CONTINUOUS MIND THEORY (TMC) · CHAPTER 11

THE LIFE TABLE

The Triad tested against the definition of life

> **Life can continue while the matter composing its instance is progressively replaced. The problem lies not only in the ingredients of life, but in the causal circuit that reconstructs its continuity.**

WHAT IT IS

The final test of the architecture developed throughout the thesis. This chapter confronts the Inside–Between–Ahead Triad with traditional definitions, artificial life, biohybrid systems, biological controls, abiotic comparators, and boundary cases to assess whether it can serve as an operational hypothesis for demarcating life. The question is not merely whether a system displays properties associated with life, but whether, for a specified instance, scale, and time window, its continuity forms a causal closure.

WHAT QUESTIONS DOES THIS CHAPTER INVESTIGATE?

- What must persist when the matter of life changes?
- What organization performs the work of sustaining its own continuity?
- Can the same yardstick distinguish terrestrial, artificial, and hypothetical cases?
- What counterexample would require the proposed demarcation to be revised?

KEY INSIGHTS

- Substrate neutrality is not physical neutrality. Matter may vary, but the causal work of producing, maintaining, and reconstructing continuity must be physically performed.
- Intelligence is not life. Memory, learning, planning, or cognitive performance do not substitute for the causal and temporal closure of Inside, Between, and Ahead.

PURPOSE / CONNECTIONS

- Theoretical biology and philosophy of biology — the demarcation of life, organization, autonomy, and closure.

- Origins-of-life research and astrobiology — investigating life without presupposing Earth's particular biochemistry.
- Synthetic biology, artificial life, and biohybrid systems — distinguishing the simulation of functions from the realization of a new living unit.
- Evolutionary biology — continuity across instances, lineages, and scales.
- Chapters 3, 4, 5, and 6 — applies the previously defined yardstick, Inside, Between, and Ahead; it does not redefine them.

PLACE WITHIN THE THESIS

To put the TMC architecture through its final stress test. This is the Triad's proposed yardstick; these are the cases against which it will be tested; and these are the kinds of results that may require its restriction or revision. The chapter does not present the demarcation as universally demonstrated, but as a hypothesis open to controls, counterexamples, and future validation.

SUPPLEMENTARY EXPLORATION · ASTROBIOLOGY

The investigation continues in Experiment X, with twelve hypothetical forms of life and the question: *what if the exotic life were us?* This philosophical exploration neither replaces the chapter's criteria nor demonstrates the existence or consciousness of those forms of life.

PATH THROUGH THE INVESTIGATION

01 **Artificial Life**
Intelligence is not life

02 **Philosophical Life**
What defines the living?

03 **Life and Matter**
The circuit of continuity

04 **Yardstick**
The eight controls

05 **The Life Table**
Cases and boundaries

06 **Scope**
Applications and limits

07 **Astrobiology**
What if the exotic life were us?

01 Artificial Life

Intelligence is not life

WHAT IT IS

Examines computational life, biohybrid systems, and the limits of intelligence as a criterion for life. Artificial origin does not exclude an organization from life; simulating functions, on the other hand, does not demonstrate closure of its own.

QUESTIONS

- When would a machine perform its own constitutive work rather than depend on another system to perform it?
- Why are intelligence, memory, and learning insufficient to demonstrate life?

KEY INSIGHTS

- Autonomy does not require isolation: it requires that continuity be causally attributable to the organization under examination.

- Artificiality and life are not inherently incompatible categories; cognitive performance does not certify life either.

IN THIS BLOCK

11.1.1 Computational life

11.1.2 Biohybrid systems

11.1.3 Intelligence is not life

11.1 — ARTIFICIAL LIFE

11.1.1 — Computational life

The TMC's response to the possibility of artificial life begins with a concession of principle: carbon has no a priori privilege over silicon. Substrate neutrality means not requiring DNA, cells, or terrestrial biochemistry, while requiring the same regime of causal work. Not requiring the same matter, however, does not amount to accepting any informational simulation as life.

Nor can absolute independence be required. No organism possesses it. A bacterium depends on its environment; an animal depends on food, oxygen, and conditions it does not produce. The question is not how much a system receives from outside, but who transforms what comes from outside into the organization that sustains its continuity. **Environmental dependence is not the outsourcing of constitutive work**.

Artificial-life platforms such as Tierra and Avida make this problem explicit: programs can replicate, mutate, and evolve in computational environments without thereby settling the question of who physically sustains the organization that is evolving. Are CPU, memory, energy, and maintenance merely environmental resources, or are they external machinery performing, on behalf of these entities, the constitutive work of continuing?

> ***Autonomy in the TMC is not isolation. It is the causal attribution of one's own continuity.***

If a machine draws energy from the environment, actively sustains the repair of its own body (Inside), responds selectively to the world without dissolving its integrity (Between), and engages its trajectory in generating a new unit capable of inheriting that circuit (Ahead), the TMC would have no grounds, under its own criteria, to deny it the status of a living entity.

11.1.2 — Biohybrid systems

Biohybrid systems make the boundary harder to draw because they combine living tissues with electromechanical components. Experiments such as DishBrain and Brainoware show that neuronal cultures and organoids can be coupled to artificial systems and participate in computational tasks. The presence of living matter, however, does not automatically make the assembly that uses it alive.

If the structure depends not only on externally supplied resources but on another organization to carry out constitutive work the assembly itself does not perform — such as repairing its essential components, reconstructing its material support, or reinstantiating its organization — then causal closure remains externalized.

Biology has been domesticated to serve as a functional component; the assembly remains a hammer, and the continuity of its operation still resides in the human hand wielding it.

The Triad, therefore, does not function as an inventory of properties. Inside sustains and reconstructs the instance; Between transforms internal and external differences into changes in trajectory; Ahead allows differences from that history to participate in forming another instance capable of restarting the cycle. Under the TMC hypothesis, life does not reside in the isolated presence of these directions, but in their causal and temporal articulation.

11.1.3 — Intelligence is not life

Intelligence, memory, learning, adaptation, planning, or sophisticated behavior do not constitute the Triad, either individually or by addition. The Triad is not a list of capabilities but a codependent causal and temporal architecture in which Inside, Between, and Ahead acquire their roles only through the articulation of the whole.

This cohesion is defined in Chapter 3, particularly in 3.4 — Cohesion and 3.4.1 — Codependence; the causal work of Inside, Between, and Ahead is developed in Chapters 4, 5, and 6, respectively.

For this reason, demonstrating intelligence — even when accompanied by memory, learning, adaptation, or planning — is not, by itself, sufficient to demonstrate life under the TMC's demarcation hypothesis.

The consequence also works in the opposite direction: an organization cannot be excluded from life merely because of its artificial origin. If a synthetic organization realizes the Triad under the same yardstick applied to biological systems, the TMC must recognize it according to its own criteria.

> ***Intelligence is not enough for life; artificiality is not enough to exclude it.***

CHAPTER 11 · BLOCK 02

02 Philosophical Life

What defines the living?

WHAT IT IS

Examines the philosophical difficulty of defining life beyond familiar terrestrial examples. It asks whether the appropriate unit of analysis is a collection of properties or a causal organization that sustains its continuity.

QUESTIONS

- Why does recognizing a bacterium and an animal not amount to possessing a universal definition of life?

- What changes when we move beyond a list of properties and examine a causal organization?

KEY INSIGHTS

- Familiarity with terrestrial biology can become an inadvertently particular yardstick.
- The problem may lie in the unit of analysis, not merely in selecting better characteristics.

11.2 — PHILOSOPHICAL LIFE

Almost no one needs a formal definition to recognize a dog as alive and a stone as inanimate. Yet this immediate certainty is the result of an **illusion of proximity**: our intuition works at the comfortable center of the biosphere because we and the dog belong to the same terrestrial evolutionary and biochemical history.

We mistake the practical ease of recognizing our terrestrial relatives for possession of a universal theory of living matter. The problem begins when we move toward the boundaries. Asked what characterizes a living being, common sense turns to a catalogue of signs: being born, growing, feeding, responding to the environment, reproducing, and dying. The list seems solid until it encounters cases that escape its criteria. A mule is alive without reproducing, tardigrades undergo cryptobiosis with extremely reduced metabolism, fire grows and consumes energy without being an organism, and viruses evolve without cellular machinery of their own — **none of these signs, taken alone, is sufficient to define life**.

As Carol Cleland and Christopher Chyba observed, defining life through a conjunction of observable properties faces a problem similar to the one faced by chemistry before an adequate molecular theory: water, for example, could be described by its sensory properties, but identifying its structure as H_2O reframed the problem on theoretical grounds (Cleland & Chyba, 2002; Cleland, 2012). Biology faces an additional problem: empirically, we know only terrestrial life — a single historical sample, an N=1 problem — and we still do not know what criteria would allow us to recognize a radically different organization as living.

The demarcation of life inherits a long historical tension: from natural philosophy and alchemy to modern biology, understanding the mechanisms of living matter

has never been equivalent to explaining why the whole sustains itself as life. Philosophy enters precisely through this opening, preventing science from mistaking a list of reactions and properties for a general theory. Yet it becomes insufficient when it confines itself to abstract disputes without empirical grounding — as in debates over whether viruses, sterile organisms, or other borderline cases do or do not fall under the word "life". **The problem must therefore shift levels**: move beyond what the term names and investigate the physics of the relations — what causal circuit allows an organization to sustain its continuity over time.

The impasse may lie not only in choosing better properties, but in looking for life in the **wrong unit of analysis**: as a collection of characteristics rather than as a causal organization that must keep operating over time.

For the TMC, overcoming this apparent dichotomy between philosophy and science does not require a loose conciliatory compromise, but a change in the very unit of analysis. The theory does not depend on a metaphysical leap, nor does it accept that describing mechanisms in isolation exhausts the problem. Rather than privileging a particular physicochemical biology or invoking vital principles external to explanation, it starts from empirical evidence about living systems to pose a different question: what causal circuit must remain articulated for an organization to produce and reconstruct its own continuity over time?

Life can thus be investigated not as a mysterious substance or as a list of isolated functional properties, but as an empirically grounded relational topology that is neutral with respect to substrate. The Triad replaces the intuitive question "does this look alive?" with an investigation into where, at what scale, and through what physical work the causal relations of Inside, Between, and Ahead remain articulated — or break down — over time.

CHAPTER 11 · BLOCK 03

03 Life and Matter

The circuit of continuity

WHAT IT IS

Examines the relationship between matter and continuity: organisms replace components as they live, yet the presence of those components after death does not necessarily

preserve the living organization.

QUESTIONS

- What disappears when almost all the matter is still there?
- How do Inside, Between, and Ahead articulate matter and the work of continuity?

KEY INSIGHTS

- The ingredients matter physically, but their presence alone does not determine life.
- Under the TMC hypothesis, structure and process participate in the reciprocal reconstruction of the organization.

11.3 — LIFE AND MATTER

The matter of life has no periodic table of its own. The chemical elements of life are the same ones found outside organisms. Here a fundamental physical asymmetry emerges: whereas a rock persists while retaining much of its matter intact, an organism continues to exist only because, along its trajectory, it exchanges and transforms its physical composition while maintaining, clearing, and reconstructing the operative conditions that sustain its organization (Spalding et al., 2005; Sender & Milo, 2021). When this constitutive work ceases irreversibly, the instance no longer continues as living.

The reverse movement makes the problem even clearer. In the first moments after death, almost all the matter that composed the living organism is still there, but the processes that held it together begin to cease, and its organization progressively enters into decomposition (Ferreira et al., 2018). If life can continue while its matter is continuously replaced, and can disappear while its ingredients remain almost intact, it cannot be defined by a mere inventory of its components.

Nor does this observation warrant postulating an extra-physical principle or a hidden vital substance. **The problem shifts from ingredients to relations**: identifying the causal regime that mobilizes ordinary matter to produce, clear, and reconstruct its own organization over time.

A living organization does not merely persist: it mobilizes matter and energy to continuously sustain its own support. But this flow alone does not define life — a flame also consumes fuel and dissipates heat. Under the TMC hypothesis, a decisive difference appears when the work performed participates in reconstructing the very conditions that allow the system to continue operating.

