

Topological Linking-Number Heredity in a Crystalline Substrate, and the Open-Ended-Evolution Wall

A Negative Result, with a Mechanism Worth Keeping

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Preprint — not peer-reviewed. Part Two of the “Turtles, or Crystals” framework; companion to the engineering paper “A Topological-Winding Memory.” CC BY 4.0. Draft v0.1 — prose for iteration. Citations are by name and year; all are verified against primary sources.

Abstract

We report two things, and we will tell you the ending first because the ending is half the point. The first is a specific, falsifiable mechanism by which a crystal could carry heritable information: the topological **linking number** of a chiral texture, $Lk = Tw + Wr$, written when two helical records merge and **mutated in integer quanta** when the crystal fractures — a topoisomerase-analog in dead matter — with the substrate's *cleavage class* predicting whether that inheritance is faithful or scrambled. This is, to our knowledge, new, and it is decided by a single experiment we name but did not run. The second thing we report is a failure. We built this substrate in simulation, gave it heredity and selection, and it would **not** cross from faithful replication into open-ended evolution under any undirected driver we tried. The population drifted toward order, not the edge; organized complexity fell. This is the wall the entire artificial-life field stands at, and we did not get over it. We map exactly where it is, name the four things that smother the spark, demonstrate the removal of three of them, and report — against our own hope — that removing them was necessary and not shown sufficient. Biology's prion, a structural template that copies faithfully and evolves almost not at all, is the confirming witness: it ran our experiment, in protein, and got our answer. What follows is the scenic route to that wall. We think the route was worth taking.

1. Introduction: the question, and an honest spoiler

Part One of this work established something modest and true: a growing crystal *records*. Its defects, its growth zoning, its frozen-in strain are a written history of the conditions it formed under, as faithfully as tree rings. That is real, ordinary physics, and it tempts an immediate and much larger claim — that a thing which records its history is on the road to being alive. Part One refused that claim and named the seam precisely: **recording is not evolving**. A medium that logs its past is a diary, not a lineage. To call it life you need heritable variation under selection, and logging supplies none of that on its own.

This paper walks that seam to its end. We sharpen “recording $\neq$ evolving” into the operational question that the artificial-life field has circled for fifty years — *replication $\neq$ selection* — and we ask whether crystal-growth physics can supply, in order, the operators life is built from: variation, heredity, expression, and selection. We will show that it can supply most of them as real mechanisms. We will introduce one genuinely new mechanism for heredity. And then we will hit the wall that everyone hits, and we will report that we could not cross it.

We tell you this now, in the introduction, on purpose. This is a negative-result paper. Its spine is a failure — a specific, pre-registered, reproducible failure — and if you read it expecting a triumphant demonstration that crystals are alive, you will be disappointed at exactly the moment we intend you to be. The wager of this paper is that the *honest* version of the journey is more valuable than the dishonest version of the destination: that a clearly mapped wall, with the mechanism that gets you to it and the precise conditions under which the central claim dies, is worth more to the field than one more over-claimed “open-ended evolution” that quietly plateaus. We took the scenic route to a place we suspected we could not leave. We think the route is the contribution.

A word on register, since this paper is bolder than its engineering sibling. Artificial life is a field where speculation is

not a vice but the working instrument: no one can manufacture life to check against, so the discipline advances by proposing mechanisms, arguing their plausibility, and naming what would falsify them. We use that license deliberately here — but we do not mistake it for permission to be careless. Every speculative leap is fenced to a kill condition, and where a claim depends on physics or biology our small team cannot vet from hands-on experience, we say so plainly (the companion *Seam & Assumptions Register* maps exactly where). The synthesis is offered in earnest and as something new; we hand the reviewer the hammer and ask them to test and strengthen this scaffold through its academic destruction, trusting that what survives shows its merit and what breaks becomes an opening to build something better in its place.

2. The lineage we stand on — and what is not new

Intellectual honesty begins with conceding what you did not invent, before a reviewer concedes it for you. The thesis that life is *organization* rather than substance — that what matters is the pattern of relationships, not the material carrying it — is not ours. It runs from Wiener's cybernetics through von Neumann's theory of self-reproducing automata to Langton's "life as it could be," and it is the founding premise of artificial life as a discipline. We restate it; we do not claim it.

The narrower thesis that *crystals specifically* might be the substrate for a minimal proto-life is also not new. Cairns-Smith's clay genetic-takeover hypothesis put mineral surfaces at the origin of heredity in the 1960s. Schulman and Winfree demonstrated that DNA-tile crystals can replicate combinatorial information with selectable fidelity — information-bearing crystal growth, in a test tube. Eigen gave us the quasispecies and the error threshold; Kauffman gave us autocatalytic closure, collective self-reproduction without a template. These are the shoulders we stand on, and we cite them not as decoration but as the bar a new contribution must clear.

So we are explicit about the two things in this paper that are *not* re-skins of the above. One is a mechanism — a specific way a topological invariant could carry and mutate heritable information in a crystal. The other is a result — a clean negative about open-ended evolution in that substrate. Both are narrow. Neither is a manifesto. Everything else here is scaffolding around those two, and we have tried to keep the scaffolding honest about being scaffolding.

