

Turtles, All the Way Up

A Substrate-Independent Framework for Minimal Life: One Fidelity Dial Across Memory, Navigation, Motion, Encoding, and Signaling

Working Draft v1 · Framework / Perspective · Preprint, not peer-reviewed · 2026

Matthew “Bear” Schulz

Independent Researcher

ORCID: 0009-0000-0956-5743

Contact: mattschulz97@protonmail.com

License: Creative Commons Attribution 4.0 International (CC BY 4.0)

Companion to “Turtles, or Crystals” (Schulz, 2026), Zenodo DOI 10.5281/zenodo.20484438. That paper examined one substrate in depth; this one proposes the framework of which it is an instance.

This synthesis deliberately brackets any numerological or cosmological framing and rests only on established literature in artificial life, evolutionary theory, information and coding theory, neuroscience, and condensed-matter physics.

Abstract

A companion paper proposed that a single topologically protected crystal defect could serve as memory, morphogen, and transducer at once. Here we ask the wider question that work implies: if life is an organization rather than a material, does the same organization recur across unlike substrates? We present a framework in which a minimal living system is described as a body — a pose moving through spacetime — carrying a code that advances a counter only when it copies, navigating by an accumulator, and bootstrapping shared signals by reinforcement, with every layer governed by one quantity: the fidelity of copying, bounded below by the need for variation and above by the error threshold. We lay out six layers (substrate, memory, navigation, motion, encoding, signaling) as a single connected picture, and we are explicit that the picture is a lens, not a result. Credibility rests instead on a small testable core, pulled out and stated with the experiments that would refute it. Foremost is a deliberately bold encoding claim: the gross architecture of the genetic code — a small, signed, redundant, framed alphabet — is derivable from copying-fidelity constraints alone, predictable from coding theory before one looks at a cell, and testable in simulation. We state it strongly on purpose, credit the error-minimization results it converges with, and invite the experiment that would refute it. We mark every seam between framework and claim, and invite the work that would break it.

1. Introduction: from one part to one pattern

A companion paper [3] asked whether a single crystal defect could carry several functions of a minimal organism at once, and fenced the speculation carefully. That question has a natural sequel. If, following the founding premise of artificial life [1] and von Neumann’s treatment of heredity as substrate-independent logic [2], life is an organization rather than a material, then the interesting object is not any one substrate but the organization itself — and the test of the idea is whether the same organization reappears in unlike media: a crystal, a fungal mesh, a genome, a hypothetical organism on another world. This paper assembles that organization as a layered framework and, crucially, separates the parts that are a lens from the parts that can be tested now.

2. The framework: one dial, six layers

We describe a minimal living system as six layers stacked on a substrate, with a single quantity running through all of them. The spine is this: a body is a pose moving through spacetime, carrying a code that advances a counter only when it copies; it finds its way by accumulating signed steps, and it coordinates with others by signals whose meaning is earned through use. The single quantity is copying fidelity — too high and there is no variation to select on, so the lineage cannot track a changing world; too low and information dissolves past the error threshold into catastrophe. Every layer below is shaped by where that one dial is set. The framework is presented as an organizing lens; with the exception of the testable core in §4, it is not claimed as a result.

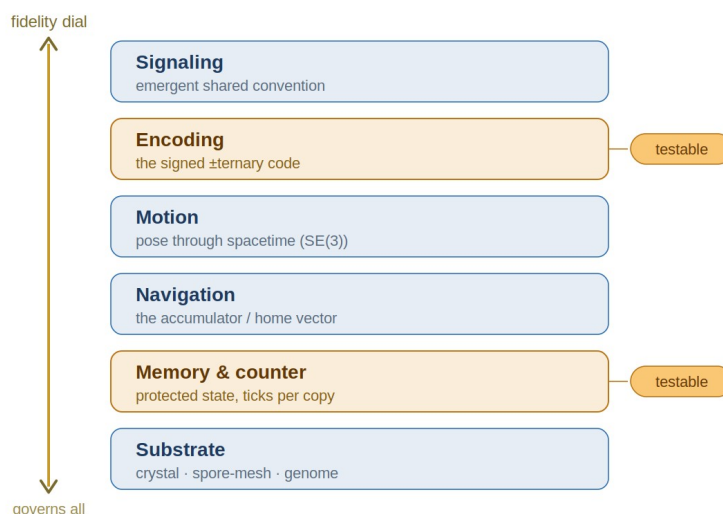


Figure 1. The framework as a stack. Six layers on a substrate, with a single fidelity / error-threshold dial running through all of them. Two layers (encoding, memory-and-counter) carry claims testable now (§4); the rest are presented as framework.