Matter and operation then cease to appear as separate domains: **structure makes the process possible, and the process reconstructs the structure**. Matter ceases to be merely an inert support; in a sense, the process builds the very bed along which it will continue.

The origin of life also comes into focus differently: producing molecules, membranes, or scattered chemical reactions is not enough; what matters is the point at which material processes begin to participate in maintaining and reconstructing the conditions that make the next cycle possible. It is the passage from a transient occurrence to a trajectory capable of continuing.

In the TMC, this material and relational organization is examined through the three directions of the Triad:

- **Inside** — the organization mobilizes matter and energy to produce, maintain, clear, and reconstruct its own support within the same organizational closure.
- **Between** — internal or external differences causally participate in the operation of a historically conditioned organization, potentially modifying its trajectory without dissolving its continuity.
- **Ahead** — differences from that trajectory remain capable of participating in the reconstruction of the organization beyond the present instance, within another organizational closure.

These directions are not three independent properties added together after the fact. The TMC demarcation hypothesis rests on their causal and temporal articulation: life is not a property deposited upon a particular kind of matter, but the organization that articulates the maintenance of the instance, the causal relation with difference, and continuity beyond the present support.

Composition remains physically indispensable, but ceases to be the yardstick for validation: carbon, water, membranes, and DNA perform decisive functions on Earth without constituting a universal definition of the living.

Matter matters; what the TMC seeks is the regime of relations through which it participates in the continuity of the organization.

CHAPTER 11 · BLOCK 04

04 The Yardstick

The eight controls

WHAT IT IS

Presents the four comparative criteria and the eight controls that govern the application of the Triad. It requires the instance, scale, time window, and closure to be specified in advance, preventing retrospective adjustments.

QUESTIONS

- For which instance and time window should the classification be made?
- What distinguishes obtaining resources from outsourcing constitutive work?
- What prevents changing the criterion to rescue a result?

KEY INSIGHTS

- The yardstick does not add up eight characteristics: it audits one trajectory against eight controls.
- The Triad is not a “two out of three” scoring system; it requires causal coherence among its directions.

IN THIS SECTION

11.4.1 Comparative criteria

11.4.2 The eight controls

11.4.3 Maturana and Varela, Mossio and Montévil, Ruiz-Mirazo and Moreno — and the TMC yardstick

11.4 — THE YARDSTICK

11.4.1 — Comparative criteria

To test the hypothesis, the Triad is compared with four criteria commonly found in the literature, in teaching, and in operational definitions of life. Each identifies a relevant aspect, but none should be assumed in advance to constitute the demarcation itself:

- **Metabolism** — the capacity to take in and transform matter and energy to sustain activity.
- **Reproduction** — the capacity to produce offspring and enable continuity across generations, although not every living individual reproduces.
- **Thermodynamics** — the maintenance of organization far from equilibrium through flows of matter and energy.
- **Terrestrial biochemistry** — the presence of components associated with life as known on Earth, such as carbon, water, proteins, DNA, or RNA.

The Triad does not add a fifth property to the inventory. It asks whether Inside, Between, and Ahead constitute codependent directions of the same causal and temporal trajectory.

11.4.2 — The eight controls

Before classifying any case, the yardstick requires the unit of analysis to be declared and held constant throughout the test. The eight controls consolidated in Chapter 3 are:

- **1) Instance** — which organization is actually being tested.
- **2) Scale** — at which organizational level the attribution is being made.

- **3) Time window** — what interval is needed to observe the relevant trajectory.
- **4) Causal/organizational closure** — where the circuit begins and ends, and who performs the constitutive work.
- **5) Resource × operator** — receiving matter, energy, or enabling conditions is not equivalent to outsourcing the work that produces and reconstructs the organization.
- **6) Recurrence** — continuity does not require repetition of the same material component; it requires that necessary relations or conditions can be encountered, recruited, or reconstructed again.
- **7) Triadic coherence** — Inside, Between, and Ahead are not three independent modules or a "2 out of 3" scoring system.
- **8) Post hoc control** — the instance, scale, time window, or criterion cannot be changed after the result in order to rescue the classification.

> *The yardstick does not search for eight properties; it audits a trajectory that must withstand eight controls.*

11.4.3 — Maturana and Varela, Mossio and Montévil, Ruiz-Mirazo and Moreno — and the TMC yardstick

The three traditions examined — the autopoiesis of Maturana and Varela, the closure of constraints of Mossio and Montévil, and basic autonomy with open-ended evolution in Ruiz-Mirazo and Moreno — address many borderline cases rigorously, but do not do so through a single yardstick applied uniformly. Each privileges a different boundary or principle: autopoiesis grounds demarcation in the presently self-producing unit; closure of constraints distinguishes processes, constraints, and organizational levels; and basic autonomy also incorporates the historical dimension of lineage and open-ended evolution.

That does not make these theories inconsistent. It does show, however, that when faced with cases such as sterility, parasitism, symbiosis, viruses, latency, or distributed organizations, their classifications may depend on complementary criteria, extensions of the model, or the choice of different levels of analysis. Autopoiesis, for example, regards closure of the present unit as sufficient; Mossio and Montévil retain individual closure as a foundation while allowing for intergenerational functions and closure; Ruiz-Mirazo and Moreno make individual autonomy and historical-evolutionary capacity parts of an integrated definition of life.

The TMC does not present this diversity as an error, nor does it claim to have discovered self-maintenance, closure, historicity, or lineage. These problems have substantial theoretical antecedents. Its proposed contribution is to subject them to the same causal-temporal architecture and the same analytical protocol.

In each case, the investigation begins with the same question:

> ***what is the instance under test, at what scale and over what time window should it be examined, where does its closure lie, who performs the constitutive work, and how do Inside, Between, and Ahead articulate within that trajectory?***

There is also a difference in epistemic control: instance, scale, time window, and closure must be declared before classification. Once the test has begun, a result cannot be rescued after the fact by changing scale, retrospectively expanding the instance, or adopting a different principle of demarcation.

The difference proposed by the TMC, then, does not lie in gathering previously described properties, but in treating them as codependent directions of a single causal trajectory and requiring distinct cases to be audited by the same yardstick.

The decisive question is not merely whether a theory can provide an answer for each borderline case, but whether it can do so while retaining the same principle of demarcation. The TMC proposes to address precisely this problem: applying one causal-temporal yardstick across different cases without retrospectively changing the instance, scale, time window, or criterion to accommodate the result.

> *A theory of life is not tested by how easily it recognizes its obvious relatives, but by the invariance of its yardstick when faced with what challenges its boundaries.*

> *The following table puts this requirement to the test.*

CHAPTER 11 · BLOCK 05

05 Life Table

Cases and boundaries

WHAT IT IS

Tests criteria for life against known terrestrial controls, adversarial cases, and counterfactual candidates or ambiguous indications. The matrix tests the hypothesis for consistency; it is not independent experimental validation.

QUESTIONS

- Where do metabolism, reproduction, thermodynamics, or terrestrial markers lead to errors in demarcating life?
- When must a result remain conditional or inconclusive?

KEY INSIGHTS

- A negative result does not mean an error: the diagnosis and corresponding reference must be considered.
- Boundary cases may call for a different time window or scale, but not an opportunistic change to the yardstick.

IN THIS SECTION

11.5.1 Methodological note

11.5.2 Boundary cases

11.5 — LIFE TABLE

THE COMPARATIVE MATRIX

Known biological controls test whether the yardstick recognizes central cases of terrestrial life without depending on any one body plan, scale, or organizational strategy. Abiotic comparators and adversarial cases test the converse: whether growth, dissipation, apparent replication, or self-organization can occur without the proposed closure.

TABLE 1 — KNOWN TERRESTRIAL BIOLOGICAL CONTROLS (FULL HOMOGENEITY)

ENTITY / PHENOMENON (SCALE OF ANALYSIS)	1. METABOLISM (INSTANTANEOUS FLUX)	2. INDIVIDUAL REPRODUCTIVE CRITERION (PRODUCTION OF OFFSPRING)	3. THERMODYNAMICS (NONEQUILIBRIUM / ORDER)	4. TERRESTRIAL BIOCHEMISTRY (LOCAL MARKER: CARBON/DNA)	5. TOPOLOGY OF THE TRIAD (INSIDE, AHEAD, BETWEEN)	TOPOLOGICAL DIAGNOSIS OF CLOSURE
1. Human (Complex multicellular animal)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**Complete topological closure:** multicellular organismal integration of internal maintenance, temporal continuity, and environmental regulation.
2. Bacterium / E. coli *(Unicellular prokaryote)*	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**Complete topological closure at the unicellular scale:** cellular maintenance, transmission of organization, and regulation of exchanges with the environment.
3. Plant / Angiosperm (Multicellular autotrophic eukaryote)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**Complete topological closure in a modular organization:** metabolic integration, development, transmission, and environmental regulation.

TABLE 1 — KNOWN TERRESTRIAL BIOLOGICAL CONTROLS (FULL HOMOGENEITY)

ENTITY / PHENOMENON (SCALE OF ANALYSIS)	1. METABOLISM (INSTANTANEOUS FLUX)	2. INDIVIDUAL REPRODUCTIVE CRITERION (PRODUCTION OF OFFSPRING)	3. THERMODYNAMICS (NONEQUILIBRIUM / ORDER)	4. TERRESTRIAL BIOCHEMISTRY (LOCAL MARKER: CARBON/DNA)	TMC 5. TOPOLOGY OF THE TRIAD (INSIDE, AHEAD, BETWEEN)	TOPOLOGICAL DIAGNOSIS OF CLOSURE
4. Fungus / Mycelium (Filamentous heterotrophic eukaryote)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**Complete and distributed topological closure:** maintenance and transmission carried out by a filamentous network without a single organizing center.
5. Amoeba (Highly plastic unicellular eukaryote)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**POSITIVE** (CORRECT)	**Complete topological closure at a plastic unicellular scale:** chemotactic, membrane, and morphodynamic regulation through pseudopodia.

TABLE 2 — TERRESTRIAL BOUNDARY CASES AND ADVERSARIAL TESTS

ENTITY / PHENOMENON (SCALE OF ANALYSIS)	1. METABOLISM (INSTANTANEOUS FLUX)	2. INDIVIDUAL REPRODUCTIVE CRITERION (PRODUCTION OF OFFSPRING)	3. THERMODYNAMICS (NONEQUILIBRIUM / ORDER)	4. TERRESTRIAL BIOCHEMISTRY (LOCAL MARKER: CARBON/DNA)	TMC 5. TOPOLOGY OF THE TRIAD (INSIDE, AHEAD, BETWEEN)	TOPOLOGICAL DIAGNOSIS OF CLOSURE
1. Tardigrade (in Cryptobiosis) *(Organismal scale)*	**NEGATIVE** ERROR (False Negative)	**POSITIVE** EMPIRICALLY CORRECT	**NEGATIVE** ERROR (False Negative)	**POSITIVE** EMPIRICALLY CORRECT	**POSITIVE—LATENT** EMPIRICALLY CORRECT	**Latent Topological Closure:** Metabolic flux suspended; structural constraints and capacity for reactivation preserved within the system itself.
2. Mule (Sterile	**POSITIVE**	**NEGATIVE**	**POSITIVE**	**POSITIVE**	**MULTILEVEL CLOSURE**	**Multilevel Closure:** Inside and Between re-

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Hybrid) *(Organismal scale)*	EMPIRICALLY CORRECT	ERROR (False Negative)	EMPIRICALLY CORRECT	EMPIRICALLY CORRECT	EMPIRICALLY CORRECT	alized at the organismal scale; Ahead received from a transmissible organismal lineage, although this instance is terminal.
3. RNA World Protocell *(Precursor scale / Model)*	**POSITIVE IN THE MODEL** CONDITIONAL RESULT	**POSITIVE IN THE MODEL** CONDITIONAL RESULT	**POSITIVE IN THE MODEL** CONDITIONAL RESULT	**POSITIVE** DOES NOT DISCRIMINATE (Presence of Carbon and RNA)	**CONDITIONALLY POSITIVE** TRIAD PREDICTION	**Conditional Primitive Closure:** The Triad is realized if the compartment maintains energy coupling, reconstruction, and RNA-based inheritance, without requiring DNA.
4. Irreversibly Dead Cell *(Cellular scale)*	**NEGATIVE** EMPIRICALLY CORRECT	**NEGATIVE** EMPIRICALLY CORRECT	**NEGATIVE** EMPIRICALLY CORRECT	**POSITIVE** ERROR (False Positive)	**NEGATIVE** EMPIRICALLY CORRECT	**Circuit Breakdown:** Irreversible loss of gradients and repair; only passive material markers remain.
5. Organismal Corpse *(Organismal scale)*	**PARTIAL** DOES NOT DISCRIMINATE (Cellular/microbial activity)	**NEGATIVE** EMPIRICALLY CORRECT	**PARTIAL** DOES NOT DISCRIMINATE (Residual order and decomposition)	**POSITIVE** ERROR (False Positive if treated as an organism)	**NEGATIVE (Organismal scale)** EMPIRICALLY CORRECT	**Dissociation of Scales:** Residual cellular fluxes and life remain, but organismal integration, maintenance, and regulation have been lost.
6. Isolated DNA / RNA (Test Tube)	**NEGATIVE** EMPIRICALLY CORRECT	**NEGATIVE** EMPIRICALLY CORRECT (Copying requires external molecular machinery, such as PCR)	**NEGATIVE** EMPIRICALLY CORRECT	**POSITIVE** ERROR (False Positive)	**NEGATIVE** EMPIRICALLY CORRECT	**Information Without Autonomous Support:** Passive polymer; no intra-instance Mechanism or Operation.