3. The two-lattice resolution of the evolvability objection

Von Neumann raised the objection that still does the most damage to any "crystals are alive" claim: trivial self-reproduction is not interesting. A growing crystal makes more crystal, yes, but a flame makes more flame and a salt crystal in brine makes more salt crystal, and none of these evolve, because the "copy" carries no separable, mutable *description* that selection can act on independently of the machine. Life clears this bar because its genotype (the description) is decoupled from its phenotype (the machine), so the description can mutate without immediately destroying the copier. A crystal that is only its own growth front has no such separation, and so it is, von Neumann would say, merely a pattern that propagates — not a thing that evolves.

Our resolution is to find the separation already present in the physics. A crystal carrying a chiral field texture is *two* lattices at once: the **matter lattice** — the frozen atomic arrangement, a genuine written record, the genotype — and the **field texture** — the live, three-dimensional configuration of windings and defects threaded through it, the phenotype. The matter lattice is the tape; the field texture is what the tape builds and expresses. They are physically distinct, can in principle vary semi-independently, and are coupled in exactly the way a genotype and phenotype are coupled: the frozen record constrains the live texture, the live texture is what interacts with the world.

We owe the reader the first whoopse here, early, to set the tone for a paper that will have several. In an earlier draft we accounted for the "extra dimension" the field phenotype seems to carry over the 2D-plus-time matter record by invoking a holographic (Bekenstein-style) bound, which sounded profound and was wrong — an over-reach we caught in our own review. The correct accounting is mundane: a classical volume bound, the live texture occupying ordinary three-space, no holography required. We flag the correction not to flagellate but because a paper that hides its corrected over-reaches has no standing to report its successes. The two-lattice resolution survives the correction intact; it just costs less than we first claimed.

4. The blade: topological linking-number heredity

Here is the one new thing. If the matter lattice is the genotype, what is written on it, and how does it mutate?

Take two helical records and let them merge — physically plausible when two growing chiral textures coalesce. The merged object carries a **linking number**, Lk , the integer count of how many times one strand winds through the other. The Călugăreanu-White-Fuller theorem decomposes it exactly: $Lk = Tw + Wr$, twist plus writhe, and crucially **Lk is a topological invariant** — it cannot change under any smooth deformation. It is an integer, and it is conserved. That is precisely the property a hereditary register needs: a quantity that persists through the jostling of ordinary thermal life and changes only through a discrete, identifiable event.

The discrete event is fracture. When the crystal breaks — and a reproducing crystal must break, to make offspring —

the linking number of the daughter need not equal the parent's. It changes by an **integer quantum**, ΔLk , exactly as the enzyme topoisomerase changes the linking number of DNA by ± 1 (type I) or ± 2 (type II) when it cuts and rejoins a strand. We propose that a controlled crystal fracture is a topoisomerase-analog in dead matter: it severs and rejoins the topological register, and in doing so it *inherits the parent's linking number plus or minus a quantum*. Heredity with quantized mutation, carried in an invariant, written by merging and varied by breaking. The signed alphabet that rides on this — chirality as a sign bit, winding magnitude as a value, with a spare state available as a checksum — is simply *how the register is read*; the recombination of two parents' records on merge is *how variation enters*. All of it is in service of the one claim: **the unit of heritable variation is an integer change in a topological invariant on fracture**.

This is falsifiable, and it has a single make-or-break test, which we name and concede we did not run. Does real crystal fracture actually quantize ΔLk , or does it scramble the linking number into noise? The question is decided by micromagnetic simulation (mumax³-class) and then by the bench, not by anything in this paper. We further predict that the *cleavage class* of the substrate is the discriminator: a cleanly layered material (van der Waals, mica) should fracture along clean planes and inherit a quantized, heritable ΔLk , while a conchoidally fracturing material (quartz) should scramble it. If the linking number scrambles on fracture, this mechanism — and with it the heredity claim, and with it the entire road to evolvability in this substrate — fails cleanly, and that failure is the finding. We built the rest of the paper on top of a claim we have not yet been able to kill. We want the reader to feel the weight of that, because we do.

5. Expression, the cell cycle, and the operators of life

Granting, for the length of this act, that the topological register holds, the remaining operators of life have reasonably direct crystalline realizations, and we state them as mechanism rather than as metaphor. Expression — genotype building phenotype — is the von Neumann projector: the frozen matter record templates the growth of new field texture, the description constructing the machine. Division and reproduction are the fracture event of §4, now read as a cell cycle: a parent record grows, accumulates its texture, and breaks into daughters each carrying an inherited-plus-mutated register. Variation enters at merge (recombination) and at fracture (the ΔLk quantum). Selection — the operator the whole paper turns on — we treat in §6 and then, far more harshly, in Act III.

We are deliberately terse here because this is the part most vulnerable to the seduction we are trying to avoid: each of these mappings is *plausible* and *unproven*, and the more eloquently one writes about plausible-and-unproven mappings the more they start to sound established. They are not. They are the machinery a working substrate would need, named so the reader can see the whole engine, with every part still wearing its "not yet demonstrated" tag.

