper)

That is the quantum sector. All of it. From four axioms. You are looking at the complete list.

Two features of the full decoherence programme remain unaddressed: (i) einselection — the environment-induced selection of preferred pointer states that are robust to further decoherence (Zurek, 2003), and (ii) quantum Darwinism — the redundant encoding of classical information across multiple environmental fragments (Zurek, 2009).

The monoid structure is suggestive for both (pointer states may correspond to eigenstates of the record-writing operation; the monoid naturally replicates records), but neither has been derived or structurally identified.

These are debts owed (see §6). The completeness claim is scoped: the foundational features are derived or structurally identified; the decoherence programme is not yet exhausted.

Cross-reference: All papers cited above.

§6 — Kill Switches and Debts Owed

6.1 — Kill Switches

KS-22 [LIVE — EMPIRICAL] — Anomalous coherence persistence. If a quantum system is shown to maintain coherence indefinitely in an environment where decoherence theory predicts exponential decay — with all known sources of environmental coupling accounted for, the factorisation assumptions of §3.3 satisfied, and no alternative explanation (such as decoherence-free subspaces or dynamical decoupling) — then the derivation's claim that environmental record-writing universally and irreversibly suppresses coherence would be falsified.

Observable: coherence persistence (measured via interferometric visibility or off-diagonal density matrix elements) in a controlled environment where the §3.3 assumptions hold.

Note on spin echo and Loschmidt echo: these phenomena achieve partial reversal of dephasing in controlled subsystems.

Under the axioms, this is consistent with Axiom R if the "reversal" is understood as refocusing within a subsystem whose environmental records remain intact — the global monoid has not lost any records, but the accessible observable has been rotated to a basis where the dephasing is invisible.

This interpretation is consistent with current experiments but remains an interpretation, not a derivation.

If a spin echo or Loschmidt echo experiment is shown to genuinely reverse environmental records (not merely refocus subsystem observables), KS-22 fires. Here is the weapon: find the reversal. Status: LIVE.

KS-23 [LIVE — EMPIRICAL] — Quantum eraser record destruction. Operational definition: in this paper, "record" means information redundantly encoded into many uncontrolled environmental degrees of freedom such that recovery would require an inverse in the record monoid — not a reversible correlation stored in a single

controllable quantum degree of freedom (which can be unitarily unmarked without violating Axiom R).

The architecture predicts that in quantum eraser experiments, the which-path information is an irreversible record in this sense, and that “erasure” is basis rotation, not record destruction (§4.3).

Operational criterion for falsification: if an experiment demonstrates that the unconditional (non-postselected) interference pattern is fully restored after which-path information has been redundantly encoded into uncontrolled environmental degrees of freedom — not merely that interference reappears in conditioned sub-ensembles, and not merely that a reversible which-path marking in a single controlled degree of freedom has been unitarily undone — then the which-path record has been genuinely destroyed in a way that violates Axiom R, and the architecture’s reading requires revision.

Note: reversible unmarking of a controlled which-path marker (e.g., a single polarisation qubit) does not trigger KS-23, because such a marker is not a “record” in the architecture’s sense.

Current experimental evidence (Scully et al., 1991; Walborn et al., 2002; Kim et al., 2000) is consistent with the basis-rotation interpretation: recovered interference appears only in postselected coincidence counts, not in the unconditional marginal distribution.

Here is the weapon: restore unconditional interference. Status: LIVE.

KS-24 [LIVE — HARD] — Quantum sector completeness. If any foundational feature of quantum mechanics is identified that cannot be derived from or structurally identified with {S, B, R, C} plus EH and QRA (both proven, AP20), the completeness claim is falsified.

Known candidates for such features that are not yet addressed in the corpus: einselection (environment-induced pointer basis selection), quantum Darwinism (redundant environmental encoding of classical information), decoherence-free subspaces, and quantum error correction thresholds.

These are listed under Debts Owed below. Here is the weapon: find the feature. Status: LIVE.

6.2 — Debts Owed

The following components are used in this paper but not derived from {S, B, R, C}. They are imported from standard physics or assumed as physically motivated conditions.

Each is a debt that either must be discharged in a future AP or acknowledged as a standing limitation.

D1 — Factorisation assumption. §3.3 assumes the environmental Hilbert space decomposes into independent subsystems with factorised initial state and that interactions are sequential and approximately independent.