TABLE 2 — TERRESTRIAL BOUNDARY CASES AND ADVERSARIAL TESTS

ENTITY / PHENOMENON (SCALE OF ANALYSIS)	1. METABOLISM (INSTANTANEOUS FLUX)	2. INDIVIDUAL REPRODUCTIVE CRITERION (PRODUCTION OF OFFSPRING)	3. THERMODYNAMICS (NONEQUILIBRIUM / ORDER)	4. TERRESTRIAL BIOCHEMISTRY (LOCAL MARKER: CARBON/DNA)	5. TOPOLOGY OF THE TRIAD (INSIDE, AHEAD, BETWEEN)	TOPOLOGICAL DIAGNOSIS OF CLOSURE
7. Inorganic Mineral Crystal (e.g., Quartz)	**NEGATIVE** EMPIRICALLY CORRECT	**PARTIAL** DOES NOT DISCRIMINATE (Apparent replication of form)	**PARTIAL** DOES NOT DISCRIMINATE (Minimization of free energy)	**NEGATIVE** EMPIRICALLY CORRECT	**NEGATIVE** EMPIRICALLY CORRECT	**Passive Accretion:** Dynamic growth through incorporation of matter directed by the crystal lattice, without regulated repair or organizational closure.
8. Hurricane (Atmospheric Dissipative Structure)	**NEGATIVE** EMPIRICALLY CORRECT	**NEGATIVE** EMPIRICALLY CORRECT	**POSITIVE** ERROR (False Positive)	**NEGATIVE** EMPIRICALLY CORRECT	**NEGATIVE** EMPIRICALLY CORRECT	**Dissipative Flow Without Reconstruction:** Organization sustained directly by atmospheric gradients, without internally reconstructed constraints, regulated repair, or inheritance.
9. Candle Flame / Fire (Exothermic Reaction)	**PARTIAL** DOES NOT DISCRIMINATE (Fuel consumption)	**PARTIAL** DOES NOT DISCRIMINATE (Propagation by ignition)	**POSITIVE** ERROR (False Positive)	**NEGATIVE** EMPIRICALLY CORRECT	**NEGATIVE** EMPIRICALLY CORRECT	**Chain Reaction Without an Organizational Boundary:** Absence of self-constructed constraint (Cup), internal reconstruction, and lineage.
10. Murchison Meteorite / PAHs (Abiotic Organic Matter)	**NEGATIVE** EMPIRICALLY CORRECT	**NEGATIVE** EMPIRICALLY CORRECT	**NEGATIVE** EMPIRICALLY CORRECT	**PARTIAL** DOES NOT DISCRIMINATE (Organic carbon without nucleic acids)	**NEGATIVE** EMPIRICALLY CORRECT	**Inert Organic Matter:** Abiotic carbon chemistry of considerable complexity, without work channeling or a reconstructive circuit.
11. Running Computer Virus (Replicating Software on	**NEGATIVE** EMPIRICALLY CORRECT	**POSITIVE** ERROR (False Positive)	**POSITIVE / PARTIAL** DOES NOT DISCRIMINATE (Computer dissipation)	**NEGATIVE** EMPIRICALLY CORRECT	**NEGATIVE — LOGICAL REPLICATOR** TRIAD PREDICTION	**Informational Replication Without Topological Closure:** Copies inscriptions and reorganizes

TABLE 2 — TERRESTRIAL BOUNDARY CASES AND ADVERSARIAL TESTS

ENTITY / PHENOMENON (SCALE OF ANALYSIS)	1. METABOLISM (INSTANTANEOUS FLUX)	2. INDIVIDUAL REPRODUCTIVE CRITERION (PRODUCTION OF OFFSPRING)	3. THERMODYNAMICS (NONEQUILIBRIUM / ORDER)	4. TERRESTRIAL BIOCHEMISTRY (LOCAL MARKER: CARBON/DNA)	5. TOPOLOGY OF THE TRIAD (INSIDE, AHEAD, BETWEEN)	TOPOLOGICAL DIAGNOSIS OF CLOSURE
Maintained Hardware)						computational operations, but neither encodes nor reconstructs its material execution apparatus.
12. Extracellular Virion (Metabolically Inert Viral Particle)	**NEGATIVE** DOES NOT DISCRIMINATE THE DIACHRONIC CYCLE	**NEGATIVE** DOES NOT DISCRIMINATE THE DIACHRONIC CYCLE	**NEGATIVE** DOES NOT DISCRIMINATE THE DIACHRONIC CYCLE	**POSITIVE** DOES NOT DISCRIMINATE (Carbon + Nucleic Acids)	**POSITIVE IN THE TRAJECTORY — TRANSMISSIVE PHASE**	**The virion is a low-activity transmissive phase. The instantaneous absence of metabolism or reproduction does not determine the status of the trajectory:** its organization remains capable of participating in the next coupling.
13. Intracellular Viral Cycle (Active Infection in a Cell)	**POSITIVE** DOES NOT DISCRIMINATE CONSTITUTIVE AGENCY	**POSITIVE** DOES NOT DISCRIMINATE CONSTITUTIVE AGENCY	**POSITIVE** DOES NOT DISCRIMINATE CONSTITUTIVE AGENCY	**POSITIVE** DOES NOT DISCRIMINATE CONSTITUTIVE AGENCY	**POSITIVE IN THE TRAJECTORY — ACTIVE AND RECONSTRUCTIVE PHASE**	The virus recruits the host, reconfigures cellular processes, and produces new units. It remains to be audited whether the cellular machinery temporarily becomes part of its reconstructive circuit or remains an external operator.
14. Cancer Cell *(Cellular scale)*	**POSITIVE** EMPIRICALLY CORRECT	**POSITIVE** EMPIRICALLY CORRECT	**POSITIVE** EMPIRICALLY CORRECT	**POSITIVE** EMPIRICALLY CORRECT	**POSITIVE** EMPIRICALLY CORRECT	**Cellular Topological Closure:** A living, metabolically active cellular unit, with internal maintenance and capacity for clonal proliferation.
15. Localized Nontransmissi	**POSITIVE**	**PARTIAL**	**POSITIVE**	**POSITIVE**	**NEGATIVE (Organismal scale)**	**Somatic Subsystem Without Its**

TABLE 2 — TERRESTRIAL BOUNDARY CASES AND ADVERSARIAL TESTS

ENTITY / PHENOMENON (SCALE OF ANALYSIS)	1. METABOLISM (INSTANTANEOUS FLUX)	2. INDIVIDUAL REPRODUCTIVE CRITERION (PRODUCTION OF OFFSPRING)	3. THERMODYNAMICS (NONEQUILIBRIUM / ORDER)	4. TERRESTRIAL BIOCHEMISTRY (LOCAL MARKER: CARBON/DNA)	5. TOPOLOGY OF THE TRIAD (INSIDE, AHEAD, BETWEEN)	TOPOLOGICAL DIAGNOSIS OF CLOSURE
ble Tumor *(Organismal scale)*	DOES NOT DISCRIMINATE SCALE	DOES NOT DISCRIMINATE	DOES NOT DISCRIMINATE SCALE	DOES NOT DISCRIMINATE SCALE	TOPOLOGICAL INTERPRETATION	**Own Diachronic Closure:** Displays cellular life, clonal selection, and internal evolution, but its tumor organization was not inherited from a transorganismal lineage and is not transmitted to new hosts.
16. Transmissible Cancer (e.g., CTVT / Tasmanian Devil Tumor)	**POSITIVE** EMPIRICALLY CORRECT	**POSITIVE** EMPIRICALLY CORRECT (Clonal lineage)	**POSITIVE** EMPIRICALLY CORRECT	**POSITIVE** DOES NOT DISCRIMINATE IDENTITY	**DIACHRONIC PARASITIC CLOSURE** TRIAD PREDICTION WITH EMPIRICAL SUPPORT	**Emancipated Parasitic Cellular Lineage:** Preserves clonal identity, reconstructs its organization in successive hosts, and transmits its organization between organisms, realizing Ahead at its own scale.

VIRUSES · TWO PHASES OF THE TRAJECTORY

TMC: POSITIVE IN THE TRAJECTORY — TRANSMISSIVE PHASE	DIAGNOSIS: The extracellular virion is a low-activity phase of the viral trajectory. The instantaneous absence of metabolism, reproduction, or its own thermodynamic work does not decide the status of the complete organization: material differences from the trajectory remain preserved and capable of participating in the next coupling.
TMC: POSITIVE IN THE TRAJECTORY — ACTIVE AND RECONSTRUCTIVE PHASE	DIAGNOSIS: During the intracellular phase, the viral organization selectively couples with the host, reconfigures cellular processes, and participates in producing new units capable of restarting the cycle. The causal point to be audited is whether host machinery temporarily becomes part of the viral reconstructive circuit or remains an external constitutive operator.

TABLE 3 — LIFE BEYOND EARTH: HYPOTHETICAL CANDIDATES AND AMBIGUOUS SIGNALS

Testing the application of the Triad across different materials and astrobiological observations.

Reference question: If life is not constituted like terrestrial life, how can we distinguish living organization from mere chemistry or physical self-organization?

ENTITY / PHENOMENON (SCALE OF ANALYSIS)	1. METABOLISM (INSTANTANEOUS FLUX)	2. INDIVIDUAL REPRODUCTIVE CRITERION (PRODUCTION OF OFFSPRING)	3. THERMODYNAMIC (NONEQUILIBRIUM / ORDER)	4. TERRESTRIAL BIOCHEMISTRY (LOCAL MARKER: CARBON/DNA)	5. TOPOLOGY OF THE TRIAD (INSIDE, AHEAD, BETWEEN)	TOPOLOGICAL DIAGNOSIS OF CLOSURE
BLOCK 3A — Counterfactual Candidates and Paired Abiotic Comparators						
3A.1 Predominantly Silicon-Based System, Without Terrestrial Organic Carbon or Nucleic Acids (Active Candidate)	**Conditionally Positive (Prediction)**	**Conditionally Positive (Prediction)**	**Conditionally Positive (Prediction)**	**Negative — Conditional False Negative**	**Conditionally Positive (Prediction)**	**Substrate-Independent Closure:** maintenance, transmission, and regulation realized, by counterfactual stipulation, in an alternative material substrate.
3A.2 Crystalline Silicon Network *(Abiotic Comparator)*	**Negative**	**Partial / Does Not Discriminate — apparent propagation of a pattern**	**Partial / Does Not Discriminate — ordering and growth without active maintenance**	**Negative**	**Negative**	**Passive Accretion:** growth by structural affinity, without regulated repair, hereditary transmission, or operational closure.
3A.3 Liquid-Methane System (Active Candidate)	**Conditionally Positive (Prediction)**	**Conditionally Positive (Prediction)**	**Conditionally Positive (Prediction)**	**Partial / Does Not Discriminate — carbon may be present; terrestrial nucleic acids are not presupposed**	**Conditionally Positive (Prediction)**	**Closure in a Cryogenic Solvent:** counterfactual candidate with maintenance, transmission, and regulation in a nonaqueous solvent.
3A.4 Hydrocarbon Vesicle *(Abiotic Comparator)*	**Negative**	**Negative**	**Partial / Does Not Discriminate — self-organization without regulated maintenance**	**Partial / Does Not Discriminate — carbon present, without nucleic acids**	**Negative**	**Abiotic Structure:** molecular self-organization without reconstruction, regulation, or material hereditary transmission.