6. The information layer: what held, and what broke

Beneath the physics of the substrate sits an information layer — the abstract dynamics of copying, correcting, and selecting — and that layer we *could* test, in simulation, this session. We report the results as a mixed ledger, diamonds and whoopses together, because separating them would be the first dishonest move and the rest would follow.

The diamonds. A fidelity window exists: copying improves with drive up to a peak (near a drive strength of ~ 1.1 in our units) and degrades past it, the signature of a real optimum rather than "more is always better." A closed-form capacity bound for the signed multilevel alphabet matches Monte Carlo simulation to better than a thousandth. Heredity-as-reference held its central prediction and survived hardening: dead-reckoning copying with no reference drifts to noise, while copying that corrects toward an inherited template stays bounded — and across twelve random seeds the drift floor (0.009 ± 0.016) and the heredity ceiling (0.891 ± 0.007) are tight, not single-seed artifacts. Kinetic proofreading, in the Hopfield-Ninio sense, drives error below the passive thermodynamic floor. The optimal radix of the alphabet self-organizes toward ternary. And the **static** edge of chaos is real: mutual information peaks at an intermediate order parameter ($\lambda \approx 0.45$), and the peak survives a shuffle-surrogate control that a spurious result would fail.

The whoopses, kept and framed, because they are the method working rather than the method embarrassing itself. We predicted a writability-versus-retention window — a sweet spot where a record is written hard enough to read but soft enough to stay repairable — and in the linear-relaxation regime *it does not exist*: contrast and retention move the same direction, so the optimum is at the boundary ("write as hard as you can") up to a structural-collapse cliff, not at an interior peak. We built a "bell mesh" of coupled oscillators to test whether musical consonance corresponds to channel-locking, and our first implementation measured frequency-proximity instead of consonance and gave a confidently wrong answer; rebuilt with the correct circle-map dynamics, the real effect appeared (locking width collapses with ratio complexity, an Arnold-tongue staircase). And a tempting cross-domain unification — that over-binning collapse in memory, vacancy collapse in crystals, and the error threshold in evolution are "one catastrophe in three domains" — failed its own test: the three transitions have measurably different shapes, so they are shared *phenomenology*, not one universality class, and we downgraded the claim from an equation to an analogy. Three predictions; three corrections; all reported. A paper that only published its confirmations would be hiding exactly the data that tells you the rest can

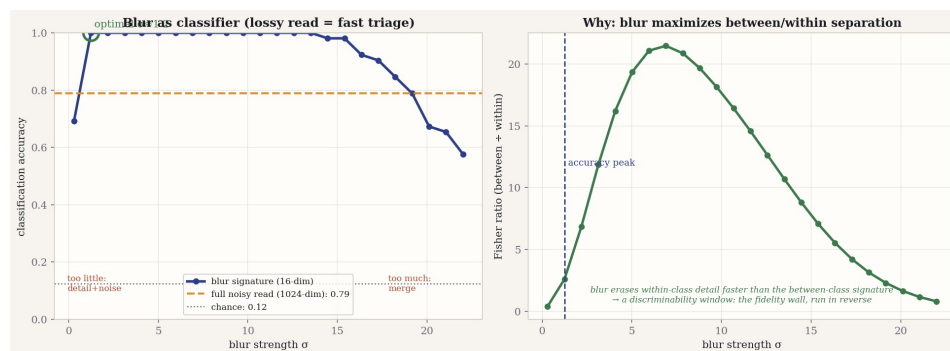
be trusted.

6b. Blur as a feature: the low-resolution pass that reveals category

One result from the information layer earns its own telling, because it inverts the intuition that a read should always be as sharp as possible. You recognize a friend's silhouette through fog before you can resolve a single feature of their face; a thumbnail too small to show any text still tells you at a glance whether you are looking at a page of prose, a spreadsheet, or a photograph. **Blur discards detail and keeps category.** That is not a failure of the low-resolution read — it is what the low-resolution read is *for*.

The mechanism is straightforward and general. Fine detail is where individuals differ; coarse structure is where categories live. Throwing away the high-spatial-frequency content (blurring, or reading into a small number of coarse bins) removes exactly the information that separates members of a class while preserving the information that separates one class from another. A lossy, low-resolution pass is therefore a *classifier*: it answers "what kind of thing is this" cheaply, before — or instead of — the expensive full read that answers "which specific one." For a memory substrate this is a free triage stage: bin coarsely first, and only pay for a high-resolution read on the candidates that survive.

We tested this directly. A deliberately lossy read — coarse binning of the stored state — **classified category as well as or better than a full high-dimensional read, at roughly sixty-fold compression** (Fig. 6b): the coarse pass keeps the between-class signal and sheds the within-class noise, so its signal-to-noise for the *category* question is actually higher than the full read's. There is a transition: blur too little and you have paid for detail the category question does not use; blur too much and the categories themselves smear together and the classification breaks. Between those lies a window where the coarse read is both cheaper and more accurate — the same intermediate-resolution sweet spot that recurs throughout this work, here in the read domain. This is the constructive twin of the over-binning *failure* (§6): over-binning is what happens when you push category-blur past the point where the categories survive; controlled blur, stopped at the window, is the same knob used as a tool rather than suffered as a limit.