3. The layers

Each layer is sketched briefly, tagged as framework (an organizing analogy) unless promoted to the testable core in §4. The point is the recurrence: each layer names a function that any minimal organism needs, in terms that do not depend on carbon.

3.1 Substrate — framework

The medium that copies: a crystal lattice, a fungal mycelium, a genome. What matters is not the material but that it supports a heritable, distinguishable state. The companion paper [3] develops the crystalline case; mycelium supplies a living network case; the genome supplies the proven case.

3.2 Memory and the counter — testable core (see §4)

State that persists and a counter that advances per copy. In biology this is the molecular clock: mutations accumulate at a roughly steady rate per replication, so genetic differences count elapsed generations — a counter that ticks only during copying and pauses otherwise (a dormant spore or a virus outside a host has a frozen counter).

Persistence requires fidelity; the companion paper argues topological protection supplies it [3].

3.3 Navigation — framework

Returning home without storing the whole path. Path integration keeps a running signed sum of movement — a home vector — in insects maintained by a ring-attractor circuit that holds a heading even with no new input [8]. This is the integrator-and-memory stage of an inertial system, not a sensor: it remembers the orientation that rotation produced. The accumulator here is, structurally, the counter of §3.2 in spatial dress.

3.4 Motion — framework

An oriented body turning and moving is a pose — position plus attitude — living in the group of rigid-body motions, its orientation cleanly tracked by quaternions. Motion alone can read as alive: simple shapes moving the right way trigger irresistible perception of intent [10]; self-propelled bodies that organize collectively are the domain of active matter [9]. Both are real; neither, alone, is life.

3.5 Encoding — testable core (see §4)

How the heritable state is written. The argument, developed in §4 and Figure 2, is that the binding constraint is not density but distinguishability and error-tolerance, which favors a small, signed, redundant, fixed-length code. The proposed primitive is presence-based and signed: two letters, each in two polarities, give four states; there is no zero in the data (counting starts at one, as counting historically did), and the only zero is silence — the rest between symbols — which serves as the unwritten operator and boundary. Because a signed value also names a direction of change, a symbol is simultaneously data and operator: it increments or decrements the counter of §3.2. The encoding layer and the navigation layer are thus the same machine.

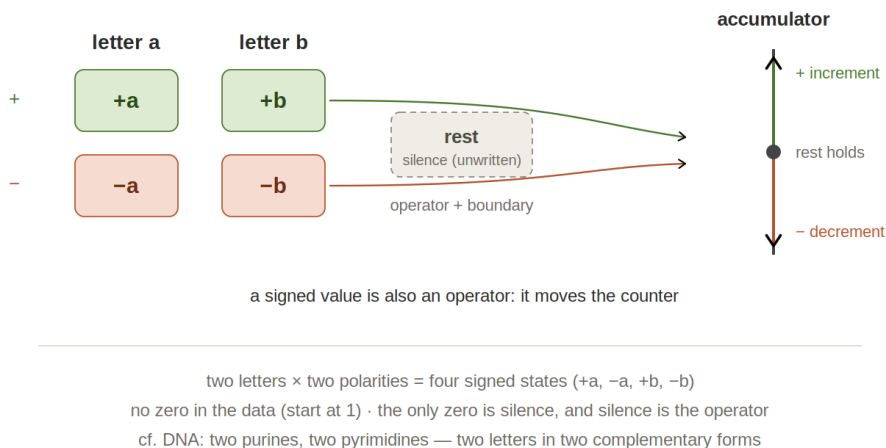


Figure 2. The signed encoding. Two letters in two polarities give four signed states; the rest (silence) is the unwritten operator and boundary. Because the sign names a direction of change, each symbol also acts on an accumulator — plus increments, minus decrements, rest holds. Two letters in two complementary forms is the structure of the genetic alphabet (two purines, two pyrimidines).