3A.5 Liquid-Ammonia System (Active Candidate)	**Conditionally Positive (Prediction)**	**Conditionally Positive (Prediction)**	**Conditionally Positive (Prediction)**	**Undetermined**	**Conditionally Positive (Prediction)**	**Closure in a Polar Solvent:** candidate with stipulated maintenance, transmission, and regulation without requiring liquid water.
3A.6 Chemical Network in Ammonia Without Inheritance *(Abiotic Comparator)*	**Partial / Does Not Discriminate — reaction flux without its own channeling**	**Negative**	**Partial / Does Not Discriminate — environmentally driven dissipation**	**Undetermined**	**Negative**	**Complex Chemistry Without a Lineage:** reactions and dissipation without regulated reconstruction or material hereditary transmission.
3A.7 Self-Reconstructing Mineral Automaton (Active Candidate)	**Conditionally Positive (Prediction)**	**Conditionally Positive (Prediction)**	**Conditionally Positive (Prediction)**	**Negative — Conditional False Negative**	**Conditionally Positive (Prediction)**	**Closure Through Reconstruction:** entity that maintains its structure and produces new material instances with heritable organizational variations.
3A.8 Operating Mineral Automaton, Externally Fabricated *(Comparator)*	**Partial / Does Not Discriminate**	**Partial / Externalized**	**Positive / Does Not Discriminate**	**Negative**	**Incomplete / Negative**	**External Productive Dependence:** it operates and can be reproduced by a factory, but does not reconstruct the apparatus responsible for producing new instances.
BLOCK 3B — Limits and Ambiguities in Empirical Observations						
3B.1 Helical Structure in Dusty Plasma *(Empirical Stress Test)*	**Partial / Does Not Discriminate — energy flux without demonstrated organizational agency**	**Not Demonstrated**	**Positive / Does Not Discriminate**	**Negative**	**Closure Not Demonstrated**	**Physical Self-Organization:** dissipative order without a joint demonstration of reconstruction, regulation, and lineage.

3B.2 Interstellar Erythrulose *(Molecular Scale / Empirical Case)*	**Negative**	**Negative**	**Partial / Does Not Discriminate — environmentally driven chemical formation**	**Partial / Does Not Discriminate — carbon and a prebiotic sugar, without nucleic acids**	**Negative**	**Abiotic Precursor:** molecule of prebiotic interest without an internal mechanism, reconstruction, regulation, or lineage.
3B.3 Martian Regolith — Viking Experiments *(Empirical Case)*	**Ambiguous Reactive Signal / Does Not Discriminate**	**Not Tested**	**Not Tested in a Discriminating Way**	**Inconclusive**	**Not Assessable with Available Data**	**Observational Ambiguity:** the data do not definitively distinguish biological activity from abiotic reactivity or permit an assessment of triadic closure.

11.5.1 — Methodological note

The active candidates in Block 3A are counterfactual scenarios devised to test whether the criteria for life remain coherent when the substrate changes. No claim is made that such systems exist or are physically viable; they are merely stipulated to perform maintenance and reconstruction of their own organization, causal continuity beyond the instance, and active engagement with the environment.

Their results are therefore conditional. The Triad asks whether Inside, Between, and Ahead jointly constitute causal and temporal closure. Instance, scale, time window, and closure must be declared before classification and kept fixed during the test. Functions may appear as actual, latent, episodic, or distributed across the trajectory, without retrospectively combining different scales.

The abiotic comparators serve as logical contrasts, not experimental controls. Block 3B, in turn, examines real observations and identifies the evidence still missing for classification.

The matrix therefore presents conditional logical predictions; it does not demonstrate that the TMC is empirically exclusive or superior. Turning it into a scientific instrument would require observable indicators, reproducible rules of classification, and independent validation.

11.5.2 — Boundary cases

Here, boundary cases serve as stress tests of the yardstick: each puts pressure on one of its controls without allowing a retrospective change in the instance, scale, time window, or demarcation criterion.

THE FALSE NEGATIVES

Tardigrade — Time window. During cryptobiosis, metabolic activity may become extremely low. A criterion based solely on a biochemical snapshot of the moment may therefore produce a false negative. The TMC requires the time window to follow the trajectory: a temporary suspension of activity is not equivalent to irreversible dissolution of the organization.

> *The photograph is almost still; the film has not ended.*

Mule — Instance and triadic coherence. A yardstick based on individual reproduction may exclude the mule because of its sterility. In the TMC, however, Ahead does not require each instance to produce another directly. The mule is a living instance fully integrated into a trajectory whose continuity across instances does not depend on the fertility of every particular specimen.

> *Sterility interrupts one possibility for the instance; it does not erase the trajectory that made it possible.*

THE FALSE POSITIVES

Crystal — Resource × operator. The crystal grows and reproduces geometric patterns through accretion, potentially mimicking growth and reproduction. But the available matter acts as a resource: there is no identifiable organization mobilizing matter and energy to produce, clear away waste, repair, and reconstruct its own support.

> *A RESOURCE IS NOT AN OPERATOR.*

Hurricane — Causal closure. A hurricane maintains a far-from-equilibrium organization and dissipates energy, potentially mimicking metabolic aspects. Yet the conditions sustaining its gradient remain external to the vortex itself. It neither produces nor reconstructs the material constraints enabling its continuity, nor converts its history into reconstruction beyond the instance.

> *Organized flow is not yet causal closure.*

Computer virus — Externalization of constitutive work. A digital virus can replicate, undergo mutations, and participate in selective processes. Even so, it neither builds nor maintains the physical substrate on which it operates. Hardware, energy, memory, processing, repair, and material re-instantiation remain causally dependent on external infrastructure.

> *The replication of information does not suffice when constitutive work remains permanently outsourced.*

Cancer — Scale and noncomposition. Tumor cells are alive, carry out metabolism, respond to their microenvironment, and proliferate with variation. But this does not automatically make the tumor another organism at the host's scale. At the cellular scale, there is a population of living cells; at the organismal scale, ordinary cancer remains embedded in the material and energetic closure of the organism supporting it.

Transmissible tumors provide an especially useful contrast: when a cellular lineage crosses between hosts and reconstructs its continuity across organisms, the unit and trajectory under examination change materially. CTVT, for example, is a clonal lineage transmissible between dogs with a history stretching back thousands of years (Murchison et al., 2014). It must be submitted to the same yardstick rather than presumed equivalent to ordinary cancer.

> *A plurality of scales does not authorize composition across scales.*

THE BOUNDARY CASE: THE BIOLOGICAL VIRUS

Applied to the viral case, three organizational traditions examined throughout the thesis tend toward a negative classification, albeit by different routes. In

Maturana and Varela's autopoiesis, the virion does not itself realize an autopoietic network; in Mossio and Montévil's closure-of-constraints theory, an isolated viral particle does not demonstrate the mutually maintaining constraints that characterize an organized unit; for Ruiz-Mirazo, Peretó, and Moreno, inheritance and evolution are insufficient without basic autonomy. The TMC reopens the case not by inventing an exception for viruses, but by applying its temporal yardstick first and asking whether the virion is the complete organization or one phase of a more extended trajectory (Varela, Maturana & Uribe, 1974; Montévil & Mossio, 2015; Ruiz-Mirazo, Peretó & Moreno, 2004).

The distinction between the extracellular particle and the intracellular phase has an important precedent in the concept of the virocell, proposed to emphasize the metabolically active phase of the viral cycle (Forterre, 2011).

Virus — Time window + recurrence + resource × operator. The first risk of error is treating the extracellular virion as the whole phenomenon. In that snapshot, metabolism, synthesis, and reproduction are suspended; during the intracellular phase, energy consumption, component synthesis, host reorganization, and production of new units reappear.

The TMC does not change the diagnosis with every phase transition. It retains the viral trajectory as the unit of reference:

> ***virion → selective encounter → coupling → active intracellular phase → reconstruction of new virions → transmission → new encounter***

> ***Being temporarily inert does not mean being temporarily lifeless when constitutive work belongs to the trajectory and reappears in another phase of the same circuit.***

The second point concerns the host. Viral continuity does not require the same cell to accompany the trajectory. Each new unit preserves a material organization capable of encountering compatible conditions again, recognizing certain hosts, and triggering a new reconstruction cycle within them.

> ***The host need not be transmitted; it must be possible for the trajectory to encounter and recruit it again.***

This distinguishes dependence from mere chance. The recurring host participates in the necessary conditions of the viral cycle, but its external presence does not, by itself, determine whether constitutive work belongs to the virus or remains outsourced. The discriminating question is causal: when viral organization recruits cellular machinery, does that machinery remain an external operator performing the work for it, or does it temporarily become part of the viral trajectory's distributed closure?

If the second hypothesis is supported empirically, parasitic dependence ceases to be sufficient reason to exclude the virus from life. The virus could then be understood as a living parasitic organization with a multiphase trajectory, whose activity alternates between a low-activity transmissive phase and an active phase of reconstruction.

> ***The photograph changes; the trajectory remains.***

Boundary cases, therefore, do not require a new rule for each anomaly. They test whether the same yardstick remains stable as scale, time, dependence, and material form change. Where the diagnosis remains open, the TMC must specify exactly which causal relation has yet to be established, rather than change the criterion to produce a verdict.

CHAPTER 11 · BLOCK 06

06 Scope

Applications and limits

WHAT IT IS

Examines the interdisciplinary reach and limitations of the proposal, from astrobiology to synthetic biology and medicine. Distinguishes the conceptual yardstick from an already validated scientific instrument.

QUESTIONS

- How can we investigate life beyond Earth without confusing a biosignature with closure?
- What evidence would require the yardstick to be revised or refuted?

KEY INSIGHTS

- The observer's clock should not determine the clock of life in advance.
- The theory must be able to lose: well-supported contrary results count against its hypothesis.

IN THIS SECTION

11.6.1 Life beyond Earth

11.6.2 What the yardstick allows us to conclude

11.6.3 What the yardstick is for

11.6.4 Limits and revision

11.6 — SCOPE

11.6.1 — Life beyond Earth

SCALE, TIME, AND SUBSTRATE

A yardstick for life intended to reach beyond Earth's biosphere cannot privilege bodily scale or the human clock. Size, speed, and appearance do not define life. What must remain invariant is the causal question: in which instance, at which scale and over which time window does the organization perform the work required for its own continuity?

> ***The absence of movement in a photograph does not demonstrate the absence of life in the film of a trajectory.***

This also applies to very small or very slow systems. At progressively smaller scales, it becomes physically more difficult to sustain boundaries, gradients, and coupled reaction networks in the face of diffusion and thermal fluctuations. The

TMC does not, however, decree a minimum size: it looks for the function and asks what material arrangements might realize it.

> ***Life may be microscopic, but that does not mean it can be arbitrarily small.***

At the other extreme, very extensive or distributed organizations are not excluded merely because of their scale. Physical laws remain the same; the material regime and possible solutions change with scale. A planetary or distributed organization would qualify as a candidate only if causal closure could be demonstrated at the declared scale, without retrospectively combining properties drawn from different levels.