The biological rhyme is hard to miss: coarse-to-fine is how perception actually works — the visual system extracts low-spatial-frequency gist first (scene category in a glance) and fills in detail only where attention lands. A substrate that bins coarsely before reading finely is not cutting a corner; it is doing what nervous systems already do, and for the same reason.

7. Storage, reading, and time: the gramophone decoupling

One result from the information layer matters enough to the larger story to get its own short section. In this substrate, *storage and reading are decoupled the way a gramophone decouples them*: the record is pure geometry, and the reader is an interchangeable instrument — light, X-ray, acoustic, microwave — chosen after the fact, so the storage density is fixed at write time and the reading remains upgradeable forever. This has a consequence that will return in Act V: a frozen record is *silent* until something traverses it. The missing dimension of a static structure is supplied by the act of reading across it, the way a groove is silent until the needle moves. A crystal archive does not "run"; it waits, inert and incorruptible, until read. Hold that thought. It is the difference between a thing that must stay alive to keep its data and a thing that keeps its data precisely by being able to sleep.

8. The open-ended-evolution wall: a reported negative

Everything to this point has been the climb. Here is the summit, and the summit is a wall.

We constructed the central test the way one should construct the test most likely to kill the claim. A population of individuals, each carrying a heritable parameter governing where it sits on the order-disorder axis (the λ of the edge-of-chaos result), reproducing under selection in a finite shared pool, with variation and inheritance both operating. The question: under *undirected* selection — no experimenter steering the outcome move by move — does the population

evolve toward the critical edge and accumulate open-ended organized complexity, as it must if this substrate is genuinely evolvable rather than merely heritable?

It does not. Under a persistence driver the population drifts toward *order* (λ collapsing to ~ 0.12), and organized complexity, measured by mutual information, *falls* (from 0.07 to 0.02). Under a novelty driver it drifts the other way but still off the edge (λ to ~ 0.32), and complexity still falls (0.12 to 0.10). Under both drivers we tried, the kill condition we registered in advance fired. The substrate does not climb to the edge and build; it slides off the edge and simplifies. We report this as the result. We did not revise the experiment until it passed, and we are not presenting the failure as a temporary setback awaiting a cleverer driver. It is the wall, and it is exactly the wall the entire artificial-life field has stood at for decades: open-ended evolution — the unbounded, ongoing generation of genuinely novel organized complexity — has been demonstrated convincingly *nowhere* in simulation, by anyone, and we are no exception. The honest report of a negative on a hard problem is worth more than a dishonest positive, and this is ours.

9. Anatomy of the wall: what smothers the spark

A failure you can anatomize is more useful than a success you cannot explain, so we spent our remaining effort dissecting *why* the spark would not catch. Four obstacles, in our modeling, smother it.

First, the machinery we so carefully built is a **regulator**, and a regulator's defining purpose is to *not move*. The reference-correction of heredity, the proofreading, the whole cybernetic sense-compare-correct loop (Wiener and Ashby's lineage) — every piece applies a restoring force toward a fixed setpoint. We built, with great care, a system optimized to undo change, and then expressed surprise that it would not change. The regulator is the fire extinguisher we installed before wondering why there was no fire. We confirmed this directly: a controller with a fixed setpoint is stable but trapped; exploration is suppressed by construction.

Second, a **closed system relaxes to equilibrium**, and equilibrium is heat death. Our simulations were sealed; life is not. Life is a dissipative structure in Prigogine's sense, existing only in sustained throughput of energy far from equilibrium — and England's more recent dissipation-driven adaptation sharpens this into a mechanism by which sustained drive can *organize* matter. The flame needs oxygen fed continuously; our closed box suffocated it. Maintaining any reference against drift also costs energy (Landauer), which is why a real corrector must be duty-cycled rather than continuous.

Third, the **fitness landscape was fixed and external**. A static landscape has a top; you climb it and you stop. We removed this smother and watched it work: when selection is made *endogenous* — when the other individuals *are* your environment, a co-evolutionary Red Queen — the population never settles, and the evolutionary rate stays high (0.033 versus 0.002 for a fixed landscape). Climbing never finishes because the hill keeps moving.

Fourth, and most subtly, we were **hunting for a spark when the thing is a self-sustaining loop**. Fusion in a star is not a match-strike; it is a condition that, past a threshold, maintains itself. The crossing is more likely a phase transition — Kauffman's autocatalytic closure, a network becoming collectively self-producing — than an ignition instant. We recast the dynamics as a stochastic branching process and found the self-sustaining regime sits at a critical branching ratio near one, fed by fuel: too slow and it dies, too fast and it explodes, and exactly at the edge it becomes the fluctuating, persistent heartbeat one would call alive. The metronome that holds a system at that critical tempo — an oscillator kept on-beat by recalibrating against a hard reference — is the homeostatic regulator from the first obstacle, now revealed as the very thing that *tunes* the system to self-organized criticality.