3.6 Signaling — framework

Two systems with no shared dictionary can still evolve one: in signaling games, meaning emerges by reinforcement when sender and receiver share an interest in the receiver being informed [6]. Among allies this yields honest, stable convention; across conflicting interests (predator and prey) it becomes an arms race, where the only honest signals are ones too costly to fake [11] and deception (mimicry) invades wherever cost can be cheated. The same fidelity dial appears once more: a signal system too rigid cannot track a changing adversary, one too noisy means nothing; conflict is part of what keeps it in the evolvable middle.

4. The testable core

The framework earns engagement only where it can be refuted. Three claims are stated now, each as prediction, experiment, and falsification. The individual ingredients are established; the bridges are, as far as we know, novel as claims and should be treated as hypotheses pending the tests below and a literature check. Not everything in this paper is a hill to die on — most of it is framework — but a paper that risks nothing teaches nothing, so we plant a flag on the one claim we are most willing to be wrong about, and we ask for the experiment that settles it rather than for agreement.

Claim 1 — The genetic code's architecture is derivable, not accidental (primary)

The flag. Reasoning from copying-fidelity constraints alone — distinguishability against noise, error-tolerance, signed increments for direction, and no zero in the data — leads to a small, signed, redundant, fixed-length code: a few well-separated states (on the order of four), in two complementary polarities, with silence as the boundary. That is the gross architecture of the genetic code: two purines and two pyrimidines, redundant codons, start/stop punctuation. We claim this structure is predictable from coding theory before one ever looks at a cell — the code is a near-optimal solution to an error problem, not a frozen accident.

Lineage (so no one need ask). We are not the first to find the code error-optimal: Freeland and Hurst showed it is “one in a million” for minimizing the impact of mutation and mistranslation [5], and a substantial literature treats the code as selected for robustness. Our contribution is an independent derivation from first principles that converges on the same answer and adds a specific, simulatable structural prediction (signed, ~four-state, redundant, framed).

Experiment. Evolve codes under tunable channel noise with an explicit fidelity-variation tradeoff; measure emergent alphabet size, redundancy, polarity structure, and framing against binary, dense multi-level, and zero-bearing alternatives.

Falsification. If error-tolerance selection robustly favors dense or token-minimized codes, or shows no preference for the signed / redundant / fixed-length structure across realistic noise, the claim is wrong. We would rather be usefully wrong here than safely vague.

Claim 2 — An error threshold for non-biological replicators

Prediction. Any heritable-defect replicator (e.g. the crystalline one of [3]) possesses an Eigen error threshold [4] set by its copying fidelity; below a critical fidelity, heritable information collapses. Topological protection raises fidelity across that threshold.

Experiment. Tune copying-error rate in a programmable crystal replicator (e.g. DNA-tile assemblies) and locate the catastrophe transition; compare protected versus unprotected encodings.

Falsification. No threshold transition, or protection failing to shift it, refutes the bridge.

Claim 3 — Substrate-independent recurrence

Prediction. The same organization — a signed accumulator/counter, an error threshold, a self-healing redundant network, and a small signed code — recurs across crystal, fungal-mesh, and genomic substrates, despite no shared chemistry.

Experiment. A comparative analysis measuring these four features in each substrate (defect/clock fidelity; threshold behavior; network redundancy and rerouting; alphabet structure), testing whether the quantitative signatures align.

Falsification. If the substrates show no common quantitative structure beyond loose analogy, the recurrence claim — the heart of the framework — fails.

5. Open seams

- **Framework versus result.** §2-§3 are an organizing lens; only §4 is testable now. The recurrence claim is the framework's heart and also its least-tested part.
- **It presumes agents.** Every layer — navigation, signaling, motion — describes what a living, interested system does; none manufactures the life or the agency. "Looks alive" (animacy, active matter) is not "is alive" (heredity under selection).
- **The encoding rhymes with biology; that is suggestive, not proof.** Convergence with the genetic code's structure is evidence the design would work, not that it is optimal or unique. Why the genetic code is error-optimal is itself debated (selection, frozen accident, neutral origin).
- **One dial is a simplification.** Treating fidelity as the single governing quantity is a deliberate reduction; real systems answer to several coupled constraints.