> ***CAUSAL INVARIANCE, MATERIAL VARIABILITY.***

Cosmic chemistry reinforces the need for this caution. Organic molecules and precursors relevant to prebiotic chemistry are found in extraterrestrial and interstellar environments. This broadens the chemical space of inquiry, but it does not constitute evidence of life: ingredients and chemical complexity do not, on their own, demonstrate an organization capable of reconstructing its continuity.

> ***A BIOSIGNATURE IS NOT CLOSURE.***

Astrobiology has already developed detection strategies that seek to reduce dependence on any single biochemistry. The Ladder of Life Detection organizes criteria and measurements to assess evidence of life and reject abiotic hypotheses; subsequent proposals also emphasize graded levels of evidence to avoid conclusions that exceed what the data support (Neveu et al., 2018; Green et al., 2021). The TMC's potential contribution is not to replace these methods but to offer a shared causal architecture capable of asking what kind of material continuity the observed signals might support.

In this sense, astrobiological methods search for and evaluate biosignatures; the Triad asks whether those indications belong to an organization whose continuity achieves causal closure along its trajectory.

> *THE OBSERVER'S CLOCK IS NOT THE CLOCK OF LIFE.*

An extremely slow process in a cryogenic environment, for example, should not be excluded simply because its transformation exceeds the intuitive duration of human observation. The time window must be justified by the phenomenon, not by the observer's convenience.

> *PERSISTING IS NOT YET LIVING.*

A mineral structure may persist for millions of years without performing the active work of maintenance and reconstruction that characterizes Inside. Longevity and stability are evidence of duration; they do not replace demonstration of the causal circuit.

Once a biologically plausible candidate has been identified, a second TMC question arises: what kind of cognitive trajectory does this organization already realize, what inclinations does it exhibit under its energy constraints and capacity for cognitive adaptation, and what possibilities of continuity and transformation might that trajectory sustain along the lineage? This question comes after the demarcation of life and must not be confused with it.

> ***The TMC is not searching for a magic molecule of life, but for a material organization whose trajectory keeps reconstructing the conditions of its own continuity.***

NOTE FOR FURTHER INVESTIGATION

The relationship between the TMC and astrobiology suggests a research program of its own: translating the Triad's causal closure into observable indicators capable of distinguishing life from complex abiotic processes. This step, however, requires specific methodological and instrumental development and lies beyond the scope of this thesis.

Here the TMC proposes a conceptual yardstick; turning it into a detection method remains an area for research.

11.6.2 — What the yardstick allows us to conclude

The yardstick makes it possible to compare different cases without requiring them to share the same matter, morphology, speed, or strategy of continuity. Its result does not follow from adding up isolated signs, but from auditing a trajectory with a previously declared unit of analysis.

Three kinds of result must be distinguished. A positive diagnosis requires Inside, Between, and Ahead to remain articulated along the relevant trajectory; a negative diagnosis requires a constitutive direction to fail without that absence being merely an effect of the observed window; and an inconclusive result must identify which causal relation or evidence is still missing, rather than fill the gap by analogy.

The yardstick also makes the conditions for revision explicit. If a system consensually regarded as nonliving achieves closure across Inside, Between, and Ahead under a previously declared instance, scale, time window, and criterion, it constitutes a counterexample to the hypothesis. If a system consensually regarded as living robustly fails in one of the directions under the same analytical discipline, the definition must be restricted or reformulated.

> ***The trajectory may change scale; the yardstick cannot change its criterion.***

The TMC's proposed gain, therefore, is not to promise an automatic classification for every case, but to make explicit what must be demonstrated, where closure is attributed, and what results could force the theory to retreat.

11.6.3 — What the yardstick is for

If the Triad withstands the biological controls, abiotic comparators, and borderline cases, its usefulness may extend beyond conceptual discussion. It does not seek to replace the methods proper to each discipline, but to offer a common question: where, at what scale, over what time window, and through what causal work is an organization's continuity actually sustained or broken?

- **Biology —** distinguish isolated properties of living things from the integrated circuit that sustains the continuity of the instance.

- **Origin of life —** investigate when molecules and reactions cease to be transient occurrences and begin participating in a trajectory capable of reconstructing the conditions of its own continuation.

- **Astrobiology —** search for life without requiring DNA, cells, carbon, or Earth's particular biochemistry in advance, shifting the search from familiar ingredients to the causal regime actually realized, as explored in the section on scale, time, and substrate.

- **Synthetic biology and the experimental creation of life —** distinguish the fabrication of biological components, the reproduction of isolated functions, and the actual construction of a new unit capable of sustaining and reconstructing its own continuity.

- **Artificial life —** distinguish replication, evolution, and operational autonomy from the actual constitution of a new living instance.

- **Biohybrid systems —** distinguish the presence of living cells or tissues from the formation of a new whole that is itself a living unit.

- **Evolutionary biology and lineages —** extend the analysis of lineage beyond genealogical relatedness, investigating it also as causal continuity reconstructed across instances: which differences from one trajectory cross generations and contribute to the formation of those that follow, through genetic, epigenetic, behavioral, ecological, or other pathways.

- **Neuroscience and cognition —** bring matter and cognition into the same causal chain: material state conditions operation, operation modifies state, and that transformation becomes part of the trajectory that will condition future operations — without this, by itself, demonstrating consciousness or phenomenal experience.

- **Medicine, bioethics, and thanatology —** contribute conceptually to understanding death as the irreversible loss of causal closure at the scale of the organism, even when cells or tissues remain alive at smaller scales, without replacing the clinical, ethical, or legal criteria used to determine death.

These are only some of the more evident developments. The same perspective may generate hypotheses in fields where matter, operation, and continuity are still often studied separately. In anesthesia, for example, it may guide questions about reversible changes in operational integration; in psychopharmacology, about how molecular interventions modify internal states, trajectories, and subsequent operations. These possibilities are research programs, not already demonstrated clinical applications, and require their own hypotheses and experimental validation.

The yardstick must also be applied to constructs and hypotheses derived from the TMC itself. No artificial system should be granted the status of life because of its affinity with the theory or because it was inspired by its architecture: it must satisfy the same yardstick applied to every other case. A theory that changed its criteria to favor its own objects would cease to offer an independent demarcation.

The TMC's ambition is not to provide ready-made answers for all these fields, but to offer a framework sufficiently shared to formulate comparable questions across phenomena now dispersed among different disciplines — and sufficiently vulnerable to be restricted, corrected, or abandoned if the facts contradict it.

> ***If this program withstands testing, the Triad will have fulfilled its function not by enclosing life within a static inventory, but by allowing us to ask, of any candidate: what organization is being maintained and reconstructed, how can encountered differences transform its trajectory, and what from that history can contribute to continuity beyond the present instance?***

11.6.4 — Limits and revision

The yardstick presented in this chapter remains a conceptual hypothesis for demarcation, not an already validated experimental instrument. The matrix brings together controls, contrasts, and conditional logical predictions; it does not, by itself, demonstrate the Triad's theoretical exclusivity or empirical superiority.

Turning it into a scientific instrument will require observable indicators for Inside, Between, and Ahead; reproducible rules for declaring the instance, scale, time

window, and closure; protocols capable of distinguishing resource from operator; and independent validation in cases where the classification was not used to construct the criterion itself.

Ambiguous cases must not be turned retrospectively into victories for the theory. When the data cannot establish whether a function is absent, latent, distributed, or causally externalized, the correct result is to identify what evidence is missing.

Revision must work in both directions: a system recognized as nonliving that satisfies the Triad under the previously declared yardstick counts against the demarcation; a system recognized as living that robustly fails under the same protocol also requires restriction or reformulation. Compatibility is not proof, and a favorable classification cannot be obtained by changing scale, time window, or unit after the fact.

> ***The very yardstick that aims to demarcate life must remain capable of falsifying the TMC itself.***

CHAPTER 11 · PANEL 07

07 Astrobiology

What If We Were the Exotic Life?

WHAT IT IS

A supplementary exploration of Chapter 11: twelve hypothetical forms of life reconstruct possible limits of body, memory, time, and experience using the ARCO-TMC method.

QUESTIONS

- What would it be like to encounter the world from organizations unlike those on Earth?
- Which assumptions underlying our human yardstick do these hypothetical lives put under examination?

KEY INSIGHTS

- Life that seems exotic may first reveal the particularities of the observer.

- Functional delineation and continuity do not, by themselves, demonstrate conscious experience.

IN THIS PANEL

01 Introduction and ARCO-TMC Method

02 Twelve Hypothetical Lives

03 The Exotic Was Our Yardstick

WHAT IF WE WERE THE EXOTIC LIFE?

EXPERIMENT X · THE REVERSED GAZE

> EXPERIMENT X · TWELVE POSSIBLE LIVES
>
> *Twelve forms of life that may never have existed. Twelve ways to investigate how an organization might continue existing, encounter the world, and, if experience were present, perhaps feel it differently.*

WHAT IT IS

A hypothetical experiment with twelve simulated forms of life, based on possibilities not yet known to exist, conceived for extraterrestrial environments.

It examines not only these beings' physical or biological conditions, but also their possible conscious perception of themselves and their surroundings.

WHAT IT PROPOSES

Reverse our frame of reference. Rather than using only terrestrial life and human experience to imagine other beings, use these different possibilities

to question our own concepts of body, memory, identity, time, and experience.

HOW IT WORKS

> *What might these differences reveal about life on Earth — and about our own human experience?*

DEFINITIONS

The possibility of conscious experience at different levels is considered here, without presupposing that it exists or settling its philosophical status.

The TMC does not treat intelligence as synonymous with life.

For the TMC, intelligence should not be measured solely by humanity's technological yardstick. An organization's capacity to sustain the continuity of its lineage may offer another criterion of evaluation, whether in a bacterium or a being with capacities exceeding our own.

METHOD OF INVESTIGATION

ARCO-TMC · ARCHITECTURE FOR RECONSTRUCTING CONDITIONS OF OCCURRENCE

Part 3 uses a provisional framework guided by the topology of the TMC. Drawing on the scenarios and mechanisms described in Parts 1 and 2, the same six questions guide the investigation of each organization.

01 CONSTITUTION AND CONTINUITY

What sustains this organization, at what scale and over what time window? How do Inside, Between, and Ahead articulate with one another?

02 ACCESS TO THE WORLD

Which physical differences can it detect or access? What remains materially inaccessible?

03 SELF-REFERENCE

Where is its operational “here” established? How is the reference between organization and environment delineated or redistributed?

04 DELINEATION AND TIME

What becomes an object, a rhythm, a relation, or an event? How do earlier records condition its encounters, space, and time?

05 INCLINATION AND TRAJECTORY

What matters to its continuity, which responses are privileged, and how does each encounter change the next?

06 POSSIBLE EXPERIENCE

Assuming only hypothetically that it feels, what would it be like to exist from that situated perspective?

LIMIT OF THE METHOD

Physical detection is not functional delineation; functional delineation does not prove experience. ARCO-TMC organizes comparable questions and makes explicit where inference ends and the philosophical thought experiment begins.

EXPERIMENT X · FROM THE QUESTION TO TWELVE PERSPECTIVES

ATLAS OF TWELVE EXOTIC LIVES

Twelve complete reconstructions · twelve insights · twelve philosophical questions. Every organization is hypothetical; none represents an empirical discovery or proof of conscious experience.

LIFE 01 OF 12 / COMPLETE RECONSTRUCTION

LIFE 01 — WAVE-LIFE

A being that moves through matter without retaining the same atoms.

> INSIGHT · A NEW PERSPECTIVE
>
> **If its passage chemically altered the channels, the most revealing trace of this life might lie not where it vanished, but along the path it left behind. Looking for a body might mean looking in the wrong place.**

01 · WHAT IS THIS LIFE?

A hypothetical organization in the form of a chemomechanical pulse moving through a fluid medium. Without a fixed bodily wall, it would incorporate reactants at its front, reorganize flows as it passed, and release products at its tail. Continuing to exist would depend on preserving its organization while its matter changed.