Standard in collisional decoherence models but not derived from the axioms. The monoid guarantees composition; it does not guarantee factorisation of the resulting overlaps.

D2 — Decoherence timescale. The quantitative expression for τ_D (§3.4) is adopted from standard open quantum systems theory.

The axioms provide the structural mechanism (environmental record-writing under Axiom R) and the exponential form from the product of overlaps, but do not predict specific coupling strengths or interaction rates, which depend on microphysical details outside the axioms.

D3 — Quantum eraser interpretation. §4.3's claim that record-erasure is basis rotation is an architectural prediction consistent with current experiments, not a derived result.

The formal characterisation of basis rotation within the monoid structure — specifically, whether it corresponds to a change of the homomorphism from the monoid to the observable algebra — is a debt owed.

D4 — Einselection (pointer basis selection). This paper derives that coherence is lost but does not address which states survive.

The environment-induced selection of preferred pointer states (Zurek, 2003) is a major component of the decoherence programme that is not yet derived or structurally identified within the record algebra.

The monoid structure may naturally select states that are eigenstates of the record-writing operation — suggestive but unproven.

D5 — Quantum Darwinism. The redundant encoding of classical information across multiple environmental fragments (Zurek, 2009) is not addressed.

The monoid naturally replicates records (composition produces multiple copies of correlated information) — suggestive but not formalised.

D6 — Scope of structural irreversibility. This paper claims decoherence is structurally irreversible (Axiom R: monoid has no inverse), upgrading the standard "practically irreversible" framing.

The bridge from "monoid has no inverse" to "no physical process can reverse the coherence loss" requires specifying the allowed dynamical class within which the no-reversal claim holds.

This paper asserts the bridge but does not provide a formal no-go theorem. The claim is: within any dynamics compatible with the record algebra, coherence loss from environmental record-writing is irreversible.

A formal proof would strengthen the paper; its absence is a debt.

Load-bearing status: §1 is structural (three regimes). §2 is the core identification (environment = accumulated record; structural identification, not derivation). §3 is the core argument (standard decoherence mechanism from AP09 + Axiom R for irreversibility, under stated assumptions). §4 is the consequence (classicality as saturated decoherence). §5 is the synthesis.

§7 — Closing

The classical world is the quantum world after enough records have been written.

Decoherence is not a new mechanism. It is Axiom R — the same axiom that gives the arrow of time and the irreversibility of measurement — applied at the scale of environmental interactions.

The environment writes records. Each record is irreversible (Axiom R). The coherence of the quantum state disperses into these records. The superposition becomes a classical mixture.

The world looks definite because the environment has already made it definite — not by collapsing the wave function, but by dispersing its coherence into an enormous monoid of environmental records that the architecture identifies as irrecoverable.

The quantum world and the classical world are not two worlds. They are one world at different stages of the break. The quantum world is the pre-state — undistinguished, coherent, superposed.

The classical world is the post-record — distinguished, decohered, definite. The boundary between them is not sharp.

It is the now — always moving, always writing, always at the frontier between the unbroken and the broken.

You live at that frontier. Every breath you take writes records. Every photon that hits your retina is a coupling event.

The classical world you inhabit is the accumulated evidence of Axiom R operating at every scale, in every direction, since the break began.

The foundational features of the quantum sector are derived or structurally identified. The decoherence programme has debts remaining (einselection, quantum Darwinism). The work continues.

The axiom is **1:1 + 1×ε**. The algebra is the record algebra. The geometry is Lorentzian. The gravity is the eye. The quantum is the opening. The dimension is the count.

The spin is the break. The limit is the minimum. The grain is the record. Don’t be a cunt, be kind.

§8 — Claim Summary

§1 (Three regimes): STRUCTURAL. Unitary evolution (no records), measurement (one definite record), decoherence (many environmental records). Framework for the derivation.

§2 (Environment as record): STRUCTURAL IDENTIFICATION. The environment identified with the accumulated record — the sum of all completed breaks. Definitional framing, not a deduction. Environmental coupling = record-writing by non-target degrees of freedom.

Monoid grows monotonically (Axiom R).

§3 (Loss of coherence): DERIVATION (from AP09 formalism + factorisation assumptions) + STRUCTURAL INTERPRETATION (Axiom R). Coherence = off-diagonal terms of density matrix (AP09 formalism). Environmental entanglement multiplies coherence by overlap factor ⟨e_B|e_A⟩ per interaction.