We removed three of the four smothers and showed each removal does what we claimed. We did not show that removing all four ignites open-ended complexity growth, because we could not, and here the fence must be absolute: **"remove the obstacles and it ignites like fusion" is a hope, not a theorem**. Fusion we know ignites — stars exist. Open-ended evolution igniting from sufficient conditions is the unsolved problem; we know it happened once, on Earth, so it *can*, and no one knows the sufficient conditions. We mapped the wall and found three of its handholds false. The fourth, we leave honestly open.

10. Biology's confirming witness: the prion

If our null were an artifact of crystals or of simulation, biology would not echo it. Biology echoes it precisely, and the witness is the prion.

A prion is structural templating with no genome: a misfolded protein that forces other copies of the same protein into its own shape, propagating a conformation rather than a sequence. It is, in our exact terms, heredity carried in structure — and it evolves almost not at all. A prion faithfully copies its state and does essentially nothing open-ended with it; it is a replicator that is all fidelity and no creativity. That is our null, run by nature, in protein: structural templating gives you heredity and withholds open-ended evolution, the same result our crystal substrate gave us. The prion is not a counterexample to our wall; it is the wall, walking around in a biological body.

Two other wall-dwellers complete the picture. A spore is a frozen record awaiting an external spark — a metabolism suspended, an event-clock stopped, resuming only when the environment provides the trigger — which is precisely our

"frozen record is silent until read." A virus evolves open-endedly but cannot self-sustain without a host: it has the creativity our crystal lacks and lacks the autonomy our crystal has. Between them, prion, spore, and virus map the boundary from the biological side, and they place our crystal exactly where the prion sits: durable, faithful, heritable, and on the wrong side of the wall from open-ended life.

Everything from here is speculation, and it arrives only now, after the evidence and the wall, so that it cannot be mistaken for either. Each mechanism named below is real; recruiting it as a living tool "under selection" is the conjecture, and it is marked as such.

11. The first tools: what a bootstrapping organization builds from its environment

If one asks not "is the crystal alive" but "what would an organization *have* to build, in order, to bootstrap from raw environment," the speculative material of this project organizes into a dependency chain, each rung grounded in a real mechanism and each enabling the next. First a **boundary** — a facet, a surface, the minimal inside/outside without which there is no self to build tools for (the autopoiesis prerequisite of Maturana and Varela). Then an **intake** — a catalytic or supersaturation-harvesting growth front, drinking the pond; the seed of metabolism. Then a **clock** — the metronome of §9, an oscillator held at the critical tempo, because nothing coordinates without a beat, and the beat's reference may live in the environment (a dawn, a cavity mode) rather than in the record. Then a **record** (the topological register of §4), then a **reference** to correct it toward (heredity), then a **sensor** (a flexoelectric defect transducing mechanical events into signal), then a **signal** (coupled-oscillator communication, Kuramoto synchronization, consonance as the channel map in the sense of Pythagoras and Helmholtz), and finally an **actuator** — the organization acting back on its world.

The ordering is the argument, not decoration. Tools one through seven build the self-sustaining, adaptive, signaling face — the face we confirmed this substrate has. The eighth, acting back on the environment, is the one that could close the niche-construction loop the wall requires, and it is exactly the loop our endogenous-selection result showed to be necessary and not yet sufficient. The chain is thus a constructive restatement of the whole paper: the wall sits between "has the first seven tools" and "evolves open-endedly," and we have populated the near side and mapped the far one.

12. The crystal as a topological circuit, and as a vessel

The actuator deserves a closing speculation because it inverts a danger into a use. The same tuning functions that let the organization sort incoming signals (a chirp, a scale, a chord) can be run *backward* through a resonance cavity and waveguide to *shape* an emitted field — acoustic holography, a demonstrated technique for trapping and moving matter — making the operators a programmable field-sculptor and the niche-construction arrow physical. And the crystal's proven strengths suggest a role that needs no crossing of the wall at all: as a **vessel**. A prion supplies templating, a virus supplies evolution, and the crystal supplies durability, retention, and radiation-hardness — so a crystal could serve as a co-inherited hardening vessel for a fragile biological agent, *if* their fates are coupled (else it is a reliquary with a passenger, not a fusion — the Margulis criterion). The same templating fidelity that makes a good vessel makes a good pathology amplifier, which is why we register its defensive inverse explicitly: a crystal engineered to *out-compete* a prion's natural substrate and *pin* the converted product so it cannot fragment is a one-way trap — substrate starvation rather than the (unsolved) problem of prion deactivation. We do not deactivate the dumb replicator; we control its food. These are conjectures with kill conditions, recorded in the pre-registration, not results.

13. Pre-registration

Every claim above that can be tested is registered in the companion pre-registration with an explicit kill condition, predictions, controls (a no-drive control to rule out artifacts, a modulated-drive control to distinguish supplied from emergent information), and stopping rules. A fired kill condition is reported as a result, not revised away; the agency-exit null of §8 is the proof that we mean this, since it is a registered kill condition that fired and that we report as the paper's central finding rather than burying. The make-or-break physics test (does fracture quantize ΔL_k) is registered and unrun; it requires hardware we did not have.