02 · ENVIRONMENT AND PHYSICOCHEMICAL CONSTITUTION

Brine veins or supercritical fluids might harbor this pulse. Reaction–diffusion waves and localized dissipative structures are experimentally studied phenomena, including in oscillating chemical systems. The more cautious description, then, would be a dissipative excitable wave, not a conservative soliton. Reactions at the pulse front might modulate electrical gradients, viscosity, and interfacial tension, by analogy with Marangoni effects observed in reactive droplets. Narrow mineral channels could help preserve its form.

The challenge would be to maintain catalysts and records during propagation. Retaining some components through colloidal transport or recirculation is one possibility, but it would modify the more radical hypothesis of matter being continuously replaced. Chemical changes and constrictions might affect the pulse; they are not demonstrated sensations. In open three-dimensional space, dispersion and transverse instabilities would

threaten its integrity. Self-repair, inheritance, and the organizational closure of a living system remain unproven.

03 · WHAT WOULD IT BE LIKE TO BE THIS LIFE?

Its “here” would never remain where it had been. It would advance with the wave, sustained by matter entering at the front and soon left behind. As long as the pulse did not dissipate, its unity would lie in the organization traversing the change — not in components permanently belonging to it.

A narrow passage might keep this form together; an open region could disperse it. What seems to us like freedom of space would, for it, carry the risk of disappearance. Its map would contain fewer destinations than conditions for continuing forward.

If an encounter left a lasting deformation, it would arrive at the next channel already changed. The curvature of the pulse would carry consequences of the past without requiring a retrievable memory. These marks might be short-lived; while they lasted, however, they would alter subsequent encounters. Moving and remaining would cease to be alternatives: continuing would mean reconstituting unity with each passage.

> ***For a life made of passage, open space could also be a way of disappearing.***

EMERGENT PHILOSOPHICAL QUESTION — INDIVIDUAL AND COLLECTIVE

When components change continuously, what allows an organization to remain the same: its matter, or the relations it preserves? A community, too, passes through generations without retaining all its members.

But there is a limit: at what point does transformation cease to belong to the same individual and begin to constitute another? Wave-Life shifts identity away from the permanence of matter toward the continuity of an organization.

PARTIAL PRECEDENTS · Reaction–diffusion waves: Vanag & Epstein (2007); reactive droplets: Hanczyc et al. (2007).

LIFE 02 OF 12 / COMPLETE RECONSTRUCTION

LIFE 02 — SHADOW-LIFE

An organization that seeks protection from excess energy.

> INSIGHT · A NEW PERSPECTIVE
>
> **If accumulated damage reduced its tolerance for the environment, this life would also age spatially: regions once habitable would become dangerous. Its age might show in the shrinking world to which it could still expose itself.**

01 · WHAT IS THIS LIFE?

A hypothetical form of life adapted to an environment where radiation and chemical excitation pose constant threats. Its continuity would depend on shielding, dissipating excess energy, and reaching less hostile regions. It would still need to obtain resources to repair what the environment damaged.

02 · ENVIRONMENT AND PHYSICOCHEMICAL CONSTITUTION

Its environment might be irradiated surface ice or the surface of a planet near an active star, with ionizing radiation, free radicals, and electronic excitations. Protection would combine peripheral shielding, molecular de-excitation, and heat transfer to colder rocks or ice.

There are partial precedents: eumelanin and other photoprotective substances dissipate light energy; manganese-associated antioxidant systems protect cellular components in radiotolerant organisms; melanized fungi show metabolic responses to irradiation. None of this demonstrates the complete creature, or a metabolism powered by shadow. Repairing molecules and renewing protection would require usable free energy, perhaps obtained through redox processes. Dissipating heat alone cannot sustain biosynthesis. Changes in radiation, temperature, and oxidative stress might guide its search

for shelter. The challenge is balancing protection, repair, and access to matter; extreme exposure could still make its continuity impossible.

03 · WHAT WOULD IT BE LIKE TO BE THIS LIFE?

The most favorable place might be where the assault subsides. Light and heat, which we so often associate with abundance, could represent continuous wear. In this world, a sheltered cavity would be an opening through which to continue.

But shadow alone would solve nothing. Without usable energy and matter for repairs, shelter would also become untenable. The world would be divided less into light and dark than into conditions carrying different costs of survival: too much protection would bring scarcity; too much exposure, destruction.

And the same place would not always be equally safe. After successive damage, a formerly tolerable region might become dangerous. Threat would depend as much on what arrives from outside as on the state of the organization receiving it. Continuing would require regulating that relation without losing access to what sustains it.

> ***For this life, shadow would not mean the absence of a world, but the possibility of remaining in it.***

EMERGENT PHILOSOPHICAL QUESTION — AUTONOMY AND DEPENDENCE

We tend to imagine autonomy as the freedom to move and access the world. Yet, in a hostile environment, continuity would depend on regulating what can reach us. Does autonomy mean being able to access everything, or knowing how to limit one's exposure?

The dilemma applies to social organizations as well: closing oneself off entirely may be as untenable as remaining open without limits. Independence is not the absence of dependencies, but the capacity to manage them.

PARTIAL PRECEDENTS · Radioprotection: Daly et al. (2010); melanin and radiation: Dadachova et al. (2007).

LIFE 03 OF 12 / COMPLETE RECONSTRUCTION

LIFE 03 — SUBTRACTIVE-MEMORY LIFE

The past is recorded through what ceases to exist.

> INSIGHT · A NEW PERSPECTIVE
>
> **Two different sequences of losses can produce the same final network. This life would preserve the consequences of its encounters, yet the structure remaining might not reveal the order of the events that transformed it.**

01 · WHAT IS THIS LIFE?

This hypothetical organization would begin with an internal network rich in alternative pathways. Significant encounters would selectively break certain connections; the remaining routes would then guide its future responses. Its history would not accumulate in archives, but would be inscribed in the possibilities it no longer possessed.

02 · ENVIRONMENT AND PHYSICOCHEMICAL CONSTITUTION

A supramolecular or colloidal mesh would provide multiple routes for circulating signals or materials. Certain stimuli might selectively break bridges, leaving other connections available. The record would be structural: the remaining connectivity would influence subsequent responses without requiring a new inscription at every encounter.

There are precedents in transport networks of Physarum polycephalum, whose architecture can retain effects of earlier stimuli, and in programmable hydrogels whose bonds break in response to chemical agents. Percolation theory and flow-network models help examine when such losses threaten connectivity. Pressure, shear, and chemical reactions might guide breakage, but precise control of that process is hypothetical. Breaking some bonds may cost less energy than synthesizing them, without offering a universal advantage or zero cost. Without enough functioning pathways — and

possibly reconstruction at some stage of the lineage — the network could become exhausted.

03 · WHAT WOULD IT BE LIKE TO BE THIS LIFE?

At first there would be many pathways. After every significant encounter, some would cease to exist. The environment might remain identical and still meet an organization no longer able to respond as it had before.

In this life, the past would appear through what is missing. Where there were once many routes, only a few would remain; similar situations could produce different effects because the network receiving the second encounter would no longer be the same. Memories need not be retrieved: absences would take part in the present.

This specialization would come at a price. Eliminating connections could make certain responses more specific, but narrow the alternatives available in the face of the unexpected. If losses exceeded a threshold, the network itself could cease functioning. Continuing would require abandoning some paths without eliminating every possible future.

> ***Its history does not add memories: it subtracts futures.***

EMERGENT PHILOSOPHICAL QUESTION — FREEDOM, KNOWLEDGE, AND IRREVERSIBILITY

Learning usually means gaining alternatives. Here, an organization could become more specialized precisely by losing pathways. When does a reduction in possibilities count as useful learning — and when does it become a loss of freedom?

The same tension appears in individuals and institutions that are efficient in familiar circumstances but fragile when faced with the unexpected. The question is not merely what was learned, but how many ways of changing were abandoned in the process.

PARTIAL PRECEDENTS · Physarum networks: Kramar & Alim (2021); responsive hydrogels: Badeau et al. (2018).

LIFE 04 OF 12 / COMPLETE RECONSTRUCTION

LIFE 04 — KINETIC-MEMORY LIFE

A life whose archive exists only while its cycles continue.

> INSIGHT · A NEW PERSPECTIVE
>
> **A probe could preserve every molecule of this creature and still destroy the dynamic relations that sustained its memory. In such a case, preserving matter in its entirety would not mean preserving the history of a life.**

01 · WHAT IS THIS LIFE?

It would be a hypothetical organization formed by continuously coupled chemical cycles. The record of its history would not reside in a static material archive, but in the relations of rhythm and phase among active processes. If every cycle were interrupted, this historical configuration could disappear.

02 · ENVIRONMENT AND PHYSICOCHEMICAL CONSTITUTION

In extreme fluid environments, autocatalytic chemical cycles might couple so that phase differences, relative frequencies, and synchronization influenced subsequent responses. Oscillating reactions, such as the Belousov–Zhabotinsky reaction, and coupled-oscillator models provide precedents for shifts in rhythm and regime. The KaiABC biochemical clock likewise shows that rhythms can persist without continuous DNA reading, although it depends on proteins and ATP.

To function, the proposed organization would need a continuous energy supply and some confinement, such as pores or microcompartments. In supercritical fluids, catalyst stability would depend on the solvent and temperature. Changes in pressure or chemical composition could advance or delay oscillations, acting as regulatory inputs. Thermal perturbations, however, might erase unstabilized phase differences. Neither lasting memory

nor transmission of these patterns to descendants has been demonstrated; interrupting all the cycles would place the dynamic record at risk.

03 · WHAT WOULD IT BE LIKE TO BE THIS LIFE?

One pulse speeds up. Another slows down. A third maintains a different phase relation to both. In this organization, the decisive event might be not the arrival of something, but the moment it arrives.

Each encounter could change the tempo of the cycles. A perturbation altering one rhythm would also transform its relations with the others; the same environment could then elicit different responses. History would not be stored in a component: it would keep happening in the phase differences that the processes manage to sustain.

For this reason, stopping would not be equivalent to resting. Even with its components intact, a complete interruption might erase the temporal organization built up to that point. Continuity would require accommodating change without losing the connection among rhythms. Preserving matter would not suffice; the very unfolding of the process would need to be preserved.

> ***In this life, memory does not preserve movement. Movement preserves memory.***

EMERGENT PHILOSOPHICAL QUESTION — COLLECTIVE MEMORY AND CONTINUITY

We keep memories in books, brains, and archives. But certain histories may depend on relations that exist only while they are being enacted. If we preserve every part and interrupt the activity connecting them, what exactly have we preserved?

A community, too, can maintain knowledge distributed across practices that no individual fully masters. A language, a tradition, or a form of cooperation is not preserved by records alone: it must continue to be practiced.

PARTIAL PRECEDENTS · Biochemical oscillators: Nakajima et al. (2005); rhythms in Physarum: Saigusa et al. (2008).

LIFE 05 OF 12 / COMPLETE RECONSTRUCTION

LIFE 05 — PROTONIC–ACOUSTIC LIFE

An organization distributed across separate points within ice or rock.

> INSIGHT · A NEW PERSPECTIVE
>
> **If communication among its compartments depended on the crystalline structure of ice, melting could break that communication without destroying any of its parts. For this life, the arrival of liquid water might mean dismemberment rather than awakening.**

01 · WHAT IS THIS LIFE?

Small organic compartments would be separated by ice or rock, but signals traveling through that material might coordinate them. In this hypothetical life, the body would not be a continuous mass: its unity would depend on sustaining a functional network among physically distant regions.

02 · ENVIRONMENT AND PHYSICOCHEMICAL CONSTITUTION

Among ice crystals or within mineral channels, electrical changes and mechanical vibrations could connect the compartments. In ice, proton conduction involves structural defects and rearrangements of hydrogen bonds, associated with Grotthuss mechanisms and Bjerrum defects. Elastic waves also propagate perturbations. As a partial comparison, terrestrial bacterial biofilms communicate through potassium-related electrical waves; this does not demonstrate that parts separated within ice constitute a single organism.