Under stated factorisation assumptions (D1), product of N factors' magnitudes decays exponentially. Specific contribution: Axiom R identifies the decay as structurally irreversible (formal no-go outstanding; D6).

Decoherence timescale τ_D derived from product form via per-interaction decoherence weight λ; quantitative parameters adopted from standard open quantum systems theory (D2).

§4 (Classical world): STRUCTURAL. Classicality = saturated decoherence. Spectrum, not boundary. Quantum eraser = basis rotation, not record destruction (architectural prediction; interference recovered only in postselected sub-ensembles, not unconditionally; testable via KS-23).

§5 (Structural meaning): STRUCTURAL. Three faces of Axiom R: arrow of time (cosmological), measurement irreversibility (single-event), decoherence (intermediate scale).

Quantum sector summary — foundational features of QM derived or structurally identified from {S, B, R, C}. Debts acknowledged: einselection, quantum Darwinism.

§6 (Kill switches): STRUCTURAL. KS-22 (anomalous coherence persistence), KS-23 (quantum eraser record destruction), KS-24 (quantum sector completeness). All live. Six debts owed (D1–D6).

§9 — Conditionality Footer

Dependencies: Paper D Phase 1 (axioms, independence, monoid structure). AP09 §3–§4 (superposition, measurement, Hilbert space). AP09 §7.2 (unitary evolution). AP09 §6 (Born rule). AP20 (EH and QRA proven).

Dependents: Any downstream result requiring the quantum-to-classical transition. The classical limit. The emergence of definite outcomes at macroscopic scale.

Open problems: None introduced beyond kill switches below.

Kill switches live: KS-22 (anomalous coherence persistence — if a system maintains coherence where the derivation predicts decay, under conditions where §3.3 assumptions hold).

KS-23 (quantum eraser record destruction — if unconditional interference is restored after which-path information has been redundantly encoded into uncontrolled environmental degrees of freedom; reversible unmarking of a controlled marker does not trigger).

KS-24 (quantum sector completeness — if a foundational quantum feature is identified that cannot be derived from or structurally identified with {S, B, R, C}).

Six debts owed: D1 (factorisation assumption), D2 (decoherence timescale parameters), D3 (quantum eraser formal characterisation), D4 (einselection), D5 (quantum Darwinism), D6 (scope of structural irreversibility / no-go theorem).

Inherited switches: All kill switches from Paper D propagate. AP20 kill switches (KS-P.1 through KS-P.3) propagate via EH dependency. AP09 kill switches propagate via dependency on quantum foundations.

What is derived or structurally identified: Decoherence mechanism from standard QM formalism (AP09) under stated factorisation assumptions (D1). Irreversibility interpretation from Axiom R (monoid has no inverse; formal no-go outstanding, D6).

The environment structurally identified with the accumulated record. Exponential decay of coherence magnitude via environmental record-writing under stated assumptions. The classical world as saturated decoherence.

The quantum eraser as basis rotation, not record destruction (architectural prediction, testable via KS-23). Three faces of Axiom R (arrow of time, measurement irreversibility, decoherence) as one axiom at three scales.

Foundational features of the quantum sector derived or structurally identified; einselection and quantum Darwinism remain as debts.

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Artist G (2026). AP11: The Spin. Artist's Proof.

Artist G (2026). AP12: The Limit. Artist's Proof.

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Cross-Reference Index

Environment = accumulated record: This paper §2.1

Environmental coupling = record-writing: This paper §2.2

Coherence loss from Axiom R: This paper §3

Exponential decay of coherence: This paper §3.3

Classical world = saturated decoherence: This paper §4.1

Quantum eraser = basis rotation: This paper §4.3

Three faces of Axiom R: This paper §5.1

Full quantum sector summary: This paper §5.2

Axiom R (record monotonicity): Paper D §I.3

Measurement as the break: AP09 §4

Born rule: AP09 §6

Hilbert space: AP09 §3.2

Unitary evolution: AP09 §7.2

Entanglement: AP09 §5

EH and QRA proven: AP20

N = 3 spatial dimensions: AP10

Spin (fermion/boson): AP11

Uncertainty principle / commutation relations: AP12

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