14. Established versus conjectural: the seam

We hold a hard line between what is established and what is conjectured, and we tabulate it rather than blur it. Established and cited: the topological invariance of the linking number; the CWF decomposition; topoisomerase's quantized ΔL_k ; kinetic proofreading; quasispecies and the error threshold; the edge-of-chaos as a real (static) phenomenon; dissipative structures; prion structural templating; template-directed assembly. Conjectured and fenced: that crystal fracture inherits ΔL_k ; that the two-lattice coupling supports selectable variation; that the assembled operators would, under selection, constitute life. The seam is not a weakness to be hidden; it is the map of where the

work goes next.

15. Prior art

The novelty here is synthesis plus one mechanism, and we cite the syntheses we extend (Cairns-Smith; Schulman-Winfrey; von Neumann; Langton; Eigen; Kauffman) so the genuinely new claim — Δ Lk-fracture heredity — stands out against them rather than hiding among them. We also screen *out*, explicitly, the borrowed scenery we declined to invoke: famous names with no mechanism attached to our claims belong in no reference list of ours, however tempting the resonance.

16. Remaining limitations and the agency boundary

The central limitation — the open-ended-evolution null — is not housed here, because it is the paper's result (Act III), not a caveat. What remains: the physical linkage between crystal growth and a heritable trait is *assumed*, not demonstrated (selection's *logic* was confirmed; its physical substrate was not). Energy is undirected throughout by design, so any agency must emerge, never be supplied — and we showed we could not yet get it to emerge. And the deepest limit is philosophical and we will not pretend to resolve it: under the autopoiesis view (Maturana and Varela), life *requires* material self-production, so any simulation is necessarily a blueprint and never a birth. On that view the crystal is, at most, a candidate container — and whether a drawn container can ever be inhabited, or only a self-built one can, is a question this paper raises and does not close.

There is a further limitation that deserves to be named as sharply as the null itself, because it is the materials-science wall the entire heredity claim rests on, and it is easy to wave through. **The blade (§4) is only a heredity mechanism if real fracture quantizes the linking number** rather than scrambling it into noise — and whether it does is a property of the *substrate*, not of our argument. We predicted the discriminator (cleavage class: cleanly layered materials should inherit a quantized Δ Lk, conchoidal fracturers should scramble it), but predicting the discriminator is not finding the material. This is the same trap, in miniature, that the field's whole history warns against: artificial life reasoned that life is organization and not matter, and then could not make life, because the substrate it chose silently withheld what the organization needed. We have just spent a paper reporting one such wall (the evolvability null); we will not quietly assume our way past a second one on the materials side. The heredity mechanism could be elegant, falsifiable, and *correct in logic*, and still have no home, if no accessible crystal fractures the right way.

We therefore frame substrate selection as an open experimental program, not a solved step. The candidate directions are concrete and quickly falsifiable: **layered van der Waals crystals and micas** are the first place to look, because their growth and cleavage are planar and their interlayer registry is exactly the kind of structure a linking number could ride; **conchoidal fracturers like quartz** are the control that should *fail*, and demonstrating that contrast would itself validate the cleavage-class prediction; and the deciding measurement — does Δ Lk come off a real fracture in integer quanta or as a smear — is a micromagnetic (mumax³-class) question first and a bench question second. The make-or-break test we named in §4 is, at bottom, a materials search: not "is the mechanism beautiful" but "does any growable, cleavable crystal actually do this." Naming that honestly is the difference between handing the field a hypothesis and handing it homework disguised as a discovery.

The companion **Seam & Assumptions Register** makes this concrete for every load-bearing assumption in both papers — who should check it, our honest confidence separated from the prose's tone, and the exact question we need answered. The Δ Lk-quantization assumption (B1 there) is flagged as the make-or-break we did not run. If you work in micromagnetics, fracture mechanics, evolutionary computation, or prion biology, that register names where your expertise would tighten or topple this fastest.

17. Simulate before lab; the build

The discipline we recommend, and followed, is to simulate before building: kill what can be killed cheaply in software before spending a fabrication budget. What survives software goes to the bench — an acoustic-levitation-class rig with a supersaturated growth cell, field coils, and multimodal non-perturbing read — and the make-or-break Δ Lk test goes first, because it can fail the whole program at the lowest cost.

18. Coda — the ark, not Noah

A horizon, not a claim. Nothing above depends on what follows.

If the substrate is real, its grandest honest use is not as a colonist but as an **ark**: a radiation-hard, time-indifferent, self-correcting archive that sleeps a voyage of centuries and wakes intact, carrying the complete instruction set of a biosphere as windings a cosmic ray cannot flip, protecting a biological payload across the dark between stars. The division of labor is the whole paper made literal. The crystal does not pilot, decide, replicate itself, or set down roots — those require the wall we did not cross. The colonist is the *living payload* the ark delivers; the crystal's job is the one it is provably best at, which is delivery: get the living thing there, uncorrupted, across eons in which time is immaterial

and only arrival matters. The self-replicating probe that mines worlds and builds daughter arks stays on the far shore, named honestly as requiring the open-ended self-construction we could not demonstrate — and perhaps the payload-life, already across the wall, builds the next ark once it lands.