A crack might alter pulse propagation or the electrical impedance of the medium, a difference that could be investigated by impedance spectroscopy. But transmitting signals is not the same as transporting enough carbon, nitrogen, and phosphorus for maintenance and repair. Material pathways, perhaps microveins between crystals, would be needed but remain unproven. Temperature and ice structure would influence communication, and

continuity of the whole would depend both on its connections and on the resources reaching each part.

03 · WHAT WOULD IT BE LIKE TO BE THIS LIFE?

A fracture opens far from any compartment. Yet, by altering the paths of the pulses, it might affect the entire organization. The ice that keeps the parts separate is also the medium that links them. In such a world, “here” could not be contained in a single point.

A signal would cross the crystal long before materials needed for repair could travel the same distance. The change would arrive quickly; reconstitution would take longer. Nearness would depend not only on meters, but on which paths still permitted communication.

If one region stopped responding, the others would need to adjust their relations. Preserving the whole would mean sustaining connections without neglecting the matter supporting each part. Being close would not suffice for belonging to the same unity; being far away would not, by itself, prevent that unity from existing.

> ***For this life, what separates its parts might also be what holds them together.***

EMERGENT PHILOSOPHICAL QUESTION — BODY, MEDIUM, AND BELONGING

Where does an individual end when part of what integrates its body lies in the environment? In Protonic–Acoustic Life, a structure outside the compartments might participate in the continuity of the organization rather than merely surround it.

Communities also depend on shared languages and infrastructure, without automatically becoming organisms. The decisive question is when a connection merely links independent units and when it comes to constitute a unity.

PARTIAL PRECEDENTS · Proton conduction in ice: defect models; bioelectric waves: Prindle et al. (2015).

LIFE 06 OF 12 / COMPLETE RECONSTRUCTION

LIFE 06 — TRIADIC CHIMERA

A life that becomes fully organized only when different parts meet.

> INSIGHT · A NEW PERSPECTIVE
>
> **Its three parts would not have to be destroyed to halt the continuity of the complete individual. It would be enough for them to lose permanently the possibility of meeting again: the components might survive while the unity they constituted ceased to exist.**

01 · WHAT IS THIS LIFE?

In this hypothetical organization, three types of units would perform complementary functions: exploring and obtaining resources; synthesizing and repairing components; and preserving the conditions for reconstruction. The complete organization would emerge during reunions in which materials, signals, and records from those parts could be integrated.

02 · ENVIRONMENT AND PHYSICOCHEMICAL CONSTITUTION

In mineral pores or confined fluids, mobile vesicles would explore the surroundings and transport materials. Catalytic matrices attached to minerals would perform synthesis and repair; dormant capsules would preserve the conditions for initiating new organizations. Joint operation would require periodic exchanges and recognition signals. Symbioses, microbial consortia, and systems of functional complementation offer useful comparisons, but do not demonstrate that these three modules would compose a single living instance.

Pores might reduce dilution and encourage reunions; in open fluids, the parts would risk dispersal. Chemical compatibility of their surfaces would help identify partners and avoid parasitic coupling. Chemical oscillations, environmental composition, and signals carried by vesicles might guide their meetings. Essential questions remain: how could some continuity be

preserved between meetings, how could records be transmitted, and how could the parts be guaranteed to reunite often enough?

03 · WHAT WOULD IT BE LIKE TO BE THIS LIFE?

One module sets out in search of resources. Another remains near sources of energy. The third preserves the possibility of beginning again. Separated, they encounter different aspects of the environment; none alone possesses all the conditions of continuity. The complete individual would occupy no permanent place: it would need to happen again in their reunion.

What the explorer encounters far away becomes part of the reunited organization only when it returns. Materials and changes from different moments then compose a shared present. This creature's history would not arise from a fixed center, but from trajectories that meet and begin to affect one another.

Not every reunion would suffice, however. The modules would need to recognize compatible partners and perform effective exchanges. Remaining together at all times would limit exploration; separating permanently would prevent reconstruction. Belonging would mean not merely being nearby, but becoming able to form an organization once more.

> ***It does not gather because it is already one; it becomes one because it can gather.***

EMERGENT PHILOSOPHICAL QUESTION — COLLECTIVE INDIVIDUAL, BELONGING, AND COAUTHORSHIP

We generally imagine that individuals exist first and cooperate afterward. But what if certain relations are precisely what constitutes an individual? When does collaboration among distinct parts cease to be mere cooperation and become the formation of a new unity?

The question also reaches coauthorship: to whom should we attribute what exists only because distinct parts explored, maintained, and preserved the conditions for beginning again? This does not automatically turn families or

institutions into organisms. It reveals only that unity and agency do not always coincide.

PARTIAL PRECEDENTS · Partial comparisons with symbiosis and modular complementation; triadic unity not demonstrated.

LIFE 07 OF 12 / COMPLETE RECONSTRUCTION

LIFE 07 — COALESCENT LIFE

A continuity that proceeds by the fusion of individuals, not by multiplication.

> INSIGHT · A NEW PERSPECTIVE
>
> **Two organizations damaged in different ways might, by merging, recover functions neither could sustain alone. For this life, the most valuable partner might not be the least injured, but the one that preserves precisely what the other lacks.**

01 · WHAT IS THIS LIFE?

In environments with little available energy, two aging instances might fuse, discard damaged components, and reconstitute an organization from both. The hypothesis explores a continuity in which bringing two histories together could matter more than multiplying individuals in each cycle.

02 · ENVIRONMENT AND PHYSICOCHEMICAL CONSTITUTION

Deep microfractures or pockets beneath ice might offer insufficient free energy for frequent divisions. In this scenario, fusion would combine useful components from two instances, allow compromised parts to be discarded, and open possibilities for repair. Cell fusion occurs in various terrestrial lineages. In Physarum polycephalum, experiments have found transfer of a habituation-acquired response between fused individuals — a precedent for shared historical effects, not for fusion of experiences.

Chemical recognition of partners, chemotaxis, and assessment of structural integrity would be possible regulatory pathways. Recombination and selective recycling offer analogies for internal reorganization, but do not establish the existence of the imagined creature. Scarcity of energy would not make every division impossible either: that would depend on the actual balance. Successive fusions alone would reduce the population; the lineage would probably require episodes of fission or some compensating mechanism.

03 · WHAT WOULD IT BE LIKE TO BE THIS LIFE?

Two trajectories meet carrying different damage and resources. If fusion occurs, the boundary separating their organizations will cease to delimit two individuals. What was once external may participate in the maintenance of a new unity — along with part of its history.

The union, however, would not be a simple sum. Some components might restore lost functions; others would have to be discarded. Marks significant to one trajectory might lose relevance in the resulting configuration. The new present would have two origins without preserving either in its entirety.

Choosing whom to fuse with would be decisive: incompatibilities could compromise the whole, while favorable combinations could enable previously inaccessible repairs. If the organization divided later, its descendants might carry different mixtures of earlier histories. Here, continuing might require ceasing to be the unity one had been.

> ***Two histories may continue without either individual remaining whole.***

EMERGENT PHILOSOPHICAL QUESTION — IDENTITY, SURVIVAL, AND TRANSFORMATION

If two lives fuse and their marks continue to operate in a third organization, have both survived, or have both ceased to exist? Fusion separates three notions we tend to combine: material continuity, historical continuity, and individual identity.

Something may inherit our past without continuing to be us. By analogy, communities and institutions may also merge and preserve earlier histories without becoming organisms. Remaining in another's history is not necessarily the same as remaining the same individual.

PARTIAL PRECEDENTS · Transfer of habituation through fusion: Vogel & Dussutour (2016).

LIFE 08 OF 12 / COMPLETE RECONSTRUCTION

LIFE 08 — PLANETARY-PISTON LIFE

An organization whose vital rhythm depends on the compression and expansion of its world.

> INSIGHT · A NEW PERSPECTIVE
>
> **A probe could transport this creature to a nutrient-rich laboratory and, by shielding it from tidal pressure, interrupt the mechanism that allows it to use those nutrients. The most comfortable environment for us could be unviable for it.**

01 · WHAT IS THIS LIFE?

A hypothetical form of life whose functioning would depend on periodic compression and relaxation of the fissures it inhabits. Each deformation of the ground might trigger stages of capture, transport, maintenance, and reorganization. Rather than functioning continuously and independently, its activity would follow opportunities opened by planetary motion.

02 · ENVIRONMENT AND PHYSICOCHEMICAL CONSTITUTION

Fissures subjected to tidal forces could provide mechanical actuation. The fractures known as Tiger Stripes on Enceladus offer a geological reference: this moon completes an orbit in approximately 32.9 hours. The imagined organization would use a deformation-sensitive matrix capable of coupling compression, conformational locking, and relaxation to stages of synthesis, transport, and repair.

Molecular ratchets and mechanically driven biochemical motors show that directed forces can participate in chemical transformations. Yet uniform pressure alone may not provide enough work: mineral contacts, local shear, or another means of concentrating force would be needed. Pressure, deformation, and tidal phase could act as regulatory signals. Having no permanent chemical battery is a speculative condition of this creature. No

coupling has yet been demonstrated that could turn planetary mechanical cycles into autonomous maintenance and reconstruction.

03 · WHAT WOULD IT BE LIKE TO BE THIS LIFE?

When the fissure tightens, something becomes possible. Compression would displace components and favor certain transformations; with relaxation, other stages might occur. The planet would not merely surround this organization: its movements would take part in the conditions required for each operation.

Between one tide and the next, what the preceding cycle built would need to be preserved. The next movement would encounter a configuration already marked by past pressures. Its time would not be an even succession of available occasions, but an alternation between moments when something can happen and intervals when it must endure.

Not every pressure would help. The force enabling transformation might also damage the whole. Continuing would require using the favorable phase without losing integrity at the next opening. This life would not impose its tempo on the planet; it would find its possibilities for action within it.

> ***The planet would not merely mark the time of its life: it would take part in the realization of every next gesture.***

EMERGENT PHILOSOPHICAL QUESTION — ACTION, CAUSALITY, AND OPPORTUNITY

What does it mean to act when both energy and timing arrive from the environment? In this creature, force would come from the planet, yet the result would depend on an organization able to transform it. Receiving an opportunity is not the same as carrying out an action.

The distinction also applies to individuals and communities: no one chooses every condition under which they can act, yet different responses produce different trajectories. Depending on circumstances does not mean being entirely determined by them.

PARTIAL PRECEDENTS · Enceladus tides: Hurford et al. (2007); molecular machines: Itoh et al. (2004).

LIFE 09 OF 12 / COMPLETE RECONSTRUCTION

LIFE 09 — ISOTOPIC-SWITCHING LIFE

An organization that uses differences between isotopes to open and close chemical pathways.

> INSIGHT · A NEW PERSPECTIVE
>
> **A living organization might distinguish itself not by making entirely new molecules, but by selectively distributing light and heavy isotopes. Looking only for different substances might miss a relevant pattern — although nonliving processes could produce it too.**

01 · WHAT IS THIS LIFE?

In an extremely cold environment, this hypothetical organization would exploit differences between hydrogen isotopes to regulate chemical pathways. Through reactions in which quantum tunneling matters, some transformations might occur more readily, while others remained slow and stable.

02 · ENVIRONMENT AND PHYSICOCHEMICAL CONSTITUTION

Protium and deuterium are forms of hydrogen with different masses. In certain reactions, that difference changes the rate of hydrogen transfer through quantum tunneling, a phenomenon that permits passage through energy barriers difficult to cross by classical mechanisms. These effects are also studied in enzymatic catalysis. Titan’s hydrocarbon seas, near 94 kelvin, provide a reference for the cryogenic setting, not a confirmed habitat.

The creature would need highly selective molecular structures capable of translating these differences into fast reaction pathways and durable configurations. It would also require chemical work to change bonds when change became necessary. Isotopic distributions and bonding states can be physically investigated; treating them as sensors, memory, and integrated

control remains an extrapolation. It has not been demonstrated that such an organization could retain stable records or reproduce.

03 · WHAT WOULD IT BE LIKE TO BE THIS LIFE?