6. Conclusion: an invitation

The companion paper made a deep cut on one substrate; this one names the pattern that cut is an instance of, and stakes its credibility on a single sharp, runnable claim: that the architecture of the genetic code is derivable from coding theory, not a frozen accident. We make that claim strongly and stand ready to be wrong about it — the simulation that tests it is cheap, and we would rather hand the field a falsifiable bet than a safe generality. Either way the picture is offered as a lens to argue with, released freely (CC BY 4.0) so that anyone — in artificial life, origins-of-life, coding theory, or condensed-

matter physics — can take a layer and try to break it. The two papers are meant to reference and correct each other as the work continues.

References

- [1] Langton, C. G. (Ed.) (1989). *Artificial Life*. Addison-Wesley (Santa Fe Institute Studies).
- [2] von Neumann, J. (1966). *Theory of Self-Reproducing Automata* (A. W. Burks, Ed.). University of Illinois Press.
- [3] Schulz, M. (2026). *Turtles, or Crystals: A Speculative Synthesis on Substrate-Independent Life and the Topological Defect as Memory, Morphogen, and Transducer*. Zenodo. DOI 10.5281/zenodo.20484438.
- [4] Eigen, M. (1971). Self-organization of matter and the evolution of biological macromolecules. *Naturwissenschaften* 58, 465–523. (Quasispecies; error threshold.)
- [5] Freeland, S. J., & Hurst, L. D. (1998). The genetic code is one in a million. *Journal of Molecular Evolution* 47(3), 238–248.
- [6] Skyrms, B. (2010). *Signals: Evolution, Learning, and Information*. Oxford University Press. (Emergence of meaning by reinforcement.)
- [7] Lewis, D. (1969). *Convention: A Philosophical Study*. Harvard University Press.
- [8] Heinze, S., Narendra, A., & Cheung, A. (2018). Principles of insect path integration. *Current Biology* 28(17), R1043–R1058. (Ring attractor; home vector.)
- [9] Marchetti, M. C., et al. (2013). Hydrodynamics of soft active matter. *Reviews of Modern Physics* 85, 1143–1189.
- [10] Heider, F., & Simmel, M. (1944). An experimental study of apparent behavior. *American Journal of Psychology* 57, 243–259. (Animacy perception.)
- [11] Zahavi, A. (1975). Mate selection — a selection for a handicap. *Journal of Theoretical Biology* 53(1), 205–214. (Costly signaling.)

Citation note: [3] is the author’s companion deposit; [5] is grounded in sources reviewed for this draft. References [1][2][4][6][7][8][9][10][11] are standard works cited from established literature — verify each against the original (years, volumes, pages) before external circulation.

Referee Report

Self-review: what is framework, what is testable, what would break it

Reviewer stance: skeptical but fair.

Summary judgment

A framework/perspective paper lives or dies on whether it labels its own hierarchy. This one does: the stack is presented as a lens (§2–§3), and credibility is staked on three pulled-out claims (§4), foremost a runnable simulation about code structure. That is the right shape: breadth for reach, one sharp handle for falsifiability. The chief risk is the recurrence claim (Claim 3), which is simultaneously the framework’s heart and its least-constrained part. Recommendation: defensible as a speculative, openly-licensed

framework explicitly paired with its instance paper [3]; the encoding-convergence simulation (Claim 1) should be run next, as it is the cheapest decisive test.

Strongest and weakest

- **Strongest:** Claim 1 (encoding convergence). It is sharp, simulatable without special equipment, and has a real empirical anchor in the error-optimality of the genetic code [5]. Run this first.
- **Weakest:** Claim 3 (recurrence). It carries the framework but risks resting on analogy; it needs quantitative cross-substrate signatures, not resemblances, to count.
- **Honest exposure:** The framework presumes agency at every layer; it organizes what life does, it does not derive life. Kept visible in §5.

For v2

- Run the Claim 1 simulation and report it; that alone would move the paper from perspective toward result.
- Specify the quantitative signatures for Claim 3 so “recurrence” is measurable, not asserted.
- Verify the non-anchor citations; confirm [3] cross-links correctly to the companion deposit.

Change log

v1 — framework established (six layers, one dial); testable core pulled out as three claims with falsification points; companion cross-reference to [3] set; encoding layer specified as the signed presence-code (Figure 2); Claim 1 sharpened into a falsifiable flag — the code’s architecture is derivable — with the error-minimization lineage [5] credited so the boldness reads as a testable bet, not a discovery claim. Open for v2: run Claim 1; operationalize Claim 3; citation verification.

— end of v1 framework draft and referee report —