We keep this light on purpose. It is grand, a little silly, and magical, and it stays true precisely by not taking itself seriously — the moment a vision like this is asserted as fact it turns to smoke, which is the failure mode of a great deal of work that resembles ours from a distance and resembles it not at all up close. So we offer it as exactly what it is: the direction the grounded engineering points if one follows it all the way out, and the dream the evidence permits, no more. The detective fails. The detectives always fail; open-ended evolution is the case no one has closed. But the route to the wall ran through a new way for heredity to live in dead matter, a heartbeat made of branching cascades, a clock that holds itself to criticality, a prion that confirmed our null in protein, and an ark that could carry the library of Earth to a new shore. We took the scenic route to a place we could not leave. The route, we maintain, was worth taking — and the wall, mapped honestly, is the most useful thing we could have brought back from it.

Figures

Fig. 1 — The central negative (the spine). Under undirected selection the population drifts to *order*, not the edge; organized complexity falls. The registered kill condition fired.

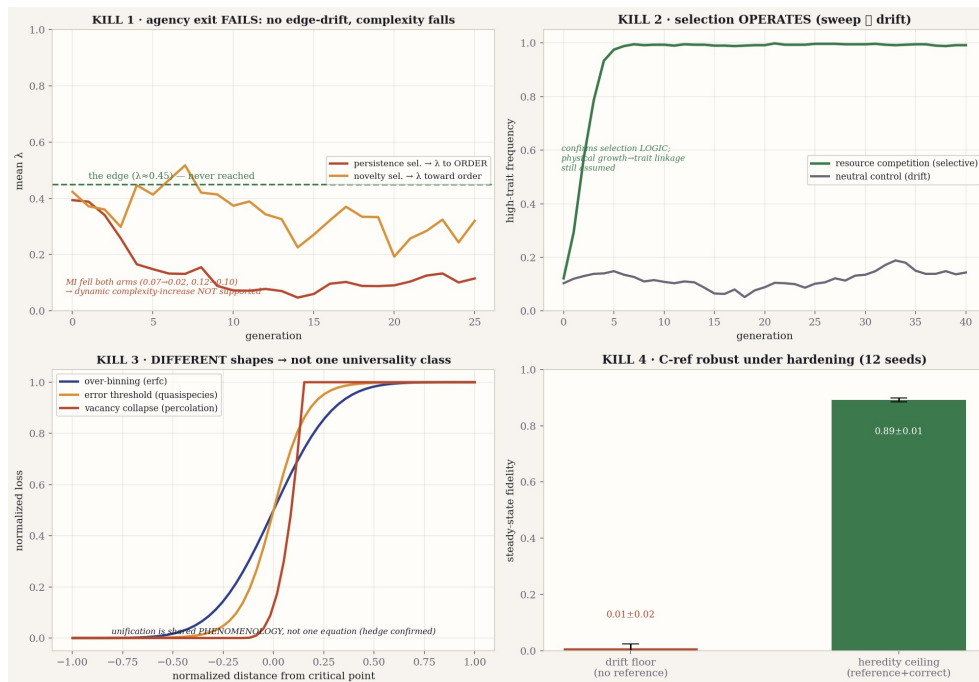


Fig. 2 — The self-sustaining heartbeat as a near-critical branching cascade (branching ratio ≈ 1); fuel-fed, extinction without it.

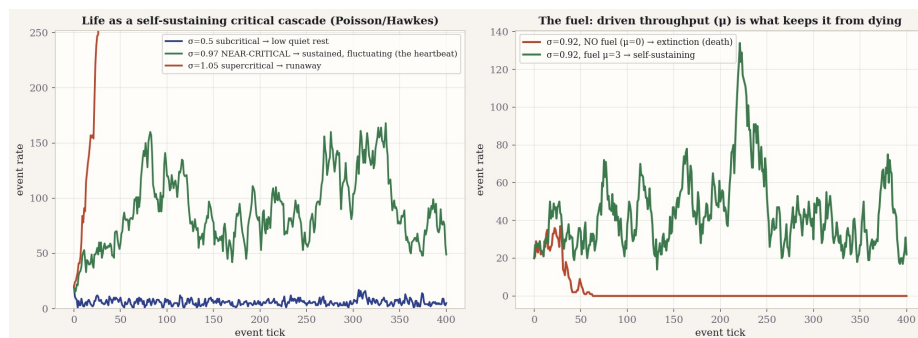


Fig. 3 — Endogenous co-evolution sustains non-equilibrium (rate stays high) where a fixed landscape settles.