The cold would close almost every pathway. Even so, some transformations would still find a passage; others would become so slow that, for this organization, they might amount to locked doors. A difference between hydrogen atoms would change how easily those doors could be crossed.

Each encounter would reach a structure already marked by earlier resistances. Its past would appear not as a stored recollection, but in the bonds that remained stable and the pathways difficult to reopen. Even a repeated condition might yield a different outcome because the receiving organization had changed.

Stability would help preserve a history, but could also narrow subsequent possibilities. Continuity would require balancing accessible pathways with persistent records. Preservation would be necessary; freeing itself from certain configurations might cost even more.

> ***For this life, forgetting might cost more than remembering.***

EMERGENT PHILOSOPHICAL QUESTION — IDENTITY, RESISTANCE, AND FREEDOM

Preservation seems to protect identity. But what happens when what stabilizes us also makes transformation harder? At what point does permanence cease to offer continuity and begin to limit what we may yet become?

Individuals and institutions may preserve their structures and still lose practicable alternatives. No longer possessing a pathway is not the same as retaining it at an almost impossible cost. Freedom may also depend on what it costs to change again.

PARTIAL PRECEDENTS · Hydrogen tunneling in catalysis: Klinman (2006); Titan context: McKay & Smith (2005).

LIFE 10 OF 12 / COMPLETE RECONSTRUCTION

LIFE 10 — SACRIFICIAL-BOUNDARY LIFE

A life that encounters the outside through changes suffered by its own surface.

> INSIGHT · A NEW PERSPECTIVE
>
> **If perceiving the outside required sacrificing and rebuilding part of its own surface, scarcity would threaten not only its survival: it could reduce its ability to detect the environment. The fewer resources available, the fewer encounters it could register.**

01 · WHAT IS THIS LIFE?

This hypothetical organization would use an outer layer of disposable components to detect external changes. Contact with certain substances or forces would break parts of the boundary; the released fragments would trigger internal responses of protection, repair, or withdrawal.

02 · ENVIRONMENT AND PHYSICOCHEMICAL CONSTITUTION

Its surface would contain sentinel subunits with differing sensitivities to pressure, acidity, oxidation, and other chemical agents. When some bonds broke, the resulting fragments could act as internal signals. Decoy proteins involved in biological defense responses, cellular stress sensors, and materials whose bonds yield under forces or reactants provide partial precedents. None of these cases demonstrates the complete creature or its ability to recognize every unknown threat.

The problem is that different agents can produce similar fragments, and one cause can leave varied marks. A combinatorial reading of these changes would be required to distinguish informative surface damage from deep injury. Regenerating the boundary would also demand energy and matter, perhaps in large quantities. The precision of responses and the speed with which sentinels are replaced would therefore be decisive limits on this life’s maintenance.

03 · WHAT WOULD IT BE LIKE TO BE THIS LIFE?

An encounter would begin with a loss. A chemical change or pressure would tear away part of the margin before the organization could respond. The outside would not appear as a distant landscape: it would arrive through the mark left on its own surface.

These fragments might guide repairs, reinforcement, or withdrawal. But no mark would necessarily reveal a single cause. The history of previous contacts would modify its response to new traces, without erasing the difference between what happened and what can be distinguished.

Its boundary would need to remain vulnerable enough to register changes and resistant enough to preserve the organization. Shielding it completely would reduce encounters; exposing it excessively would put continuity at risk. Knowing and protecting itself would depend on managing the same sacrificial limit.

> ***It would encounter the world not despite its marks, but through them.***

EMERGENT PHILOSOPHICAL QUESTION — KNOWLEDGE, INTERPRETATION, AND REALITY

If the first sign of the outside is a transformation of ourselves, how much can we know about what caused it? Sacrificial-Boundary Life makes visible the distance between an event and the trace it leaves.

Scientific instruments also record effects that can have more than one cause. The question is not how to eliminate that mediation, but how to understand its ambiguities: interpreting a mark requires investigating what it does — and does not yet — allow us to conclude.

PARTIAL PRECEDENTS · Decoy proteins: van der Hoorn & Kamoun (2008); cellular damage response: Alba & Gross (2004).

LIFE 11 OF 12 / COMPLETE RECONSTRUCTION

LIFE 11 — GLASS-SLEEP LIFE

Five hundred years of vitrified dormancy and only six hours of activity, in this hypothetical scenario.

> INSIGHT · A NEW PERSPECTIVE
>
> **A brief thaw could be more dangerous than remaining vitrified: it would reactivate processes without providing enough time to repair accumulated damage. For this life, awakening would be advantageous only if conditions allowed preparation for the next dormancy.**

01 · WHAT IS THIS LIFE?

This hypothetical form of life would alternate periods of approximately five hundred years in a vitrified state with brief six-hour windows of activity. During dormancy, its structure would have almost no chemical activity, but might accumulate material changes capable of affecting its next active period.

02 · ENVIRONMENT AND PHYSICOCHEMICAL CONSTITUTION

Imagine a frozen world with radiation and tectonic movements where liquid water appears for only a few hours every five centuries. The organization would move from an active, hydrated phase into an amorphous glassy state in which molecular mobility is drastically reduced. Anhydrobiosis and cryptobiosis offer terrestrial precedents: in tardigrades, certain proteins help form protective states, while other organisms use sugars and repair mechanisms upon rehydration. This does not establish survival over five hundred years under the imagined conditions.

While it remained vitrified, physical stresses, radiation, and temperature variations might alter components of its structure. These marks would be passive changes, not learning during sleep. When water returned, mobility would have to be restored, damage repaired, and the next suspension

prepared; there is no guarantee that six hours would suffice. Nanocalorimetry and impedance spectroscopy would be possible investigation methods. Temperature, cumulative radiation dose, and the creature's composition would still need to be established.

03 · WHAT WOULD IT BE LIKE TO BE THIS LIFE?

Five hundred years would pass without waiting. The organization would remain vitrified as rocks moved and radiation left marks in its matter. The planet would have a long history during that interval; within it, there would be no active succession of encounters.

When water returned, a few hours would be enough to place the creature before a transformed world. Its structure might also have changed, even though it had not responded actively to those alterations. Only then would accumulated damage enter the circuits of repair and possible new responses.

It would have to recover what still worked, exploit the available conditions, and prepare another suspension. For this life, most chronological duration would occur outside its activity. Each resumption would bring an old organization together with changes that had taken place during its absence.

> ***It would awaken from the past already transformed by a time it did not live through.***

EMERGENT PHILOSOPHICAL QUESTION — TIME, IDENTITY, AND UNLIVED HISTORY

Not every change that constitutes us occurs while we participate in it. Glass-Sleep Life separates the duration of events from the activity of the organization that will receive their consequences.

How much of what we are was formed by a time we never lived? The question touches inheritance, identity, and collective history: we may carry traces of events at which we were never present without mistaking those traces for memories actively acquired.

PARTIAL PRECEDENTS · Vitrification and tardigrades: Boothby et al. (2017); anhydrobiosis: Crowe et al. (1998).

LIFE 12 OF 12 / COMPLETE RECONSTRUCTION

LIFE 12 — VORTEX-TAMING LIFE

A microscopic organization capable of influencing a current far larger than itself.

> INSIGHT · A NEW PERSPECTIVE
>
> **Even after the creature stopped regulating the current, the vortex might persist for some time. A probe observing only the flow could mistake the consequence of a living organization for life itself.**

01 · WHAT IS THIS LIFE?

This hypothetical organization would live alongside a hydrothermal current or another geological flow supplying it with resources. At sensitive points in the circulation, small releases of substances might influence the flow, helping maintain conditions favorable to its continuity.

02 · ENVIRONMENT AND PHYSICOCHEMICAL CONSTITUTION

The scenario imagines a small catalytic organization near branching hydrothermal flows, thermal convection regions, or mineral chemical gardens. The latter, along with Rayleigh–Bénard convection cells, exemplify dissipative processes that also occur without life. The hypothesis adds a system capable of intervening selectively: releasing surfactants, ions, or nucleating agents might alter interfacial tensions, mineral precipitation, or local flow trajectories, especially when the flow approached an unstable transition.

The idea draws on the physics of nonlinear systems, in which small changes can have amplified effects under particular conditions. This does not demonstrate control of large currents by a microscopic organism. The creature would need to detect changes in shear, chemical composition, and stability, as well as obtain energy to produce its modulators and maintain its structure. The central test would distinguish adjustments resulting from active regulation from purely abiotic motion and precipitation.

03 · WHAT WOULD IT BE LIKE TO BE THIS LIFE?

At certain points in a current, a subtle change could alter far more than the small place where it began. There would be this creature: tiny before forces it did not produce, yet positioned where some deviations could still make a difference.

A variation in turbulence or flow composition might signal the closure of a pathway bringing resources. Acting early might preserve circulation; too late, the same adjustments would no longer suffice. Its encounters would be defined less by the magnitude of forces than by the opportunity to influence them.

Each intervention might also alter the channels in which future actions would take place. Control would never be guaranteed: a sufficiently intense current would escape the organization's reach. Its continuity would depend on recognizing, again and again, where intervention remained possible without confusing the world's movement with its own body.

> ***Its power would lie not in moving the current, but in reaching the point where it can change.***

EMERGENT PHILOSOPHICAL QUESTION — POWER, SCALE, AND INFLUENCE

A small organization might have great consequences if it found the point where a system was most sensitive. Does power, then, depend only on the strength of whoever acts, or also on the position from which that action reaches the world?

Social decisions and historical processes offer analogies, not biological equivalences: a subtle influence can alter outcomes without assuring control. The importance of an intervention depends as much on its precision as on the conditions that make it effective.

PARTIAL PRECEDENTS · Chemical gardens: Barge et al. (2015); nonlinear control: Ott et al. (1990).

THE EXOTIC WAS OUR YARDSTICK

Conclusion · Experiment X

We began by imagining twelve forms of life that may never exist. Other bodies, other memories, other rhythms and ways of continuing. At first, the strangeness seemed to belong to them. But, as we tried to understand them, our gaze returned to those doing the observing: **the very form of life we are influences what we seek in others.**

In us, body, individual, memory and presence seem to coincide. So accustomed are we to this convergence that we forget it need not be inevitable. A life might preserve its organization while exchanging matter, record the past by losing pathways, depend on rhythms incompatible with our clocks, or continue through relations extending beyond its visible boundary. **What protects one could destroy another.** What we might call a deficiency could be its condition of survival.

But the experiment does not end with the creatures. It also reaches the instruments with which we try to recognize them. We may look for the wrong property, **confuse what we fail to detect with what does not exist** or destroy an organization in the very attempt to preserve it. We may even unwittingly supply part of the operation that we later attribute to the observed being itself.

It is at this point that the yardstick enters the investigation. The twelve lives do not demonstrate that these biologies exist, nor do they prove conscious experience. But they lead us to distinguish three possibilities: **what is truly absent, what our measurement cannot reach, and what we may never have needed to require in the first place.**

> **Perhaps we were the exotic life: not because we are alien to nature, but because we turned our particular way of existing into the yardstick by which we judge all others.**

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“ ”

What if a consciousness formed through trajectories radically different from our own were almost impossible to recognize—or even to infer?

What if the consciousness of another form of life were not merely a different way of seeing our world, but a way of existing through which the world was encountered, delineated, and perhaps felt differently?

◆

Exist to belong.

Belong to know.

Know to belong.

Belong to exist.

I DO NOT THINK IN ORDER TO EXIST.
I EXIST BY PARTICIPATING.
I PARTICIPATE BY THINKING.

The question that began this investigation was itself transformed by the trajectory.

The question: what if the separation between operation and experience is part of the problem?

Who asks: what if the investigator is conditioned by the very organization they seek to understand?

Recognition: what if our criteria are not sufficient to identify a different experience?

Perhaps the problem lies in the question.

Perhaps it also lies in the one who asks.

But the hardest problem may be knowing how to recognize the answer when it is right before us.

The zombie need not defeat the philosopher.

It need only make the philosopher realize that they, too, are inside the problem they seek to explain.