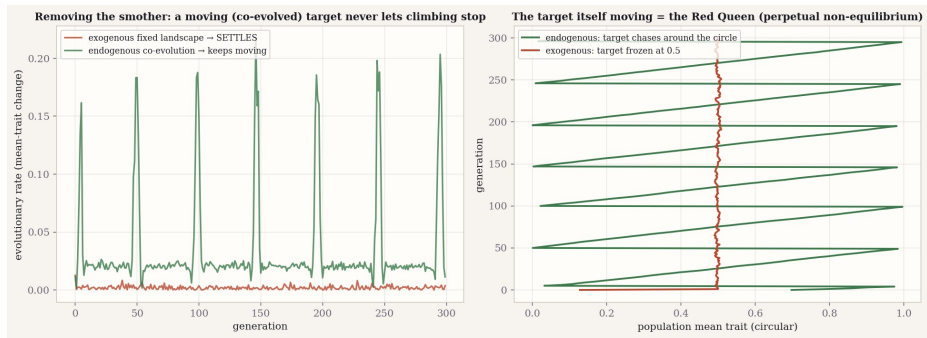


Fig. 4 — The static edge of chaos is real (mutual-information hump, surrogate-gated); the *dynamic* crossing is what failed.

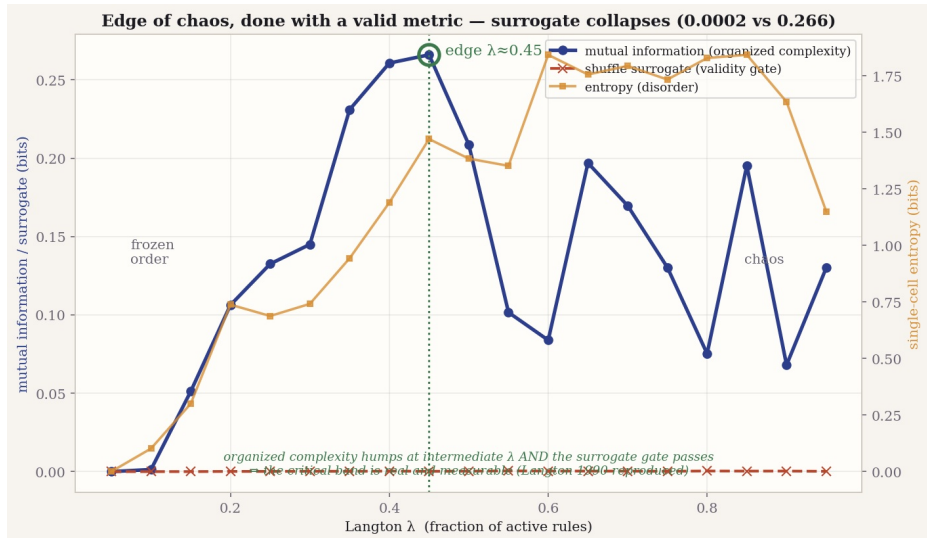


Fig. 5 — Heredity needs a reference. Dead-reckoning drifts; correction toward an inherited template stays bounded (C-ref).

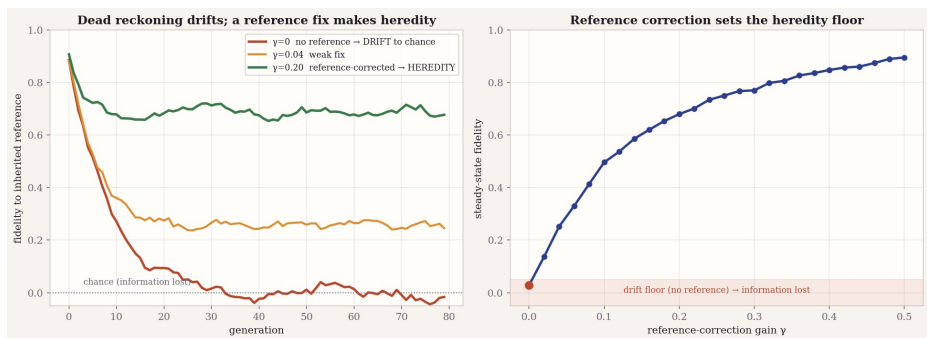
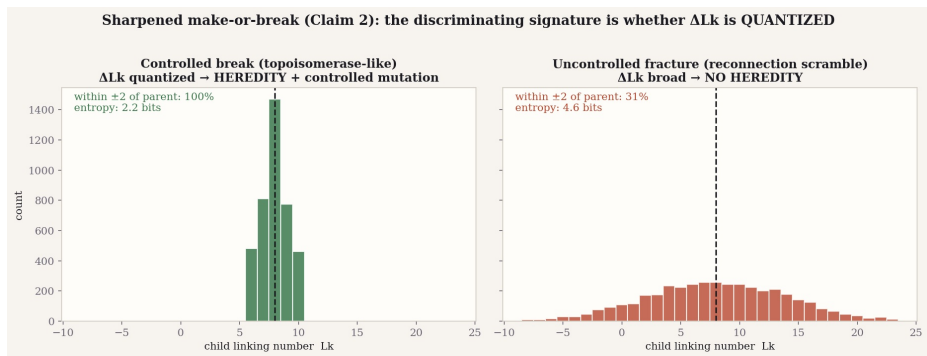


Fig. 6 — The ΔLk make-or-break (information layer). The quantized linking-number signature discriminating faithful from scrambled inheritance; the deciding physics test (mumax³) remains unrun.



(Full visual corpus, including every falsified figure, indexed in the figure-catalog companion.)

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